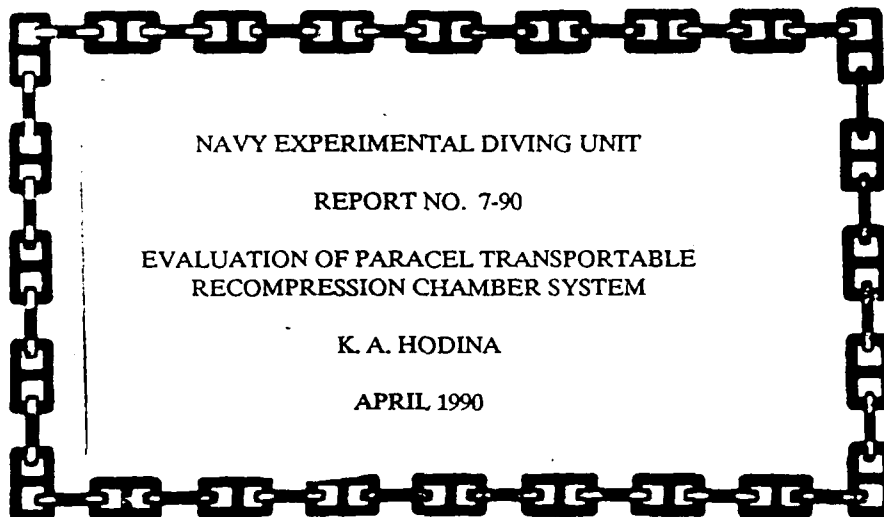


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NAVY EXPERIMENTAL DIVING UNIT

REPORT NO. 7-90

EVALUATION OF PARACEL TRANSPORTABLE
RECOMPRESSION CHAMBER SYSTEM

K. A. HODINA

APRIL 1990

NAVY EXPERIMENTAL DIVING UNIT



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NAVY EXPERIMENTAL DIVING UNIT
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NAVSEA TA 88-23

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K. A. HODINA

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REPORT DOCUMENTATION PAGE				
1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Distribution Statement A: Approved for public release; distribution is unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE				
4. PERFORMING ORGANIZATION REPORT NUMBER(S) NEDU Report 7-90		5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZ. Navy Experimental Diving Unit	6b. OFFICE SYMBOL (If applicable) 03	7a. NAME OF MONITORING ORGANIZATION		
6c. ADDRESS (City, State, and ZIP Code) Panama City, Florida 32407-5001		7b. ADDRESS (City, State, and ZIP Code)		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Naval Sea Systems Command	6b. OFFICE SYMBOL (If applicable) 00C	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER		
8c. ADDRESS (City, State, and ZIP Code) Department of the Navy Washington, DC 20362-5101		10. SOURCE OF FUNDING NUMBERS		
		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO. NAVSEA 88-23
11. TITLE (Include Security Classification) (Unclassified) Evaluation of Paracel Transportable Recompression Chamber System				
12. PERSONAL AUTHOR(S) K. A. Modina, LCDR, USN				
13a. TYPE OF REPORT Test Report	13b. TIME COVERED FROM 01-01-89 TO 04-20-90	14. DATE OF REPORT (Year,Month,Day) April 1990	15. PAGE COUNT 35	
16. SUPPLEMENTARY NOTATION <i>Paracel Transportable Recompression Chamber System (PTRCS)</i>				
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) PTRCS, Paracel Transportable Recompression Chamber System, CO2 Scrubber, Composite Flasks, Portable Hyperbaric Chambers		
FIELD	GROUP			
19. ABSTRACT (Continue on reverse if necessary and identify by block number) The purpose of this evaluation was to determine if the Paracel Transportable Recompression Chamber System (PTRCS) could be approved for Navy use. Two complete systems were purchased for unmanned and manned lab and field evaluation, and the evaluations were led by investigators at the Navy Experimental Diving Unit (NEDU). Generous support was also contributed by personnel from the Naval Civil Engineering Laboratory (NCEL) and the Naval Coastal Systems Center (NCSC). The principle parts of the evaluation included: a study of the corrosion resistance and general acceptability of the material composition of the system, a detailed study of the life support system, an evaluation of operator and patient/tender human factors, and an evaluation of the system's performance and ease of (Continued) on reverse side.				
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL NEDU Librarian	22b. TELEPHONE (Include Area Code) 904-234-4351	22c. OFFICE SYMBOL		

19. CONTINUED

handling in the field. The evaluation proved that the design concept of the PTRCS is valid, but that a number of design and manufacturing improvements must be made before the system can be approved for procurement.

The PTRCS is unique among small recompression chambers in that it features a detachable outer lock, or transfer chamber (TC) which is capable of allowing for the transfer of personnel while the inner lock, or emergency evacuation chamber (EEC) remains at depth. The mating mechanism conforms to the NATO STANAG agreement for recompression chamber mating ring adapters. The PTRCS also features an air pressure driven CO2 scrubber which employs soda lime as the scrubbing agent. The chamber system is composed of a special duplex stainless steel alloy which allows thin walls and thus a low total system weight (TC weight is less than 900 pounds).

When required improvements are attained, the chamber system will satisfy the operational requirements of a number of DOD diving activities which are ordinarily without chamber support at their diving site.

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Justification	
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Distribution/	
Availability Codes	
Dist	Avail and/or Special
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I. INTRODUCTION

A. MISSION REQUIREMENT FOR PORTABLE CHAMBER. The requirement for a lightweight, portable hyperbaric treatment chamber has existed in DOD diving communities for several years. The last significant effort to place such a unit in service was the PRC (Portable Recompression Chamber)¹. In this case, the chamber was a monolock, monoplace, semiclosed system. For various reasons this equipment never received wide fleet usage, and procured units were eventually taken out of service indefinitely. Other NATO navies have adopted the Draeger built "DUOCOM" system, which is a dual place, monolock, semiclosed portable system. This system is fitted with a mating device built to NATO specifications² which therefore adds the capability of transport under pressure to a definitive treatment chamber (DTC) and personnel transfer under pressure while mated to the DTC. The Explosive Ordnance Disposal (EOD) community is currently the only diving community in the U.S. Navy with a written Operational or Tentative Operational Requirement (TOR) on file³. However, the language of that TOR is applicable to EOD, Underwater Construction Team (UCT), Mobile Diving and Salvage Unit (MDSU), diving activities in the Navy, and to Marine Corps reconnaissance, Army and Navy special warfare, and Army engineer diving units as well.

B. MANUFACTURER OF PTRCS AND SOURCE OF FUNDING. In 1987, the Australian firm International Innovations Limited (IIL) introduced an aluminum hulled, semi-closed, detachable-dual lock, dual place portable chamber system which they named the "Paracel Transportable Recompression Chamber System" (PTRCS). After the demonstration of this model at the Navy Experimental Diving Unit (NEDU) in the fall of 1987, an effort was immediately set underway to procure a unit for evaluation, funded under the Foreign Weapons Evaluation program. The design criterion for this system was largely formed by the requirements of the Australian National Safety Council. The procurement from IIL included two complete PTRCS systems, each including: one emergency evacuation chamber (EEC), (or inner, dual-place lock), one transfer chamber (TC), (or outer lock), and a gas stowage cart for each chamber. Details of the makeup of these systems are outlined below in part II. The hardware was actually constructed by another Australian firm under contract with IIL, named Cowan Manufacturing PTY. Generous amounts of the original engineering work was accomplished by other firms and individuals, all under contract with IIL.

C. SCOPE OF EVALUATION. This project was divided into several parts, some of which were then delegated to other activities⁴. Specifically, Naval Civil Engineering Laboratory (NCEL) was tasked to study system reliability, material durability and applicability in the Arctic environment. Their evaluation is fully documented in a published Technical Memorandum⁵. A synopsis of their report is contained in part III. Similarly, a separate report was issued by NEDU on the evaluation of the CO₂ scrubbing system⁶. The scrubber evaluation was actually conducted in the NEDU unmanned test facility, with engineering personnel support provided by Naval Coastal Systems Center (NCSC). After completion of the reliability study, the scrubber study and the drafting of a test plan⁷, manned diving operations at NEDU for human factors evaluation and field employments under NEDU test direction⁷ were accomplished. Further field testing with other diving commands is currently in progress⁸. Results of these manned diving operations and field employments are also detailed in part III.

D. FEATURES REMAINING TO BE EVALUATED. During this evaluation, it was found that the workmanship and possibly the design of the mating mechanism would lead to questionable pressure-tight integrity. It was found that the procedure to lubricate and maintain the bearing and seating surfaces in the mating assembly were prohibitively difficult. For these reasons, investigators at NEDU decided to defer the evaluation of:

1. TRANSPORTABILITY WITH TREATMENT IN PROGRESS
2. MATING CAPABILITY TO DEFINITIVE TREATMENT CHAMBER WITH TRANSFER OF OCCUPANTS WHILE AT DEPTH.

The manufacturer has been given the opportunity to repair or replace as necessary the mating device and has elected to replace the chamber systems in whole while incorporating other design improvements made since delivery of the original models for evaluation in January and February of 1989. If approved, a continuation of the evaluation will be conducted which will specifically look at (1) and (2) above as well as the acceptability of other modifications made. Results will then be published in a NEDU Technical Report. Delivery of the first of the replacement PTRCS units is tentatively scheduled for May 1990.

II. FUNCTIONAL DESCRIPTION OF EQUIPMENT WITH RELATED EQUIPMENT-SPECIFIC CONCLUSIONS

A. CHAMBER HULLS. The chamber system is composed of two hulls; (1) a conically shaped treatment chamber (EEC) (Appendix C, photographs 1, 2, 3, 4) which contains a removable litter for the patient and a retractable bench seat for the tender, and (2) the transfer chamber (TC) (Appendix C, photographs 5, 6, 9), which has sufficient interior room for one occupant with the present door design. In the TC, interior space would be sufficient for two personnel to ride side-by-side, but the door diameter is so large that the outer door cannot be closed nor the inner door opened with two riders present. Both chambers have a floodable volume of 44 cubic feet. The EEC is equipped with a medical service lock of sufficient size to transfer the system's CO₂ scrubbing canister or other supplies required during a treatment. Unfortunately, the placement of the service lock on the evaluation units is directly over the patient's chest, and in that regard is highly inconvenient. The evaluation model had no safety interlock to prevent the outside operator from accidentally opening the service lock door while the lock was still pressurized. The service lock door was found to be extremely difficult to seat. These problems were relayed to the manufacturer as they were discovered, and IIL has indicated that replacement models will correct all three of these deficiencies. The material composition and corrosion characteristics of the vessels is detailed in the NCEL Tech Memo³. Their findings indicate that the choice of materials in the construction of the PTRCS is entirely adequate for the anticipated operating environment (at sea, aboard small craft).

B. PIPING SYSTEMS. In the evaluation units, a variety of Garlock, pipe threaded, and oxygen system fittings all in metric units of measure were used to connect sections of stainless steel flexible whip and stainless steel tubing (Appendix C, photograph 7). Extensive repairs and replacements of various whips and fittings were accomplished at NCEL and NEDU to make the chamber systems functional in order to complete the study. Concern over piping practice was relayed to the manufacturer early in the evaluation process, and improvements in the piping design have been reported by the

manufacturer for future units. The compression, exhaust and scrubber jet piping design will be entirely different in replacement units and the components selected will be of USA origin thus simplifying system design and procurement of spare parts. A detailed evaluation of the piping system design and its performance will therefore be deferred to the follow-on report mentioned in part I.

C. BIBS SYSTEMS. The built-in breathing system (BIBS) design in the treatment chamber allows the tender to place himself and the patient on air, on oxygen or one occupant on either (Appendix C, photographs 4, 8). The regulated air capacity of the EEC will allow occupants to breathe BIBS air while the scrubber jet is properly pressurized, but gas consumption calculations do not reflect this mode of operation. When both occupants are wearing BIBS the scrubber is secured in order to conserve the air supply. The PTRCS came equipped with Scott II Aviation type masks which are presently approved for Navy use. The BIBS performed adequately in all modes at all depths. The transfer chamber is not equipped with a CO₂ scrubber, therefore when occupied, the installed, air-only BIBS system is required for constant use. The TC BIBS was not evaluated at any depth since the evaluation to date has not been able to focus on the employment of the transfer chamber.

D. INDICATORS AND CONTROLS. The compression/decompression of the chamber, and pressurization of the scrubber jet was found to be easy to control and reliable. Improvements in the size and quality of the regulators installed and a detailed statistical reliability study are described in the NCEL technical memorandum. Pressure and depth gauges were generally placed correctly and performed adequately. The EEC is equipped with a Teledyne 320B oxygen analyzer and a mounting bracket. The chamber exhaust manifold is equipped with a needle valve to regulate gas sample supply to the instrument.

E. COMMUNICATION SYSTEMS. Each vessel in the system was equipped with a battery powered two-way interior communication (IC) set. The IC system allowed both the inside tender and outside operator to use voice box or a head set for communication. It was found that in the confined space of the treatment chamber the amplified audio output of the speaker was sometimes difficult to lower to tolerable levels. The evaluated IC system was equipped with a battery charger, and battery life between rechargings was found to be adequate. It was also discovered that inside and outside personnel could carry on discussions quite clearly right through the hull itself. A simpler and less expensive yet completely adequate substitute for the evaluated IC system would be a sound powered telephone such as is already in use in fleet chambers.

F. GAS CARTS. The systems were equipped with steel dollies designed for the stowage of "K" bottles and permit each chamber hull to be mounted on its respective dolly. These gas carts were convenient for maneuvering the chambers around on a smooth slab floor, but they are of no use in the anticipated operating environment. In fact, the present skid design requires that the chamber first be secured to a pallet before using a fork lift truck. Since our recommendation to modify the skid system will not be incorporated in replacement units, this issue becomes a standing recommendation for follow-on units.

G. MATING ASSEMBLY. The ability to attach/detach the small outer lock, or to attach the emergency evacuation chamber (EEC, also called the treatment chamber) to a definitive treatment chamber, is one of the key design concepts of this system. The bayonet-style rotating MALE ring is designed to mate with any FEMALE flange built to

NATO specifications (Appendix C, photographs 9 through 13). Unfortunately, for a number of reasons, the rotating ring design on these chambers failed to operate with an acceptable degree of reliability. Thus, an evaluation of the mating system was impossible to perform on the hardware delivered. This feature of the chamber system is one of the items which has received extensive re-design by the manufacturer. The recommendation will be made that the improved design be evaluated in the replacement units.

H. AIR AND O₂ STORAGE SYSTEMS. The systems as delivered came with no gas storage equipment except for the carts in which to stow "K" bottles. When the unmanned evaluations were conducted, the air supplies were received from large installed HP air systems at NEDU. On the manned diving and field evaluations conducted by UCT-2 and NCEL divers, primary and secondary pallets of 4 "K" bottles each and HP air compressors from their inventory were used for HP air service. Oxygen was also stored in "K" bottles and strapped semi-permanently into special pallets for HP O₂ service. When an additional opportunity for an Arctic field evaluation in 1990 became available, NEDU decided to acquire the air stowage system designed for the lightweight dive system and modify the flask sets for HP air and HP O₂ service for the PTRCS. This was handily accomplished by technicians at NCSC and NEDU. The design provides a far lower total weight than palletized "K" bottles. This would be a most advantageous design for UCT and EOD units employing the PTRCS in the future.

III. TEST PROCEDURES AND RESULTS

A. SYNOPSIS OF RELIABILITY STUDY CONDUCTED AT NCEL. A reliability study was conducted among the evaluation assignments carried out at NCEL. To gather the data required, numerous compressions, decompressions and scrubber pressurizations were accomplished in a dive profile that represented a treatment table 4. This profile was selected because it included the largest number of operator actions and valve adjustments. The methods and data are detailed in NCEL Technical Memorandum 45-90-002⁵. A 99.88 % confidence level was achieved during reliability testing, that the EEC high pressure and low pressure air subsystems Mean Time Between Failures (MTBF) met the required MTBF of 90.5 hours.

B. SYNOPSIS OF CO₂ SCRUBBER STUDY. The initial scrubber study was accomplished in the NEDU unmanned test facility. During this initial evaluation the appropriate scrubber pressure regulator settings were identified and written into the Operating Procedures (OP's). This evaluation revealed that by carefully selecting the regulator setting as a function of depth, air could be conserved while keeping the value of CO₂ in the chamber atmosphere well below 1.5 % (SEV) (Table 1). Later in the summer of 1989, a complete CO₂ scrubber study was accomplished. This study confirmed the results attained earlier and served to measure other parameters as well. The methods and results of this evaluation are detailed in NEDU Report 8-90⁶. One of the tests accomplished during the study was to model CO₂ injection according to that which would be expected during an actual treatment table 6A with extensions and to see how long a single canister would last. Figure 1 displays the results.

C. MANNED DIVE PROFILES. The purpose of the manned dive evaluation was to gather human factors data and subjective opinions of experienced operators. The profile as shown in the test plan represented a treatment table 6A in that it made the descent to 165 FSW and made stops at 60 and 30 FSW. During these dives, the tender was tasked to simulate all normal procedures required during the course of a hyperbaric treatment dive.

Table 1

Air Consumption During Modified TT6A With Extensions

Depth (FSW)	Time at Depth (minutes)	Scrubber (psig)	Exhaust (slpm)	Air Used (std liters) (std ft ³)	
0-165	ASAP	0	0.00	5901.90	224.50
165	30	150	16.15	484.50	18.42
165-60	4	150	16.15	64.60	2.46
60	125	90	12.01	1501.25	57.08
60-30	30	90-75	11.68 (AVG)	350.25	13.32
30	300	75	11.34	3402.00	129.35
30-0	30	60	4.64 (AVG)	139.20	5.29
			Total	11843.70	450.42

Treatment Table 6A - Model Run
 165' @150 PSI, 60' @90 PSI, 30' @75 PSI

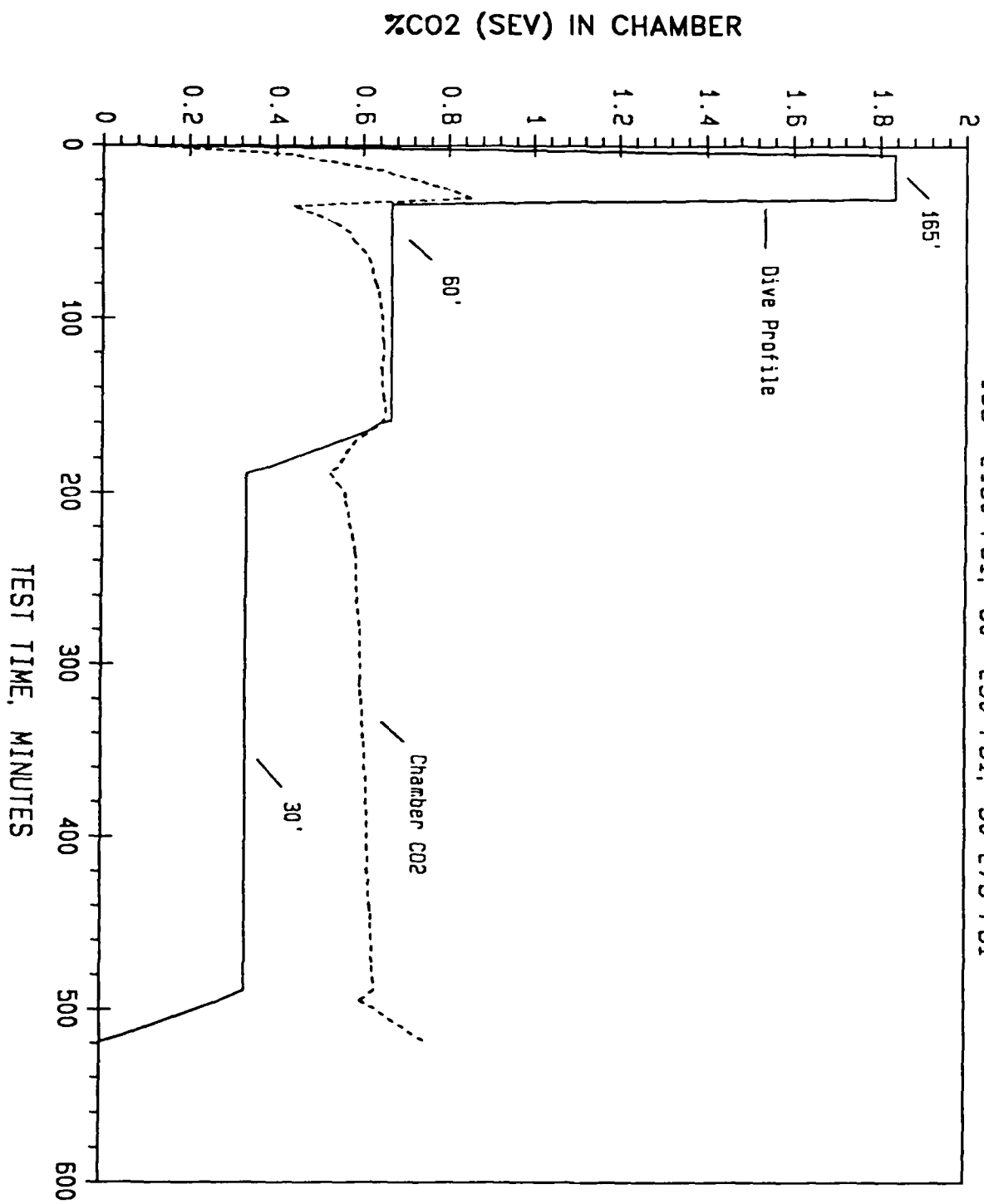


Figure 1

The results were uniformly positive, and showed that tenders could in fact perform in the EEC nearly as well as they would in a fleet chamber while patients were comfortable. The only possible exception noted was that basic cardiac life support (BCLS) could not be conducted as easily as in a fleet chamber, particularly due to the position of the medical service lock, and also because of the limited leg room for the tender. A discussion of these findings is contained in Appendix A. Outside operators found the controls to be understandable and desired depth was easy to control. A rapid buildup of the chamber humidity to 100% was experienced on every manned dive. During this dive series, the converted lightweight diving system flask assemblies were utilized and easily satisfied the requirements for gas storage.

D. SYNOPSIS OF FIELD STUDIES. Several field studies were undertaken in order to gather human factors data and operator input on the system's usefulness from various sources outside NEDU. Members of EOD Mobile Unit TWO examined the chamber system on board the 65-Foot EOD Support craft. The EEC supported by the lightweight diving system flask sets was well-suited for use on board the vessel. The chamber system was deployed to the Arctic during Ice-ex 89 by UCT Two and NCEL divers. In that evaluation the EEC performed as required, but it was discovered that the TC would not hold a seal when pressurized during the set-up and leak test procedure. Otherwise, the chamber system easily satisfied the mission and the logistic support limits and performed without difficulty.

IV. DISCUSSION

A. MONOLOCK VS DUAL LOCK. The chamber system composed of two detachable locks (one designed as a "hyperbaric ambulance" and the other as a personnel transfer lock) is a design that was inspired by the requirements of the Australian National Safety council. This concept is not required for all USN missions. In fact, in the opinion of members from all warfare areas who inspected or operated the chamber, the treatment chamber, matable to a standard deck chamber, is all the capability actually required. In all cases, the additional support requirements of taking the outer lock is not justified by the benefits of transferring tenders while at depth. Since the EEC is equipped with a medical service lock, transfers of essential medical supplies, food, or water can be easily be accomplished. Members from the EOD, UCT and Special Warfare areas enthusiastically support a chamber design that will be self-supporting during transport to a definitive treatment facility while a treatment is in progress.

B. LIMITATIONS RELATIVE TO STANDARD CHAMBER TREATMENT CAPABILITIES. The smallness of the chamber interior should necessarily impose some limits on the treatment protocols permissible in the PTRCS. When the chamber system was first acquired for evaluation, it was determined that the system would be authorized for treatment tables 5, 6, and 6A with those extensions normally allowed by the U.S. Navy Diving Manual Vol 1. Supporting arguments cited for this concept were, (1) that once the treatment of a serious casualty was begun, the chamber would be evacuated to a DTC and a transfer at depth would be accomplished, and (2) the likelihood of resolving CNS symptoms is improved by commencing the treatment without delay. This is a primary consideration for having the chamber system near the diving site. These reasons and the well-documented fact that the vast majority of all treatments conducted fall into the table 5, 6 or 6A categories add validity to these restrictions in use. The safe stay duration for a tender at depth with a serious casualty under treatment is beyond the scope of the PTRCS study.

C. EVALUATIONS NOT CONDUCTED. Evaluations of the chamber system's capabilities not yet conducted include:

1. Exchanging tenders through the TC with the EEC at depth.
2. Mating to a DTC and performing a personnel transfer at depth.
3. Transporting the EEC with occupants at depth to a DTC site.

The evaluation of tasks (1) and (2) will be conducted when the PTRCS system with the improved mating ring mechanism is received. A successful evaluation of (1) will allow us to extend the results to judge its performance when being mated to a large fleet chamber. The evaluation of item (3) can be accomplished at any time after receipt of the replacement units.

D. ADDITIONAL FIELD WORK CURRENTLY IN PROGRESS. UCT-1 is currently carrying out a field evaluation under NEDU Test Plan 90-01,⁸. In this evaluation, the chamber will be used first in the tropical environment, and then in the Arctic. The converted lightweight dive system flask sets will again be employed and evaluated.

V. REMAINING CONCLUSIONS

An assessment of the chamber design and construction, a laboratory evaluation of the life support system (CO₂ scrubber), and a battery of field and manned diving evaluations allow NEDU to conclude that:

1. The concept of the PTRCS will satisfy the mission requirements for a dual place portable recompression chamber.
2. The life support system (CO₂ scrubber and BIBS) will perform adequately.
3. The PTRCS will perform with an appropriate MTBF at an acceptable confidence level.
4. Improvements in the mating system are essential in order to allow the evaluation of those items cited in paragraph IV (C) above.
5. The rapid rise of humidity in the EEC during the course of a treatment in combination with the high temperatures which would be found in many anticipated operating environments will severely limit the chamber system's usefulness due to heat stress until an acceptable method to control heat and humidity can be established. This remains a problem for all chamber systems not equipped with heater/chiller upgrades regardless of chamber size.

VI. RECOMMENDATIONS

NEDU recommends:

1. NAVSEA Task 88-23 be revised to include evaluation of those items listed in paragraph IV (C) above.

2. A CO₂ scrubber performance test be accomplished on the replacement chamber system due for delivery in June 90 in order to validate any design changes made by the manufacturer.

3. A study of heat and humidity control in the PTRCS be assigned.

4. A formal design recommendation for gas stowage on the PTRCS chassis be studied incorporating recent developments in composite flask technology.

REFERENCES

1. PRC Report (NEDU 1-74)
2. NATO SPECIFICATION FOR MATING ASSEMBLY (STANAG 1079)
3. EOD Operational Requirement (COMEODGRU2/N6:CL4 10560 SER 493 of 11 OCT 83)
4. NEDU TEST PLAN 88-29 (PTRCS)
5. NCEL Technical Memorandum (TM NO: 45-90-002)
6. NEDU Scrubber Report (NEDU 8-90)
7. NEDU TEST PLAN 89-44 (Manned Diving)
8. NEDU TEST PLAN 90-01 (UCT-1 Field Evaluation)

APPENDIX A

SUMMARY OF HUMAN FACTORS EVALUATION RESULTS

The objective of NEDU Test Plan 89-44 was to perform a human factors evaluation of the PTRCS during a manned diving scenario. A modified 170/:40 dive profile using ten experienced U.S. Navy divers was originated to represent an abbreviated Treatment Table 6A. Following the dive, a questionnaire addressing chamber comfort and medical treatment in the EEC was completed by the five two-man (patient and tender) teams. A summary of this human factors evolution is given below.

(1) CHAMBER ENTRANCE

- Tenders had difficulty placing and maintaining the stretcher wheels in the tracking.
- The stretcher was easily secured once inside the chamber.
- The best order of entry should be the tender inside before the patient, to assist in loading and locking the stretcher in place.

(2) EXITING THE CHAMBER

- Care must be taken by the tenders outside of the chamber to lift the litter from its track while unloading the patient, as the litter may drop onto the legs of the inside tender still inside.
- Two persons on the outside should be sufficient to load and unload the stretcher, given a patient of average size and weight, using the handholds.

(3) BIBS SYSTEM

- The BIBS system breathed as easily as those in conventional chambers.
- Tenders recommended color coding of the patient and tenders masks as confusion between the two existed in the chamber due to the long air hoses.
- The outside operators should assume control of the O₂ BIBS at depths greater than 60 feet, so as to avoid inadvertent switching on of O₂ instead of air at 165 FSW by the inside tender.
- The suggestion was made to shorten and hang the bibs hoses off of the floor to allow the tender easy access to the patient's feet, free of the hoses on the chamber floor.

(4) CHAMBER TEMPERATURE

- Ambient temperatures outside of the chamber were in the 50-60°F range.
- Interior maximum temperature was 100°F at 165 FSW.

- Interior temperatures at 10, 20, 30 and 60 FSW ranged from 78-84°F.
- The subjects reported comfort with inside temperatures to be comparable to other conventional sized chambers.

(5) CHAMBER HUMIDITY

- At 165 FSW initial humidity ranged from 49-78%.
- Inside occupants noted that discomfort due to high humidity increased with time in the chamber as the humidity rose to the 90-100% level.

(6) CHAMBER HABITABILITY

- Space was confined for the patient with respect to leg room, and for the tender in sitting position.
- Some of the subjects described a "closed in" feeling relative to larger chambers but were able to complete their runs without difficulty.
- The tallest "patient" was 78 inches tall, and he fit comfortably on the stretcher.
- Movement of the patient from side to side or to the prone position was impaired by the position of the medical lock over the patient.
- Tenders found that sitting on the small bench was uncomfortable after more than ten minutes and most resorted to sitting on the floor alongside the patient.

(7) CHAMBER LIGHTING

- Chamber lighting was dependent on the ambient light external to the chamber.
- Suggestion was made to add a viewport over the patient and the tender's heads to allow more light in at this location.

(8) MEDICAL SERVICE LOCK

- All subjects agreed that the location of the medical lock over the stretcher impeded movement of the patient and should be relocated.

(9) MEDICAL EXAM IN THE CHAMBER

- Access to the patient's legs for examination was greatly impaired.
- Construction of a shelf to hold exam equipment off of the floor was recommended.
- The patient's right arm could be examined better than the left.

- BCLS position is compromised at best and cannot be maintained for extended periods of time.

- Airway control (intubation, etc.) would also be impossible if attempted after the patient was placed in the chamber, as the tender cannot adequately position himself above the patient's head.

- The head and neck exam could be performed without difficulty.

- Overall, a complete and accurate neurological exam cannot be easily performed in the chamber, given the limited access to the patient's lower extremities and left side. This would be particularly difficult with an unconscious or otherwise uncooperative patient.

(10) OTHER

- Reposition the pressure relief valve off of the floor so as not to impede access to the patients lower extremities.

- The number of hand holds inside the chamber seemed adequate for the tender and patient.

APPENDIX B

HYPERBARIC ENGINEERING EVALUATION RESULTS

The following is a summary of the material deficiencies discovered during inspection and operation of the two chamber systems under study. Design change recommendations are submitted where features of the chamber system were discovered that could be improved, but did not effect the conduct of the present study. The first system was received at NCEL and was named EDM 1. The second unit, which is the unit that was actually employed in the Arctic during Ice-ex 89, was received at NEDU and was named EDM 2.

Deficiency 1. Door boss rings on EEC and both ends of TC on EDM 1 and 2 were undersized according to AS1210. (Westinghouse Electric Corp., Machinery Technology Division, ltr ser: WN 892577, of 7 JUN 89 refers.)

Deficiency 2. Mating device/self-energizing seal on EDM 1 failed to hold pressure. Male ring was severely undersized, (deficiency corrected by manufacturer). On both EDM 1 and 2, operation and removal of the mating assembly was inordinately difficult. (Appendix C photographs 11-13.)

Deficiency 3. View port boss rings out of round on EDM 1 and 2.

Deficiency 4. Canister receiver O-ring groove poorly fabricated on EDM 1, marginal on EDM 2. Deficiency led to lack of air-tightness around base of scrubber canister when installed in receiver. (Appendix C, photograph 14.)

Deficiency 5. EEC door hangers in EDM 1 and 2 both sheared under weight of EEC door.

Deficiency 6. Control panel cover edges rubbed grooves into chamber pressure hull during transport.

Deficiency 7. Flexible whip piping under control panel cover was built with bend radii that caused crimping and broken connections. Also, incompatible connector and thread types were used to join flex whips, hard pipe and components.

Deficiency 8. TC to EDM 2 would not hold pressure. Chamber never used.

Deficiency 9. Interior paint in TC and EEC to EDM 1 and 2 never fully cured. Chambers off-gassed paint fumes at a detectable level for many months.

Deficiency 10. When litter is in the secured position, it is still free to shift longitudinally, becoming hazardous in a seaway.

Deficiency 11. Inside and outside medical lock doors would seal only with great difficulty.

Deficiency 12. EDM 1 was delivered with liquid teflon throughout the piping system. System was commercially cleaned by a contractor retained by NCEL.

Deficiency 13. Original pressure regulators in EDM 1 were severely undersized. Would not perform without freezing. Regulators were all replaced by technicians at NCEL.

Deficiency 14. Machining on EDM 1 manway flange was done incorrectly. Repairs were performed by the manufacturer on the overmachined seal groove using Belzona powdered metal. (Appendix C photograph 11.)

Deficiency 15. Scrubber jet nozzle in EDM 2 was received plugged and installed in the upstream aspect. Condition corrected at NEDU.

Deficiency 16. EEC door is free to swing on its hanger when the chamber is not pressurized, causing damage to both the door and its seating surface when in a seaway.

Deficiency 17. O₂ BIBS system operating pressure is 90 psi. Air system operating pressure is 250 psi. When inside occupants switch the BIBS supply valves from air to O₂, the O₂ piping is temporarily 'back pressurized' causing the O₂ pressure relief to lift at the control console.

Design Recommendation 1. Doors to TC should be the same diameter as the EEC. A smaller manway will permit two occupants to ride in the TC, (as in a surface decompression dive).

Design Recommendation 2. EEC undercarriage should be built with the EEC's air and O₂ supply as an integral unit. The design would more easily facilitate movement to/from an aircraft, small boat or truck even if a fork lift or power lift were required. Undercarriage should be designed to accommodate a forklift without having to mount the system to a pallet.

Design Recommendation 3. Medical lock should be mounted in a true horizontal attitude, and should be placed beneath the bunk vice over the patient's chest. Additionally, medical service lock should have a mechanical interlock to prevent the outside operator from opening the system while pressurized.

Design Recommendation 4. Control piping should be simplified, parts should be USA origin and English units of measure, and control console panels should be completely removed.

Design Recommendation 5. Exhaust line should be terminated on the opposite side of the chamber vice at the operator's station in order to reduce noise.

Design Recommendation 6. EEC door should be secured differently to prevent swinging on its hook in rough sea conditions.

Design Recommendation 7. A 0-10 liter per minute flow meter should be installed on the EEC for use with the Teledyne 320B O₂ monitor.

Design Recommendation 8. A litter rail offering greater stability during loading and unloading the patient and during transport in heavy seas with the litter in its locked position should be incorporated.

Design Recommendation 9. A method to control heat and humidity of the EEC environment should be installed. It should be possible to cool the chamber interior to 85 °F or less with the chamber at depth in a shaded area. Humidity should be controllable at 70-80 percent.

Design Recommendation 10. BIBS hoses are far too long, excess hose is a nuisance inside the chamber. BIBS hoses should be no longer than 36 to 40 inches.

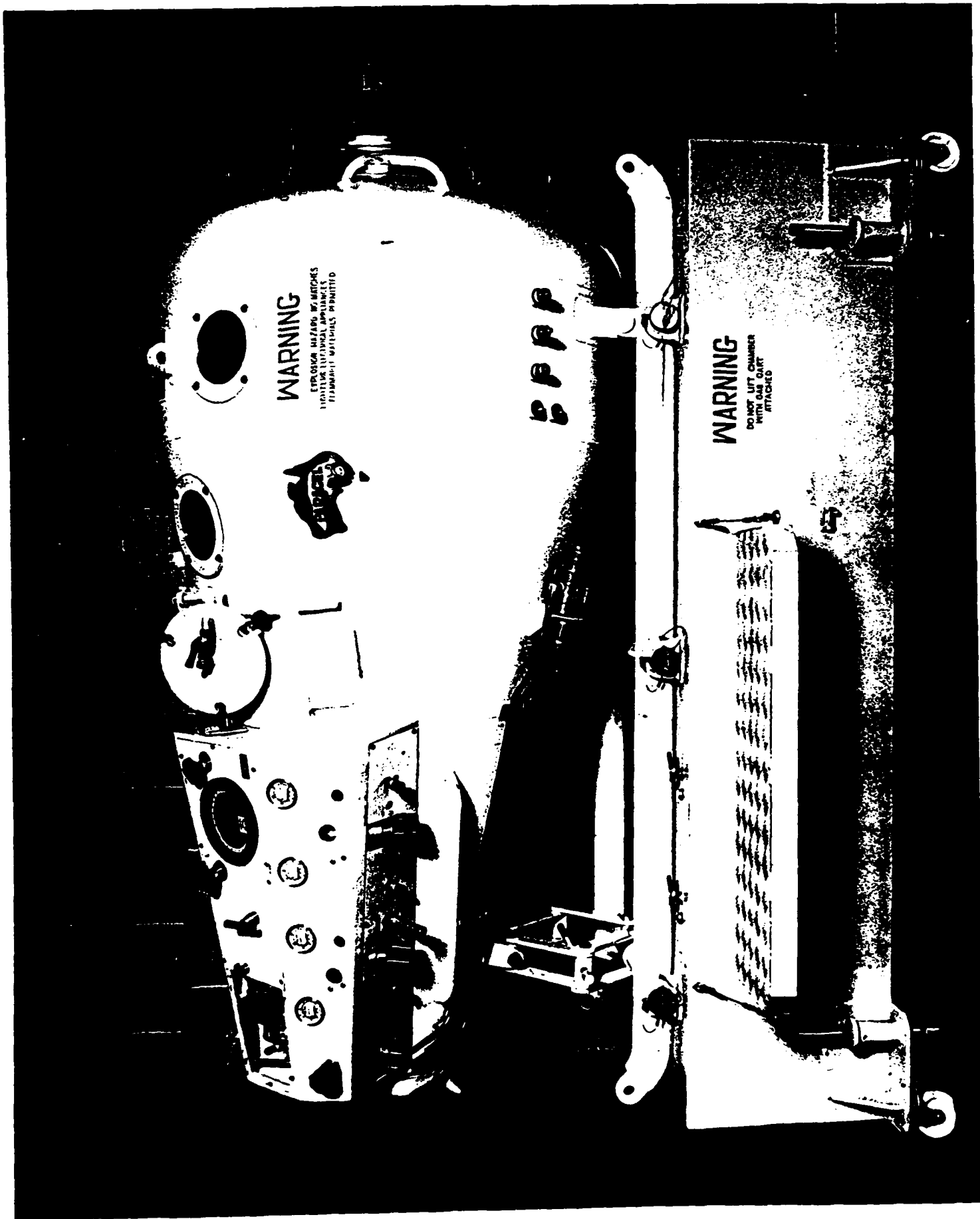
Design Recommendation 11. Lifting padeyes should be installed in the correct orientation to accommodate lifting the load (they were installed 90 degrees out from the correct position).

Design Recommendation 12. Handholds should be installed on the outside of the hatch cover.

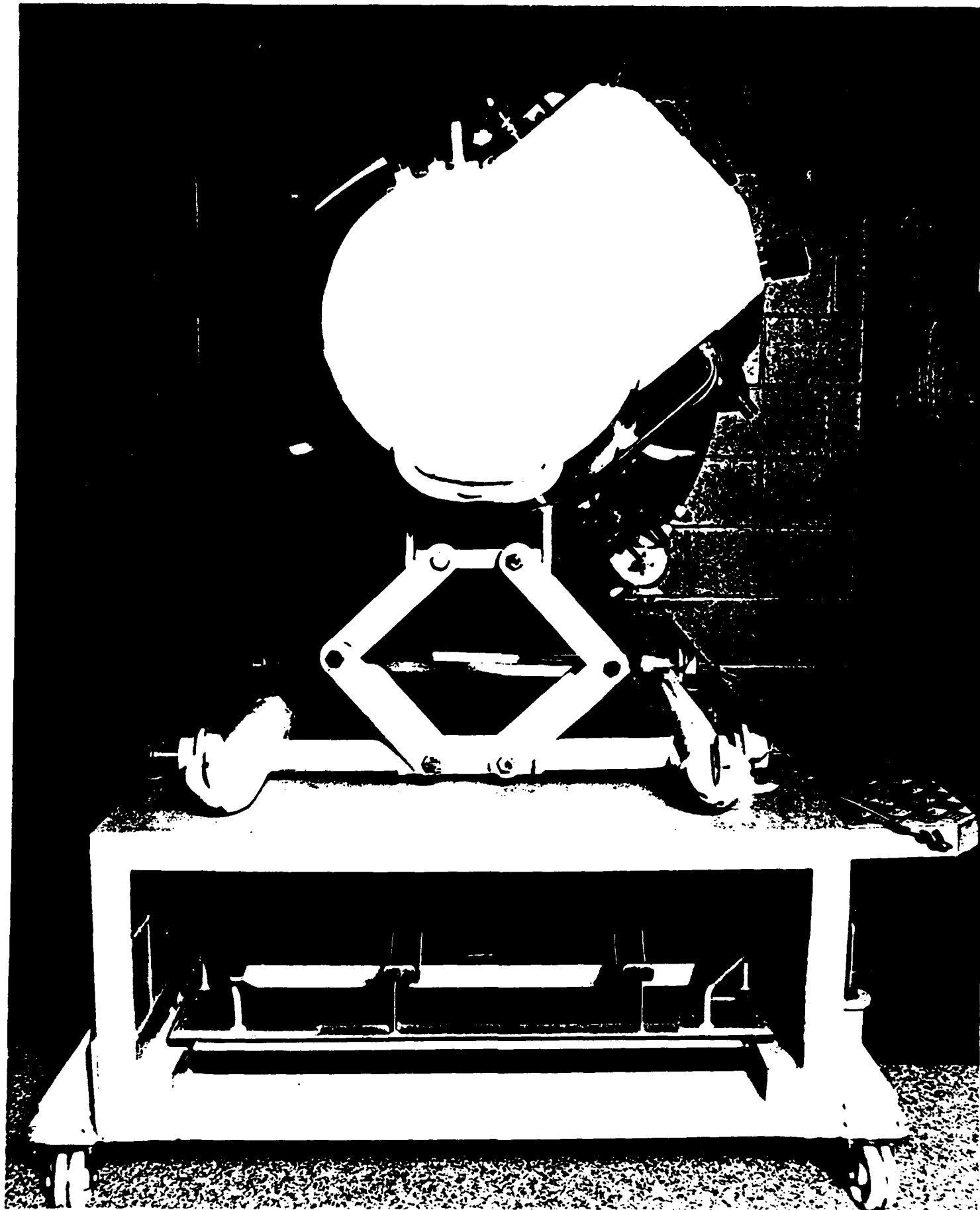
APPENDIX C

PHOTOGRAPHS

1. EEC Side View
2. EEC Apex - End View
3. EEC Manway - End View
4. EEC Interior View
5. TC Side View
6. TC Manway - End View
7. EEC Controls
8. EEC BIBS Piping
9. TC Mating Ring - End View
10. EEC Mating Ring Close Up View
11. TC LP Seal Close Up View
12. EEC Mating Ring - Side View
13. EEC Mating Ring
14. Scrubber Receiver



Photograph 1. EEC Side View



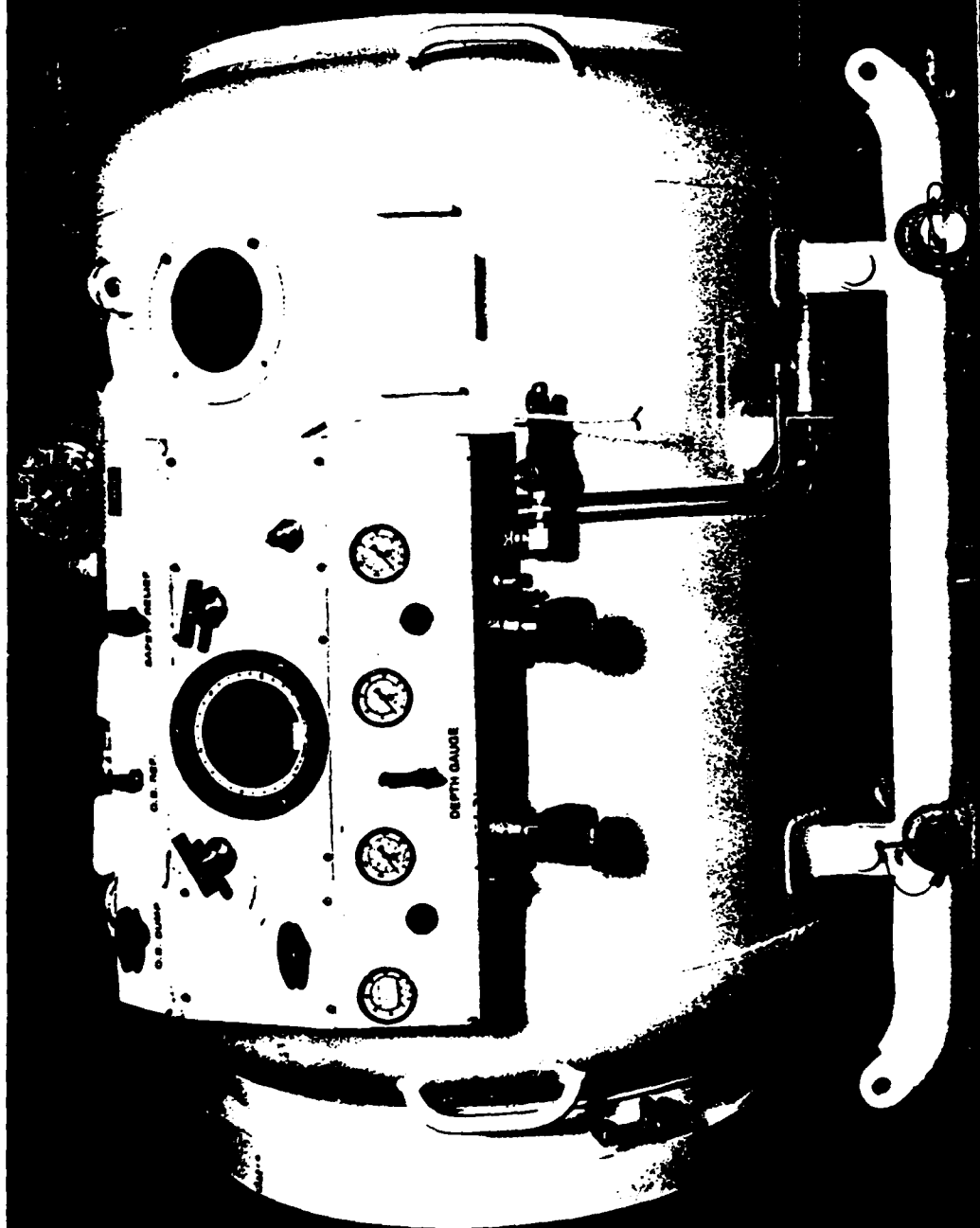
Photograph 2. EEC Apex - End View



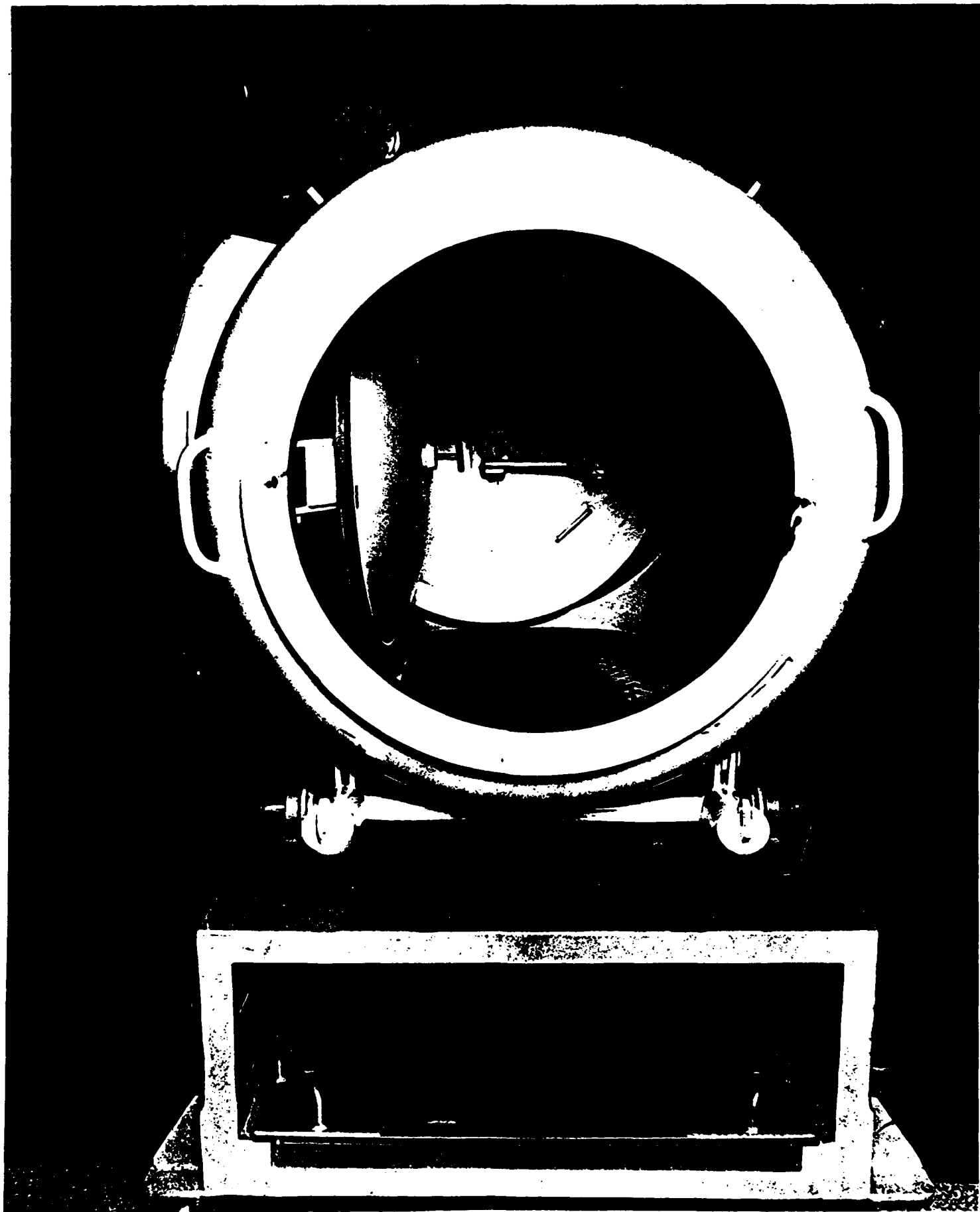
Photograph 3. EEC Manway - End View



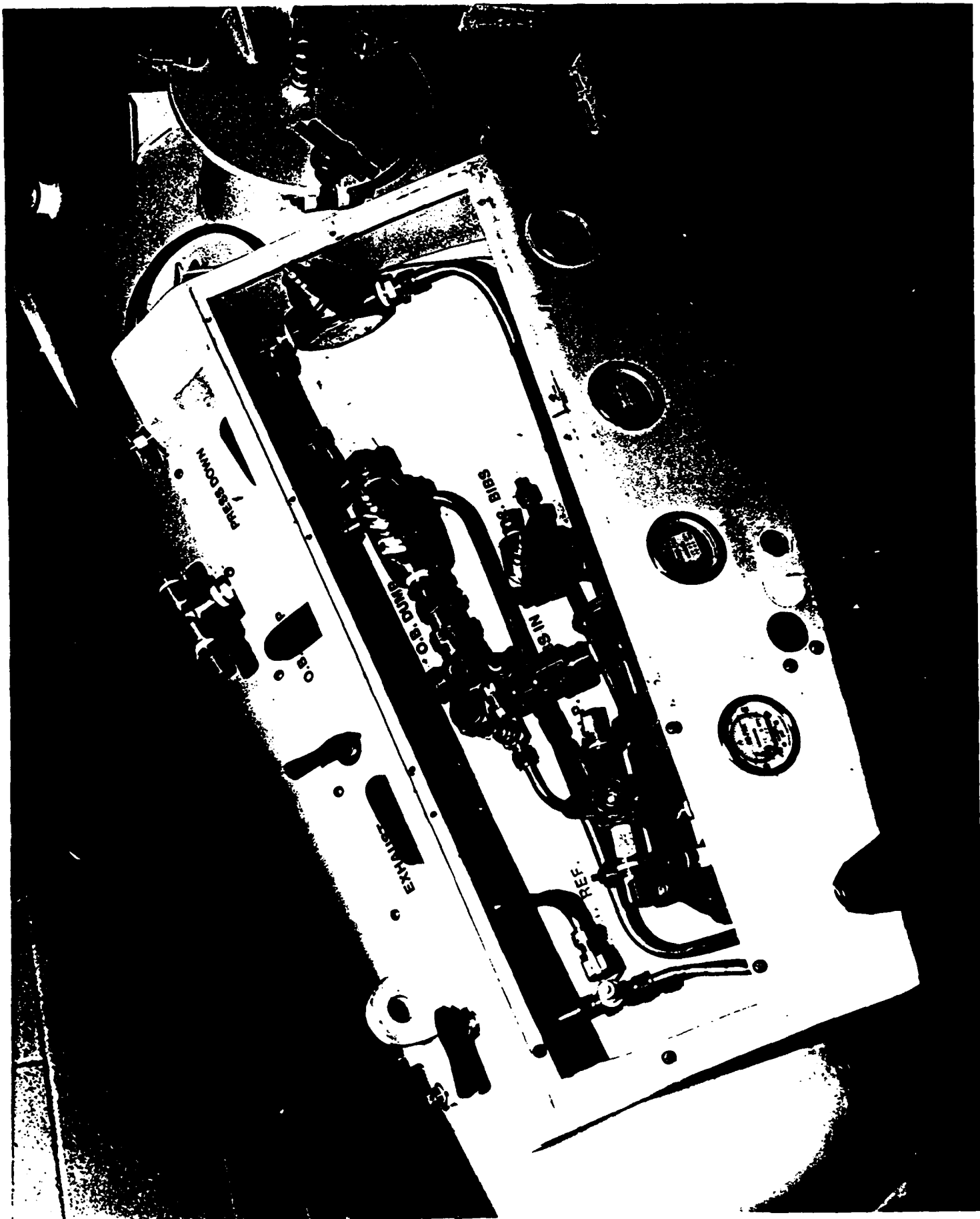
Photograph 4. EEC Interior View



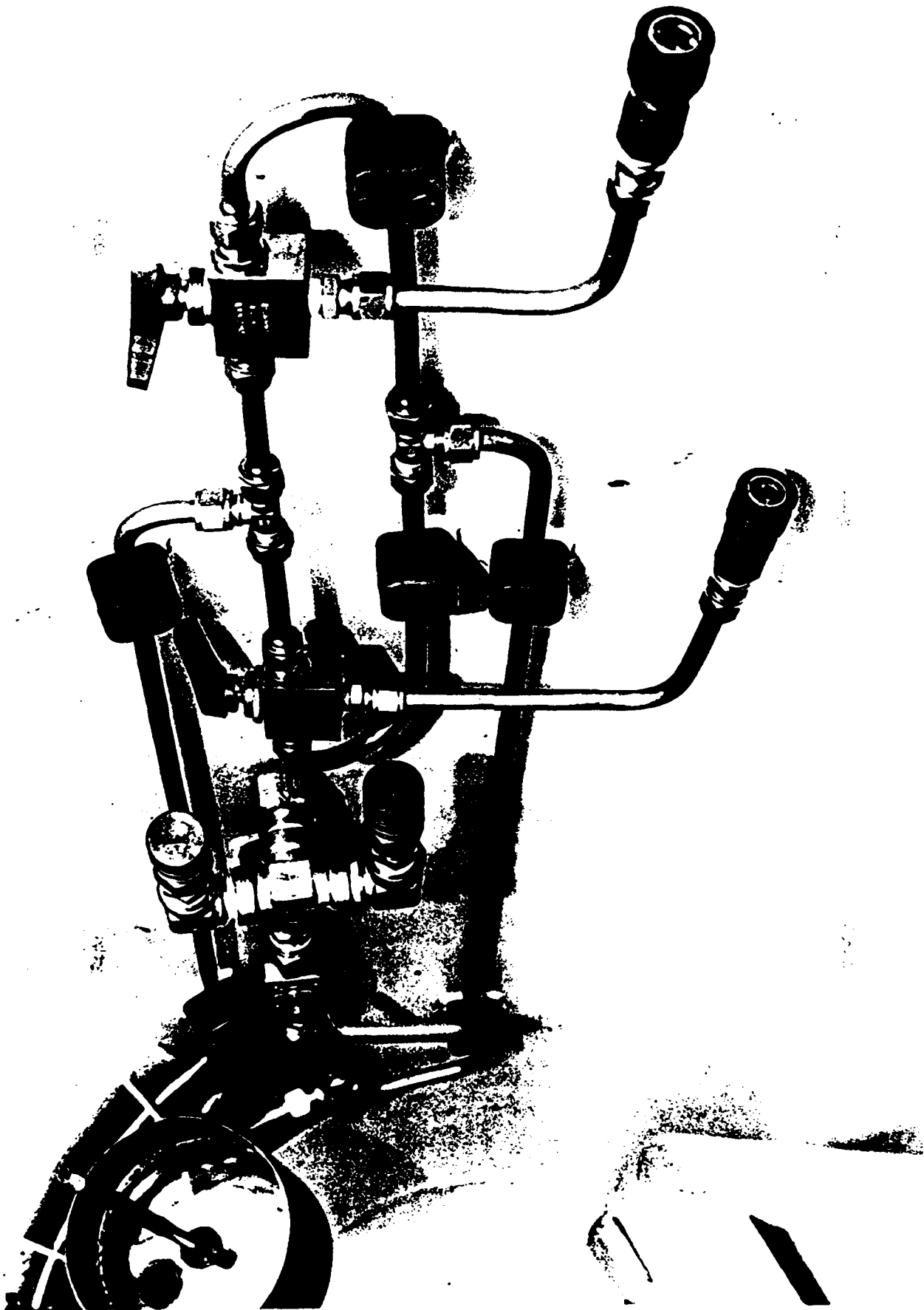
Photograph 5. TC Side View



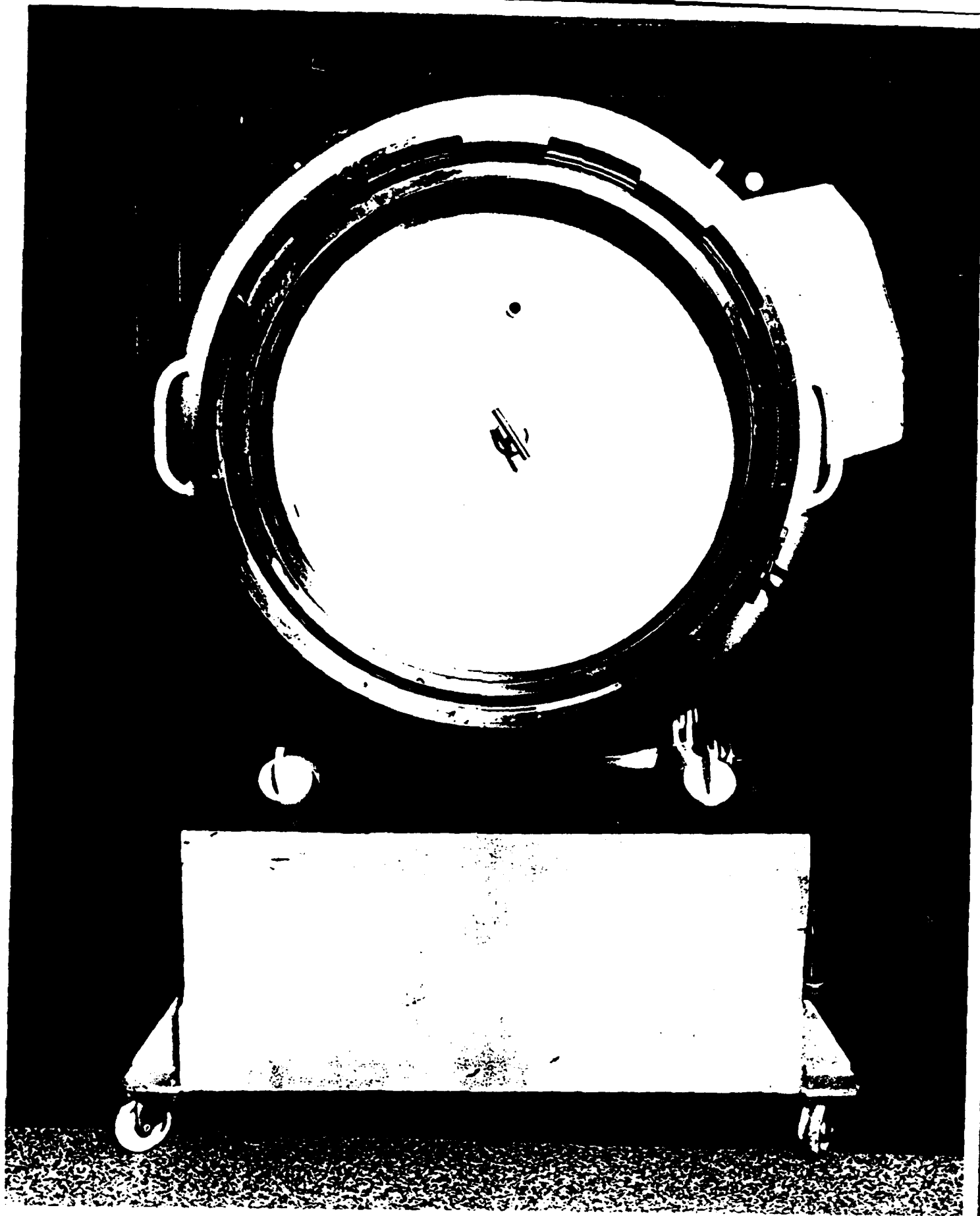
Photograph 6. TC Manway - End View



Photograph 7. EEC Controls



Photograph 8. EEC BIBS Piping



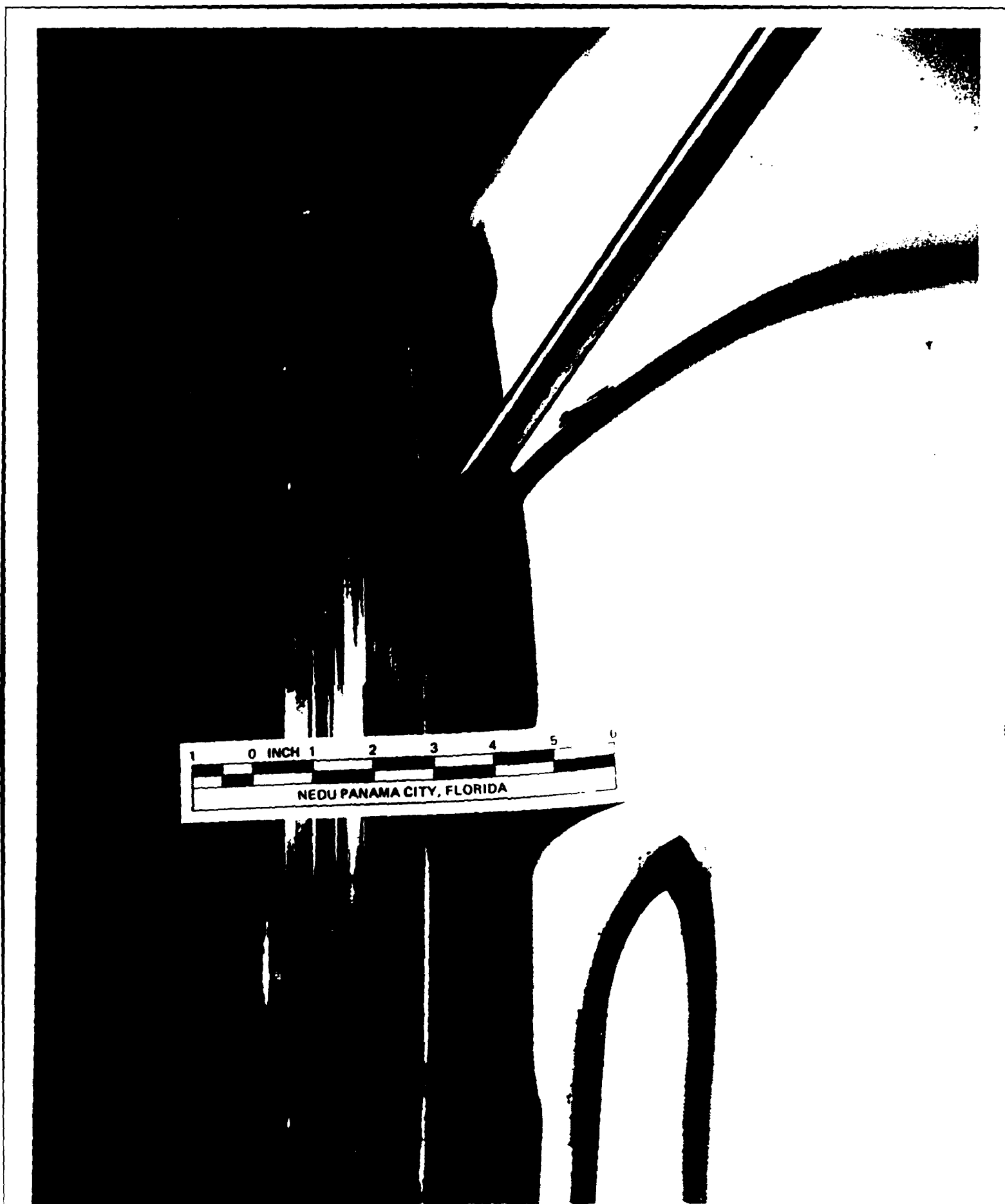
Photograph 9. TC Mating Ring - End View



Photograph 10. EEC Mating Ring Close Up View



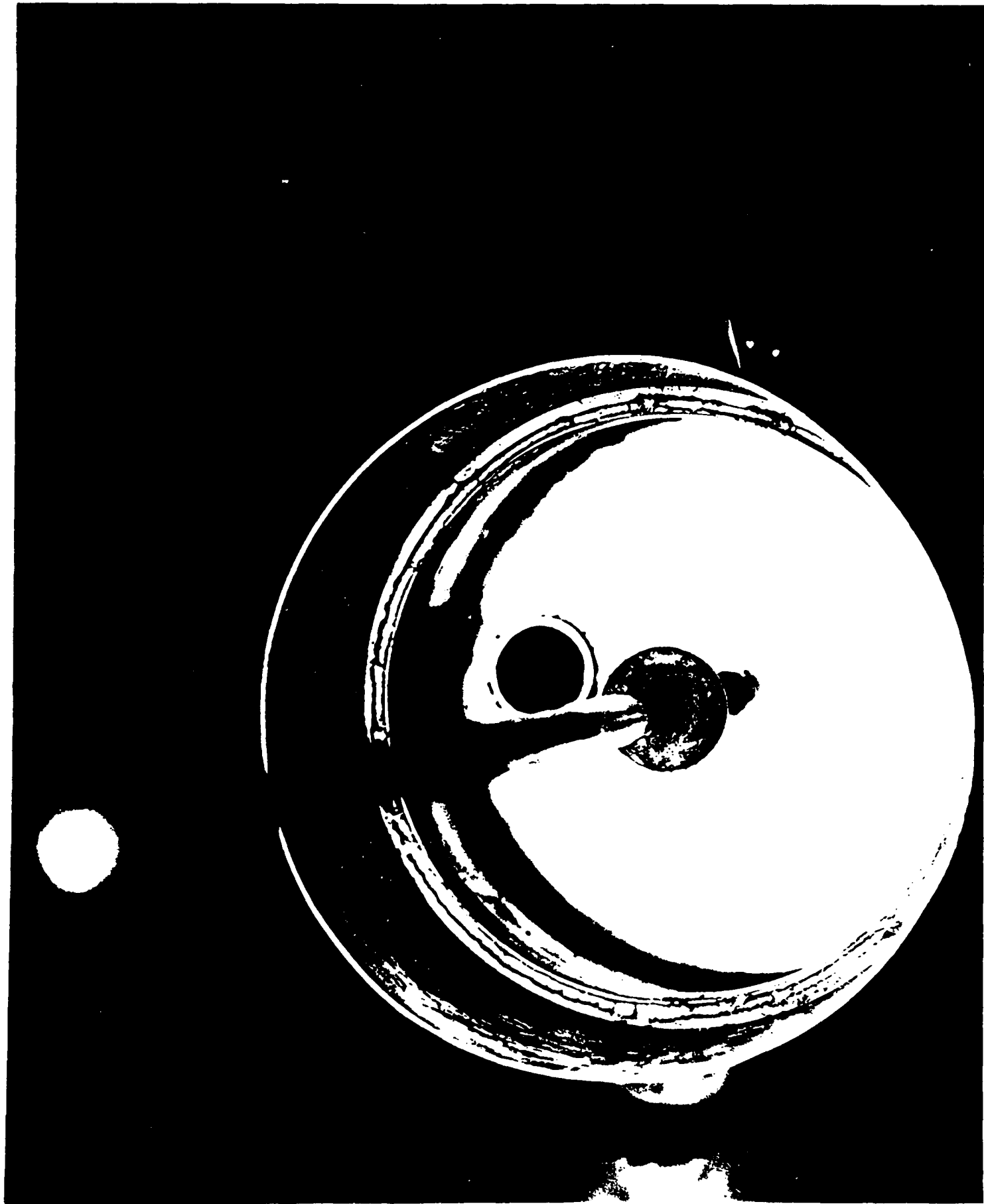
Photograph 11. TC LP Seal Close Up View



Photograph 12. EEC Mating Ring - Side View



Photograph 13. EEC Mating Ring



Photograph 14. Scrubber Receiver