XA04N1287

PROCESS SYSTEMS OF PHWR INDIAN EXPERIENCE

BY

T.S.V. RAMANAN

MADRAS - INDIA

TECHNICAL COMMITTEE MEETING

ON

EXCHANGE OF OPERATIONAL SAFETY EXPERIENCE

OF PRESSURISED HEAVY WATER REACTORS

EMBALSE, CORDOBA, ARGENTINA

3-5 APRIL 1991

PROCESS SYSTEMS

OF PHWR

INDIAN EXPERIENCE

T.S.V. RAMANAN
DY. CHIEF SUPDT.,
MAPS, INDIA.

PROCESS SYSTEMS OF PHWR - INDIAN EXPERIENCE

(T.S.V.Ramanan, Dy. Chief Superintendent, MAPS, INDIA)

ABSTRACT:

Three operational problems are discussed in this paper.

The reactors in Madras Atomic Power Station (MAPS), India are Pressurised Heavy Water Reactors (PHWR), similar to Douglas Point PGS. The moderator heavy water is pumped into the bottom half of the calandria (horizontal reactor vessel) through one inlet manifold plenum chamber and horizontal louvers which help to distribute moderator evenly at a very low velocity. The outlet from the calandria is through a smaller manifold structure at a higher elevation. The moderator is held on the shell side of the calandria by means of helium gas pressure differential between top of calandria and dump tank located below. The primary coolant system consists of 306 coolant channels containing the fuel and steam generators (SGs) and pumps on either side of the reactor. Each SG consists of 11 Nos. inverted U tube vertical heat exchangers where heat is transferred from primary coolant heavy water to secondary light water to produce steam.

PROBLEM NO.1:

In early 1989, following a leak detected in a calandria tube in Unit-2, inspection of the calandria internals revealed that a portion of the inlet manifold located just in front of the inlet nozzle had sheared off and fallen on the dump ports. Surprisingly similar incident was also found to have occurred in the other MAPS Unit when it was later inspected. As an interim measure, alternate routing of moderator piping was done externally directing heavy water into the calandria through the original outlet manifold. The calandria spray flow (for cooling internal structures of calandria) was increased in order to enhance total flow into calandria. The heavy water in calandria was allowed to spill over the dump ports continuously and to return from dump tank to suction of the pumps. Since the total inflow into the calandria is less than the design, the reactors are being operated at 75% of capacity.

PROBLEM NO.2:

After completion of piping modifications when the performance of the system was being checked, the observed moderator dump timings of shut down system was above normal by more than 50%. The dump valves opening time was as fast as per design. The above abnormal timing was measured from the level drop from calandria operating level to dumped level, in a fast speed recorder. Investigation revealed that heavy water was getting accumulated in the gas space on the calandria side of the dump valves and was affectiong the helium equalising flow during dumping. The gas space has a drainage arrangement through gas trap and a drain *valve. It was established that the drainage capacity was not adequate for the heavy water accumulation (over the dump valves) which got increased after the calandria spray flow was increased under the modification programme.*

PROBLEM NO.3:

During warming up of the primary coolant system, low channel flow alarmed in few of the 16 flow monitored channels. The flow instrumentation was checked okay. Earlier to this problem, in the preceding unit outage in January 1990, maintenance works were undertaken in the primary circuit valves, for which the four steam generators (SGs) were drained on the heavy water side and system opened up. After completion of the jobs, the SGs were filled back by pulling vacuum.

On experiencing the low channel flows, some air entrapment was suspected in the inverted U tube bend of the SGs, leading to air lock and throttling of flows. Though system was normalised as per the procedure, entrapped air was probably not removed completely due to passing past the seats of the closed isolation valves. There is no direct measurement to indicate that SGs are filled completely and free of any entrapped air. Therefore the south bank SGs were again drained, vacuum pulled and refilled.

PROCESS SYSTEMS OF PHWR - INDIAN EXPERIENCE

T.S.V.Ramanan, Deputy Chief Superintendent, MAPS.

1.0 INTRODUCTION

Madras Atomic Power Station (MAPS) is a twin unit station comprising of two reactors of pressurised heavywater type each with a rated output of 235 MW (Electrical). The reactors are natural uranium fuelled heavywater moderated and heavywater cooled with on load refuelling facility. This paper describes three significant problems faced in the operation of the reactors in the recent past.

2.0 BRIEF DESCRIPTION OF THE REACTOR SYSTEMS

2.1 *The reactor vessel (Calandria) is horizontal with 306 calandria tubes (Zircalloy 2) rolled into the tube sheets at either end. The moderator is on the shell side of calandria. The fuel channels are concentric with the calandria tubes and pass inside the calandria tubes. The fuel channels are rolled into end fittings located in the end shields at either end of the reactor. The calandria is connected by an expansion joint to the moderator dump tank which is located directly beneath it. The general arrangement of the reactor is showin in Figure-1.*

2.2 *The moderator heavywater is held in calandria by a helium gas balance system. The dump tank is maintained under helium pressure. The difference in helium pressures between the top portion of the calandria and dump tank maintains the heavywater level in the calandria. A set of fourteen dump ports each shaped like the letter "S" lying on its side form the bottom part of the calandria. The helium heavywater interface is maintained in the central vertical arm of each dump port. Shut down is effected by equalising the helium pressures between the top portion of the calandria and dump tank by opening six quick acting butterfly valves (dump valves) arranged in three parallel lines connecting the helium gas header on the top of calandria to the top of dump tank and the heavywater is quickly drained to dump tank by gravity. The heat due to moderation is removed by circulating the heavywater in the calandria by four pumps through two heat exchangers, rejecting the heat to the process water system. The entire moderator system is shown in Figure-2. The dump port arrangement is shown in Figure-3.*

2.3 *The primary heat transport system is a pressurised heavywater system with the coolant maintained at a pressure of 85 Kg/cm2 at the outlet headers. In the 306 fuel channels, coolant flow in the adjacent channels are arranged to be in opposite directions. The fuel channels are connected by feeder pipes from the end fittings to a set of inlet and outlet headers on either side of the reactor. In between the reactor outlet header and inlet header on either side are connected four set of steam generators and primary circulating pumps. The set of steam generators and pumps on either side form a series parallel loop as shown in Figure-4. Each steam generator is a combination of eleven vertical, inverted U-tube heat exchangers with primary heavywater on the tube side and secondary feed water on the shell side. The heavywater side of the eleven heat exchangers are joined to a common inlet and outlet headers which in turn connect to the reactor headers. All the 11 heat exchangers are connected to a common steam drum. The arrangement of the feeders reactor header and steam generators is shown in Figure-5. Details of steam generator headers and their connection to primary circulating pump and reactor headers are as given in Figure-6. Cross section of a single U tube heat exchanger forming part of the steam generator is shown in Figure-7.*

3.0 *Three significant operational problems encountered in the recent past are described under this section.*

1. *Problem with moderator inlet distribution manifold.*
2. *Retarded heavywater dumping rate.*
3. *Low flow problems in fuel channels.*

3.1 *PROBLEM WITH MODERATOR INLET MANIFOLD:*

3.1.1 *Description:*

The inlet manifold is designed to introduce moderator evenly along the length of the calandria at a very low velocity and to avoid mixing so that stritified flow will take place. This gives the minimum average moderator temperature and best moderation. The inlet pipe from the moderator pump discharge and heat exchangers opens into a plenum chamber inside the calandria which distributes the moderator along the length of the calandria and also upwards along the side face of the shell. Horizontal louvres, arranged one above the other, progressively closer to the shell, each skim off a portion of the flow and direct it towards the bottom part of the calandria. Since the manifold projects into the reflector portion, Zircalloy-2 (4mm thick) is the material used for construction from point of neutron economy. The manifold is secured by nuts on threaded studs welded to the calandria shell. The flow *arrangement is shown in Figure-8. The inlet manifold can be seen in Figures 1 and 3.*

3.1.2 *Problems in inlet manifold:*

In the later half of 1988, Unit-2 experienced a calandria tube leak and the leaky tube was identified to be in the third row from the bottom. Later the exact tube was identified by monitoring fuel channel outlet temperature at this location with the heat transport system cool and moderator kept warm. This was confirmed by detecting moisture in the annulus space between calandria and end shield adjacent to this tube. Fuel channel at this location was removed and the leaky calandria tube was blanked off at the tube sheets by specially developed self supporting plugs.

Subsequently, one of the moderator pumps developed a problem and while attending to it, some zircalloy pieces were located in the pump casing. These were identified to be part of calandria tube material and a small supporting bracket of the louvres in the inlet manifold.

In the meanwhile a minor fuel channel (pressure tube) leak was experienced in Unit-1 in the second row from the bottom. The exact leaky tube was located by acoustic emission technique and failed fuel history in this channel. After defuelling this channel and isolating the leaky pressure tube from heat transport system, operation was resumed, but shortly afterwards calandria tube leak was noticed at this location.

Calandria tubes at these locations in both units were removed and inspection of the internals of the calandria with a camera, revealed that a portion of the zircalloy plate forming part of the inlet pelnum chambers just in front of the moderator inlet pipe connection had given way in both units (Refer Figure-9). Somce of the pieces from the manifold were lying on top of the dump ports. The failure of the calandria tubes/pressure tube was attributed to direct impingement by jet of heavywater from moderator inlet pipe. The failure of the manifold is believed to have been initiated by failure of welding of the holding studs to the calandria shell. This has to be confirmed by metallurgical examination of the failed portions of the plate and studs, which are planned to be retrieved shortly.

3.1.3 *Interim Measures:*

The damaged portions lying on the dump port were picked up and deposited in a cavity adjacent to the tube sheet where the forces during dumping will not dislodge them. The calandria tube sheet opening was blanked. After *performing necessary stress analysis and thermal hydraulic analysis, it was decided to connect moderator inlet to the original outlet pipe so that the heavywater enters the calandria through the original outlet manifold but the flow rate was kept lower as a matter of caution and consequently the power was limited to 75% FP. The heavywater was allowed to spill over the dump ports continuously into dump tank and return to moderator pump suction through dump tank outlet line. The modified scheme is shown in Figure-2.*

3.1.A *Proposed Permanent Measures:*

In order to restore the moderator flow to original configuration and achieve full power, development work was undertaken and it is proposed to cut pressure tubes and calandria tubes at three lattice locations near the bottom of the calandria and install sparger tubes made of Zircalloy. These will be rolled into the calandria tube sheet. Another stainless steel insert extending upto the fuelling machine vaults through the end shield lattice bore openings will be rolled into the calandria tube sheet thus sandwitching the sparger tube between the tube sheet and the insert. Moderator piping which is routed into the fuelling machine vaults will connect to these extended inserts and the layout ensures that this arrangement will not hinder movement of fuelling machine to do refuelling in adjacent channels. Hydraulic studies were made on models and suitable provisions based on these studies have been incorporated to achieve required flow distribution through these spargers. The proposed sparger and the rolled joint are given in Figures 10 and 11. As a parallel measure, provision of a third moderator heat exchanger to bring down the moderator inlet temperature and operate the reactors at higher power in this mode itself are being studied.

3.2 *RETARDED DUMP RATE*

3.2.1. *Problems encountered:*

Subsequent to the altered flow path of moderator into the calandria, the calandria spray cooling flow joining the top of the calandria was also increased in order to take advantage of this flow for increased heat removal capability from the moderator in the calandria. Performance tests were being conducted to assess the operation under the altered conditions. While dumping this, tests were conducted with fast recorders to record the calandria moderator level with respect to time, it was found that in Unit-2 there was a significant increase in the time taken for the level to reach 35% from full tank level as compared to the design values. The level measurement was also indicating an oscillatory *pattern as shown in Figure-12.*

3.2.2. *Investigations done:*

In order to check for flow blockage in the gas headers access to the calandria side gas header above the dump valves was made through the rupture disc connection. Though no blockage could be found, D2O was found to be present at the bottom portion of the horizontal run of this header. Design had expected that a small amount of heavywater will be present in the line due to condensation from helium. However the quantity present was found to be more than expected. Provision existed in original design to drain off any condensed heavywater on the top of the dump valves, through a float type trap to a low pressure portion of the moderator system. This float had an isolating valve of diaphragm type on the downstream side. The arrangement is showin in Figure-13. Accumulation of significant quantity of heavywater on top of the dump valves was suspected causing an increase in dump timing by impeding quick pressure equalisiation. To confirm this, the system was operated with the isolating valve of the trap closed for varying periods ranging from 6 to 14 hours and dump test was repeated at the end of each period. Accumulation of heavywater over dump valves was confirmed by ultrasonic methods. The dump tests revealed that higher the time of accumulation, the slower the dump rate. Examination of the isolating valve of trap revealed that the diaphragm was slightly bulged. This is suspected to have impeded the drain flow. This alongwith increased ingress of heavywater had caused accumulation over the dump valves.

It was felt that improper nozzle orientation in the sprays provided in the gas balance line near the top of the calandria was possible. This combined with increased spray flow would have rendered the slope provided in the gas balalnce line to drain off the heavywater towards calandria ineffective due to higher reach of the sprays and caused more ingress towards the top of the dump valves.

3.2.3. *Action Taken:*

The calandria spray flows were reduced to original design values. The diaphragm valve in the drain line was eliminated. An additional drain trap was provided in parallel with the existing one to cater to single failure criterion. Level measurement with alarm facility was provided to detect heavywater accumulation in the gas space above the dump valves to alert the operator. These modifications are also shown in Figure-14.

3.3. LOW FLOW IN FUEL CHANNELS

3.3.1 Arrangement of Coolant Circuit:

The layout of the coolant circuit is shown in Figure-5. The arrangement of the feeder connections are such that fuel channels in one quadrant of the reactor are connected to a location in the inlet and outlet headers nearest to the tap off for a particular steam generator pump circuit. Out of the 306 fuel channels, flow is monitored in 16 channels distributed in each zone i.e. four in each quadrant. Out of these four, twe each are provided to measure flow in channels with flow in opposite directions. The flows are graduated in percentage of design values and low flow alarm is set at 80% of the design value. Low flow trip of the reactor set at 60% of design flow is provided in six of the above flow monitored channels.

3.3.2 Events prior to the Incident:

In early 1990, maintenance work on one of the steam generator inlet valves on the south bank was attempted. For this, the procedure calls for establishing header level control (i.e.) coolant circulation through core is maintained by a shutdown cooling pump and the inventory in the System is adjusted such that the heavywater level remains below the elevation of the respective values. As an additional precaution, all the four steam generators on the bank are drained on heavywater side to avoid possibility of leakage past the isolating valves of the steam generators which will affect regulation of header level. The draining of steam generators is by connecting them by opening drain valves to a tank kept under vacuum. Subsequently, the vacuum is broken by filling the steam generators with nitrogen.

When attempts were made to remove the bonnet of the valve requiring maintenance, it was realised that header level control was not fully effective causing fluctuations causing the level going above the valve elevation. Hence the attempt was aborted and the valve was boxed up and it was decided to start up the unit.

3.3.3 Description of Incident:

In preparation for power operation, all eight primary circulating pumps were started after degassing the system. (Normally the degassing is terminated when a steady level is achieved in storage tank). The reactor was critical at low power, with flow indications in all 16 flow monitored channels normal (above 100%).

After a few hours of operation, low flow alarmed in one of the flow monitored channels in the lower west *quadrant and the flow was 78%. Another channel in upper west quadrant was showing 84% and a few other flow monitored channels in quadrants other than upper east were recording flows of just over 90% of design. Flow instrumentation impulse tubing was checked and found to be free of blockage and a new replacement flow transmitter substituted for flow measurement in the lowest flow channel confirmed that the reading was indeed genuine. Power was raised upto about 20% to confirm from channel outlet temperatures about the low flow phenomena. However, due to variation in power distribution during at start up, no positive conclusion could be drawn. The current drawn by the circulating pump motors also did not show any significant difference.*

The reactor was tripped and cooled down. The primary heat transport system was depressurized. All the flow instrumentation was rechecked. System was pressurised and the system was degassed by circulating through all steam generators. However, on restarting the circulating pumps, the phenomena of low flow continued to exist, even though no channel was exhibiting flow lesser than alarm value. Disturbances created intentionally, by operating pump discharge valves and by running pumps in unequal numbers on either side did not show any effect on the flow pattern.

Since the flow reduction observed was not very high and as the reactor power had been limited to 75% by other regulatory restrictions, it was decided to proceed with power operation at 50% FP initially, in order to find out clues to the low flow phenomena from channel temperature data at steady power operation.

After about 3 days of operation, the flows in the lower west quadrant improved to near normal values gradually but the flow indicated in the flow monitored channels in the upper west quadrant continued to be low.

Delayed neutron counts taken during this period, indicated an increase in global count rate, but the channels showing higher DN ratio was continuously varying, indicating that these were not genuine. A slight power reduction of 5% resulted in a large reduction in global DN counts. The I131 content in the coolant was also low indicating that fuel integrity was good and not impaired in any way due to low flow phenomena.

The radiation monitors near the steam generaor cabinet was indicating more than normal value though later on it was partially attributed to drift in calibration at higher values. It was felt that it could be due to increased N-16 activity.

From Physics simulations, the channel powers were calculated and the expected channel outlet temperatures at normal flow values were compared with actual values. It was concluded that marginal low flow is existing in channels in upper west quadrant.

All the observations led to the belief that some gas pockets could be existing which could not be got rid off during normal degassing.

3.4 ACTION TAKEN

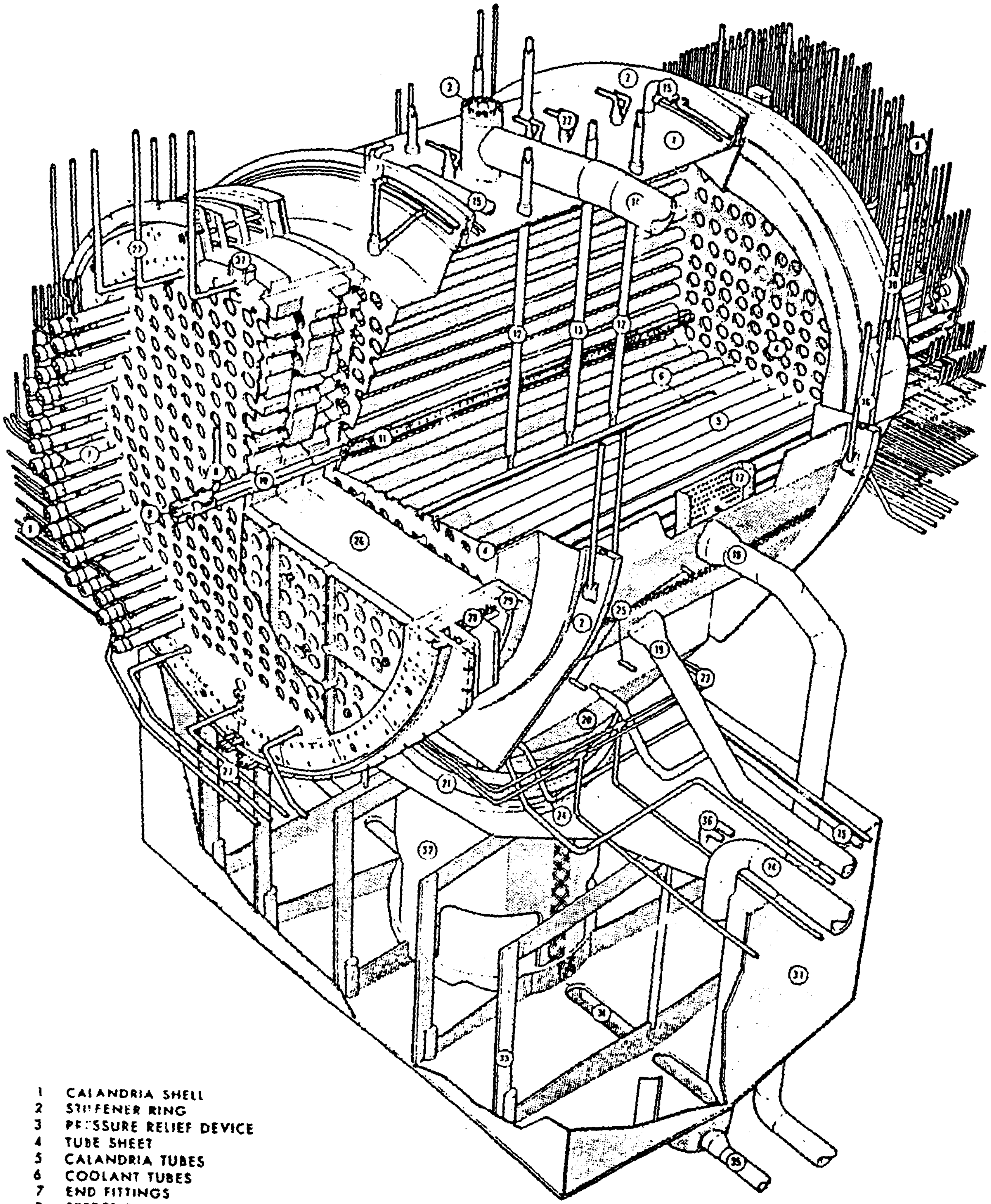
During subsequent poison outage after a week, the south bank steam generators were drained on heavy water side, vacuum was pulled thoroughly and then refilled. During the subsequent start up, the flows in all the quadrants returned to normal.

3.5 CONCLUSIONS

From the observations available, it is concluded that the following could have caused the low flow phenomena.

During the attempted maintenance on the steam generator inlet valve, header level control was not effective and during the level fluctuations, air could have entered the reactor outlet header through the slightly drawn out valve bonnet. This could have remained trapped in the header without getting disturbed initially. After full flow was established, the locked up air could have found its way into steam generators and occupied top portions of some of the U-tube heat exchangers. Probably the differential pressures available were not sufficient to flush out the trapped air. When the south bank steam generators were drained, evacuated till steady good vacuum was achieved and refilled, the air had been got rid off.

Our experience suggests that the evacuation of steam generators prior to filling is at times not effective due to suspected passing past the seats of the isolating valves which causes continuous D2O inflow from the reactor headers to the service system vacuum tank causing inability to achieve the desired level of good vacuum. Reason for higher activity near boiler cabinets could not be conclusively established even though it may be due to N-16 forming and accumulating in air pockets, in the heat transport circuit.



1 CALANDRIA SHELL
2 STIFFENER RING
3 PRESSURE RELIEF DEVICE
4 TUBE SHEET
5 CALANDRIA TUBES
6 COOLANT TUBES
7 END FITTINGS
8 FEEDER PIPES
9 SEALING PLUG
10 SHIELDING PLUG
11 FUEL
12 ADJUSTER FLOW TUBES
13 ADJUSTER FLOW TUBES
14 HELIUM BALANCE LINE
15 HELIUM PURGE LINE
16 CALANDRIA HANGERS
17 OUTLET MANIFOLD
18 MODERATOR OUTLET
19 MODERATOR INLET
20 TRANSITION SECTION
21 EXPANSION JOINT
22 CALANDRIA SPRAY COOLING
23 DUMP BOX SPRAY COOLING
24 TRANSITION SECTION SPRAY COOLING
25 LEVEL INDICATING INLETS
26 END SHIELD
27 END SHIELD COOLING PIPES
28 END SHIELD RING
29 THERMAL SHIELD BLOCK
30 END SHIELD HANGERS
31 DUMP TANK
32 SHIELDING AND STIFFENER STRUCTURE
33 STIFFENERS
34 DRAIN SLOTS
35 DUMP TANK OUTLET
36 DUMP TANK AND EXPANSION JOINT SPRAY COOLING
37 END SHIELD KEY BLOCK

FIGURE-1 CUT-AWAY VIEW OF REACTOR

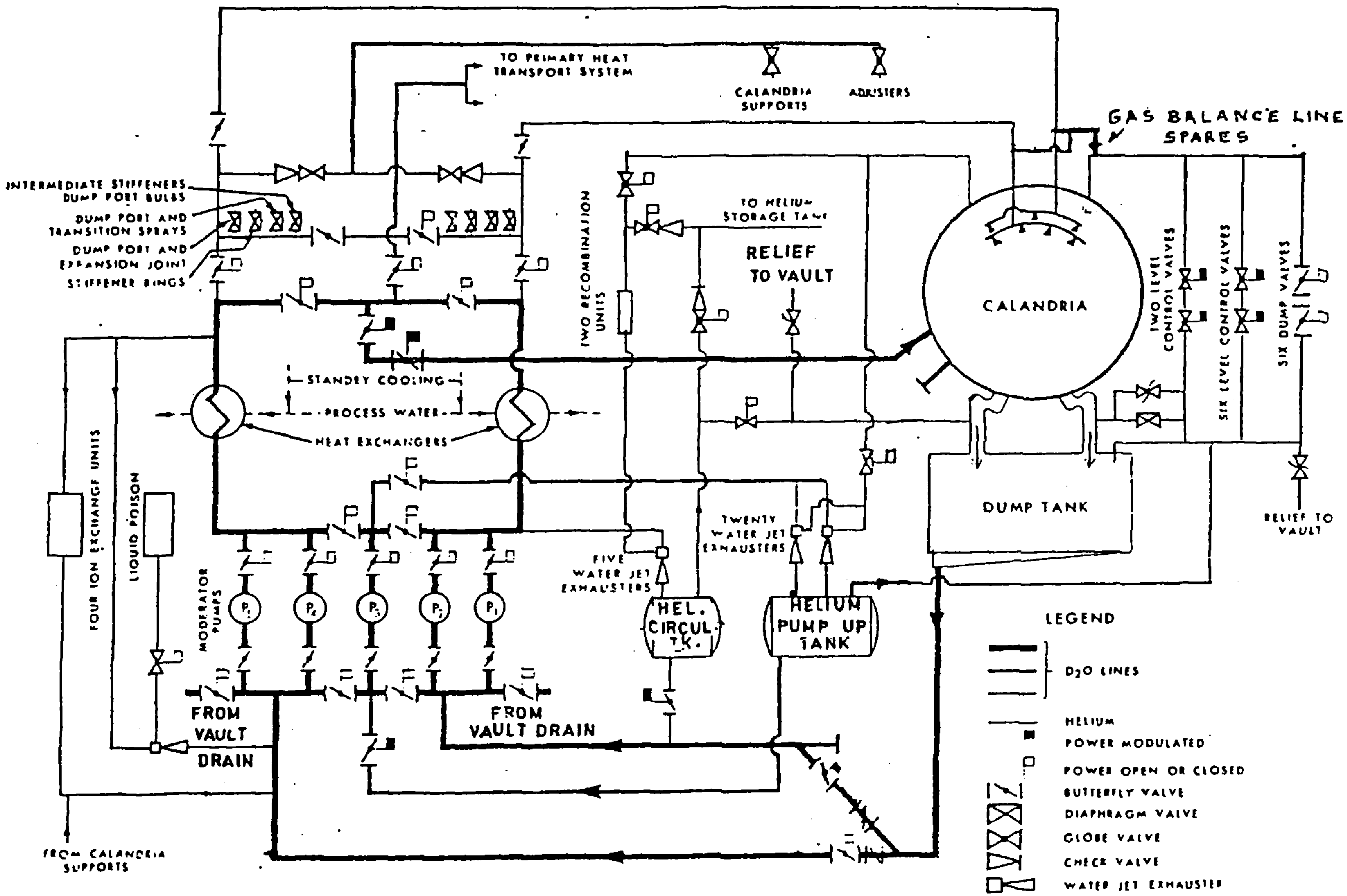
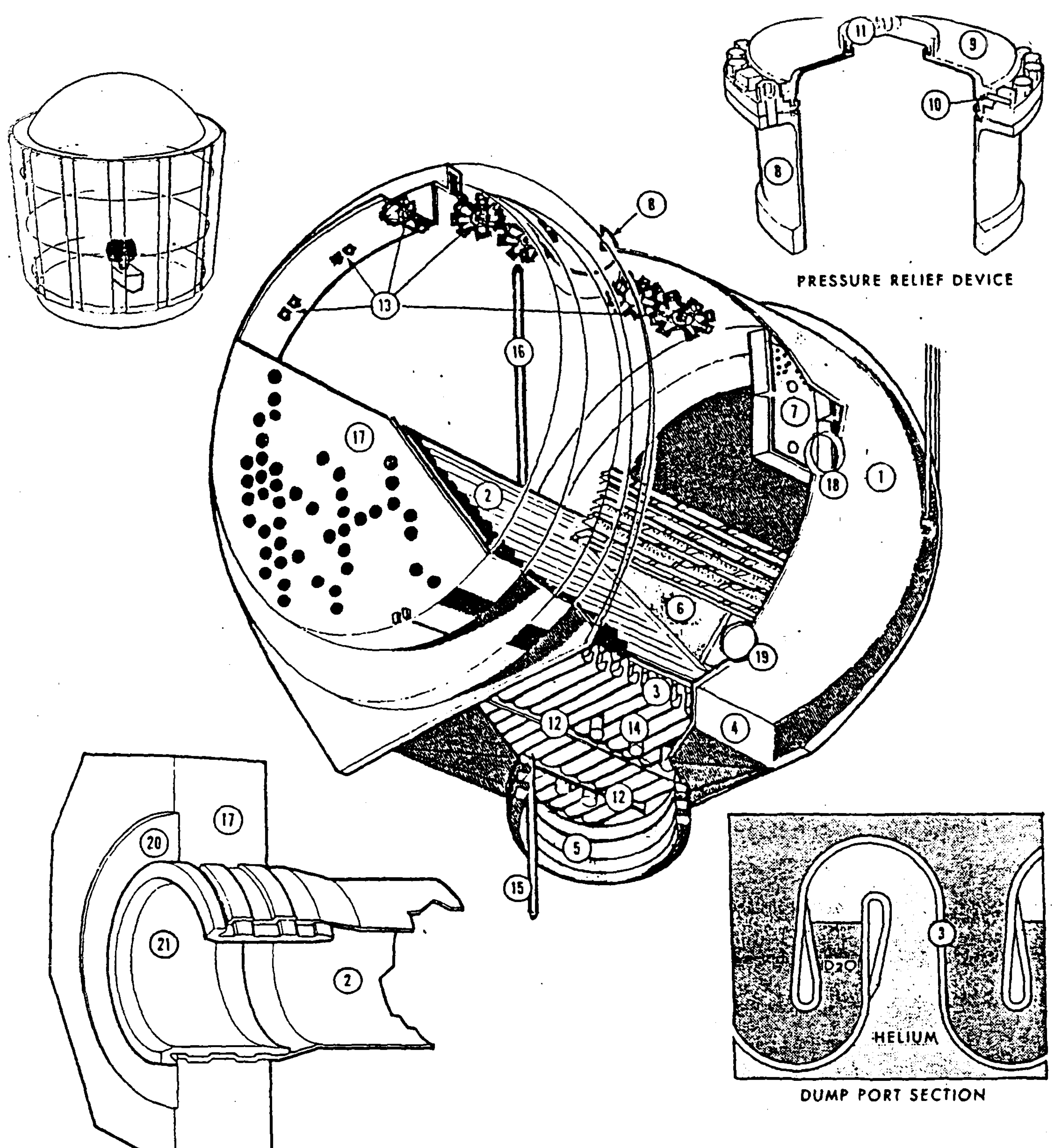


FIGURE-2 MODERATOR AND COVER GAS SYSTEM SIMPLIFIED FLOW SHEET



1 CALANDRIA SHELL
2 CALANDRIA TUBES
3 DUMP PORTS
4 TRANSITION PIECE
5 EXPANSION JOINT
6 INLET MANIFOLD
7 OUTLET MANIFOLD
8 PRESSURE RELIEF FLANGE
9 PRESSURE RELIEF COVER
10 SHEAR PIN
11 INSTRUMENTATION OPENING
12 TRANSVERSE STIFFENER
13 COOLING SPRAY HEADS
14 ADJUSTER THIMBLE MOUNTING SLEEVES
15 ADJUSTER LOWER THIMBLE
16 ADJUSTER FLOW TUBE
17 TUBE SHEET
18 OUTLET CONNECTION
19 INLET CONNECTION
20 SPOT FACE
21 LANDED INSERT

FIGURE – 3

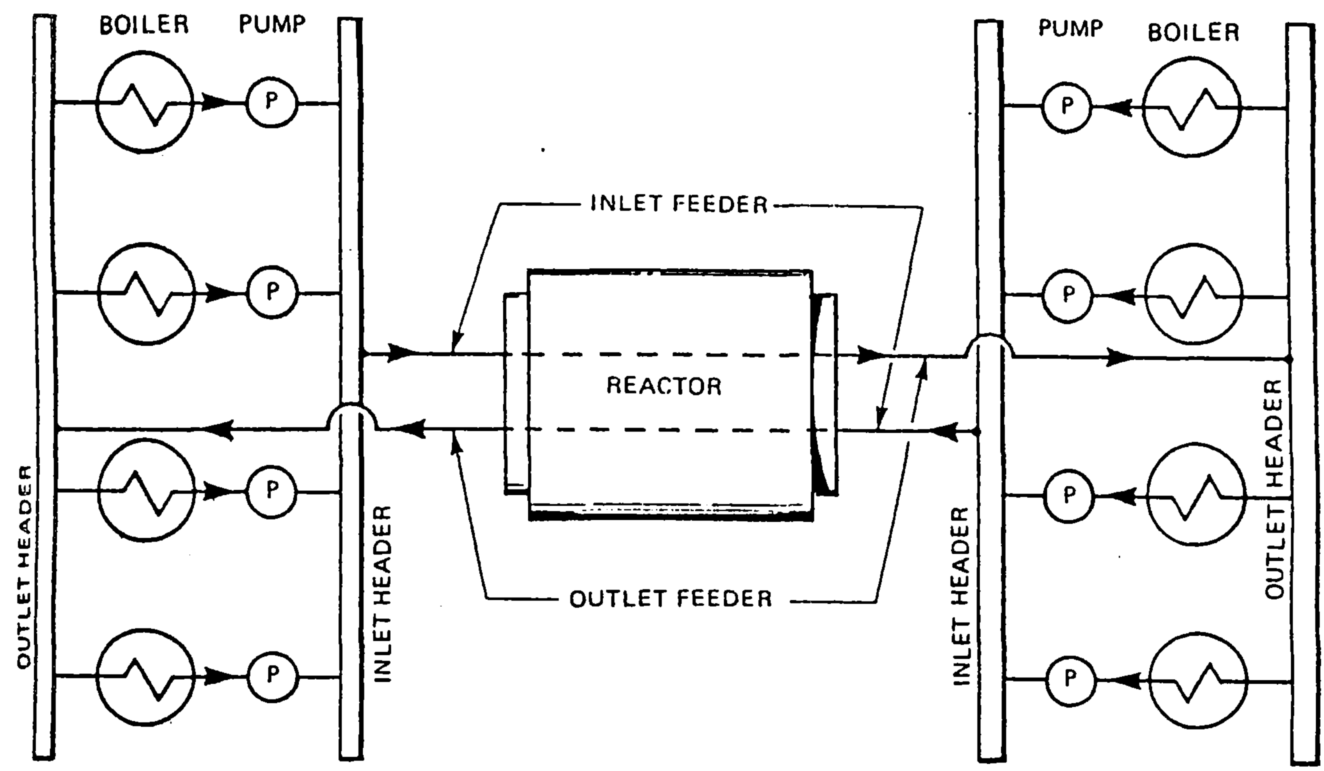
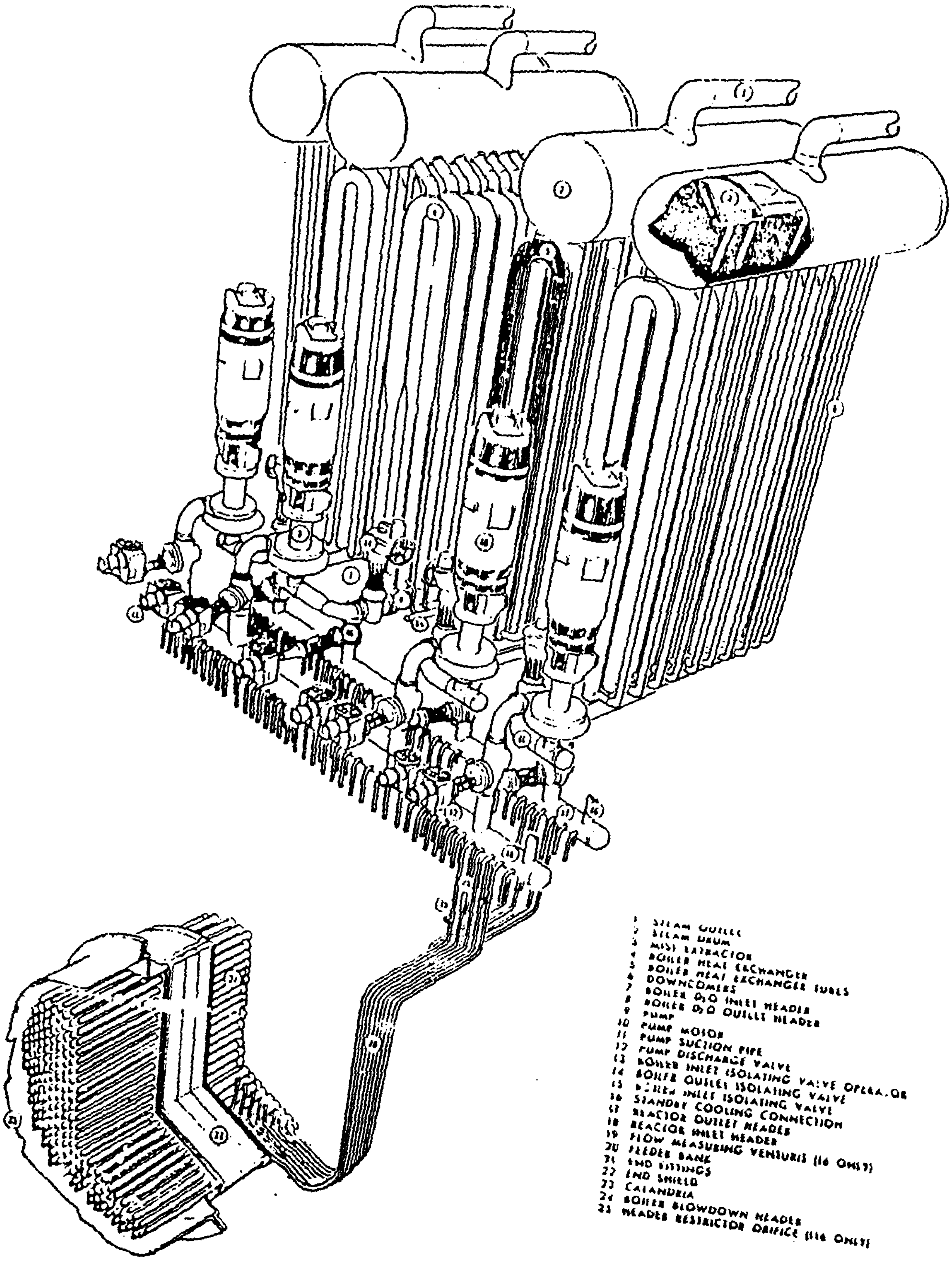
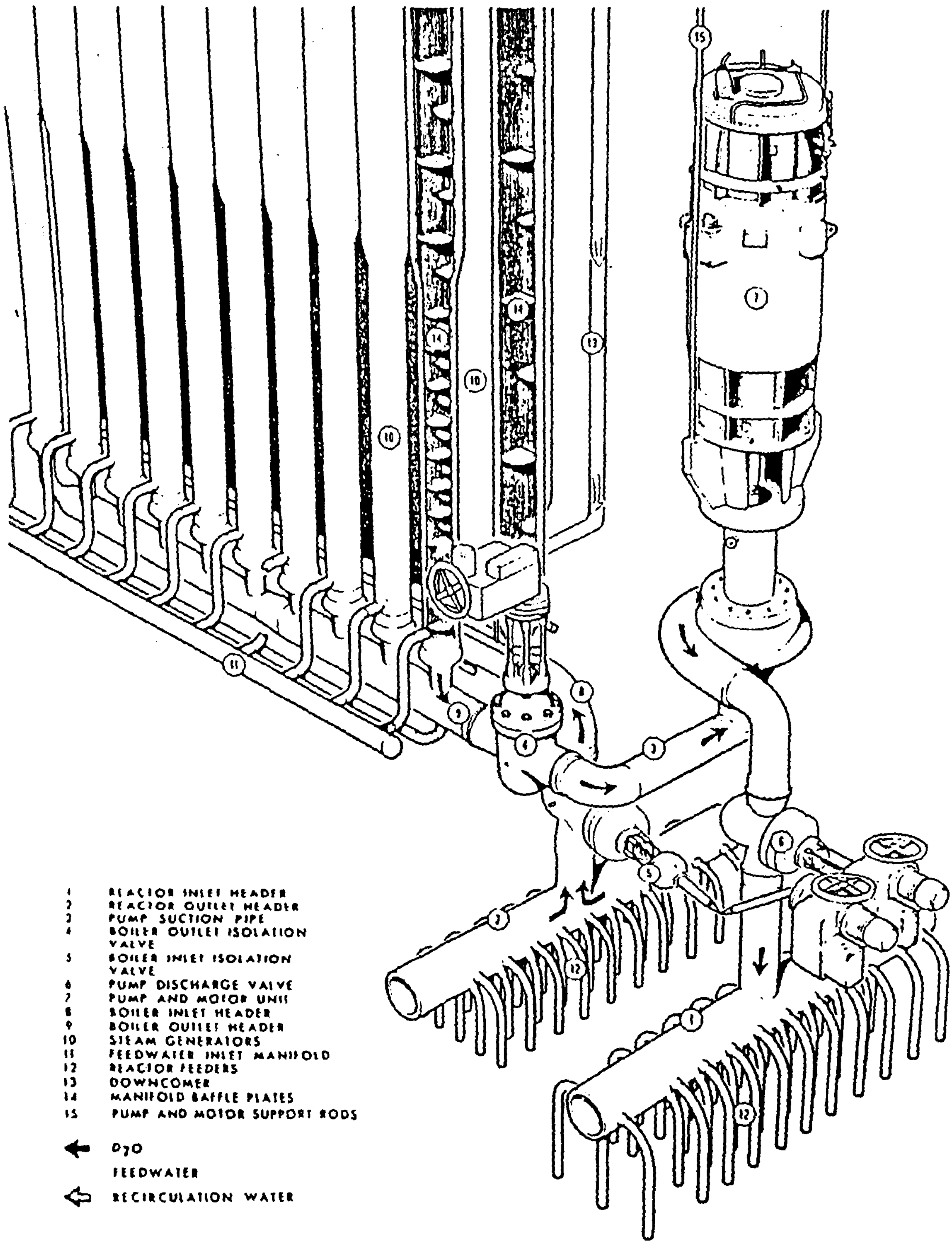


FIGURE 4 SERIES - PARALLEL PUMP SYSTEM



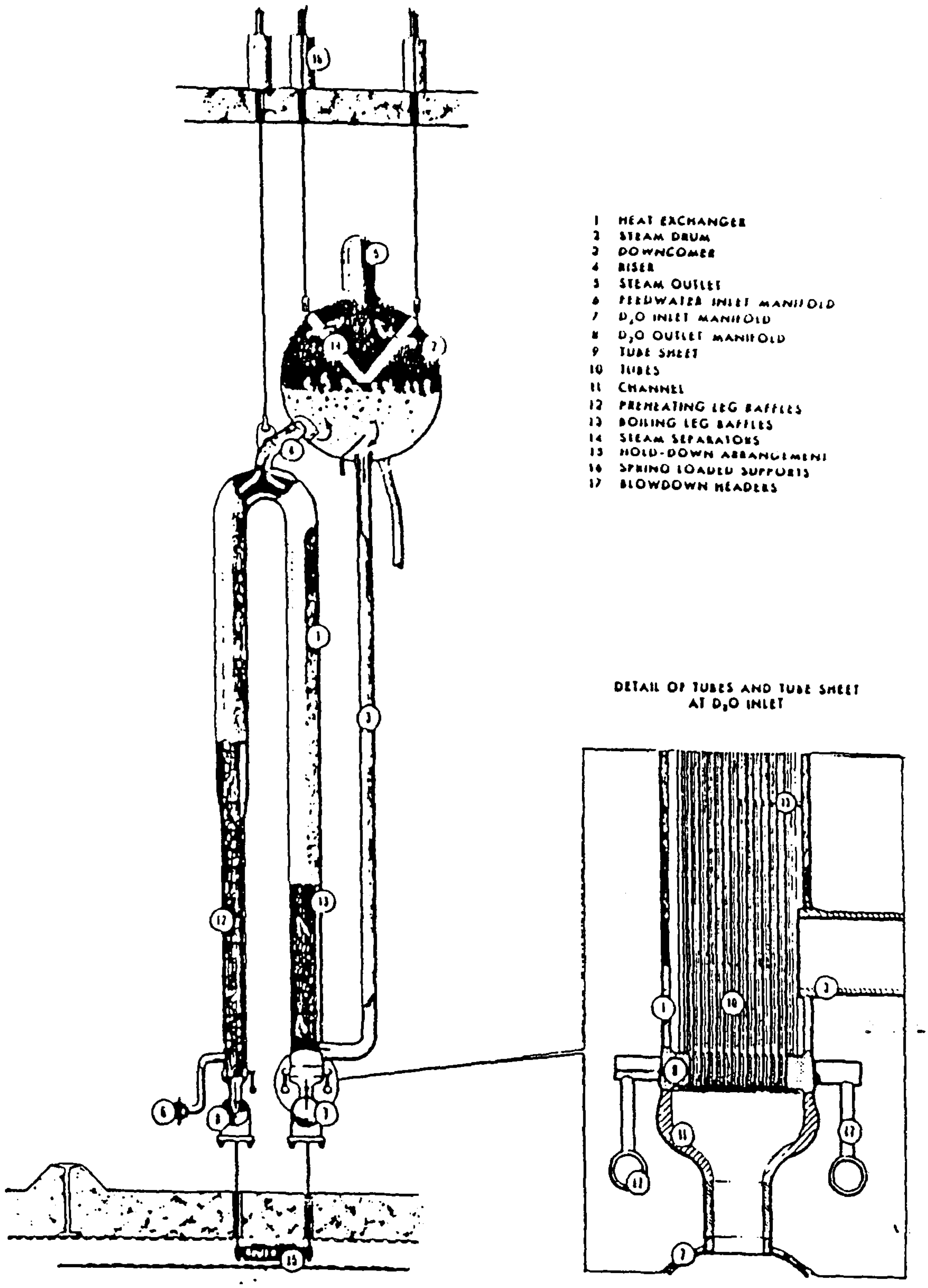
MAIN COOLANT CIRCUIT EQUIPMENT

FIG. 5



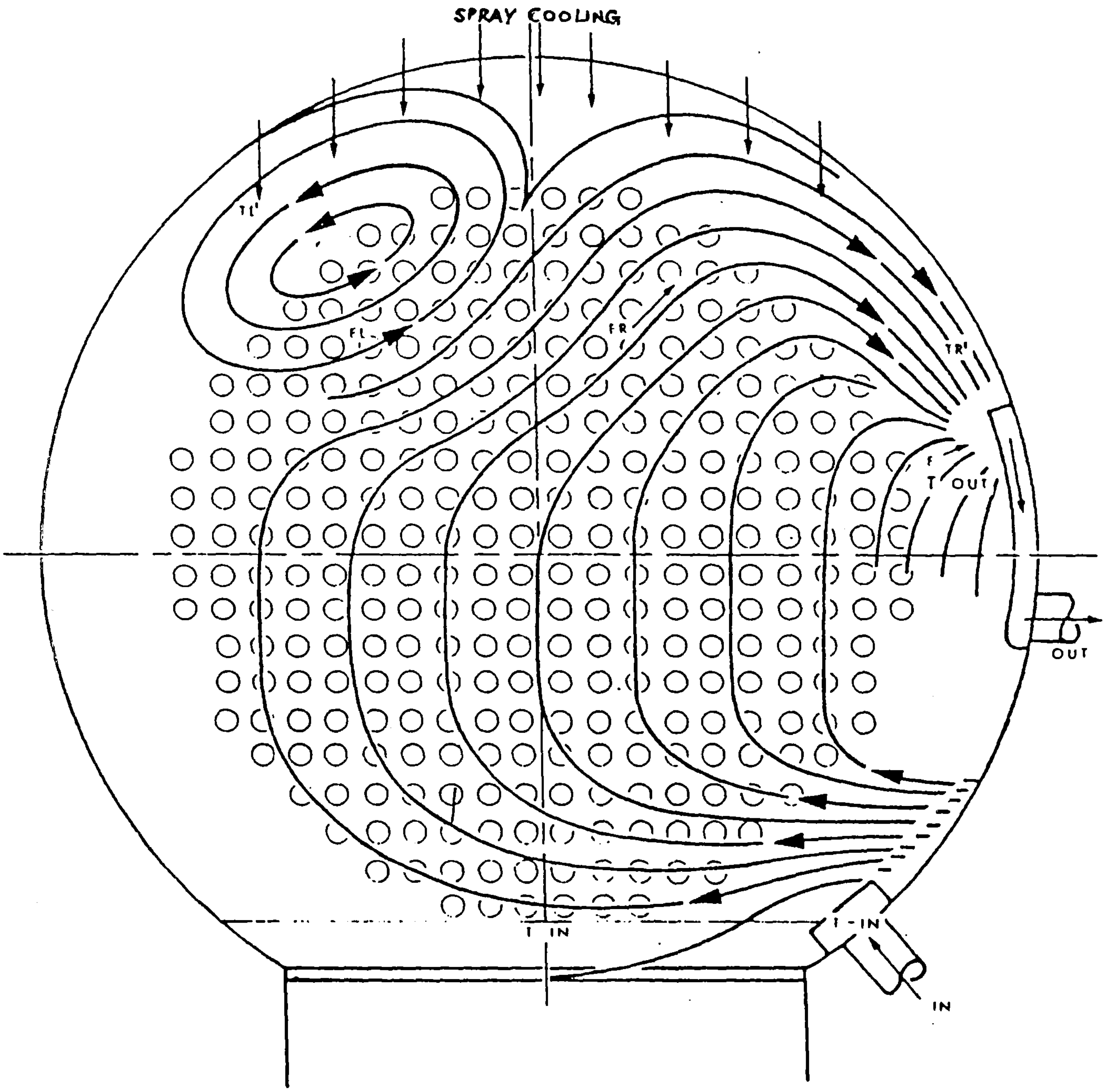
PRIMARY PUMP HEADER AND BOILER ARRANGEMENT

FIG. 6



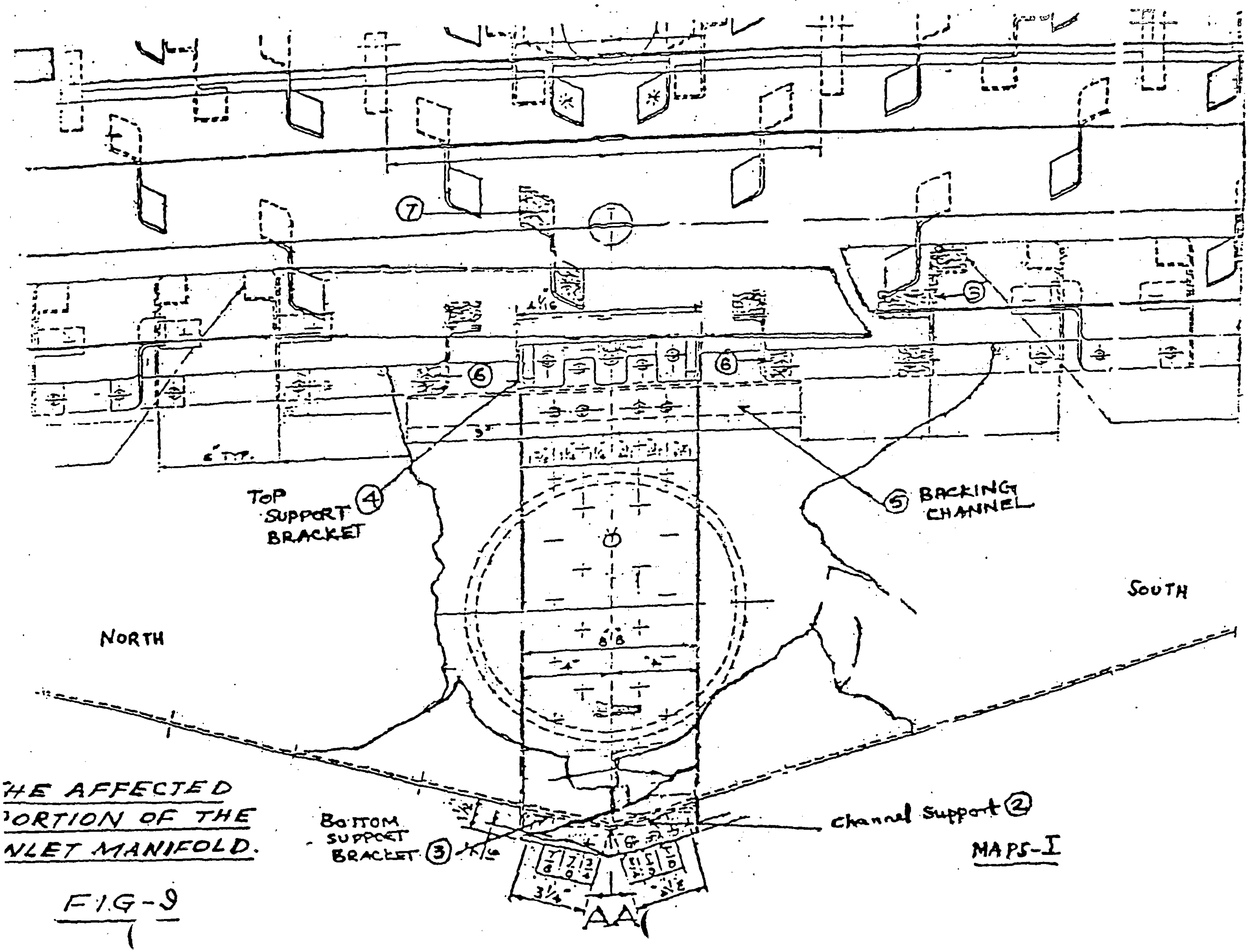
PRIMARY SYSTEM BOILER

FIG.7



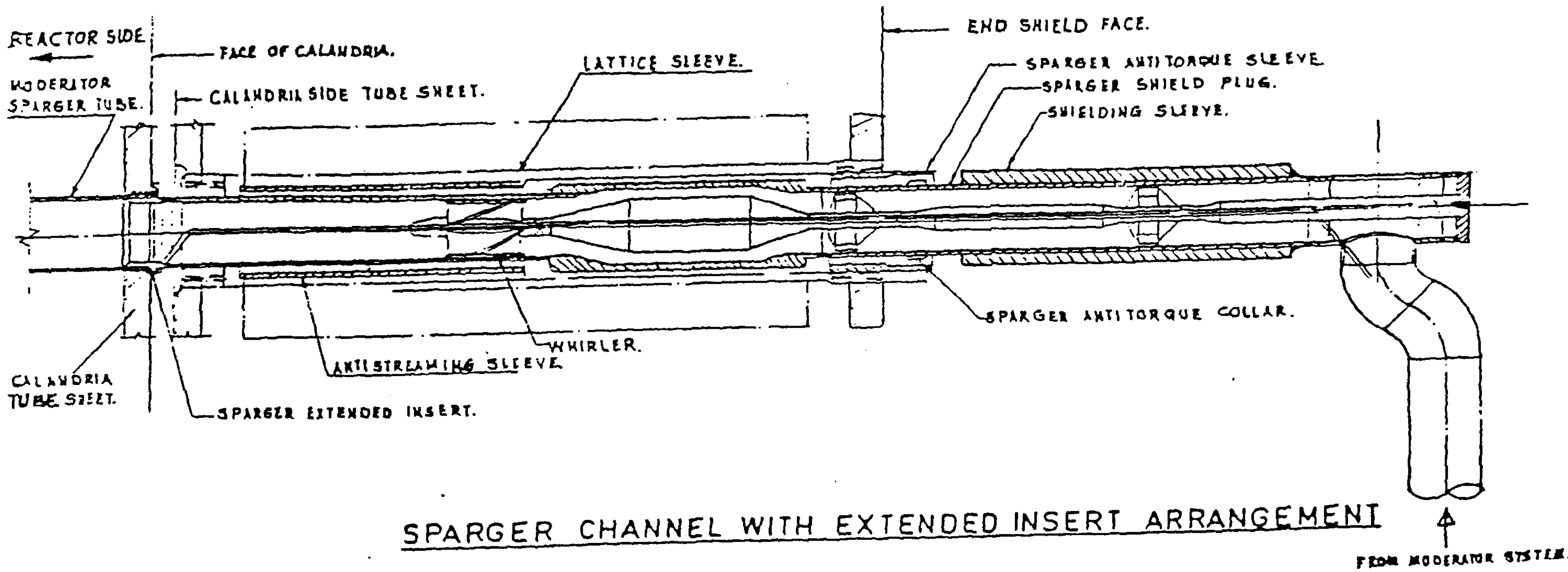
THE SCHEMATIC FLOW PATTERN IN CALANDRIA SHOWING INLET AND OUTLET MANIFOLDS AS ORIGINALLY DESIGNED.

FIG-8



HE AFFECTED
ORTION OF THE
NLET MANIFOLD.

FIG-9



SPARGER CHANNEL WITH EXTENDED INSERT ARRANGEMENT

FIG-10

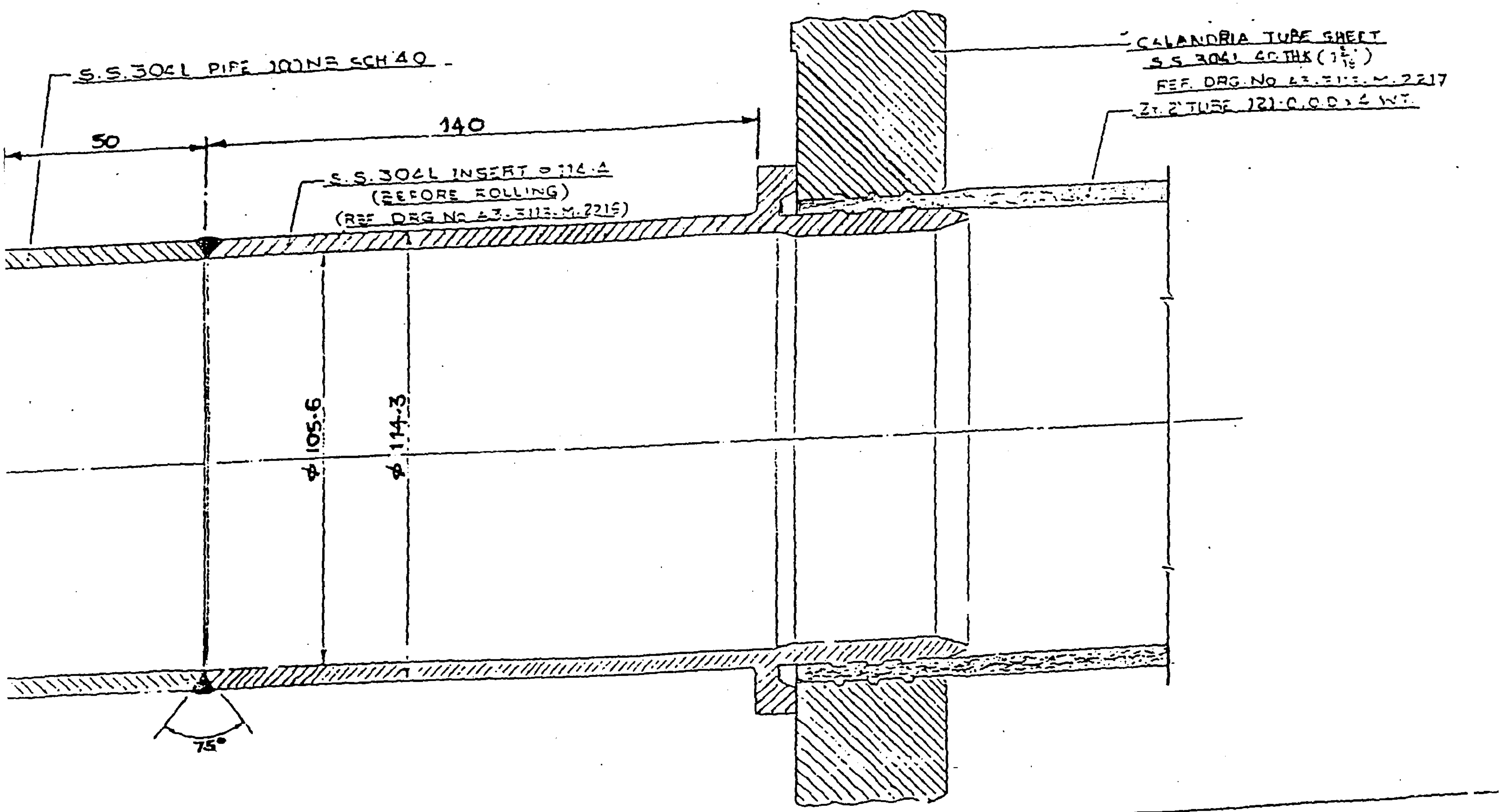


FIG-11

TITLE MAPS SPARGER CHANNEL
CALANDRIA TUBE SHEET TO TUBE, ROLLED JOINT ASSLY.

MAPS-2
DUMP TEST
12-11-1989

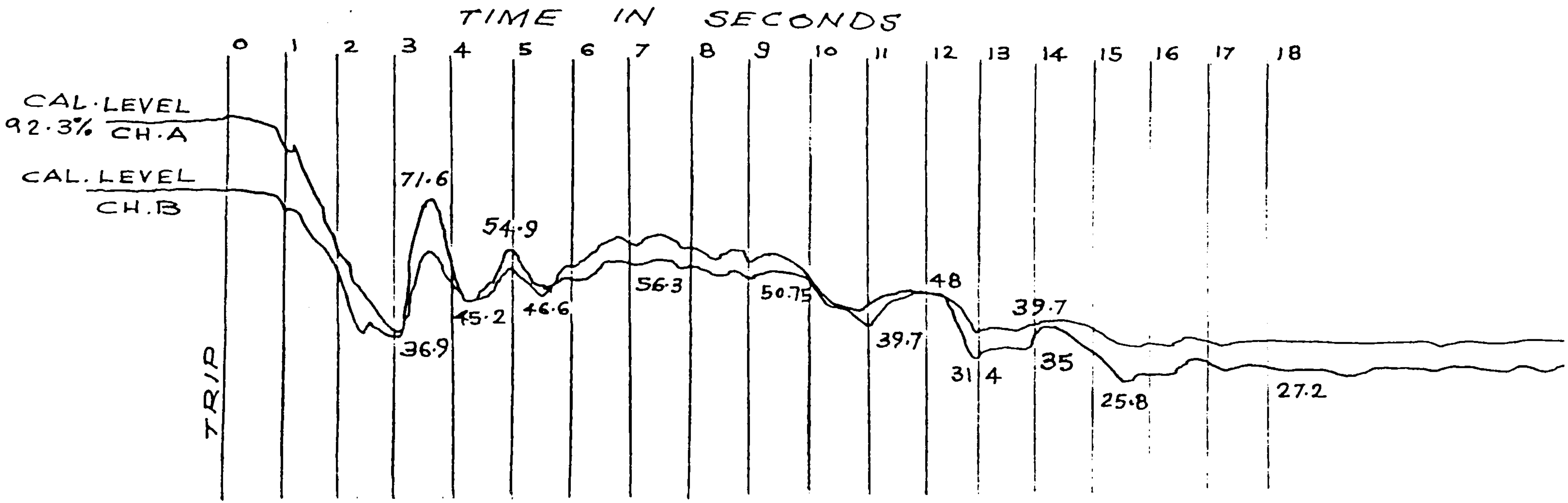
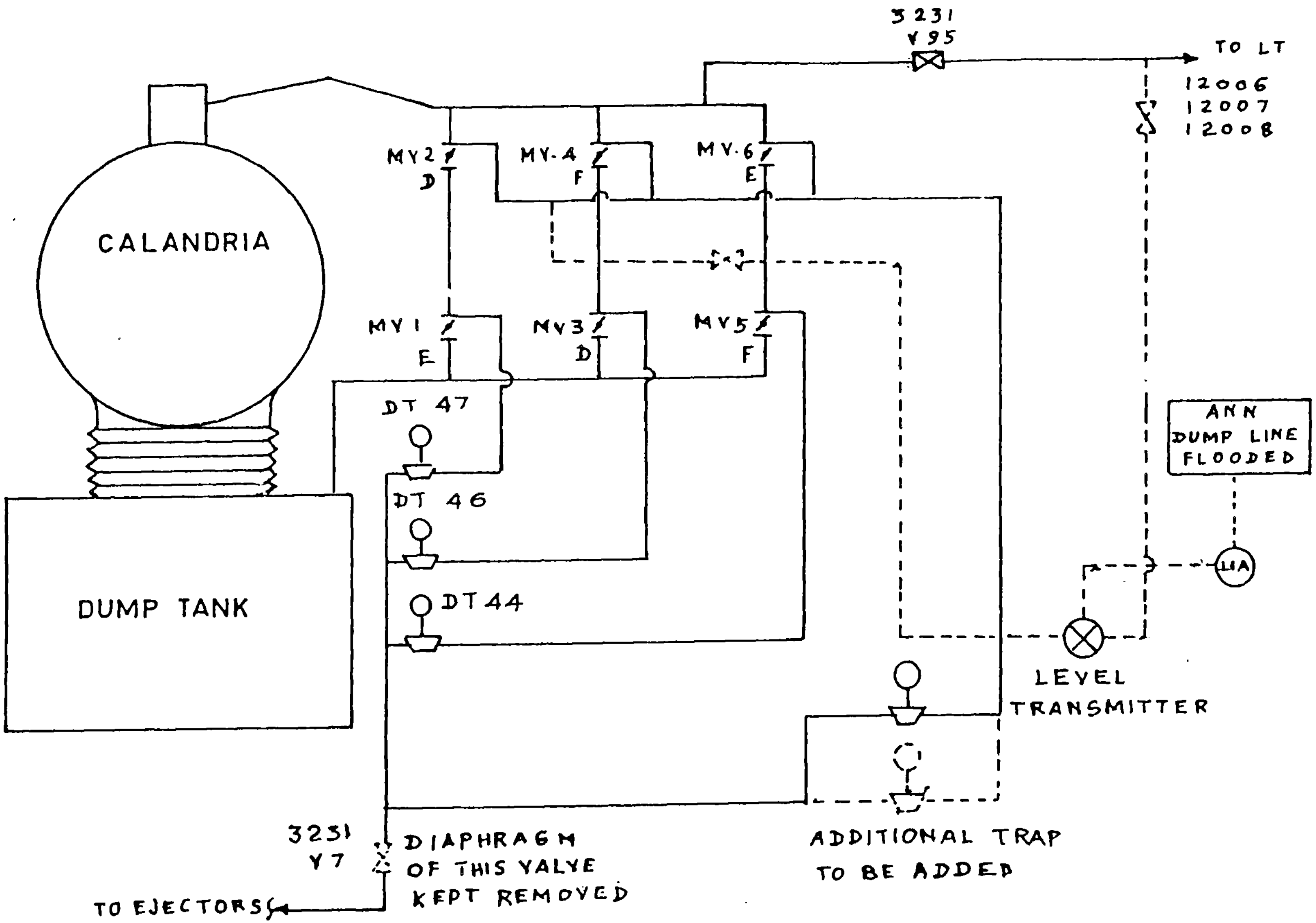


FIG-12



PROPOSED SCHEME OF DRAINING FOR GAS SPACE

ABOVE MODERATER DUMP VALVE

FIG. 13