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September 9, 1982

Mr. Harold R. Denton, Director
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Subject: Byron Station Units 1 and 2
Braidwood Station Units 1 and 2
Waterhammer Prevention
NRC Docket Nos. 50-454, 50-455,
50-456 and 50-457

Reference (a): July 30, 1982, letter from
B. J. Youngblood to L. O. DelGeorge.

(b): August 5, 1982, Memorandum from
S. H. Chesnut to B. J. Youngblood
summarizing July 27, 1982, meeting
with Westinghouse.

Dear Mr. Denton:

This is to provide information requested in reference (a) regarding the design features and procedural controls related to prevention of waterhammer of the type which apparently occurred at the KRSKO plant in Yugoslavia in July, 1981.

Attachment A to this letter contains our responses to each of the questions contained in reference (a). Several of the questions requested information pertaining directly to the KRSKO plant. Those responses have been prepared with the assistance of Westinghouse but, as indicated in the text and in the meeting discussed in reference (b), there still remains some uncertainty in the circumstances surrounding the KRSKO event.

It should be noted that in Commonwealth Edison's Motion for Summary Disposition of DAARE/SAFE Contention 9(a) concerning water hammer events, L. Bowen stated in her affidavit that Edison would be installing temperature sensors per recommendations made by Westinghouse. During the intervening months since filing of that affidavit, further research into operating guidance provided for the feedwater bypass systems has been performed which indicates that optimimum operation of this system requires constant feedwater flow through the upper steam generator nozzle. This flow precludes the possibility of waterhammer such as that which occurred at KRSKO. Hence, Commonwealth Edison no longer intends to install temperature sensors on the bypass feedwater line.

B001

Please direct further questions regarding this matter to this office.

One signed original and fifteen copies of this letter are provided for your review.

Very truly yours,

F. G. Lentine

for T. R. Tramm
Nuclear Licensing Administrator

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Question 1

For the KRSKO reported event, provide KRSKO plant and operational information which describes:

a) Plant operating state, activities, (i.e. testing) underway at the time of the reported waterhammer event and the operating conditions for the steam generator(s) feedwater, auxiliary feedwater, and the feedwater bypass systems.

Response

As a general comment, the exact time at which the incident occurred is not known. The damage was discovered several weeks after the Hot Functional Tests during which it is believed to have occurred. The conditions at the time of the incident cannot, therefore, be established with confidence. Based on the evidence, it can only be assumed that at some time, the necessary condition for bubble collapse waterhammer did exist.

Subsequent to the incident, the KRSKO plant feedwater system was modified to address the issue of steam generator (SG) preheater tube vibration. The material which follows is based on the system as it existed at the time of the water hammer incident.

The incident is believed to have occurred during the plant Hot Functional Tests, more specifically, during the tests of the Auxiliary Feedwater System (AFS) pumps conducted during July 1981. At this time, the steam generator pressure could have been as high as 900 psia and the water temperature as high as 532$^{o}$F. It was during the Hot Functional Tests that a hammer or bang was heard.

During the course of the AFS tests, ambient temperature water was introduced through the auxiliary nozzle. The flow path included a section of 6 inch bypass piping between the junction of the 4 inch AFS pipe and the auxiliary nozzle.

The main feedwater system was probably not in service when the incident is believed to have occurred.

Question 1(b)

Details of damage discovered in August, 1981, how and when damage was detected, and what evidence (if any) of a water hammer occurring in July, 1981 at the time of stated occurrence.

Response

A flow diagram showing the main and auxiliary feedwater systems is presented in Figure 1. Isometric sketches of the loop 2 bypass piping inside containment and outside containment, up to the junction of the Auxiliary Feedwater System, are shown in Figure 2 and 3, respectively.

The extent of the damage to the loop 2 bypass piping inside and outside containment, is presented in Table 1. In Figure 2, the numbers in ovals identify the pipe hangers which were affected. On both Figures 2 and 3, the length in meters of the pipe sections are given. A bulge or blister was observed in the bypass piping, in the horizontal section, downstream of the secondary shield wall, approximately midway between the shield wall and elbow in Figure 2. The bulged region was approximately six to eight inches long, with the bulge located on the top side of the pipe. At the bulge, the pipe diameter was increased approximately one quarter inch.

The only indication of any change to loop 1 was the observation that the bypass line had moved down seven to nine mm at the secondary shield wall penetration.

The loop 2 bypass line and hanger damage was discovered during a final hanger inspection on August 7, 1981. Also at about this time, it was observed that the AFS pipe paint back to the AFS pumps was blistered or discolored indicating that hot water and/or steam had at some time been present in the normally ambient temperature system.

The basis for believing that a water hammer event did occur is the nature of the damage and because a logical sequence of events can be postulated, Table 2, which could lead to a waterhammer.

One point not included in Table 2 is that the control and isolation valves in the discharge lines of the AFS pumps are normally open and, therefore, would not have prevented backleakage.

Question 1(c)

Plant corrective action(s) taken in terms of redesign, repair, operator instruction or procedures, etc. for avoidance in the future.

Response

With respect to KRSKO plant repair, the section of bypass piping, containing the bulge, between and including the second and third upstream elbows was replaced. Also the hanger damage was repaired.

Also with respect to plant operation, the customer was instructed to maintain the steam generator water level above the top of the auxiliary feedwater discharge pipe inside the steam generator as much as possible. With the discharge pipe covered, only hot water and not steam could leak back into the bypass and AFS piping, thus greatly reducing the potential for waterhammer.

To reduce the likelihood of backleakage, the Auxiliary Feedwater System check valves which were known to leak, valves 11005, 11007, 11077 and 11079, on Figure 1 were refurbished. The check valves associated with the turbine driven AFS pump discharge were not inspected as a pyrometer check under hot condition indicated no leakage.

In the eventuality that the presence of steam is suspected in the bypass lines of all loops, based on temperature data and water level status and history, there would not be any operable loops with which to shut down the plant. In this situation, the recommended course of action is to slowly refill one loop at a time with the AFS. An analytical study by the Westinghouse R&D Center shows that for the KRSKO plant, the safe refilling flow rate is in the range of 15 to 123 gpm per steam generator. To be conservative, we recommend the 15 gpm valve or as close to this as can be provided.

Under normal conditions, between 0 and 100% power some flow is provided continuously through the auxiliary nozzle, thus effectively preventing the backflow of hot water or steam from the steam generator. When the feedwater flow is through the main nozzle, a tempering flow of one to two percent is maintained through the auxiliary nozzle. The purpose is to maintain the auxiliary nozzle at feedwater temperature thus reducing the induced thermal stresses when the feedwater is transferred from the main to auxiliary nozzles, during plant unloading, for example. However, the tempering flow also effectively prevents backleakage.

At very low load or hot standby conditions, when the feedwater flow to each steam generaor is minimal, the operator is instructed to supply the feedwater continuously rather than intermittently. The reason is to minimize the probability of feedline cracking, but it also eliminates the possibility of backleakage.

The principal modification was to provide a series of temperature measurements on the bypass piping of each loop in the first vertical leg upstream of the auziliary nozzle. Two strap on RDT's have been installed in each loop, one three meters below the first elbow and a second four meters below the elbow. The RTD's are connected to the plant's DATA-SCAN Temperature Monitoring System which allows for printing out the temperature values in the control room on request. The system activates an alarm if the temperature values exceed predetermined setpoints. Recommended operating guidelines were provided to the customer for utilizing the temperature data during the operations of Plant Heatup and Cooldown and for Power Operation.

Question 2

With respect to plant (KRSKO) operational states information (See Item 1), provide the following information:

(a) Water level in the steam generator relative to the auxiliary feedwater nozzle elevation.

Response

During normal operation, the indicated water level is constant with power level at 488 inches above the tube sheet. At full power, the actual water level is approximately four inches higher because of velocity head and circulation ratio effects. The differential increases and then decreases with power level; it is 0 inches at 0 power, approximately six inches at 50 percent power and approximately four inches at 100 percent power. The top of the auxiliary nozzle discharge pipe is 473 inches above the tube sheet. The water level is, therefore, nominally 15 to 21 inches above the top of the auxiliary nozzle discharge pipe, depending on power level. Accounting for normal channel accuracy of ± five percent of span or ± 12 inches, which is believed to be conservative, the water level could be as close as three inches above the top of the discharge pipe.

Question 2(b)

Steam generator pressure, temperatures, and flow rates.

Response

At the time when the waterhammer event is believed to have occurred, the steam generator pressure could have been as high as 900 psia with a saturation temperature of 532$^{\circ}$F.

Question 2(c)

Flow rates, temperatures and pressures in the feedwater and auxiliary feedwater sources supplying flow to the steam generator.

Response

It is possible that the waterhammer incident occurred during testing of the AFS pumps. The pumps provide feedwater to the auxiliary nozzles through the four inch diameter AFS piping and a section of six inch diameter bypass piping. The capabilities of the motor-driven and turbine-driven AFS pumps are 350 gpm and 700 gpm, respectively, against a back pressure in the steam generator eouivalent to the set pressure of the lowest set safety valves. The water would be at ambient temperature since the pumps take suction from the condensate storage tanks.

During the testing, the pumps were started and stopped. The intervals between pump stop and restart were up to 30 minutes long. During those intervals, there was no forward flow through the auxiliary nozzles.

The steam generator water level was not intentionally lowered below the auziliary nozzle discharge pipe prior to each test to accept the AFS water.

Question 3

Provide systems design and piping details for the feedwater, auxiliary feedwater, and the feedwater bypass systems for both the Byron and KRSKO plants. This information should be in the form of piping drawings, piping schematics or P&ID's which clearly define piping layouts, valves, and elevations relative to the steam generator feedwater and auxiliary feedwater nozzles. Valves which are controlled from the control room should be identified, along with operation requirements (or procedures) which are at the disposal of the operators.

Response

1. KRSKO

The schematic diagram, Figure 1, shows part of the KRSKO plant main feedwater system and auxiliary feedwater system. The diagram includes the feedwater system from the main feedwater header to the steam generator as it was at the time of the waterhammer incident. It has since been modified to permit feeding simultaneously to the main and auxiliary nozzles during high power operation.

As discussed earlier, based on the evidence of blistered and discolored paint, hot water and/or steam leaked back from the steam generators through a section of the six inch Sch 80 bypass piping and then into the AFS. The section of loop 2 bypass piping of interest is indicated in Figure 1 as between Points A and B.

Two isometric pipe sketches of the bypass piping are presented in Figures 2 and 3. Figure 2 shows the bypass piping inside containment from the six inch auxiliary nozzle to the containment vessel penetration. Figure 3 shows the section of bypass piping from the containment penetration back to the point where the four inch Sch 80 AFS pipe connects.

With respect to the postulated backleakage path of hot water and/or steam, the pertinent valves are all in the AFS. The AFS motor-driven pump discharge lines are each provided with two check valves and with a pneumatically operated, normally open, control valve which is operable locally and from the control room.

The AFS turbine driven pump, by means of a cross connect line, connects with the two motor-driven pump discharge lines. The flow path from the turbine driven pump to either SG auxiliary feedline line includes two check valves and a pneumatically operated control valve as is the case for the motor-driven pumps. In addition, each leg of the cross connect line is provided with a pneumatically operated isolation valve. The control and isolation valves are operable locally and from the control room.

2. Byron and Braidwood (B/B)

Figures 6 and 7 are simplified diagrams of the B/B AF and main feedwater systems. Detailed P&ID's accompany this response. The following table lists the valves that are controlled from the control room.

AF System

| | | | |
|---|---|---|---|
| 1. | Suction Valves from the Essential Service Water (ESW) System | AF007A-1&2<br>AF007B-1&2 | Auto open |
| 2. | AF Steam Generator Flow Control Valves | AF005A thru H | Auto capability |
| 3. | AF Steam Generator Isolation Valves | AF013A thru H | |

Feedwater System

| | | | |
|---|---|---|---|
| 4. | Feedwater Reg Valve Isolation Valve | FW006A(B,C&D) | |
| 5. | Feedwater Reg Valve | FW510(520,530, 540) | Auto capability |
| 6. | Feedwater Reg Valve Bypass Valve | FW510A(520A, 530A, 540A) | Auto capability |
| 7. | Feedwater Isolation Valve | FW009A (B,C&D) | Auto capability |

The remainder of the valves shown in Figures 6 and 7 are either manual valves, automatically operated valves or locally operated valves.

Accompaning this response are one line diagrams that show the elevation of the upper feedwater nozzle at the steam generator and its relation to the other piping.

Question 4

Provide steam generator "internals" design details for both the Byron and KRSKO plants. This information should be in the form of drawing which clearly define Feedwater and Auxiliary Feedwater nozzles, penetrations, flow distributors, etc. This information will be used to determine similarities and differences between the proposed Byron Steam Generators and KRSKO Steam Generators.

Response

1. KRSKO

The internals of the KRSKO Model D4 steam generator are shown in Figures 4 and 5. Figure 4 for the upper shell shows the auxiliary nozzle and internal extension. Also indicated is the actual water level for 100 percent power.

In Table 3, the KRSKO SG internal elevations and setpoints are tabulated.

2. B/B

The internals of the B/B models D-4 and D-5 are shown in figures 8 and 9 respectively. Figures 8 and 9 show the auxiliary nozzle and interal extension and actual water level for 100 percent power.

In Tables 4 and 5 the B/B SG internal elevations and setpoints are tabulated.

Question 5

Given the information requested in Items (3) and (4), summarize similarities and differences between Byron and KRSKO feedwater, auxillary feedwater, feedwater bypass systems, and steam generators. Relate to the Byron plant operational procedures and temperature sensor installation.

Response

The bypass line and AF system pipe routings are similiar for the KRSKO and B/B plants. The number of check valves in the bypass and AF lines are essentially the same with the exception of an additional check valve in the B/B piping at the upper steam generator nozzle. Valves in the AF system are normally open in both plant designs.

B/B Operation

In contrast to the KRSKO start up operations the B/B plants utilize a start up feedwater pump for heat up and start up rather than the AF system. Flow is through the feedwater reg. valve bypass valve, the preheater bypass valve and the upper steam generator nozzle. The feedwater reg. valve bypass valves are automatically controlled to maintain steam generator level. Leakage through the feedwater reg. valves is eliminated by closure of the upstream isolation valve. Hence, sufficient flow control is present to ensure flow at all times through the upper nozzle. During hot standby conditions, SG level may be controlled by blowdown. Slug feeding of the steam generators is not recommended.

During power operation below a nominal 20% power, flow is directed to the upper nozzle by the preheater bypass valve. There is an automatic switchover to the lower nozzle at higher power levels. However, flow is maintained through the upper nozzle via the tempering flow line.

Therefore, during plant operation flow is present at all times to the upper nozzle. With constant flow the conditions for backleakage, either of steam or hot water, into the AF lines are eliminated. Furthermore since the steam generator level is automatically controlled at all times, the possibility of uncovering the nozzle in the steam generator is minimized which limits further the potential for backleakage of steam even in absence of flow.

During operation, on-line testing of valves in the tempering flow and bypass feedwater lines is recommended by Westinghouse. If the testing requires valve stroking, Westinghouse recommends that the valve not be closed longer than 30 seconds. This recommendation will be followed at Byron/Braidwood.

During plant hot functional tests the same precautions apply. There should be flow through the upper nozzle at all times. If flow is interrupted for any reason it will be re-initiated slowly to ensure that, if steam back leakage into the piping has occurred, water hammer will not occur.

If flow is stopped and re-initiated for any reason during testing, a physical inspection of piping and hangers will be undertaken to ensure that no damage has occurred due to water hammer.

Because of these operating procedures, the temperature sensors recommended by Westinghouse will not be installed on the B/B feedwater piping. These sensors and associated operating procedures will not add any significant margin of protection from water hammer due to the procedural requirements to maintain flow through the upper nozzle at all times.

Westinghouse has further recommended that testing be performed to ensure there is no backleakage through AF system check valves. Procedures will be written to accommodate this recommendation.

Byron plant operating and startup procedures have not been written as yet. The recommendations discussed above will be incorporated when these tests are written.

Question 6

Provide the test plan which would be used by Byron plant for verification that steam generator waterhammer will not occur (as noted in the staff's Byron SER Evaluation, Section 10.4.7). Describe how this test plan will demonstrate that the Byron plant will not experience a waterhammer such as reported at KRSKO.

Response

First of a kind steam generator waterhammer tests have been conducted for the Model D4 Steam Generator at the KRSKO plant. The tests verified that if the feedwater bypass system is operated in accordance with the Westinghouse recommended guidelines, SG waterhammer will not occur.

Startup test procedures for Byron/Braidwood will be written in accordance with the guidance provided in NUREG/CR 1606. These tests, when written, will be available for NRC review.

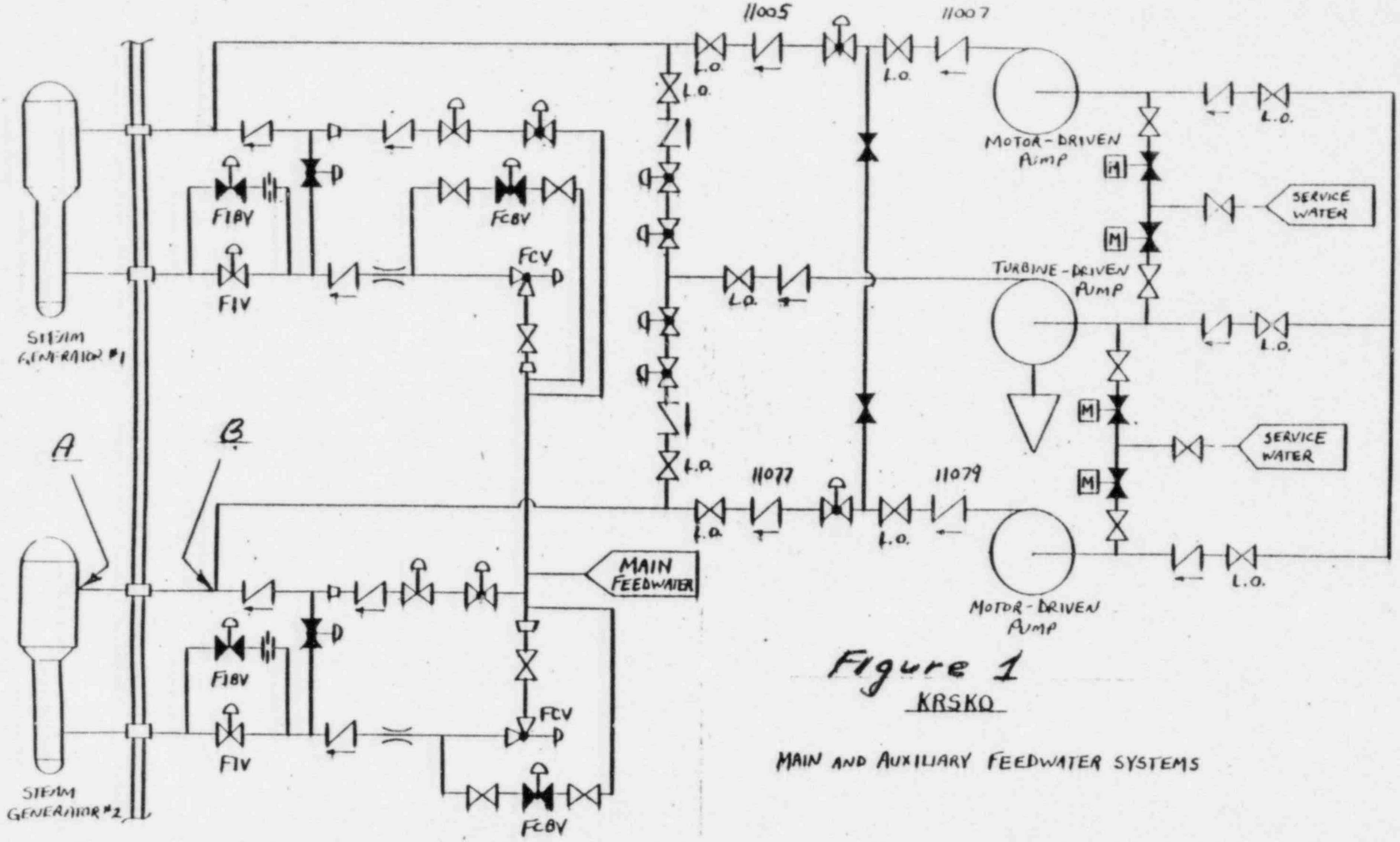
The KRSKO test plan did not include testing related to steam backleakage into the bypass line and AFS. Any test for this purpose would be directed toward verifying that necessary steps have been taken to prevent steam backleakage.

As stated above, preoperational tests will be written to ensure that there is no backleakage through AF system check valves as recommended by Westinghouse.

## References

1. Docket Numbers STN 50-454, 50-455, 50-456, and 50-457, subject: Additional Information on Byron/Braidwood Waterhammer Prevention, B.J. Youngblood, Chief, Licensing Branch No. 1, Division of Licensing, NRC, July 30, 1982.

2. "Operating Procedures for Counter-Flow Preheat Steam Generator with Main Feedwater Bypass System", May, 1981, Westinghouse Electric Corporation.




# Figure 1

KRSKO

MAIN AND AUXILIARY FEEDWATER SYSTEMS

Figure 2, KRSKO

Bypass Line, Loop 2

Inside Containment

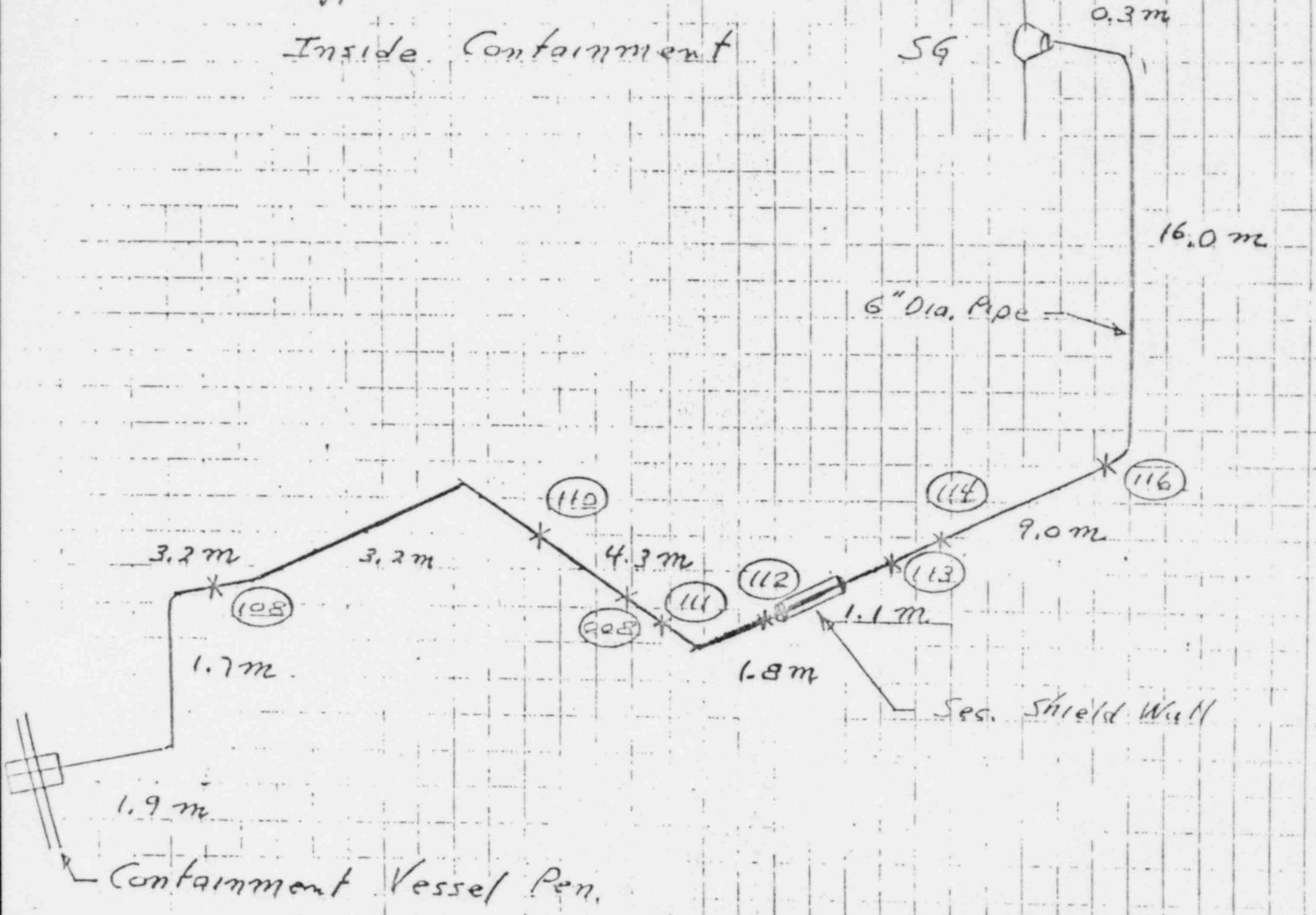


Figure 3, KRSKO

Bypass Line, Loop 2

Outside Containment

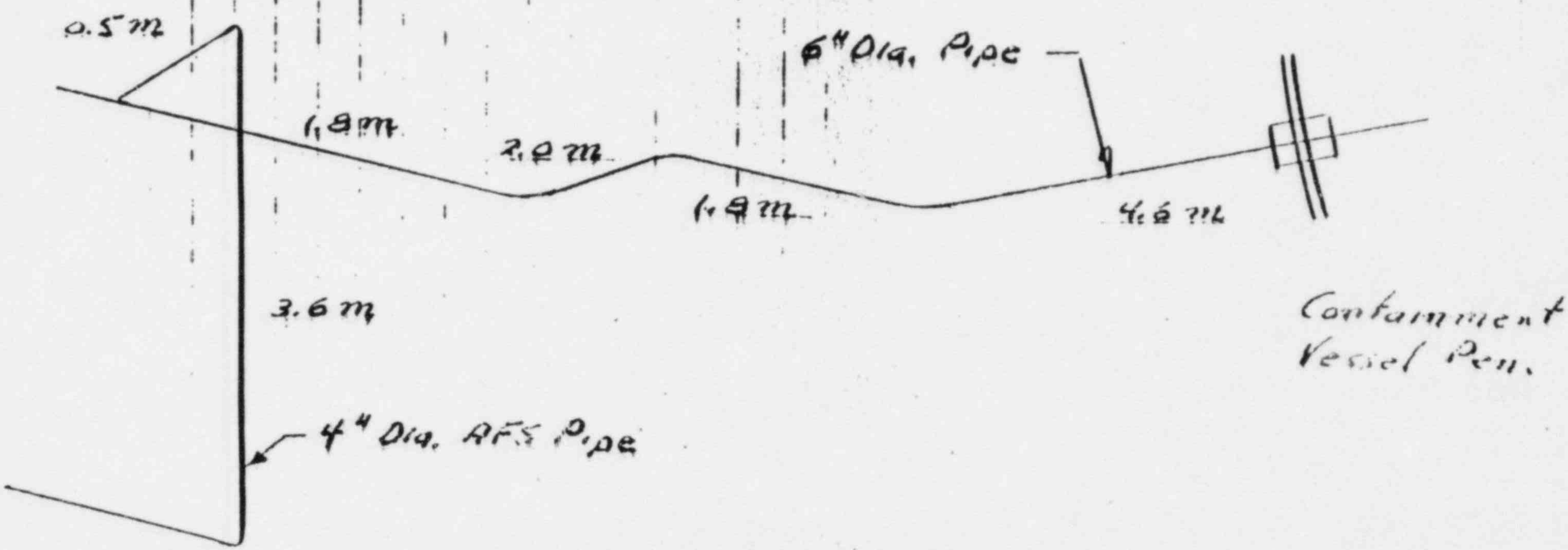
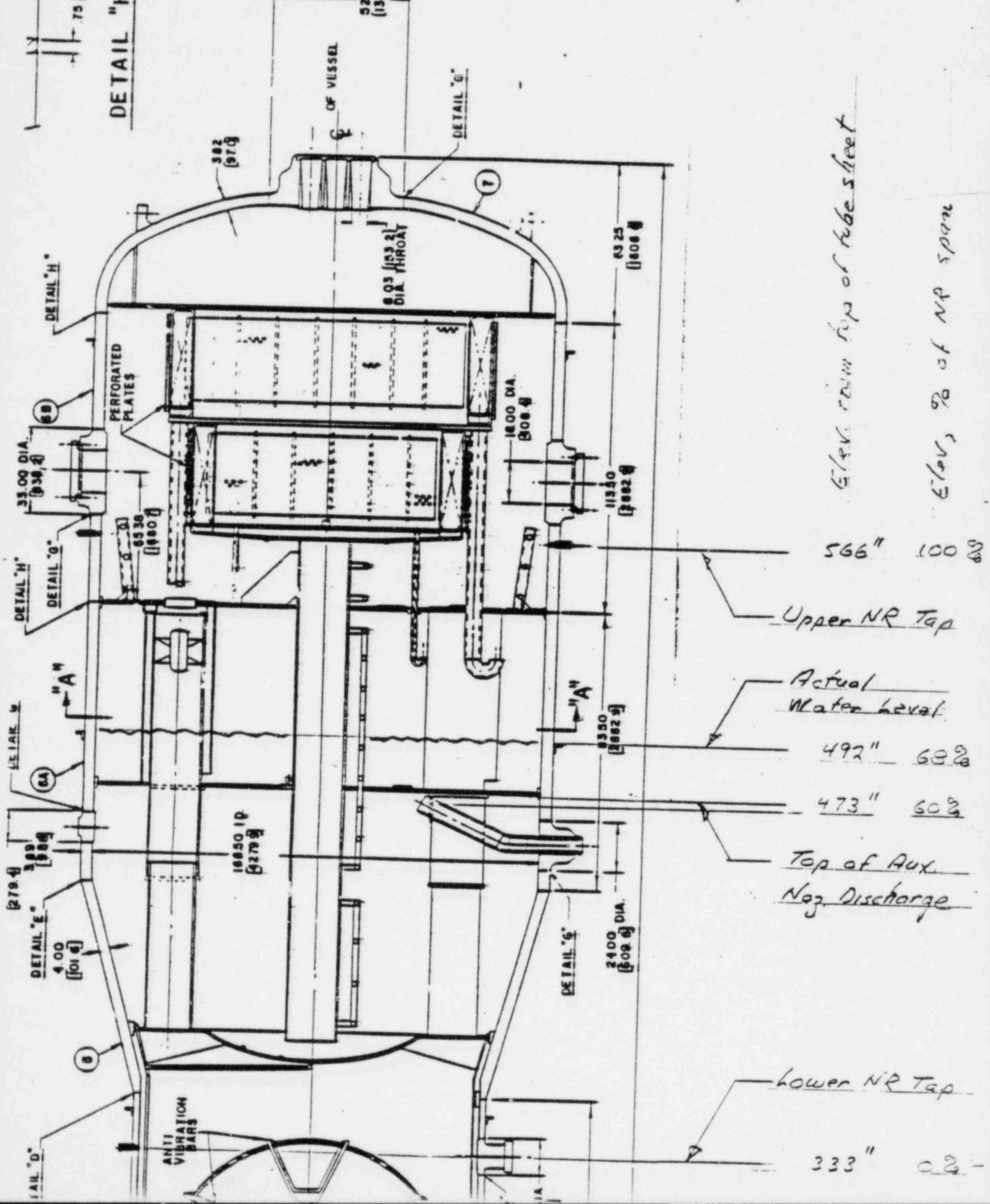



FIGURE 3, KRSKO

Fig. 4
KRSKO D4 SG



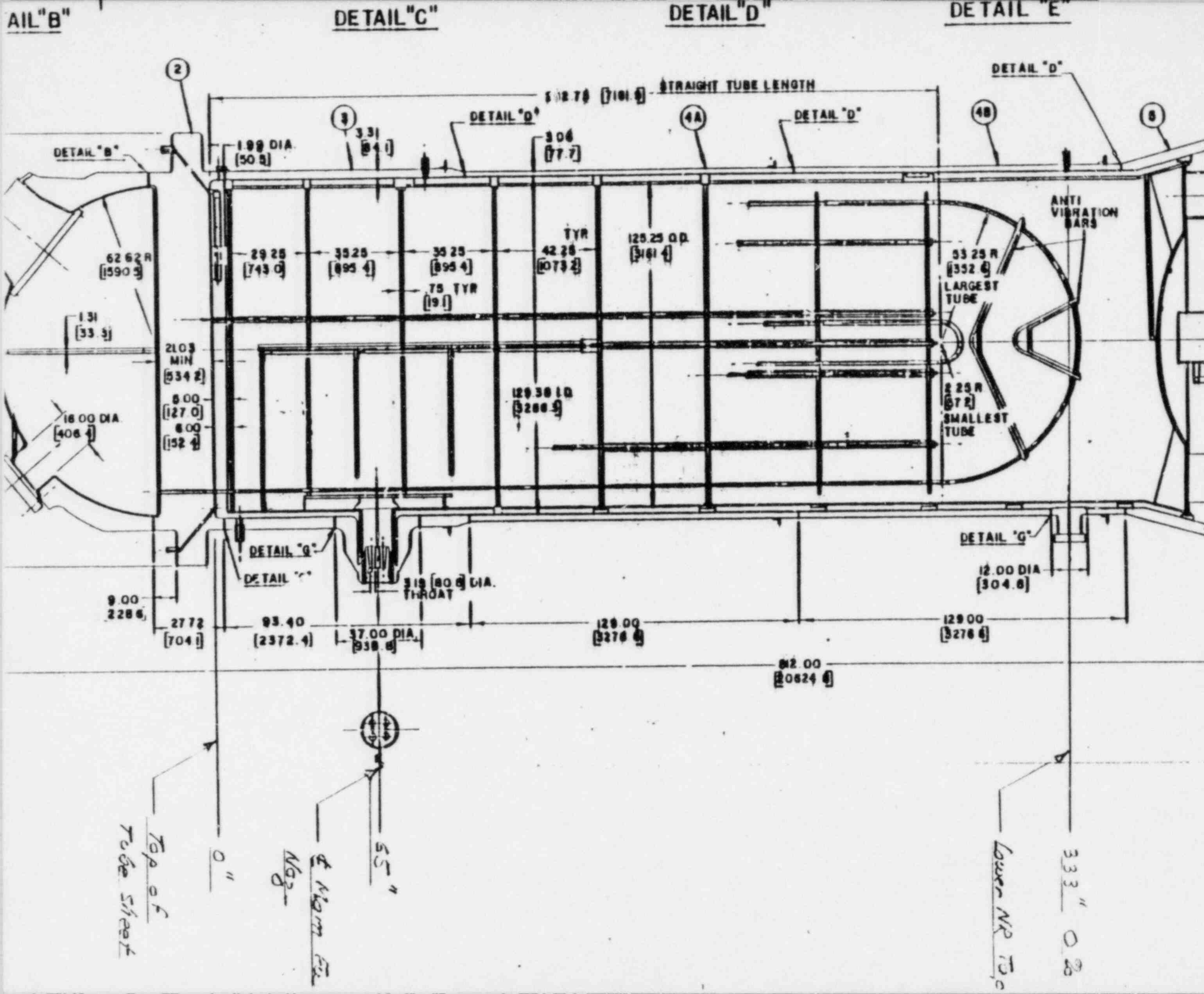



Fig 5
KRSKO D4 SG

FIGURE 6 BYRON AFW SYSTEM

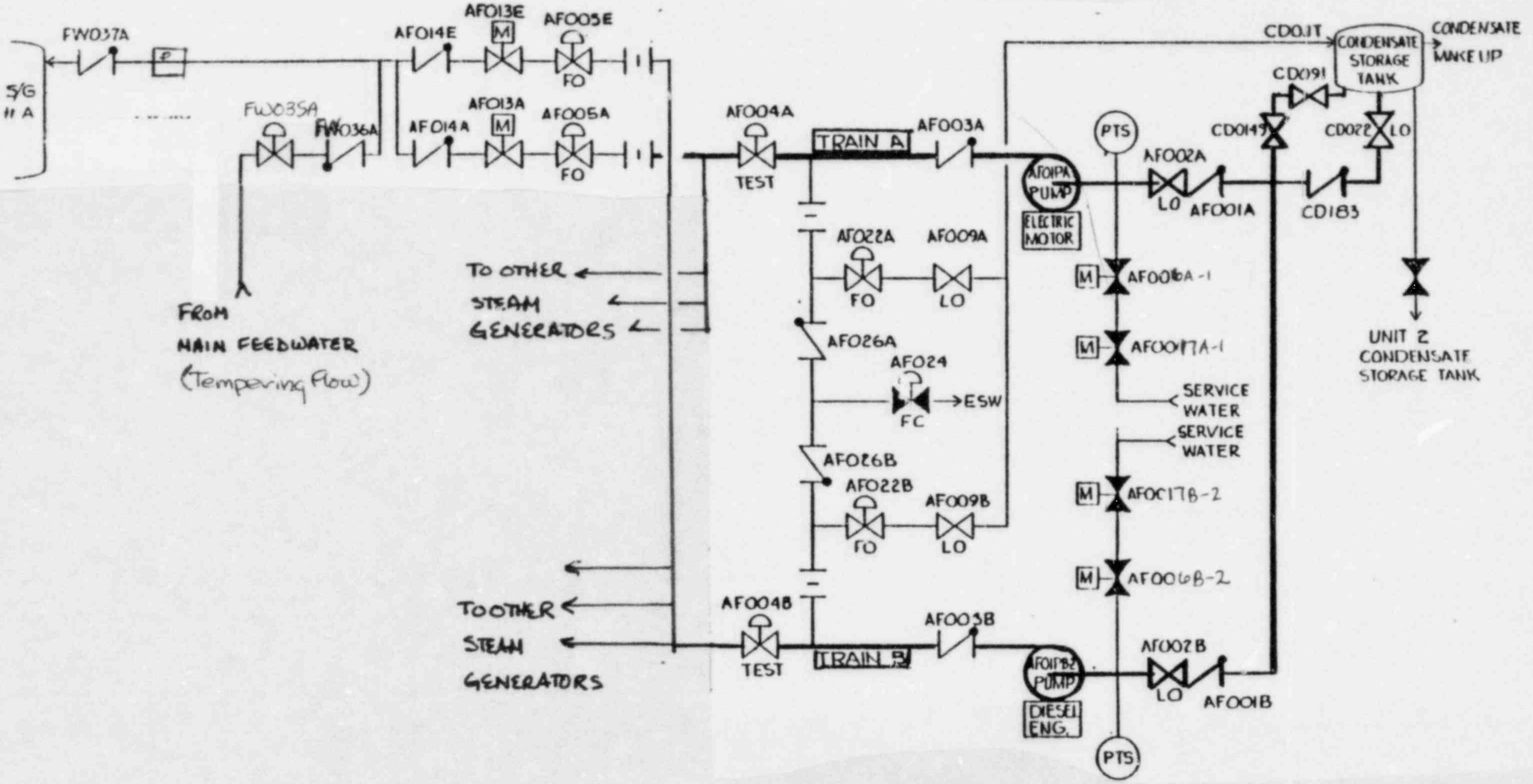


*FIGURE 7*

FEEDWATER BYPASS SYSTEM

SIMPLIFIED FLOW DIAGRAM

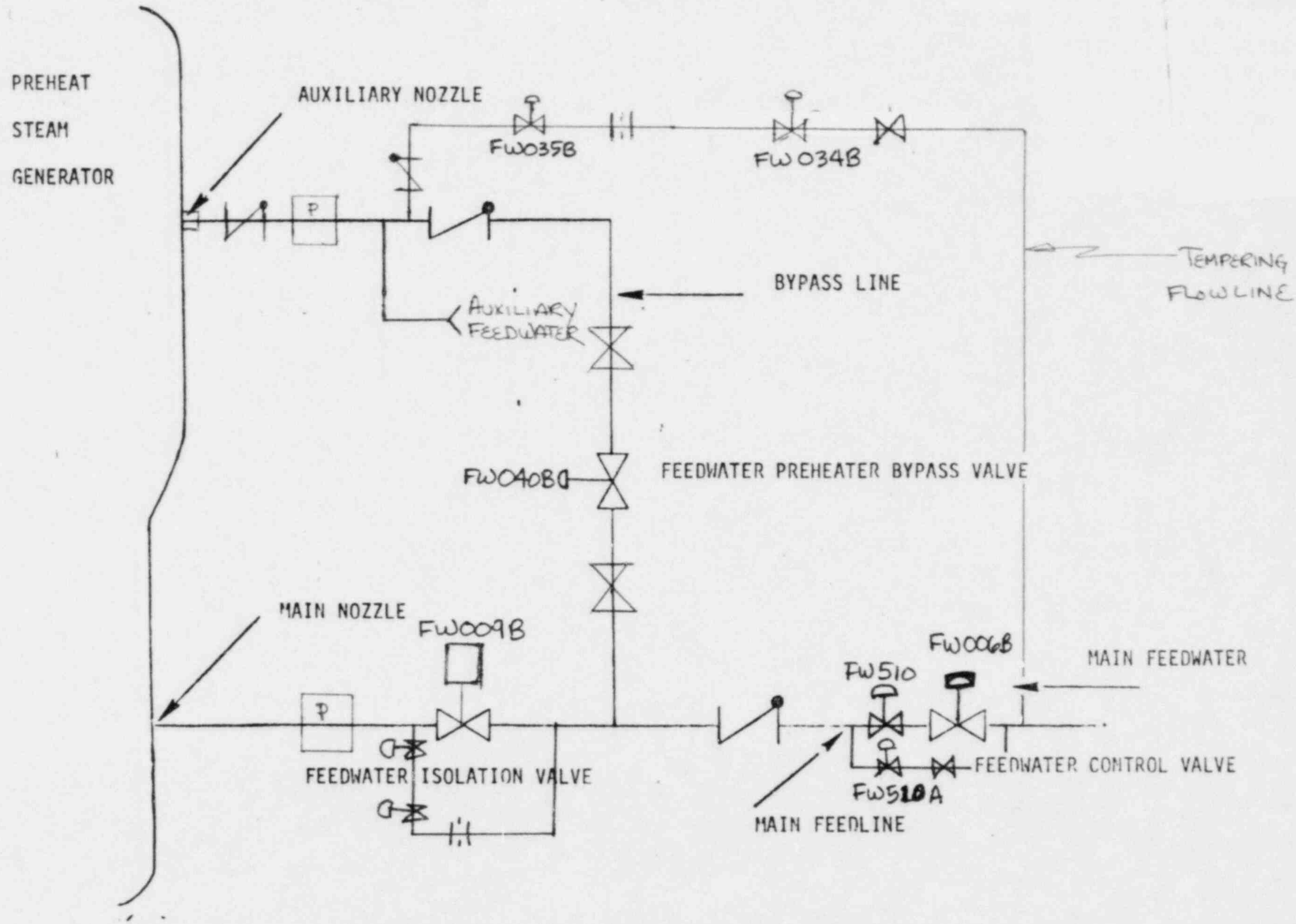


Figure 8

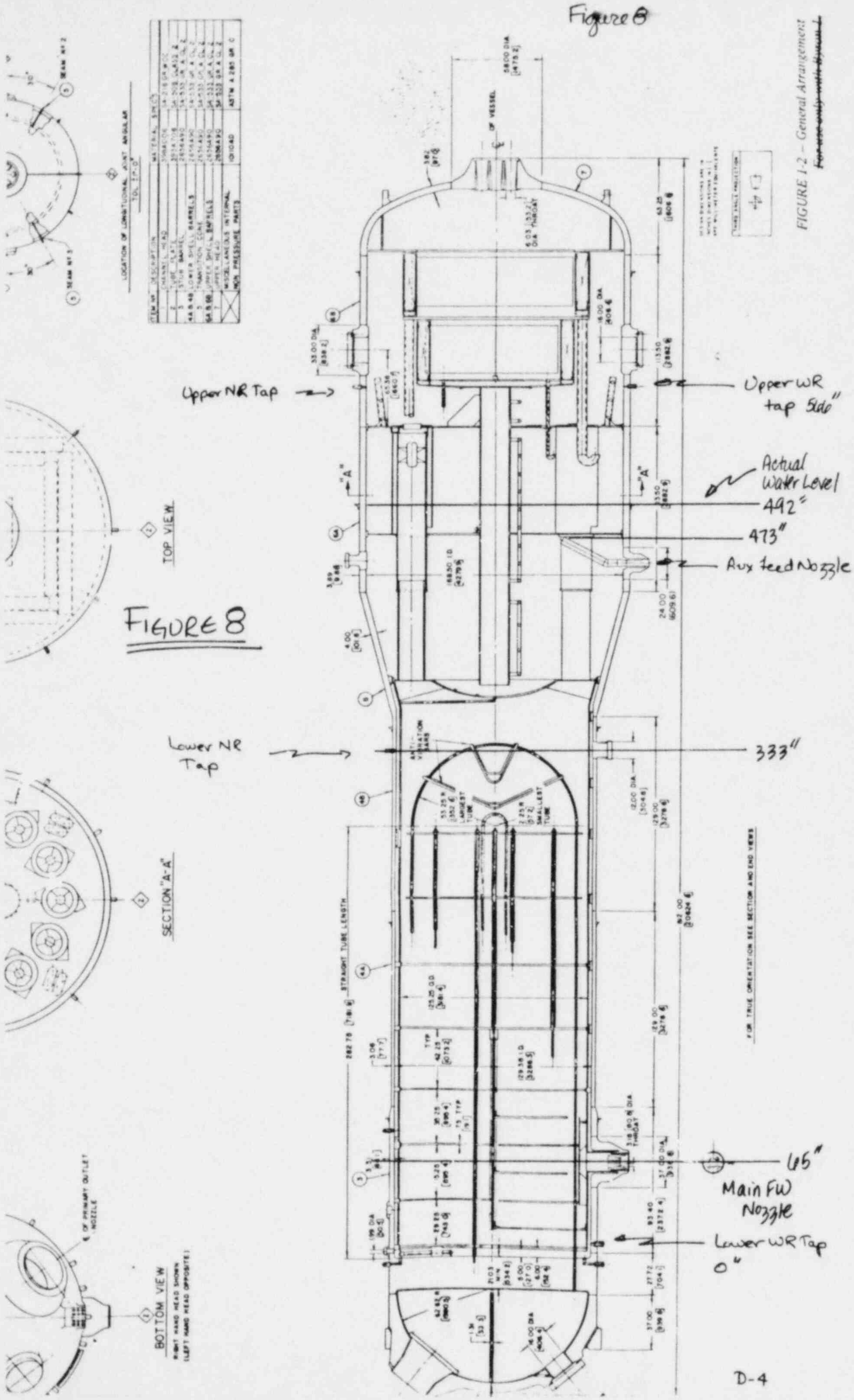



FIGURE 1-2 – General Arrangement

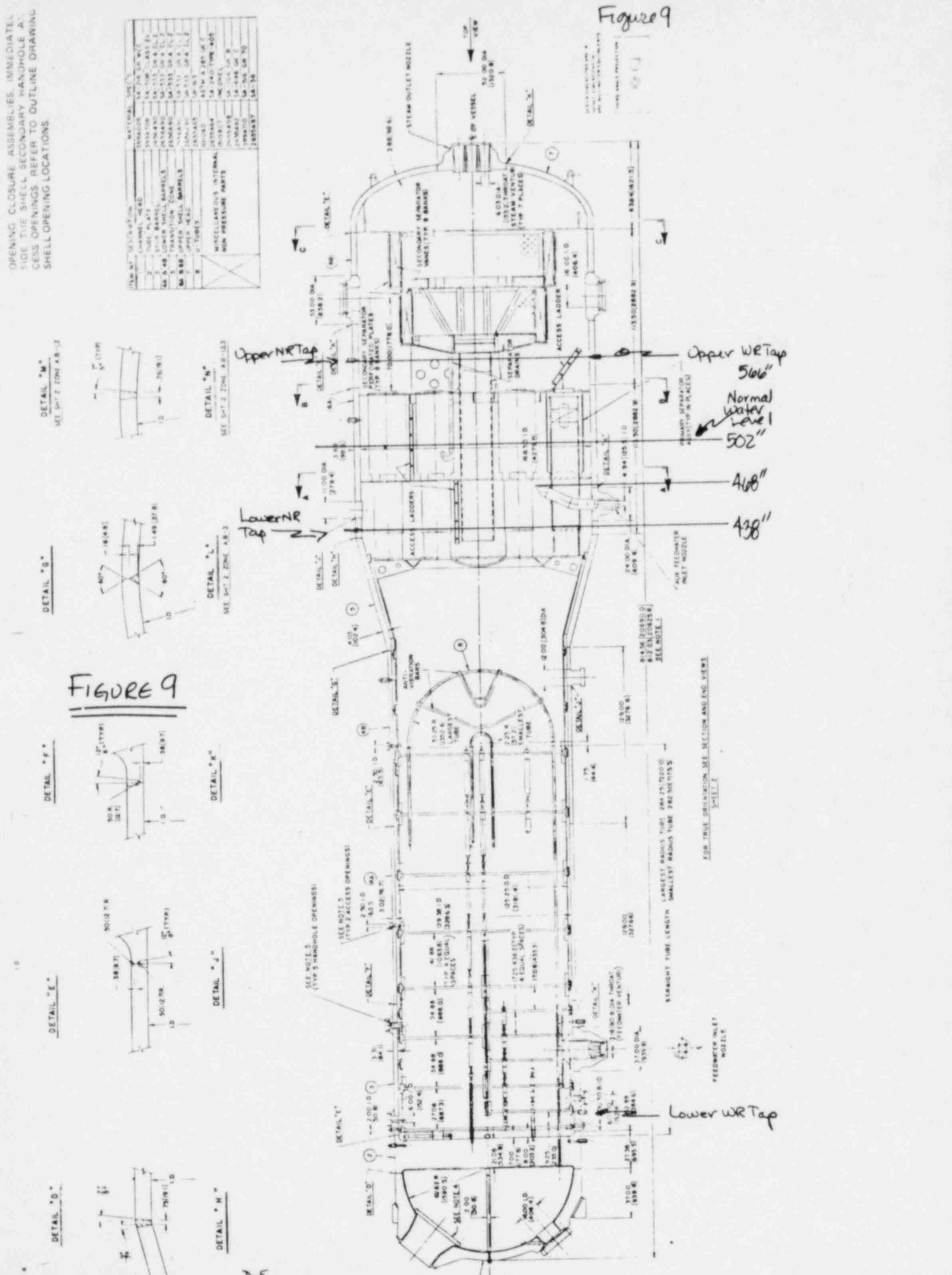


Figure 9
Upper NR Tap
Upper WR Tap
566"
Normal Water Level
502"
468"
Lower NR Tap
438"
Lower WR Tap
FIGURE 9

Table 1

## RESULTS OF EXAMINATION

- LOOP 2, INSIDE CONTAINMENT
  - EMBEDMENT PLATES MOVED, BOLTS LOOSENED, PIPE CLAMPS LOOSENED AND MOVED, (AFFECTED HANGERS ARE IDENTIFIED BY NUMBERS IN OVALS),
  - PIPE CHANGED LOCATION
  - PIPE BULGED 1/4 INCH NEAR SECONDARY SHIELD WALL.

- LOOP 2, INTERMEDIATE BUILDING
  - PIPE MOVEMENT WAS NEGLIGIBLE
  - AUXILIARY PIPE PAINT WAS BLISTERED BACK TO THE MDAFS PUMPS
  - MDAFS PUMP CHECK VALVES WERE FOUND TO HAVE SOME NICKS, SCRATCHES, AND UNEVENNESS.

*Table 2*

## SEQUENCE OF EVENTS

- THE STEAM GENERATOR WATER LEVEL WAS BELOW THE AUXILIARY NOZZLE INTERNAL EXTENSION DISCHARGE AND THERE WAS NO FEEDWATER FLOW THROUGH THE NOZZLE. (DURING THE HOT DUNCTIONAL TESTING OF THE AFS, THE PUMPS WERE STOPPED AND RESTARTED).

- STEAM LEAKED BACK THROUGH A SECTION OF THE BYPASS LINE AND THEN BACK THROUGH THE AFS PIPING TO THE MDAFS PUMPS. (THE EXTENT OF THE BACK LEAKAGE WAS INDICATED BY BLISTERED PAINT ON THE AFS PIPING).

- FOR THE LEAKAGE TO HAVE OCCURRED, THE TWO CHECK VALVES IN EACH OF THE MDAFS PUMP DISCHARGE LINES MUST HAVE BEEN LEAKING.

Table 2 (Continued)

## SEQUENCE OF EVENTS (CONTINUED)

- WITH STEAM PRESENT IN THE BYPASS LINE PIPING, THE AFS PUMPS WERE STARTED, BRINGING IN COLD WATER. THE WATER RAPIDLY CONDENSED THE STEAM RESULTING IN WATERHAMMER.

- AS ANOTHER POSSIBILITY, STEAM LEAKED BACK THROUGH A HORIZONTAL SECTION OF BYPASS LINE OVER COLD WATER ALREADY PRESENT. AT SOME POINT A STEAM BUBBLE WAS FORMED DUE TO A SURFACE DISTURBANCE AND THE BUBBLE CONDENSED BY COLD WATER CARRIED UP FROM THE BOTTOM OF THE PIPE.

- A BANG OR HAMMER WAS HEARD DURING THE HOT FUNCTIONAL TESTING.

## TABLE 3

## KRSKO D4 STEAM GENERATOR ELEVATION AND LEVEL DATA

| | ELEVATION FROM TOP OF TUBE SHEET | PERCENT OF NARROW RANGE |
|---|---|---|
| Upper NR Tap | 566" | 100% |
| Main Deck Plate | | |
| Top of Swirl Vane | 542" | |
| Hi-Hi Level | 530" | |
| Actual Water Level (100 % Power) | 492" | 68% |
| Indicated Water Level | 488" | 66% |
| Mid Deck Plate | | |
| Top of Auxiliary Nozzle Discharge | 473" | 60% |
| Lo Level | 464" | |
| Lo-Lo Level | 420" | |
| Lower Deckplate | | |
| Top of Tube Bundle | 336" | |
| Lower NR Tap | 333" | 0% |
| Main Feedwater Nozzle ℄ | | |

TABLE 4

BYRON 1 D4 STEAM GENERATOR ELEVATION AND LEVEL DATA

| | ELEVATION FROM TOP OF TUBE SHEET | PERCENT OF NARROW RANGE |
|---|---|---|
| Upper NR ~~Top~~ Tap | 566" | 100% |
| Main Deck Mate | | |
| Top of Swirl Vane | 542" | |
| Hi-Hi Level | 530" | 85% |
| Actual Water Level (100 % Power) | 492" | 68% |
| Indicated Water Level | 488" | 66% |
| Mid Deck Plate | | |
| Top of Auxiliary Nozzle Discharge | 473" | 60% |
| Lo Level | 440 | 46% |
| Lo-Lo Level | 420" | 37% |
| Lower Deckplate | | |
| Top of Tube Bundle | 336" | |
| Lower NR ~~Top~~ Tap | 333" | 0% |
| Main Feedwater Nozzle ℄ | | |