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ULTRASONIC INSPECTION OF REACTOR SYSTEMS

by

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ULTRASONIC INSPECTION OF REACTOR SYSTEMS
(UNCLASSIFIED)

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Ultrasonic inspection techniques have been developed for application to the moderator piping and tank wall welds of the Savannah River Site reactors. The reactor tanks and piping systems in the primary cooling loop are constructed of as-welded Type 304 stainless steel. Intergranular stress corrosion cracking in the weld heat-affected zones and other heat affected areas has caused leaks in the moderator piping of all three operating reactors and the C-Reactor tank. The ultrasonic inspection procedures provide early detection and sizing of cracks for the purpose of preventative maintenance and evaluation of service life.

Ultrasonic inspection of the moderator piping welds was initiated in 1984. A P-Scan[R] remote data acquisition system operated by certified inspectors is used to interrogate the areas of interest which include butt welds, flamewashed areas,longitudinal weld seams, and pipe brace attachment welds. To date over 1800 locations have been inspected.

Approximately five percent of the locations were found to contain intergranular stress corrosion cracks. A total of 25 pipe sections have been replaced with Type 304L stainless steel components and an additional 38 locations containing minor cracks are being monitored annually as a result of these inspections. A second five-year cycle of inspection of all accessible welds in the moderator piping system will begin this year.

A special robotic arm and ancillary equipment has been designed and built for ultrasonic and eddy current inspection of the interior surfaces of the reactor tanks. The inspections will be conducted on the heat affected zones of the reactor tank wall welds and other heat affected areas on the tank walls. The robotic arm and other in-tank equipment is designed to pass through a 4-inch diameter fuel entry port, operate under water in a high radiation field, and feed data to a remote operating center. The inspection system is based on an AMDATA Intraspect-98[R] remote data acquisition system. Development of the equipment has been underway since 1986. The equipment fabrication and testing and inspector training will be complete in July, 1989. Initial tank wall weld inspections will be conducted in P-Reactor starting in late July.

Acceptance criteria for both inspections is based on stress analysis and fracture mechanics analysis of the reactor systems. Both inspections will be incorporated into the long range in-service inspection plan for the Savannah River Site reactors.

ULTRASONIC INSPECTION OF REACTOR SYSTEMS

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Introduction:

(Slide 1)

Good afternoon Ladies and Gentleman. My name is Ed Majzlik and I work at the Savannah River Site (SRS) in the Savannah River Laboratory. Today is a day of firsts for me. This is my first presentation at a WANTO Meeting and my first off-site presentation as a representative of the Westinghouse Savannah River Corporation. It's a pleasure to be here. I've enjoyed several excellent presentations in the last two days and appreciated the fine facility tour provided by our host the Allied-Signal Aerospace Company.

(Slide 2)

The subject of my presentation is ultrasonic inspection of reactor systems. I will describe two current programs underway at Savannah River Site which provide state-of-the-art ultrasonic inspections of weld heat-affected zones in the primary cooling loop of the Savannah River Site reactors. I will describe the automated remote inspection equipment being developed and employed; speak briefly about the procedures being used; and give you a general idea of the future direction of two major programs: Moderator Piping Inspection Program and the Reactor Tank Wall Weld Inspection Program. The objective of these programs is to provide inspection techniques to more fully determine the condition of the reactor primary systems and provide data for prediction of maintenance needs and remaining service life. Detection and sizing of intergranular stress corrosion cracking is the focus of these programs.

Description of Reactors:

(Slide 3)

The SRS reactors were constructed in the early 1950's for production of plutonium and tritium required for defense programs. The typical appearance of the SRS reactor buildings is shown on this slide. Presently, three reactors (P, K, and L) are in active status and two (C, and R) are in stand-by status.

(Slide 4)

The inspections I will describe are focused on the primary cooling loop and reactor tank wall welds. A cut-away drawing of the reactor tank and primary cooling loop is shown in this slide.

The reactor tank and piping are constructed of Type 304 stainless steel in the as-welded condition. The reactor tank is approximately 16 feet in diameter and 20 feet tall with 1/2-inch thick walls. The primary piping is 12 to 24-inches in diameter and has a wall thickness of 3/8 to 1/2-inch.

The primary cooling loop of the reactors contains heavy water which acts as a neutron moderator and coolant. The moderator is circulated in a closed-loop from the reactor tank through tube-and-sheet heat exchangers by large capacity pumps. There are six primary cooling loops and 12 heat exchangers per reactor.

Maximum operating temperature in the system is 95°C. The reactor tank operates at hydrostatic head pressure plus a 5 psig blanket gas pressure. Maximum pressure in the piping is 225 psig at the pump discharge.

Intergranular Stress Corrosion Cracking

The reactor systems have routinely been inspected and monitored for cracking and leaking by various methods since the earliest days of operation. Intergranular stress corrosion cracking

(IGSCC) similar to that which the commercial nuclear industry has experienced in recent years has been observed in some areas of the SRS reactor systems. The ultrasonic inspection programs are aimed at early detection and characterization of IGSCC in the weld zones of SRS piping and reactor tanks.

IGSCC typically occurs in sensitized Type 304 stainless steel when it is exposed to a sufficient tensile stress in the presence of oxygenated water. The reactor moderator typically contains 1PPM oxygen. Therefore, conditions supporting IGSCC exist in the heat-affected zones of the fabrication welds and other heat-affected areas in the SRS reactor cooling systems.

(Slide 5)
Typical IGSCC which was detected adjacent a butt-weld in a 16-inch diameter moderator pipe is shown in this slide. The cracks originate on the inner surface of the pipe and are oriented both circumferentially and axially. Cracking is confined to the heat-affected areas.

(Slide 6)
IGSCC has also occurred in the bottom-knuckle of the C-Reactor as shown in this slide. The knuckle is a specially fabricated and heat treated component unique to C-Reactor. C-Reactor is

temporarily out-of-service pending development of an acceptable crack repair method.

No cracking or leakage has been observed to date in any other region of C-Reactor or any of the other three reactor tanks.

(Slide 7)

The cracking observed in the piping and C-Reactor knuckle was classic intergranular stress corrosion cracking. The typical between-the-grains path of the cracks is illustrated in this photomicrograph of a circumferential crack adjacent a butt-weld in a moderator pipe. The magnification is approximately 200X. The intergranular nature of the cracking in the C-Reactor knuckle was confirmed by remote in-tank metallography and analysis of boat samples.

Moderator Piping Inspections

(Slide 8)

Ultrasonic inspection of the weld areas in the moderator piping began in 1984. The typical arrangement of a single moderator loop is shown in this slide. A portion of the welds in each reactor system were inspected on an annual schedule with the intent to inspect all accessible welds in a 5-year period.

(Slide 9)

The inspection points include butt welds, flame-washed areas, pipe brace attachment welds, and some portion of the longitudinal seam welds. Acceptance criteria are based on stress and fracture mechanics analysis of the piping system. Allowable flaw size is limited to 20% of the pipe circumferential and 50% of the wall thickness.

Since 1984 over 1800 locations have been inspected. About 5% of the areas have contained cracks. A total of 25 pipe sections have been replaced with Type 304L stainless steel and 38 cracked areas are being inspected annually to monitor crack propagation.

(Slide 10)

The inspections are performed by subcontracted inspectors certified by the Electric Power Research Institute (EPRI) for detection and sizing of IGSCC. The equipment used is the P-Scan R remote data acquisition system owned by Det Norske Veritas, Houston, Texas. A 45° shear wave signal of 1.5 to 2.25 mega-hertz projected on a 1 1/2 vee path is used for detection and sizing of the cracks. A sizing accuracy of ±0.1

inch on depth and ±0.5 inch on length is provided. The pipe scanner is operated in the semi-automatic and manual modes. The P-Scan unit provides a three view projection graphic display of the inspection data.

(Slide 11)
The P-Scan data acquisition system is setup in a central location adjacent the piping in the process area. An inspector operates the unit during data acquisition as shown in this slide.

(Slide 12)
Another inspector installs the scanner on the pipe as shown in this slide. Typically an hour is required to scan a circumferential weld using the semi-automatic scanner. Longitudinal welds and flame washed areas, and welds in difficult locations are scanned manually.

An inspection crew is comprised of 4 to 5 inspectors. Typically, they inspect 120-150 weld areas in a 3-week period working a 12-hour shift daily.

(Slide 13)
The program for inspecting moderator piping is well underway. All accessible welds will be inspected on a 5-year cycle.

Unacceptable piping is replaced with new Type 304L components. Known cracks which do not exceed the allowable flaw size are inspected annually. The inspection program will be in the second 5-year cycle this year. Additional development of advanced equipment and procedures to extend ultrasonic inspection to limited-access welds is underway.

Reactor Tank Inspection

Application of ultrasonic inspection to the reactor tank wall weld zones presents a number of unique challenges.

(Slide 14)

The reactor tanks are fabricated from several rolled 1/2-inch thick Type 304 stainless steel plates. The tank seam welds are double vee welds produced in the shop. The top courses of the tanks were joined to the welded outlet nozzle assembly by a field weld after the upper and lower portions of the tank were set in the reactor building. There are approximately 400 feet of weld in each tank arranged as shown in this slide.

(Slide 15)

Development of specially designed remote controlled robotic equipment was required for implementation of ultrasonic inspection of the reactor tank wall welds. The unique design of the SRS reactors and high radiation fields in the tanks imposed several stringent requirements on the tooling. It must fit through a 4-inch diameter fuel port and extend downward approximately 20 feet. It must operate under heavy water which provides radiation shielding and couplant for the probe. It must manipulate both an ultrasonic and an eddy current probe along the weld seams. And, it must operate from a remote control center to reduce radiation exposure to the operators.

(Slide 16)
Design of the equipment began in early 1986. Fabrication and check-out of the prototype system was completed this spring. Final testing and training of operators and inspectors is underway. Total cost of this project will be $20 million dollars over a 5-year period which will include initial reactor tank inspections.

The in-tank tooling consists of a robot mast and arm, three CCTV camera/light assemblies, and a calibration mast. A tank-top view of the equipment is shown in this slide taken at the mock-up facility. The inspection robot is shown in the center, with the three camera/light assemblies and the calibration mast arrayed around it.

(Slide 17)

An in-tank view of the equipment in the reactor tank mock-up is shown in this slide. The tank seam welds are apparent in the background. The robotic arm is shown in the extended position with the inspection probes in contact with the tank wall. The arm can scan in the horizontal and vertical directions and is equipped with feedback systems and a built-in compliance device which maintains proper alignment of the probes to the tank wall. An in-tank camera/light assembly and the calibration mast with a calibration block are shown to the left.

(Slide 18)

The in-tank inspection equipment and the inspection and data acquisition units are remotely controlled either manually or by computer programming from a mobile control center. The mobile control center will be located outside the reactor building approximately 300 feet from the inspection tools in the reactor tank.

The non-destructive examination control console is shown in this slide. The center module allows the inspector to manipulate the robotic arm manually or by computer control.

The panel to the left is the ultrasonic inspection control and data acquisition system. The console on the right is the eddy current system.

Two additional, similar control centers are provided for independent control of the robotic arm and camera/light systems.

(Slide 19)
The ultrasonic inspection system is an AMDATA Intraspect-98^R remote data acquisition system. A 45° shear wave probe operating at 2 mega-hertz will be used for both detection and sizing of flaws.

The eddy current inspection system is a Zetec MIZ-18^R coupled to a Hewlett-Packard computer which uses an AMDATA^R software package.

Both units provide C-Scan and other graphic data displays as well as permanent data records.

(Slide 20)
The equipment and personnel for inspection of reactor tank wall welds will be ready in July. The inspectors will be

subcontracted personnel who are certified by EPRI for ultrasonic detection and sizing of IGSCC. Additionally, EPRI is developing, under subcontract, a site-specific certification program which the inspectors must complete prior to conducting inspections.

The initial inspection is presently scheduled to be a 30% inspection of the tank wall welds in the P-Reactor. Approximately, 40 days of in-tank work will be required to complete the inspection.

Acceptance criteria for the tank wall inspection are based on stress and fracture mechanics analysis of the reactor tanks. The acceptance criteria are presently being formulated by a panel of independent experts and will be in place before the inspections start.

The reactor tank wall inspections will be included as a requirement of the long range in-service inspection program for the SRS reactors.

Conclusion

Inspection of the primary cooling system of the SRS reactors has been provided by various means throughout the operation of the plant. In recent years, ultrasonic inspection has been applied to the welds of the moderator piping system. These inspections have provided for detection and monitoring of intergranular stress corrosion cracking adjacent the piping welds and in other heat-affected areas. A state-of-the-art ultrasonic inspection system has been developed for inspection of the welds zones of the reactor tank walls. This inspection will provide additional information on the the condition of the reactor tanks in terms of maintenance needs and service life. These inspections will be incorporated into the in-service inspection plan for the SRS reactors.

ULTRASONIC INSPECTION OF REACTOR SYSTEMS

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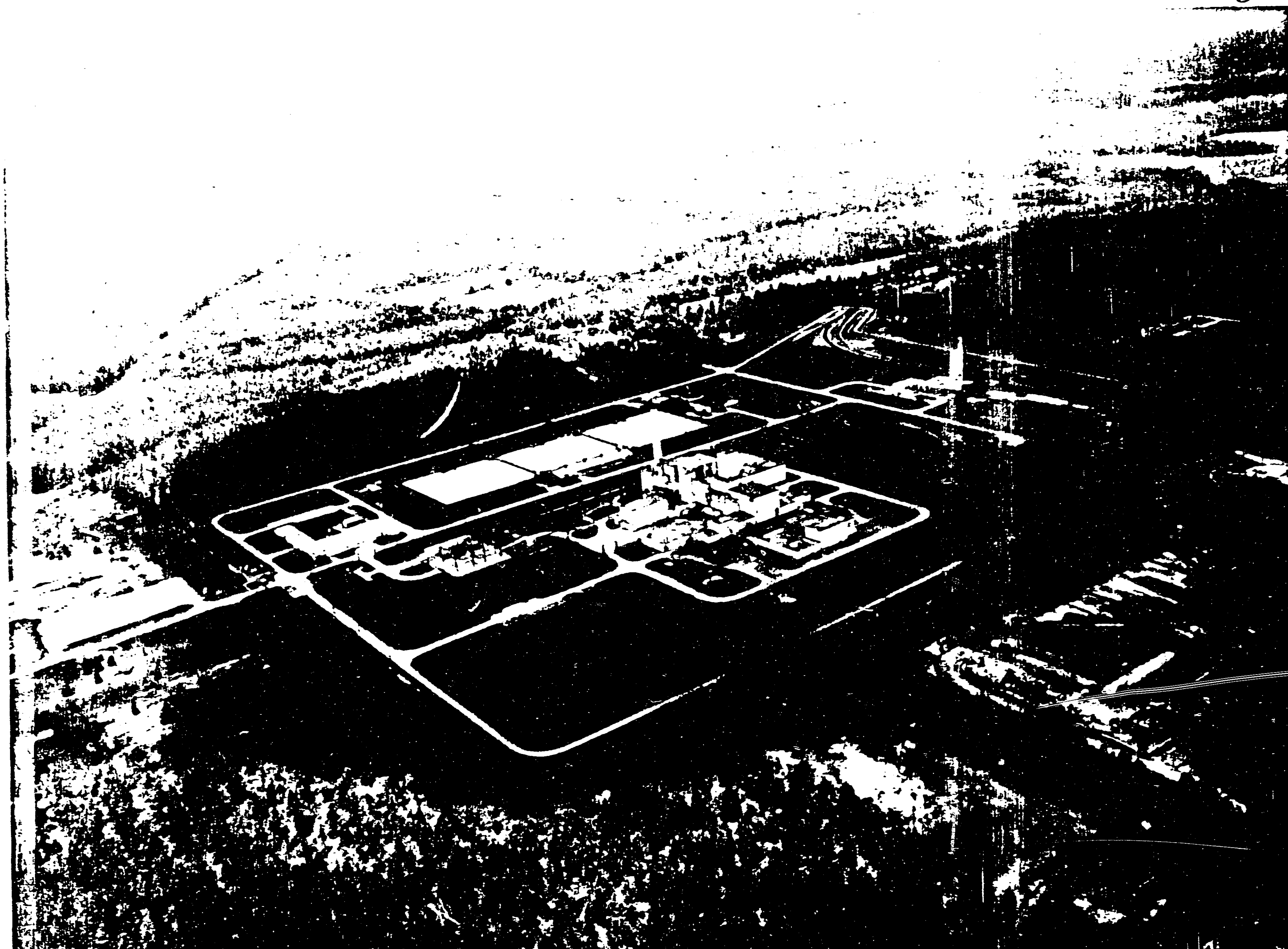
SAVANNAH RIVER SITE

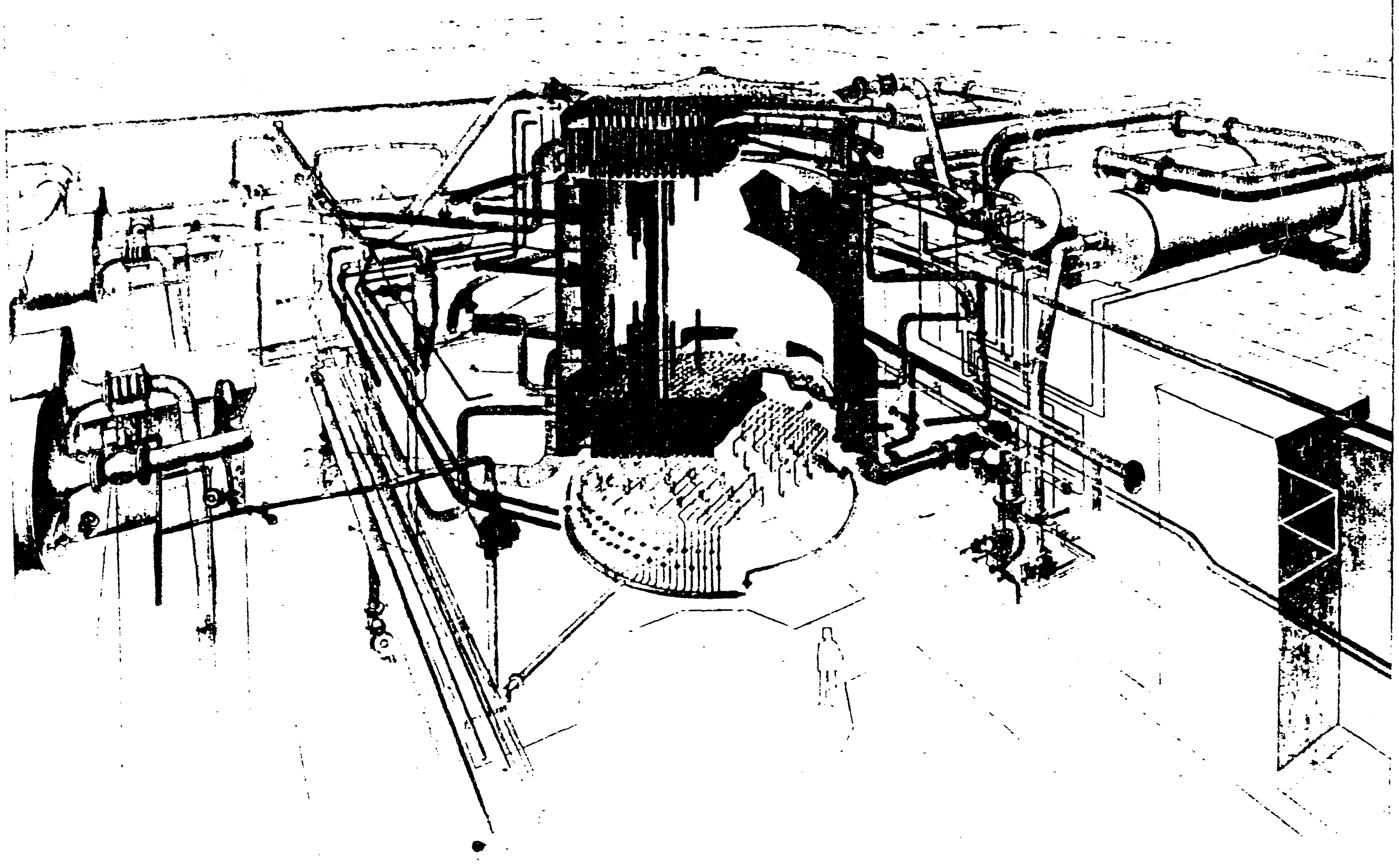
EQUIPMENT ENGINEERING DIVISION

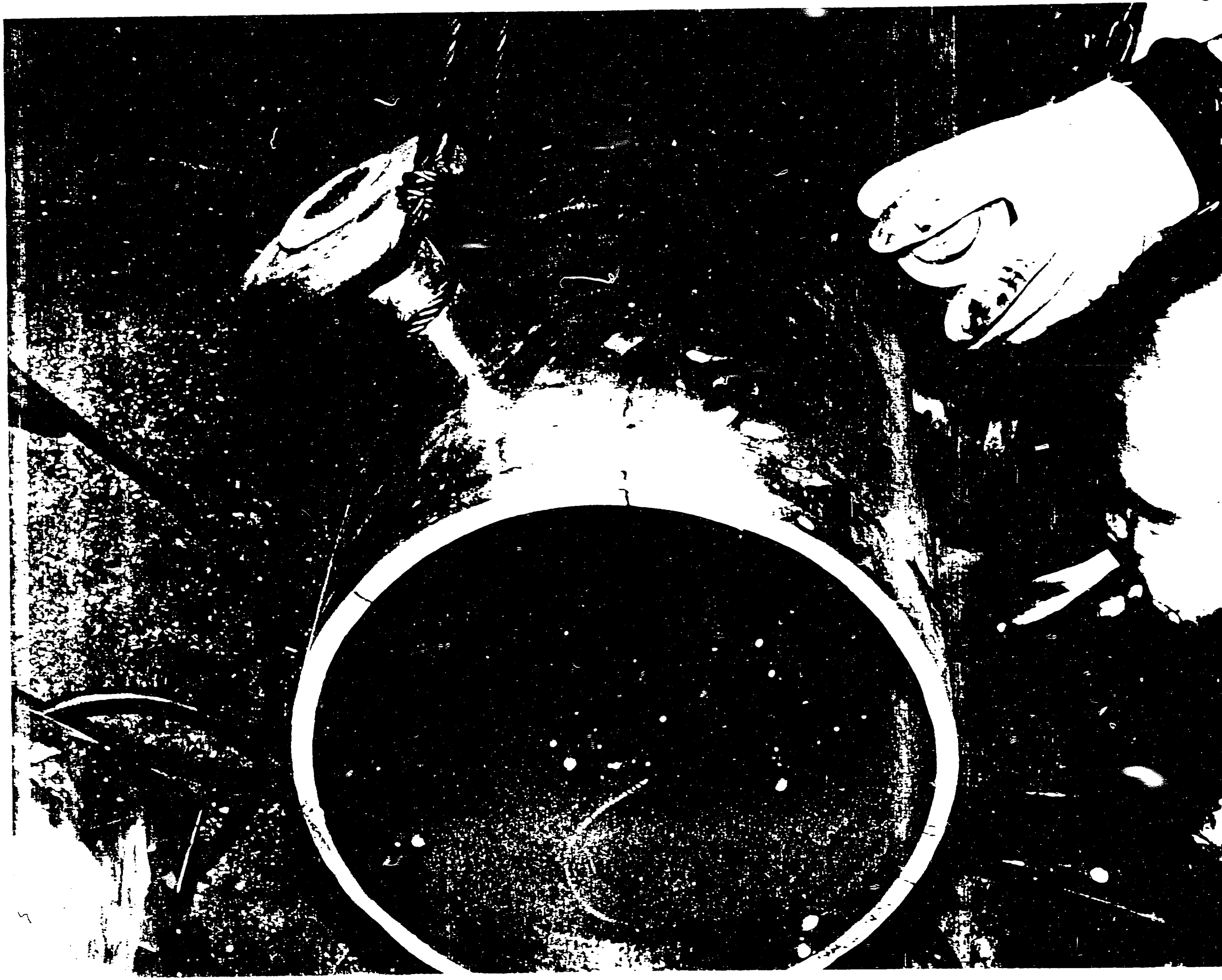
ULTRASONIC INSPECTION OF REACTOR SYSTEMS

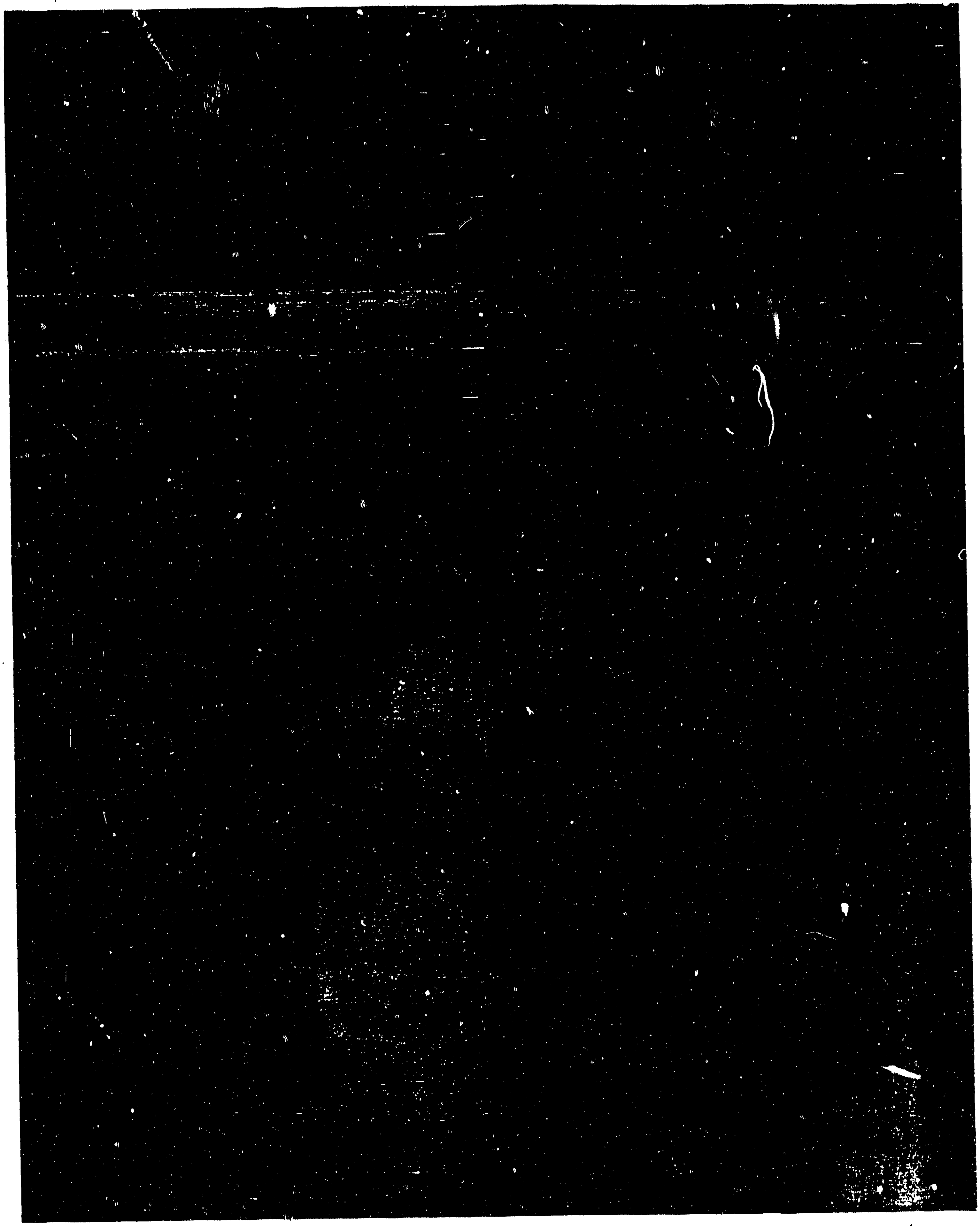
- MODERATOR PIPING INSPECTION
- REACTOR TANK WELD INSPECTION

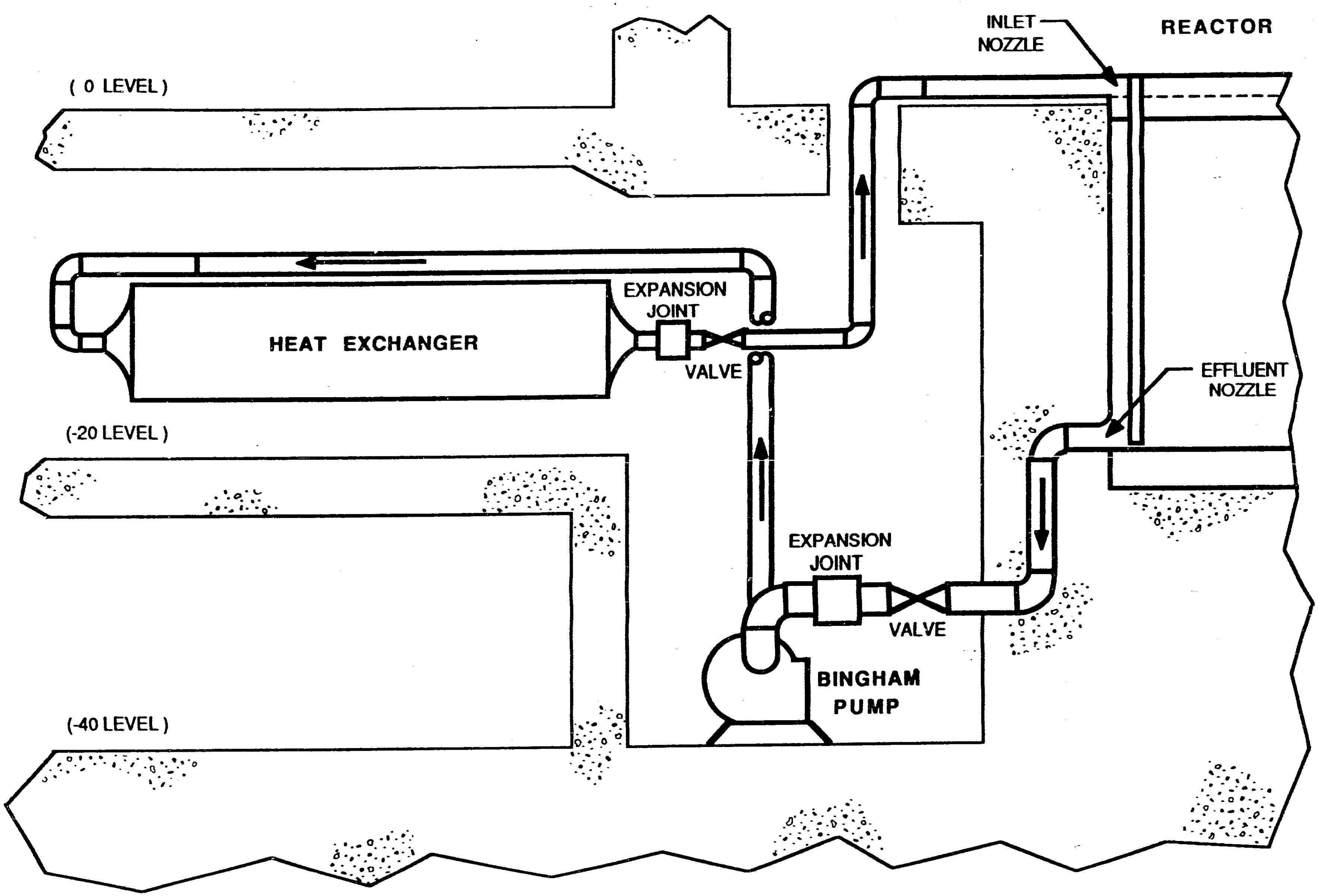
EQUIPMENT ENGINEERING DIVISION










REACTOR
INLET NOZZLE
EFFLUENT NOZZLE
(0 LEVEL)
(-20 LEVEL)
(-40 LEVEL)
HEAT EXCHANGER
EXPANSION JOINT
VALVE
EXPANSION JOINT
VALVE
BINGHAM PUMP

MODERATOR PIPING ULTRASONIC INSPECTION

- INITIATED 1984
- BUTT WELDS, FLAMEWASHED AREAS, BRACES
- FRACTURE MECHANICS
- 5% OF WELDS CRACKED

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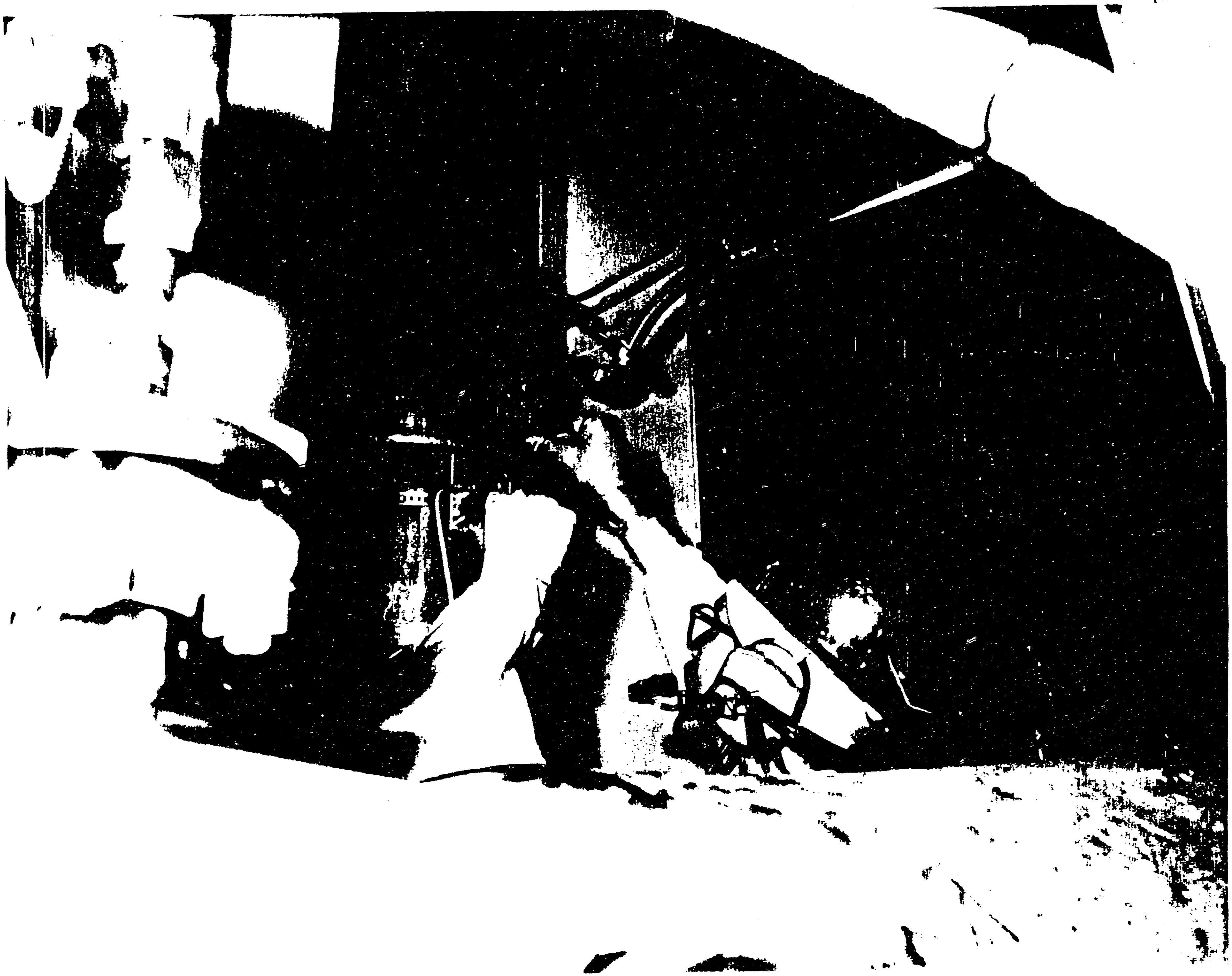
MODERATOR PIPING ULTRASONIC INSPECTION

- P - SCAN UNIT
- REMOTE DATA ACQUISTION
- 45° - 52° SHEARWAVE — 1.5 - 2.25 MHz
- SEMI - AUTOMATIC AND MANUAL SCANNING

EQUIPMENT ENGINEERING DIVISION



MODERATOR PIPING INSPECTION PROGRAM

- ALL ACCESSIBLE WELDS EVERY 5 YEARS
- REPLACE UNACCEPTABLE PIPE
- INSPECT CRACKED WELDS ANNUALLY
- SECOND 5-YEAR CYCLE

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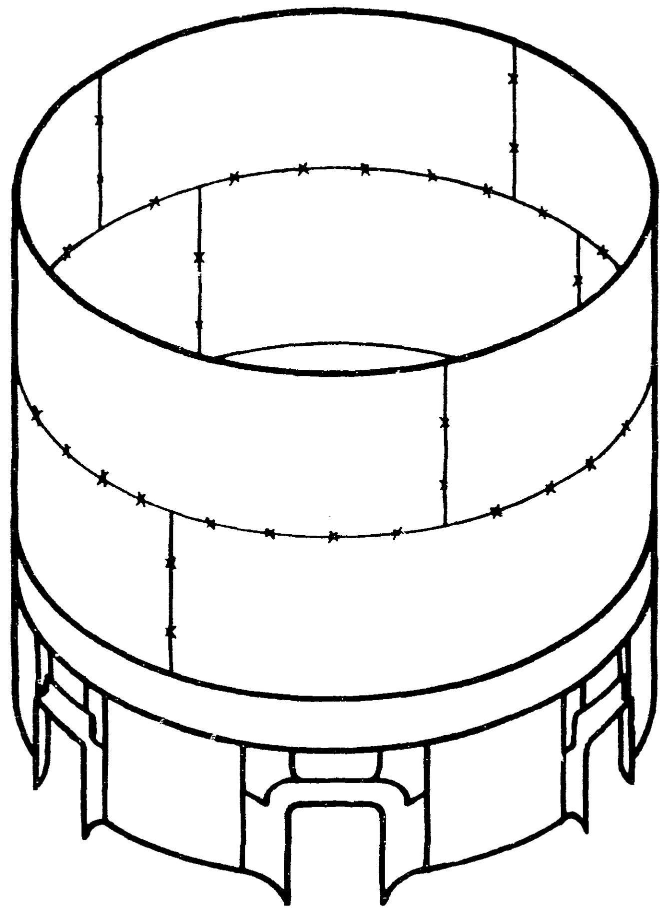

TANK WALL WELDS IN K, L AND P REACTORS

EQUIPMENT ENGINEERING DIVISION

REACTOR TOOLING REQUIREMENTS

- 4 - INCH DIAMETER HOLE
- OPERATE UNDERWATER
- MANIPULATE INSPECTION PROBES
- REMOTE OPERATIONS

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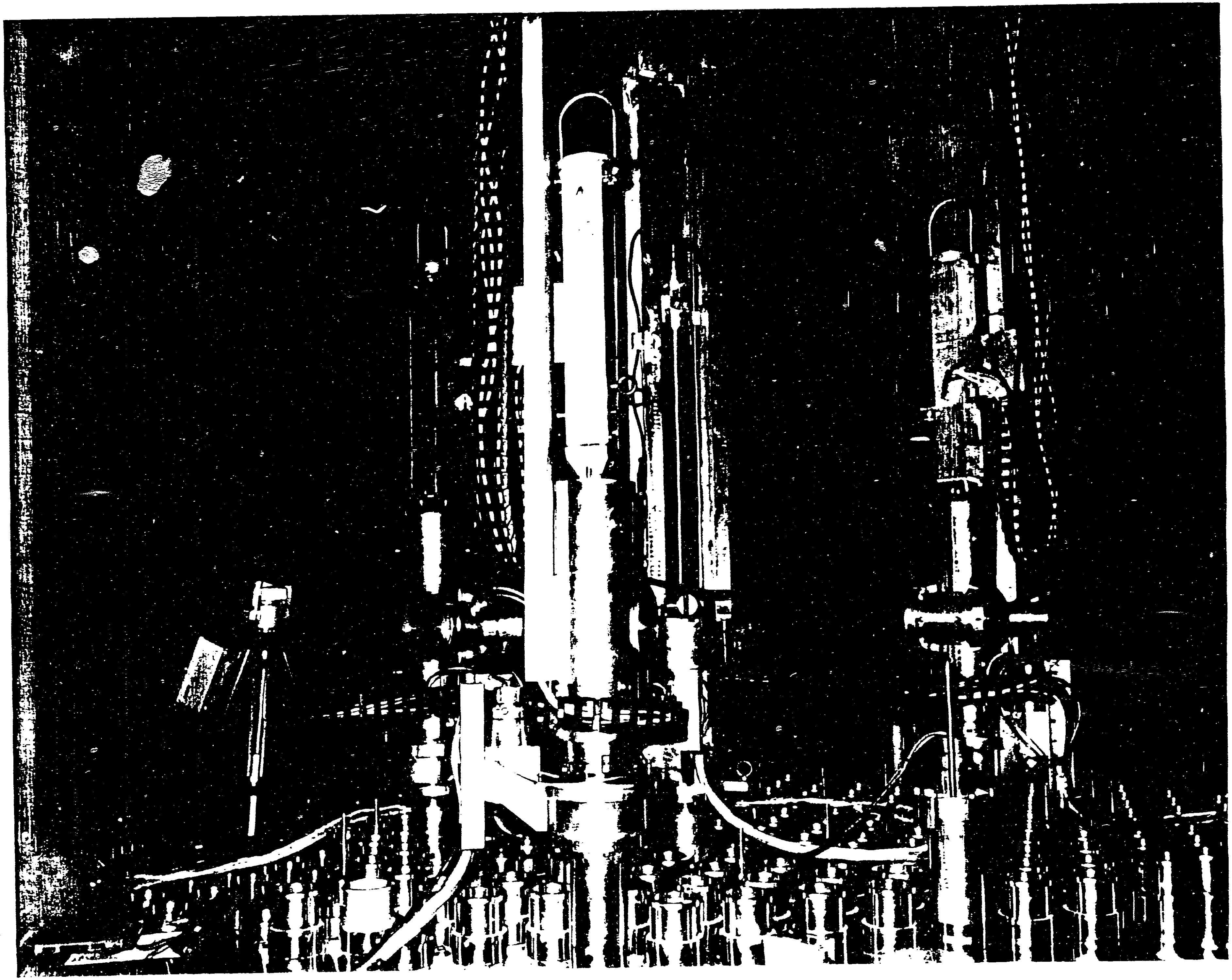

REACTOR TANK ULTRASONIC SYSTEM

- AMDATA I - 98
- REMOTE DATA ACQUISITION
- 45° SHEAR — 2 MHz
- DETECTION AND SIZING

EQUIPMENT ENGINEERING DIVISION

REACTOR INSPECTION PROGRAM

- EQUIPMENT AND PERSONNEL READY JULY
- INITIAL INSPECTION — P - REACTOR
- ACCEPTANCE CRITERIA COMPLETE
- IN - SERVICE INSPECTION

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END

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