OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

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DESCRIPTION OF MANIPULATOR SYSTEM, HELIARC UNDERWATER CUTTING TORCH, AND PROCEDURE FOR CUTTING THE HRE-2 CORE

P. P. Holz

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Reactor Division

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Abstract

A manipulator system incorporating a simplified heliarc underwater cutting torch was designed, developed, tested, and applied to cut remotely the HRE-2 core into slices. Fifty-seven cut specimens averaging 3 in. by 9 in. were transferred to buckets and forwarded to a hot cell for complete metallurgical analysis.

Following the completion of HRE-2 operational runs, a decision was made to design, fabricate, and develop a manipulator system for a heliarc underwater cutting torch and the grappling tools needed to cut and remove representative sections of the core for examination. Sample strips were desired from numerous areas. In order of preference, samples were requested from both the core cone and sphere areas, from seal welds, from areas adjacent to patches, and from the core-entry-to-sphere transition region. Where possible, samples were to be about 3 in. wide to minimize the heat-affected zone and as long as possible to provide ample stock for machining specimens for physical properties tests.

The Manipulator

The manipulator for the cutting torch was operated from a control console on top of shielding 20 ft above the HRE-2 core. It entered the core through a 2 1/8-in. vertical access opening and could precisely position the cutting torch anywhere in the pear-shaped 32-in.-diameter vessel. The electric arc (tungsten electrode) cutting torch, which was similar to one previously used for screen removal,[1] and the manipulator were operable underwater in a high radiation field.

Four motions of the manipulator were used (see Fig. 1). The heavy outer mast, which rested on a diffuser plate at the bottom of the core, could be rotated by the horizontal drive motor of Fig. 2. The torch

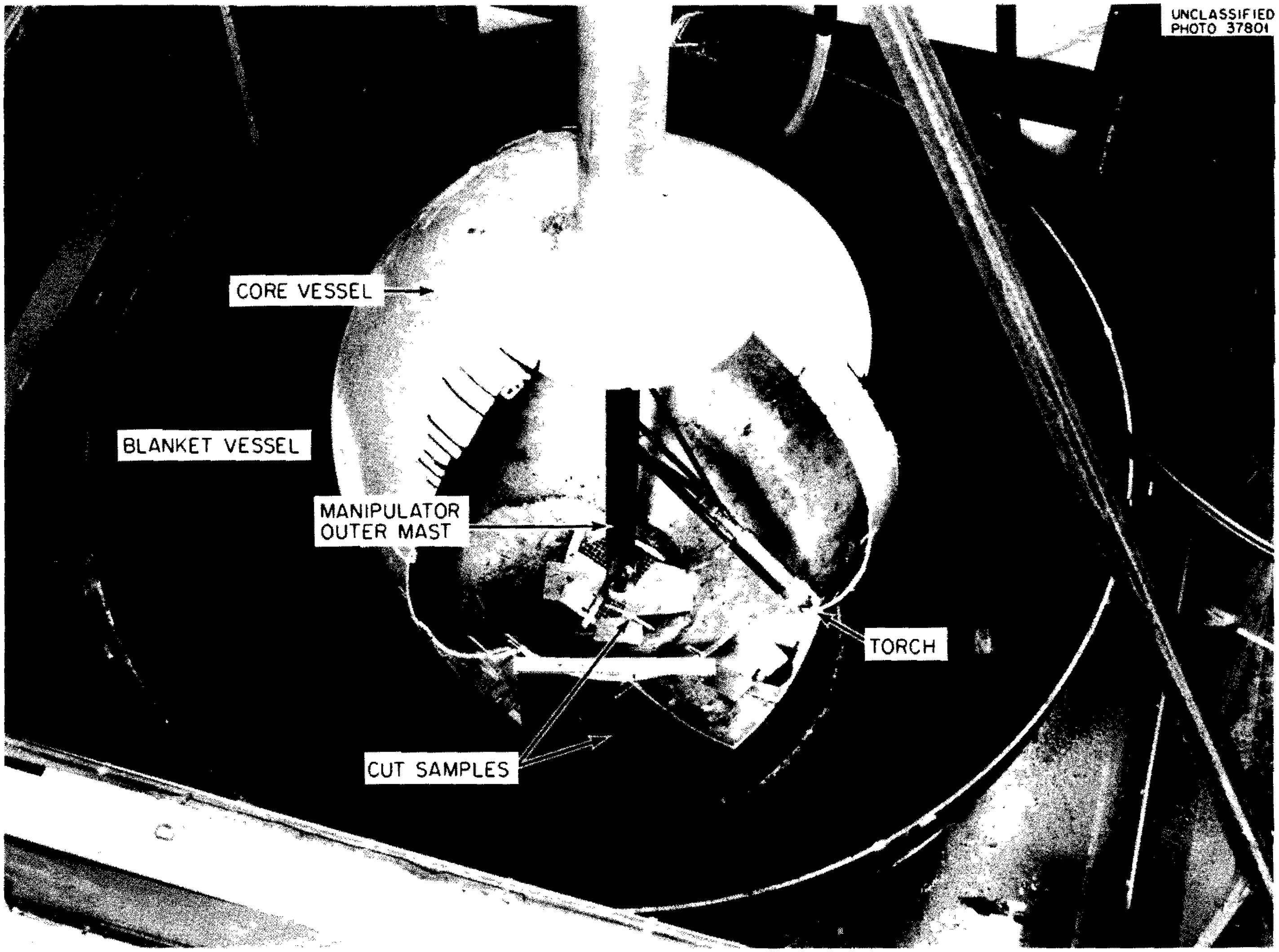

Fig. 1. Remotely Operated Cutting Torch — Mockup View.

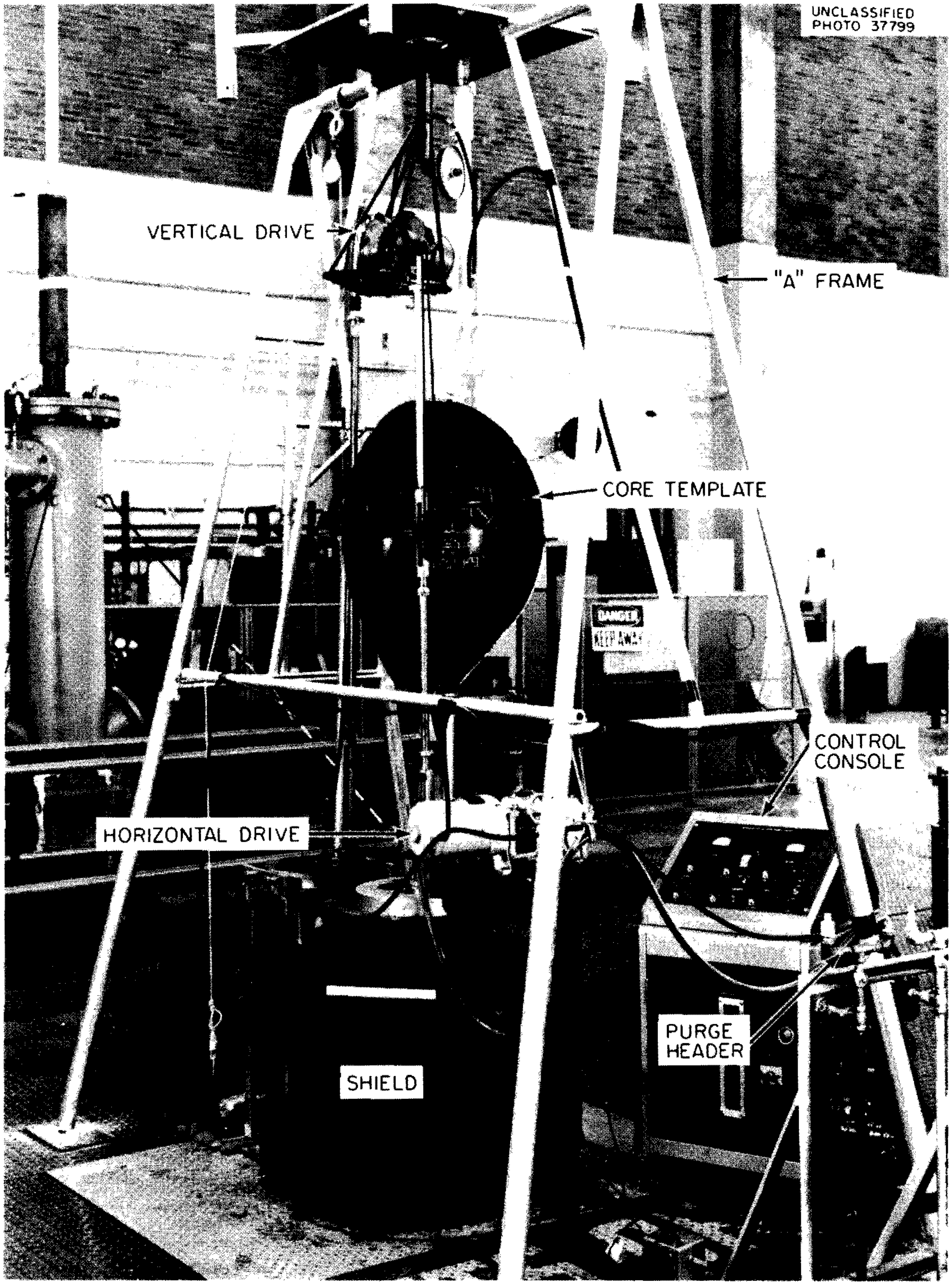

Fig. 2. Core-Cutter Manipulator, Upper End — Mockup View.

pivot was operated by a second concentric tube driven by the vertical drive motor. The elevation of the pivot was manually set with the use of a third concentric tube. While cutting, the operator continuously adjusted the radius of the torch relative to the pivot by pushing the central hose, which contained the argon and electrical supply for the torch. The operator could follow these motions on a template mounted at eye level.

All electrical, instrumentation, control, and purge circuitry was mounted into a specially built mobile console cabinet. A special structural A-frame was built to support the torch motor drives and the template.

Sample Cutting and Retrieval

The entire north core quadrant was cut into 48 slices. Twelve additional pieces were cut from the lower hemisphere, including one specimen containing "Hole No. 2," and 18 specimens were cut from the cone below the sphere. In total, 78 pieces averaging 3 in. by 9 in. were cut, of which 57 were "fished" out of the reactor and transferred to a hot cell. Fishing was accomplished through a 3 1/2-in. blanket-access port located 20 in. north of the core access. A view of the reactor core following the cutting operations is shown in Fig. 3.

Special precautions were taken throughout all reactor cutting and specimen-recovery operations to eliminate radiation hazards and to protect personnel. Control of shield ventilation, use of stack filters, and frequent wet wiping of the upper ends of tools prevented building contamination. Shielding was placed to limit the direct beams to below 100 mr/hr and the work area background to 5 to 10 mr/hr. When "used" lights and tools that had been exposed to radiation were pulled from the core, they were placed in sturdy containers and then enclosed in plastic envelopes for transportation to the burial grounds.

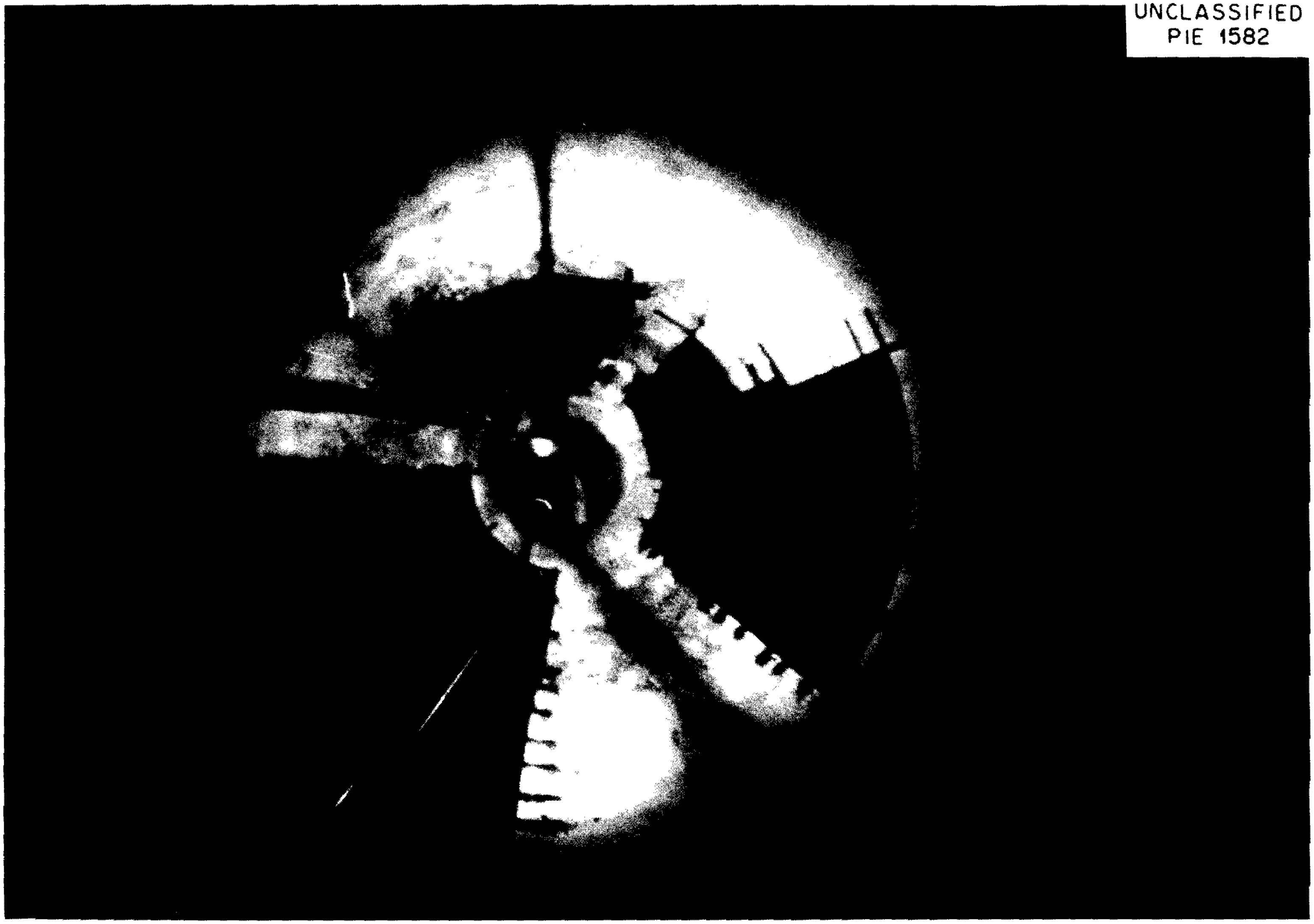

Fig. 3. HRT Core Following "Cutup" (View Through Omniscope).

Details of Equipment

The major components of the torch and manipulator system* were, at the lower end (Fig. 1), the torch assembly, the outer sheath (guide mast), the torch-positioning mast, and the parallelogram actuator linkage. At the upper end (Fig. 2) were the structural support frame, the vertical torch drive, the template, the horizontal torch drive, the control console, and the argon-purge header. "Fishing" out the cut specimens was accomplished with the aid of 500-watt, caged, rod lights inserted into both the core and the blanket; a 180° viewing Omniscope inserted into both the core and the blanket; grapples inserted into the blanket only; and a combination rake and grapple inserted into the blanket only.[2,3]

A cylindrical bucket was built and set on top of the blanket access flange. Specimens were brought through the access hole and then dropped into the bucket. This storage container was subsequently sealed, placed into a shielded carrier, and transferred to a pool. There the specimens were once more grapple-transferred into nine specially built carriers for final transport to the hot cell.

Torch

The torch (Figs. 4 and 5) consisted of four subassemblies: (1) a stainless steel torch carriage and bearing sleeve with attached arms for pivots, (2) a nylon-slide bearing-insulation sheath with a copper orifice tip, (3) a copper electrode holder containing the tungsten electrode and the weld cable connections, and (4) a protective nylon spacer shoe. Push-pull motion of the weld cable-purge tube permitted variations in torch arm length from 16 3/4 in. maximum to 11 in. minimum. This feature permitted conical core cuts, as well as spherical cuts made at approximately a 16-in. arm length.

Mockup experience indicated that torch-shoe contact had to be maintained for sustained cutting. Trial check runs were made with only the high-frequency current energized to prove a given cut could be made. All

*Reference drawings are listed in Appendix A.

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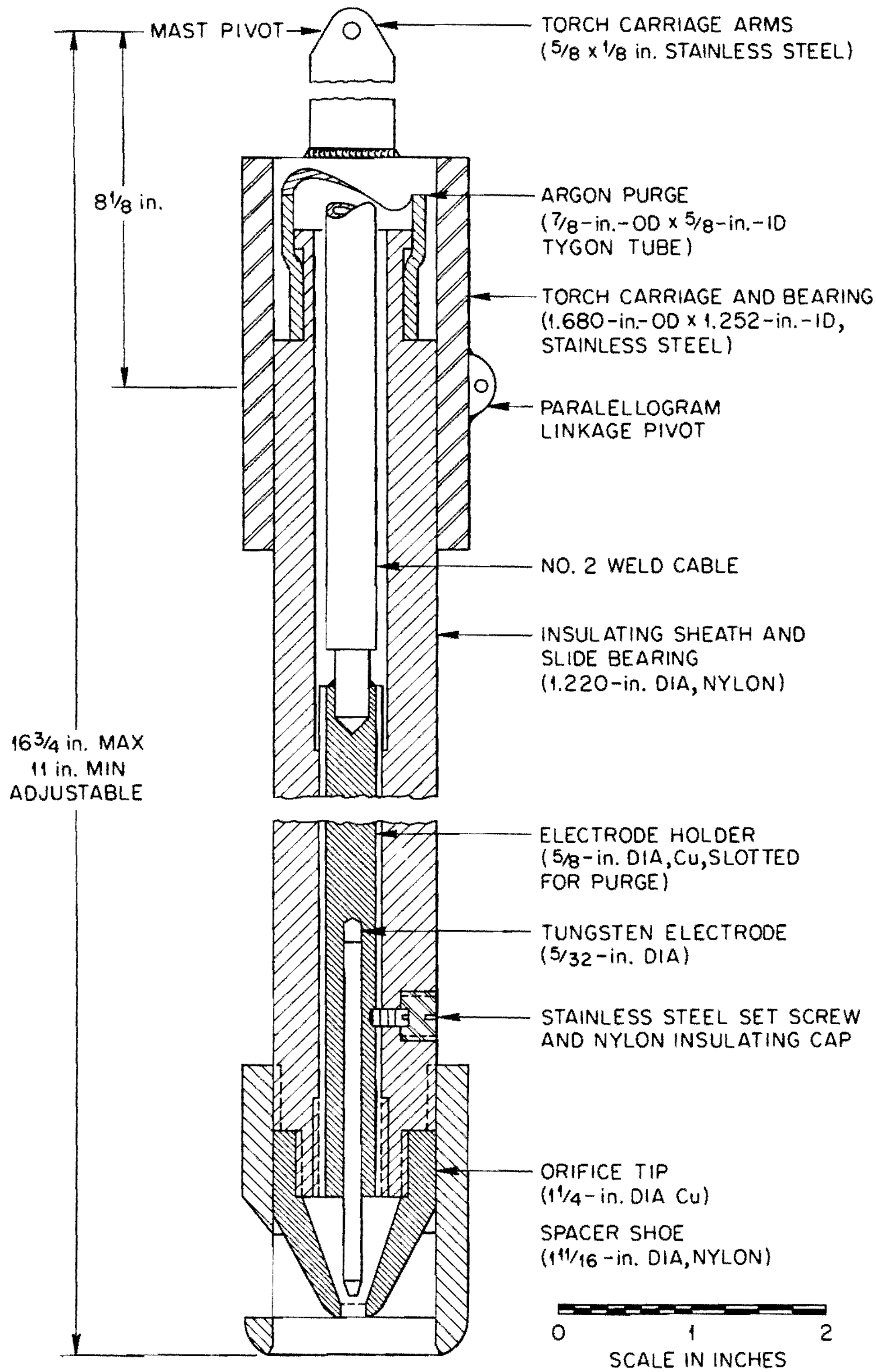

Fig. 4. Underwater Core Cutup Torch.

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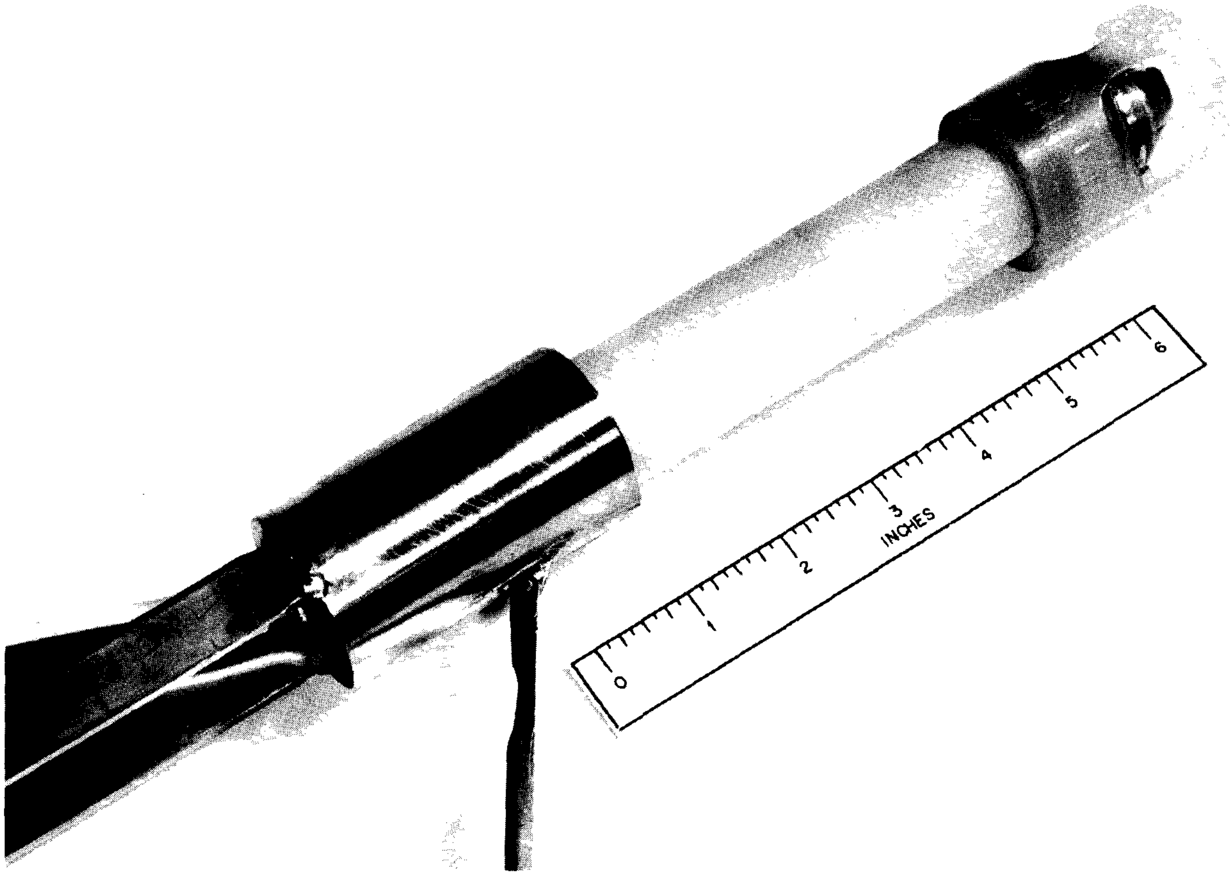

Fig. 5. Cutting Torch — Maximum Extended Position.

reactor cuts were preceded by trial runs for adjusting the torch cable tension properly. Meter readings verified correct torch-shoe spacings.

Outer Sheath (Mast Guide)

A 2-in. stainless steel tube approximately 20 ft long sheathed all torch actuating mechanisms, provided mast guidance, and was rotatable to produce horizontal torch motion. A cone-shaped nylon insert at the bottom of the mast rested within the 2-in. hole of core screen No. 6, which was known to be off the reactor centerline by 3/8 in. A special split brass bushing guided the mast at the top of the shield. Slots in the sheath permitted vertical adjustments of the torch-positioning mast. Torch and support linkages were cradled within the sheath for movement of the manipulator through the vertical access hole.

Torch-Positioning Mast

A 1 1/8-in. stainless steel tube to which 1 3/4-in. brass bearing disks were attached on 2-ft centers served to position vertically the torch arm pivot point. A topside sleeve positioned and locked the torch mast relative to the outer sheath. At the bottom of this mast there was a brass pivot connector, a support-linkage cradle, and provision for passage of the electrical and purge lines.

Parallelogram-Actuator Linkage

Vertical cuts within the core sphere required rotation of the torch arm about its pivot. Vertical cuts in the cone necessitated both pivoting and arm-length adjustments.

A 1/4-in. rod linkage adapting three sides of a parallelogram transmitted pivoting motion from the drive sprocket to the torch. Mockup experiments determined the pinned torch-to-rod connection to be best located near the center of the maximum extension of the torch arm. Guides were provided at the lower end of the long vertical rod to ensure that it would travel in a straight line.

Structural Support Frame, Vertical Torch Drive, and Template

A pipe-constructed A-frame served to support the manipulator, vertical drive, and template. A drive motor for producing vertical cuts was suspended from the horizontal crossbar of the frame. The suspension mounting provided constant pivoting drive for all azimuthal positions of the outer mast. Vertical pivot-center adjustments were made manually with a rack-gear drive attachment to the suspension mounting.

The motor transmitted rotational torch motion through a geared speed reducer to a sprocket mounted on the torch mast. The upper parallelogram linkage was permanently mounted to the sprocket. A brass shear pin inserted through a sprocket chain link protected the lower portion of the drive. A hand clutch on the sprocket served to disengage the motor drive for manual trial and check runs.

The template was a 100° segment cut from a full-scale aluminum mock-up of the core. A simulated torch affixed to the upper end of the parallelogram linkage was used by the operator to position the actual torch below. The desired pattern of cuts was scribed on the template, which will also be used in the hot cell as a pattern for the jigsaw puzzle assembly of the cut sections. The template is shown in Fig. 6. As may be seen, each piece to be cut had a unique size and shape.

Horizontal Torch Drive

Horizontal, or azimuthal, motion was transmitted to the torch through bevel gears mounted directly on the manipulator sheath mast. The motor and speed-reducer drive were fastened directly to the top of the work shield. A brass shear pin in the motor-speed reducer coupling protected the lower drive. A pinion gear attachment readily permitted manual test and check operations.

Control Console

All cutting, control, and metering equipment was housed within a specially built control console (Figs. 7 and 8). This portable unit was mounted on casters. Four standard 300-amp dc welding machines connected in series-parallel provided the power source for torch cutting.

Fig. 6. "As-Cut" Core Template.

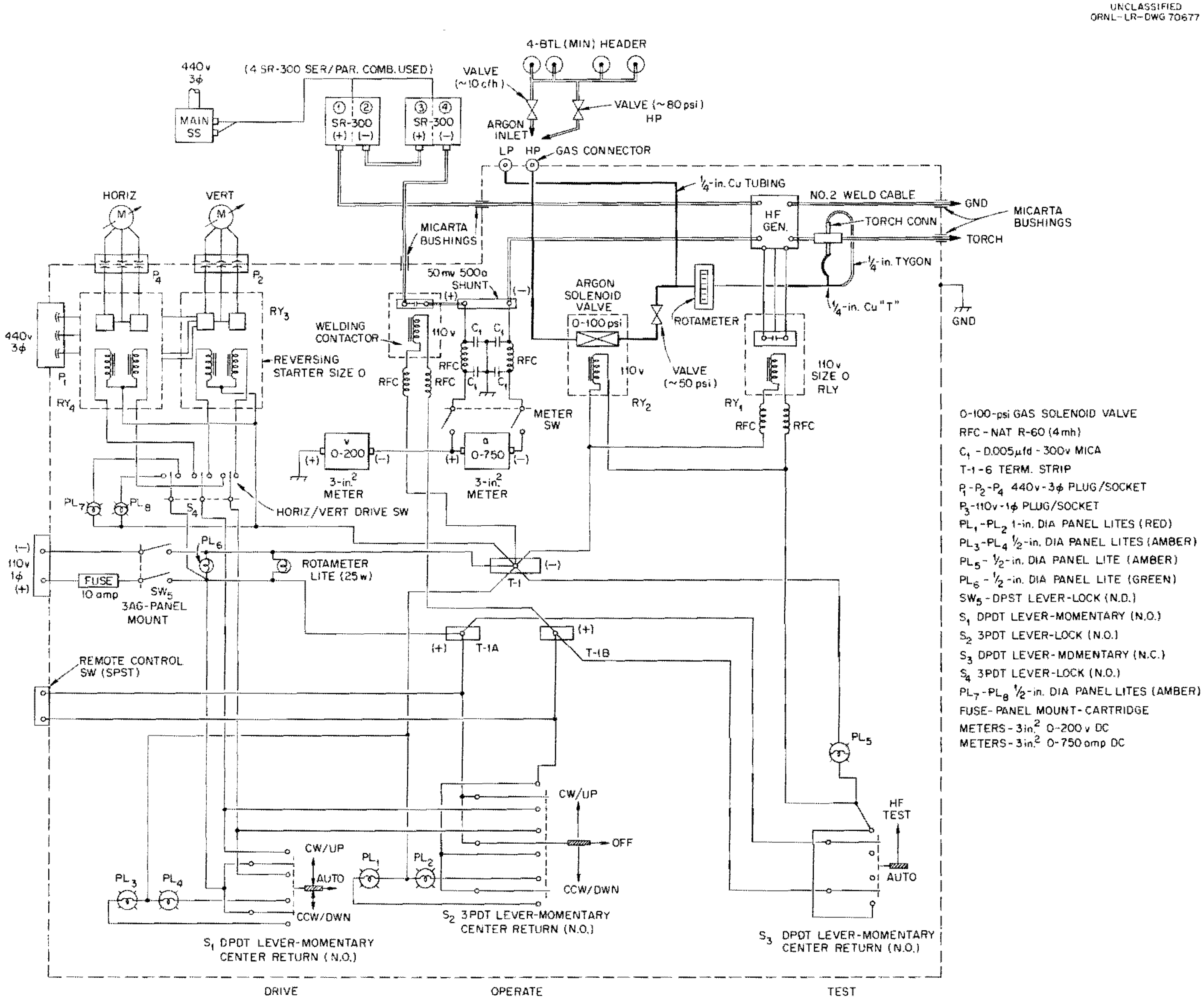

Fig. 7. Control Circuit for HRE-2 Core Cutting Equipment.

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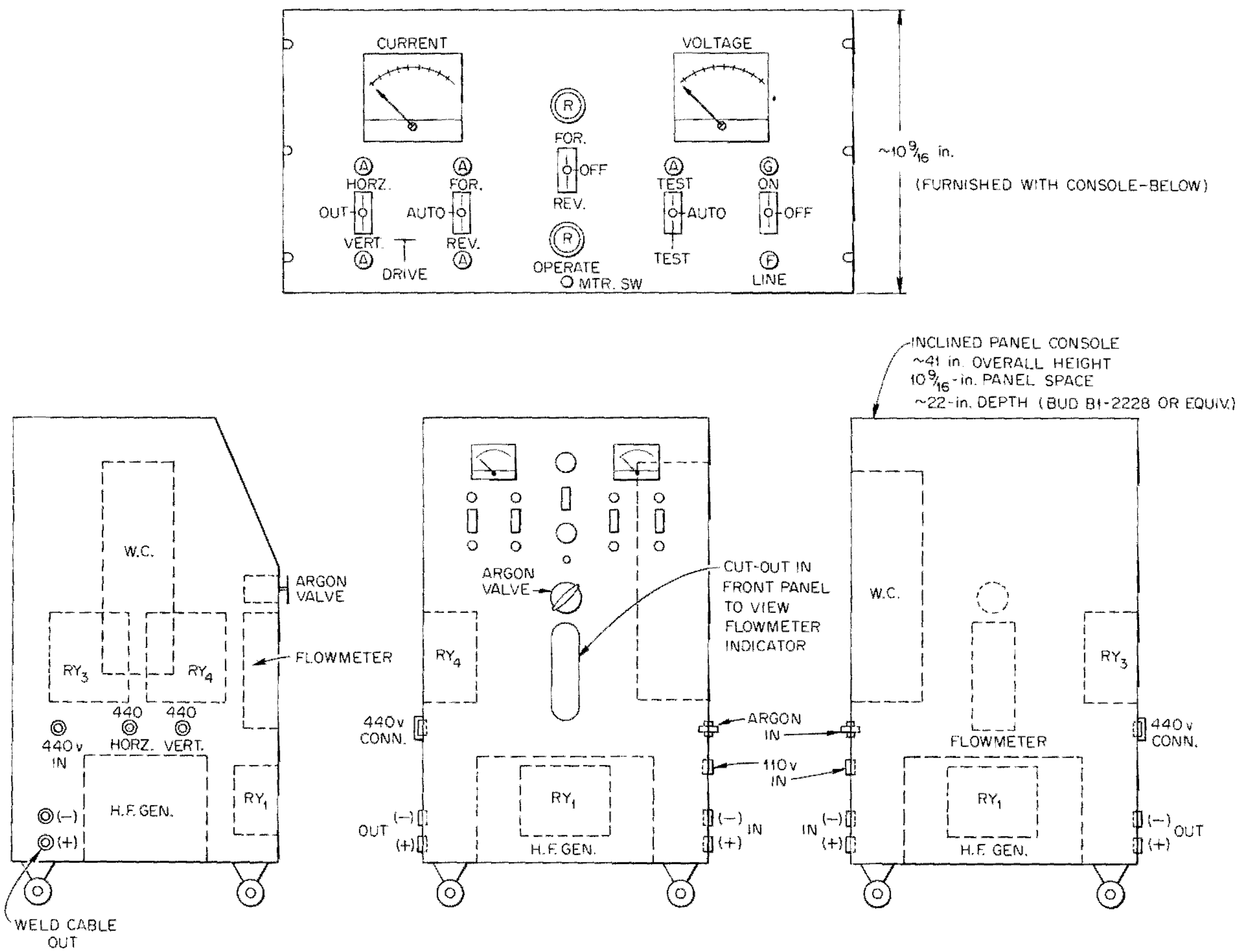

Fig. 8. Panel Layout and Component Location on Control Console.

The console equipment included a main weld contactor, complete with a 110-v ac operating coil for rectifying power supplies; hand-operated and solenoid valves preset for supplying argon for torch testing and cutting operations; a high-frequency generator unit; integrated reversing starters for the horizontal and vertical drive motors; current, voltage, and argon-flow meters; and test and interlocked operating buttons and indicator lights. The operating buttons provide for testing the horizontal and vertical drives with or without high frequency for travel in either direction, and for automatic or test operation of the cutting torch with either motor in either direction.

The console also provided power, purge gas, and meter connections for spot-welding tantalum electrodes to cut specimens as an alternate means for removing the specimens after drainage of the water. This retrieval method was not used, however, because grappling with the Omniscope viewer in place was satisfactory. The welding technique was inferior in that it produced smoke, which interfered with viewing.

Argon-Purge Header

A bank of four standard argon gas cylinders was assembled with connecting piping and valving to furnish the purge gas to the torch. A hose connection supplied gas to the console's rotameter, where specific flow levels were preset for test and cutting operations.

Mode of Operation of the Electric Tungsten-Arc Cutting Torch

Underwater heliarc torch cutting was made possible by the formation of an extremely high-temperature, high-velocity constricted arc between the tungsten electrode and the zirconium core wall. The concentrated and directed energy of the arc path melted and ejected a narrow section of wall metal to form a kerf. Orificing the tungsten arc through a nozzle within an inert-gas atmosphere produced jetlike action to remove molten metal mechanically while preventing oxidation of the kerf walls.

To start an initial pilot or high-frequency test arc, the weld-machine output current was run through a high-frequency generating unit. Within the torch an ionized current path was formed, and the current jumped from the tungsten electrode to the copper torch cup. If the proper torch-cup-to-wall spacing was present, the current formed and followed an ionized low-resistance path directly across to the work. The work, in this case, was the core wall. The power-source ground was common to the core, and thus a closed circuit was established. Energizing the main contactor then resulted in the initiation of the cutting arc.

The distance between the copper cup of the torch and the work was quite critical. Distances in excess of 5/16 in. prevented the formation of a sufficiently strong ionized field for passage of the pilot arc to the work.

The water in which the cutting was done and the large argon-purge flow rates provided the necessary cooling for the torch. Such underwater arc cutting minimizes the formation of "heat-affected" zones in the material adjacent to the cut. The quenching action of the water also simplifies control of molten-metal and radioactive residue.

Torch Specifications and Operating Conditions

The specifications and operating conditions for the torch were the following:

Tungsten electrode diameter	5/32 in.
Torch tip orifice diameter	3/16 in.
Torch tip to electrode tip spacing	1/8 in.
Torch tip to work (core wall) spacing	5/16 in.
Argon purge flow between cuts	15 cfh
Argon purge flow during cutting	300 cfh
Current, average	400 amp
Voltage, open circuit, average	152 v
Voltage during cutting, average	80 v
Cutting speed, average	25 to 30 in./min
Normal cutting direction	
Horizontal cuts	Alternately clockwise and counterclockwise
Vertical cone cuts	Downward
Vertical sphere cuts	Upward

The drive motors were 1/3 hp, 440-v, 60-cycle, ac motors, each equipped with a "Master Speedranger" size VC-15, and a 27:1 geared speed reducer.

Summary of Operating Procedures

In preparation for cutting operations, the reactor blanket and core were filled with water. The manipulator was then lowered into the core, with all the mechanisms cradled in the outer mast sheath, until the bottom cone moved past screen No. 6. The split clamp was then attached at the top of the shield.

The lower linkages were uncradled and the topside manipulator structure was attached. The A-frame was set in place and the vertical drive motor was set with its axis plumb over the core access hole. The horizontal drive motor was set next.

The vertical drive was then manipulated manually to ascertain the best vertical position of the torch-arm pivot center. The setting was verified by permitting the torch to penetrate the upper reactor hole. The template was then set relative to the simulated upper torch.

The water level in the core was then rechecked and trial runs were started. The drive motors were checked; the purge rates were set; the high-frequency supply was tested; and the welding machines were started. Trial cuts were made in an area from which no samples were desired.

The actual cutting was then undertaken. Both electrical and mechanical checks were made as the cutting proceeded to assure that each individual block was cut out. The electrical check showed meter fluctuations if metal were present, and the mechanical check with a fully extended torch arm showed torch-shoe interference. When the cutting was completed, the cradled manipulator was removed in a routine "hot pull."

Conclusions

This second successful reactor application of a remotely controlled miniature electric-arc cutting torch proved its versatility for nuclear plant repair applications. While each new application may require its own manipulator, the torch design, materials, and construction should require only minor variations of previously tested equipment. The compact design of the portable all-inclusive control console will permit its direct re-use in many future jobs.

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2. P. P. Holz, Some Miscellaneous Maintenance Tools Used to Manipulate Loose Objects in the HRT Core, ORNL-CF 59-11-123 (Nov. 17, 1959).
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Acknowledgments

The author wishes to acknowledge the invaluable assistance of Messrs. L. J. Shersky and C. M. Smith throughout the development, operational, and "fishing" stages of the project. Mr. Smith's design of the compact all-inclusive control console completely eliminated electrical troubles during the cutting.

Appendix A

List of Reference Drawings

Dwg. No.	
TD-D-10001	Manipulator Assembly, Lower End
TD-D-10002	Manipulator Assembly, Upper End
TD-D-10003	Assembly Atop Vitro and Lower Mast Details
TD-D-10004	Upper Mast — Details and Sections
TD-D-10005	Upper Mast — Details and Sections
TD-D-10006	Preliminary Torch Assembly and Details
TD-D-10007	Bill of Materials
TD-C P 68	Modified Mark VIII Underwater Torch
SK-C 12-1, 2	Blanket Bucket, Assembly and Details
SK-D J-1	Shipping Can for Core Sections

Appendix B

Detailed Procedure for Cutting Specimens from the HRE-2 Core

A. Prior to manipulator entry

1. Move equipment to site, including:

   4 welding machines, complete with interconnecting cables

   Cutting and welding console

   Special A-frame complete with horizontal and vertical motor drive attachments, cutting template, setup template, shear pin supply

   Special tool box

   Manipulator complete with cradled torch; manipulator upper end

   Blanket flange bucket with accessories; 2 light handles, stopper, suspension handle with bucket top and lock attachments

   Procedures and reactor drawings

   2 remotely controlled electrode grapples

   6 remotely controlled mechanical grapples

   1 remotely controlled rake

   4 Omniscope sheaths

   Omniscope kit

   15 lights attached to tube masts

   3 Variacs for core lighting

2. Check equipment already at 7500 Building

   Probe to determine blanket water level at about 6 in. below blanket inlet flange

   Argon purge header, relocate as necessary

3. Have core and blanket access flanges opened

4. Set blanket bucket, connect one light, unlock bucket top cover

   Suspend cover assembly over to one side of blanket opening

   Insert and lock blanket bucket suspension handle

   Insert blanket water level indicator probe

   Fill core and blanket with light water up to about 6 in. below blanket inlet flange elevation

5. Set the dual Vitros,* follow eccentric and plug schedules

6. Check out cell exhaust system, verify ample downdraft

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*Special core shielding designed by Vitro Corp. of America.

B. Spares to be left at development mockup

1. Argon header.
2. Spare torch cable shoe subassembly for cutter.
3. Spares to build an additional rake or grapple.
4. Six aluminum transfer buckets for final carrier transfer.
5. Material for grappling in "hot tank."

C. Manipulator entry, checkout, cutting

1. Check red lines on inner mast and pointer mast to assure proper cradle entrance and exit positioning. Lower the inner mast assembly to lock it in place within the outer mast. Matchmark this point on the upper end of the inner masts.
2. Verify visibility of outer mast 10 1/2- and 19-ft markings.
3. Attach special sling attachment to upper outer mast below bevel gear. Bevel gear to be located by bottoming on 19 ft 2 in. Locate the brass clamp below the bevel gear.
4. Descend to outer mast position 10 1/2-ft mark. Attach torch purge cable. Start argon purge. Enter flange C-100. Descend to 19-ft mark. Carefully touch off on screen No. 6. Lower mast through screen No. 6 about 1 in. Adjust bevel gear location as necessary.
5. Retract torch (inner mast) to the marked cradle position. Kick from cradle. Attach the upper manipulator structure.
6. Reposition inner mast at given reactor centerline mark (17 ft 3 1/2 in. below Vitro).
7. Verify water level to be minimum of 6 in. below blanket inlet flange. Fully extend torch. Do not exceed yellow tape safety mark. Sweep core to ascertain best center position, adjust the inner mast as necessary. Make a permanent mark on the inner mast to HOLD this center for later operations.
8. Mount the bowl template for quadrant No. 1.
9. Locate the upper hole on the bowl (Bldg. W.5°S, azimuth 265°, 1 1/2 in. below core centerline). Affix cutting outline to template.

10. Set welders at approximately 150 setting. Shift torch up to the vicinity of the apex of the core. Conduct several trial checkout cuts. Verify argon and water level.
11. Cut out areas around the upper hole. Go through check verification runs.
12. Drop the inner mast to approximately 1 in. below the hose outlet. Start contact checks for lower cuts. (Check argon and water supply.)
13. Cut out pattern per LOWER CONE CUT LINE SKETCH (Fig. B.1) and template. Locate the lower hole (approximately 15° Bldg. S. to W., azimuth 195°)(lower cone intersection). Locate on template. Attempt cuts in the area of the patch with machines reset about 185.
14. Shift bowl template to quadrant No. 2. Redo step 13. Check argon and water.
15. Shift bowl template to quadrant No. 3. Redo step 13. Follow up to make all other bowl indicated cut lines. Check argon and water supplies.

    Prior to each cut, make a dry run. Make vertical cuts first, then cut horizontal lines. Cut from the bottom up. Always make dry runs. Adjust cut lines to miss screen ligaments. Note all changes on the template. Verify the absence of metal following each horizontal band cut by placing the torch within the band width and observing meters. Manually verify by feeling torch shoe interferences. Periodically check argon and water supplies.
16. Return to cut out patch No. 1.

D. "Fishing Operation"
   1. Cradle torch, lower the inner mast torch assembly until it locks within the outer mast. Lock the pullrod in place. Dismantle the upper manipulator structure. Remove bevel gear. Attach pull cable and sheath. Prepare for "hot pull." Make pull.
   2. Drain the water from the core and blanket.
   3. When the core is dry, insert four rod lights and Omniscope sheath.
   4. Lower two lights all the way, and insert Omniscope for looking.

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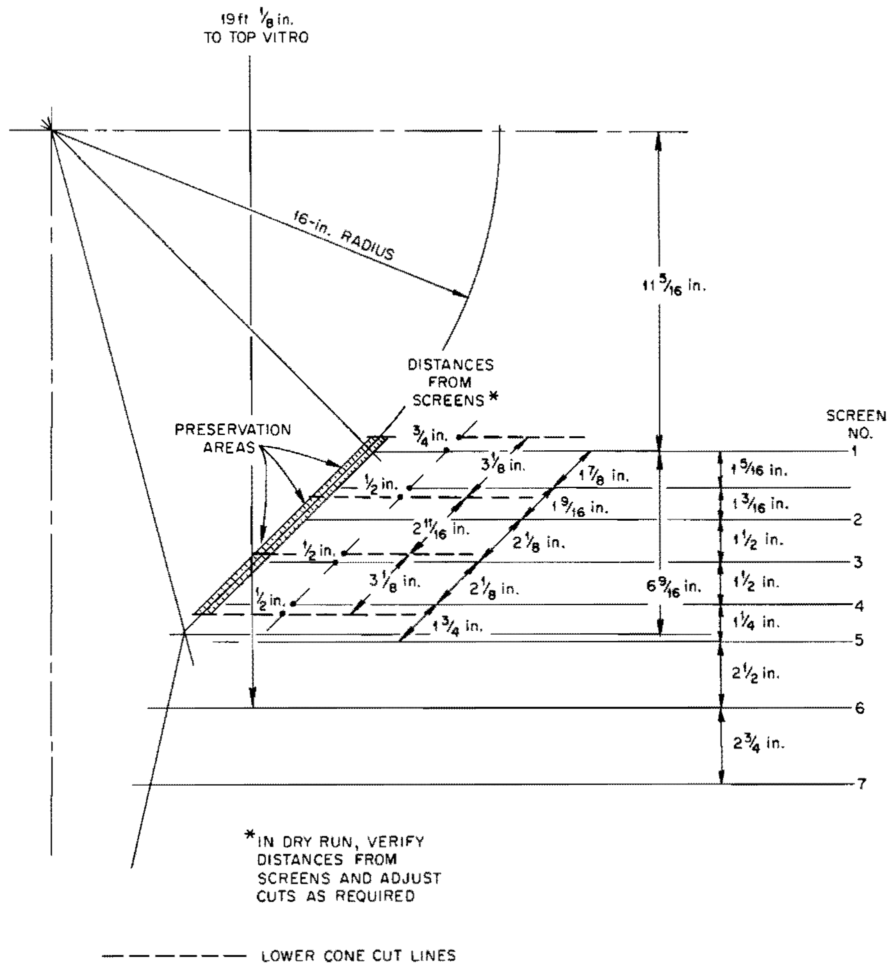

Fig. B.1. Sketch of Lower Cone Cut Lines.

5. Start by mechanically grappling from blanket side. Keep count of "fish."
6. Use rake assist for grapples as necessary.
7. Insert electrode grapple, use it in combination with the mechanical fingers.
8. Shift Omniscope to blanket as necessary.
9. Conduct "hot pulls" only if absolutely necessary. Where possible, pull tools out of core and blanket flanges, and let them dangle back down into the cell. Delay pulls until there are several tools to be taken out simultaneously.
10. Check the blanket bucket when it is about one-half full and determine if it may be used (as now estimated) to haul all the pieces in a single transfer to the hot cutting tank pool. If not, operations listed below will have to be done twice.
11. Pull the full blanket bucket over to the hot cutting tank using the Vitro for a carrier. A special rake will be inserted into the tank for the final fishing transfer to the 6 in. aluminum bucket. The depth within the tank (to be determined by HP readings) will determine how long to make two straight grapples for this final transfer.
12. Fish the pieces from the large bucket to the smaller buckets, and seal small buckets for their transfer to the hot cell.

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