GE Nuclear Energy

General Electric Company
175 Curtner Avenue, San Jose, CA 95125

October 20, 1993

MFN No. 170-93
Docket STN 52-004

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Attention: Jerry N. Wilson, Acting Director
Standardization Project Directorate

Subject: **SBWR Test Program**

Reference: Purdue Testing Meeting, GIRAFFE Testing Program RAIs, October 1, 1993

This letter transmits responses to questions posed prior to and during the referenced meeting.

Sincerely,

P. W. Marriott
SBWR Project Manager
M/C 781, (408)925-6948

Enclosure: Two (2) copies of each of the following:

A. Requests for Information by Purdue University prior to meeting on October 1.
B. GE Answers to Purdue University Questions on SBWR Systems (Given to Purdue staff during meeting on October 1, 1993)
C. Additional responses to Questions and Requests from Attachment A not covered in Attachment B
D. Responses to Questions made to GE by Purdue staff during meeting on October 1, 1993

cc: M. Malloy, Project Manager (NRC)

LTRBK 93-58

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1/1

ATTACHMENTS

A. Requests for Information by Purdue University prior to meeting on October 1, 1993.

B. GE Answers to Purdue University Questions on SBWR Systems (Given to Purdue staff during meeting on October 1, 1993)

C. Additional responses to questions and Requests from Attachment A not covered in Attachment B.

D. Responses to Questions made to GE by Purdue staff during meeting on October 1, 1993.

ATTACHMENT A

Requests for Information by Purdue University prior to meeting on October 1, 1993.

PURDUE UNIVERSITY

SCHOOL OF NUCLEAR ENGINEERING

September 15, 1993

A Draft of
Required Informations From GE About Prototype SBWR System

1. Feed Water Line
   a. During a feedwater line break the flow will be choked/restricted by the area of the sparger. Therefore we need detailed design of the sparger.
   b. Isometric drawing of the Feedwater supply line is needed to know the elevation difference etc. in case of break.
   c. What action is taken with feedwater supply line during a LOCA? Which valves are closed (There is one manual valve, three check valves and one motor operated valve on each line. Which of these are closed during LOCA)? See attached Table 3.1 in SBWR Response to Loss of Feed Water. At Level 2, what actions are taken?
2. Provide detailed information on the loss coeffecients for all the lines. In particular give the minor loss coeffecients of all the valves in the following lines:
   a. Main Steam line
   b. IC Supply line (from vessel to IC)
   c. IC condensate drain and vent line
   d. PCC supply, drain and vent line
   e. GDCS drain line
   f. Equalization line
   g. CRD line (into vessel bottom)
   h. RWC/SDC system line
   i. Drywell & wetwell spray lines (flow rates also needed)
   j. Feed Water line
3. Provide the following information for the ICCS and PCCS :
   a. What is the design of the headers and the separators? (drawings are needed). In particular please provide the loss coeffecients for these.
   b. IC pool water level depletion as a function of time (up to 3 days). Can we reduce the volume?

NUCLEAR ENGINEERING BUILDING • WEST LAFAYETTE, IN 47907 • [illegible]

c. Provide the elevation of the PCCS condensate return line.

d. Do we have IC tube rupture detection system? What is the automatic detection system? Line break (return) need not be consider.

e. Detailed design of the ICS and PCCS modules.

4. RPV:

a. What is the insulation material? (its physical thermal properties and thickness are needed)

b. What is the loss coefficient across the steam separators?

c. Explain the pressure drop data across the lower plenum and the core plate. K values of the core inlet flow restrictors (orifice K values) is needed.

5. How are the upper drywell and the lower drywell connected? Detail of drywell design including neutron shield outside the vessel are needed. (drawings, flow area, loss coeffiects).

6. Need isometric drawings for pipings of the following auxiliary systems :

a. Reactor water cleanup system/Shut Down System

b. Control Rod Drive System

c. Fuel and Auxiliary Pool Cooling Systems

d. Feed Water Lines

7. Can GE provide us with their code calculations of blowdown phase? We are interested in the thermal hydraulic parameters at about 150 sec. After MSL break, information on vessel liquid level (time dpendent level due to swelling), quality, void fraction, and exact decay heat power levels will be useful.

8. During the initial transients following LOCA or blowdown, say at and after 150psi, what are the status of the following lines?

a. Is RWC/SD System operating? What valves are open?

b. In CRD system what valves are open? Are pumps active?

c. Is FAPCS active? What valves are open? Are pumps active?

d. Is FWL pump is tripped? How does it work during and after this stage of transient? What valves are open?

e. How the vacuum breakers operate during transient? What is the ΔP to open them?

9. What is the setpoint to open vacuum breakers? What logic are used to open three valves?

10. Operating procedures and actuation logic for low pressure coolant injection of FAPCS and CRD and RWCU/SDC.

11. Fault tree analysis for SBWR needed to develope test matrix. Detection of ICS tube rupture? Any automatic function to handle ICS tube rupture.

Question and Requests on GIST Facility

1. How were heaters fitted to the vessel? How heater surface temperatures were measured?
2. Provide the loss coeffecients in all the lines of GIST facility.
3. Need detailed test results and conditions for five GIST tests used for TRAC G calculations in order to run similar experiments as required by NRC. Need design of the break simulation using pipe and valve on various lines of GIST facility.
4. How the pressure sense line were connected to the vessel and pressure transducers?
5. What flow meters were used to measure a) water, b) steam and c) two-phase flow in pipe? And what flow meters were used for downcomer liquid flow rate?

Other Questions

1. Can GE supply us heaters with built-in surface thermocouples?
2. Who made GIST heaters?

Table 3.7 Summary of SBWR system automatic action setpoints 5/92

Level	Elev. (mm)	Component or System	Action
9	19364	Feedwater Pumps	Trip
8	18790	Reactor Power	High Level Scram
		Main Turbine	Trip
		Feedwater Pumps	Runback ([illegible])
NWL (normal water level)	18260	Normal Operation	
3 (~1 m below NWL)	17255	Reactor Power	Low Level Scram
2	14095 ~9.6 m above TAF (~31')	MSIVS	Close
		Isolation Condenser	Initiates
		CRD Injection	Initiates with 130 s delay
1 (low-low)	10095 ~3.6 m (~12') above TAF	ADS	Initiates: 4 SRVs immediately; 4 SRVs @ [illegible] 10 sec; 2 DPVs @ [illegible] 25 sec; 2 DPVs @ [illegible] 100 sec; 2 DPVs @ [illegible] 15 [illegible]
		GDCS	Initiates ([illegible] 15 min ?)
	6493 (21.3')	TAF	
	3738 (~12')	BAF	

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ATTACHMENT B

GE ANSWERS TO PURDUE UNIVERSITY QUESTIONS

ON SBWR SYSTEMS

NOTE: All answers are based on currently available data. In many cases this data is preliminary and all necessary verification has not been completed.

Answers to Purdue University Questions

1. **FEEDWATER LINE**

a. During a feedwater line break, the flow will be choked/restricted at the sparger inlet as shown in the figure.

Detail sparger dimensions given in figure.

b. Isometric drawing of Feedwater Supply line (inside containment) is attached.

c. Actions taken with FW supply line during a LOCA:

- During a LOCA, no action is taken with the feedwater supply line, unless the reactor water level rises to Level 8. At level 8, equipment protective action will trip the main turbine and reduce feedwater demand to zero. The feedwater pumps will be tripped if the water level reaches level 9.

- If the water level drops to Level 2, the high pressure make-up function of the CRD system will be initiated. Isolation condenser system automatically initiates, and the MSIVs close.

  If RPV water level drops to Level 1, the Automatic Depressurization system initiates.

2. **MINOR LOSS COEFFICIENTS FOR VALVES**

- Per Crane Technical Paper

  "Flow of Fluids through Valves, Fittings and Pipe"

- Valve types and sizes per P&IDs. (included in the SBWR SSAR)

- MSIVs are Y-pattern globe valves, all other globe valves are not y-pattern.

- Main Steam SRVs are throttled Angle Valves

- Conventional Swing Check Valves: $K=50f_T$

- GDCS and Equalization Line Check Valves:

  C_V, flow coefficient per attached figure

- GDCS and Equalization Line Squib Valves:

  $C_V > 876$ gpm/psi$^{0.5}$

- Turbine stop/control valve: 0.03 x Pressure = Pressure loss

  DRYWELL AND WETWELL SPRAY MAX FLOW RATE

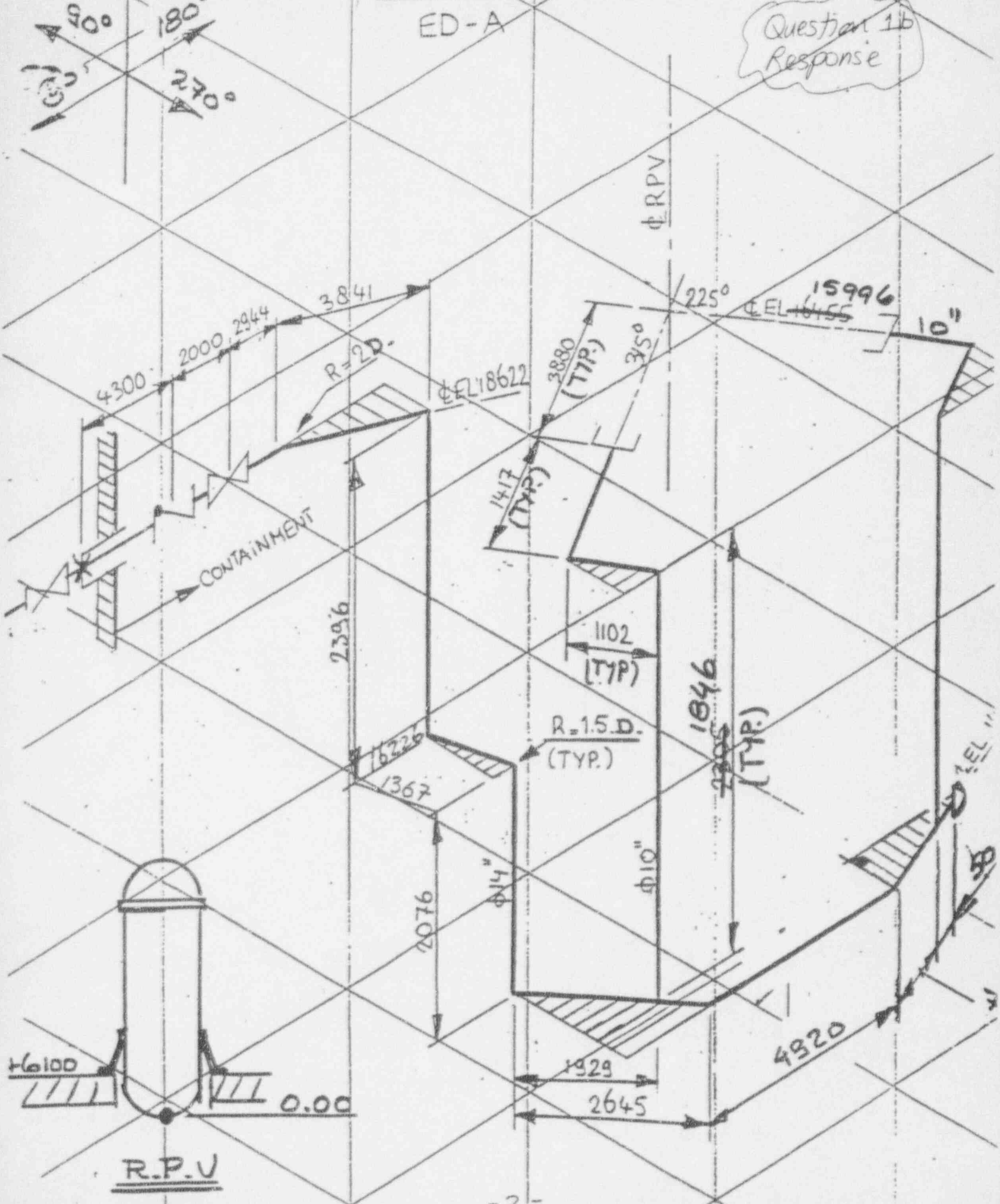
  94 Kg/sec

~~ATT. 2~~

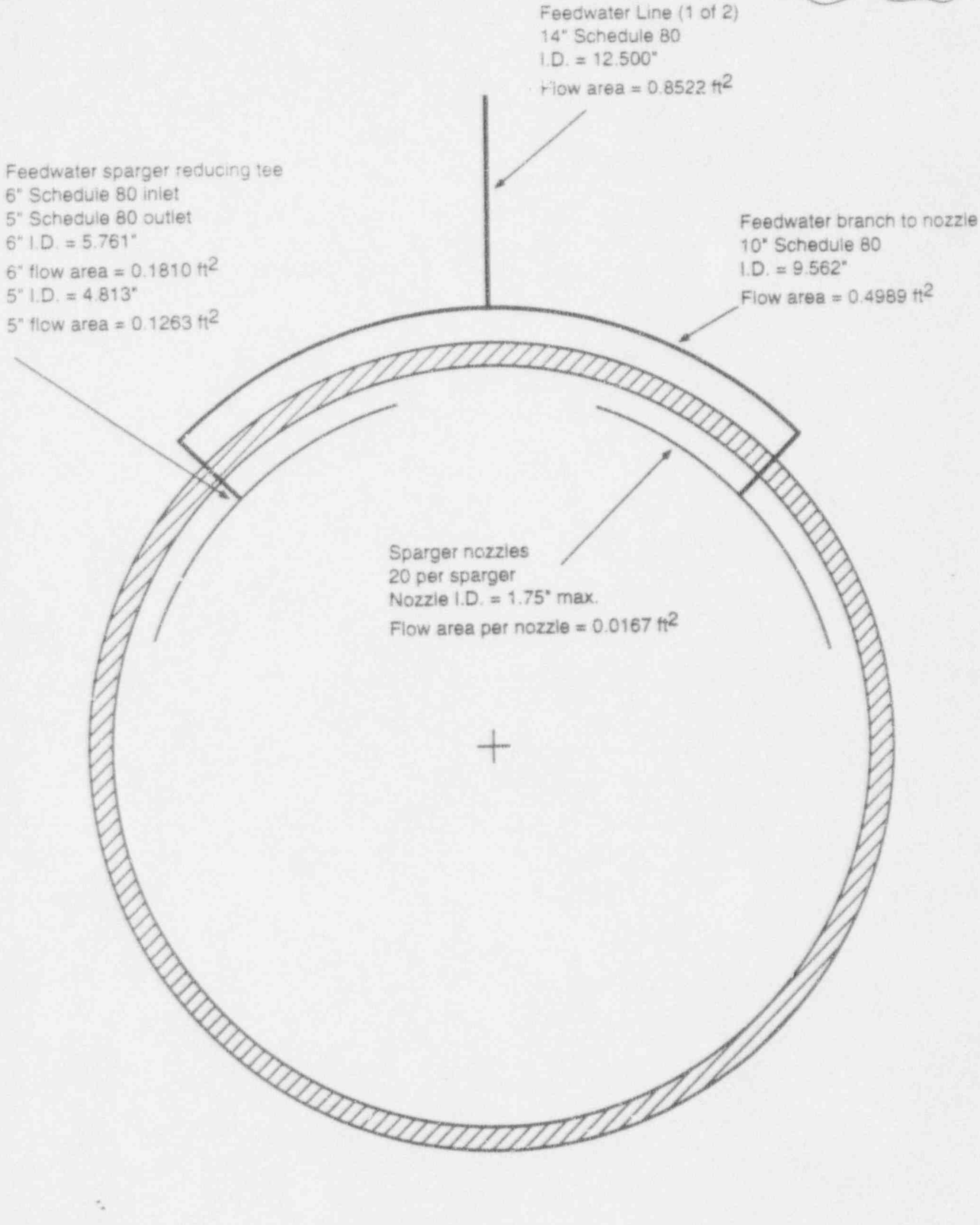
Question 1b Response

FEEDWATERLINE

ED-A



Question 1a Response



Feedwater Line Break Area Calculation

Question 1a Response

Feedwater Line Break Area Calculation Summation

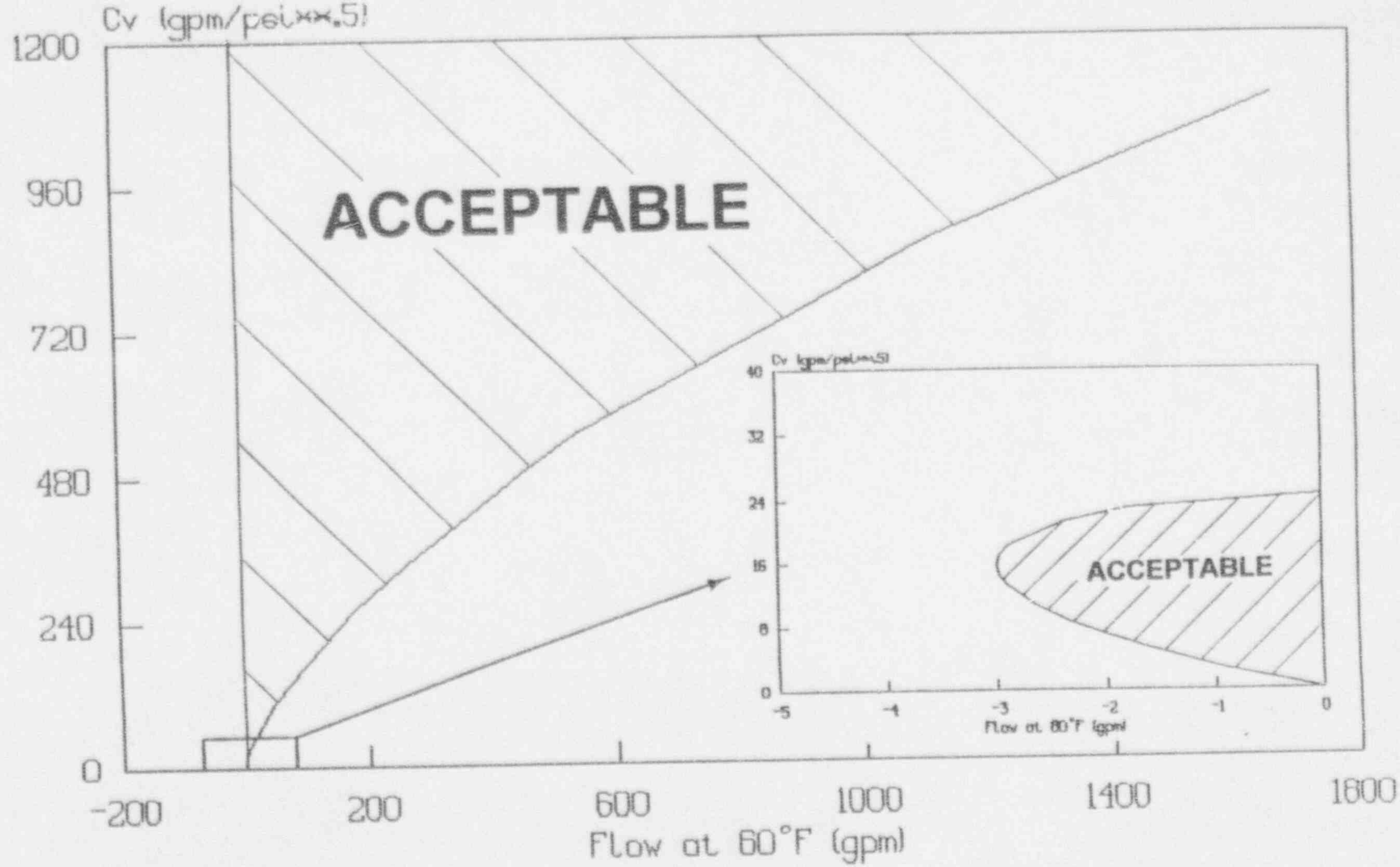
14" feedwater line	1 line	0.852 ft^2
10" feedwater branch to nozzle	2 lines	1.00 ft^2
6" Tee inlet	2 lines	0.362 ft^2
5" Tee outlet	4 lines	0.504 ft^2
Sparger nozzles	40 total	0.668 ft^2

Conclusion - Limiting break area = 0.362 ft^2

file: 3.2.4

GE Nuclear Energy

Response to Question 2 for GDCS



GDCS

Figure 4.3.3-2. Check Valve Minimum Required Flow Coefficient (English Units)

NEO 807 (REV 4/88)

3. **ICCS AND PCCS INFORMATION**

a. Design of headers and separators is shown in the drawings.

<u>Loss coefficients</u>: calculated using Crane Technical Paper

b. IC pool water depletion as a function of time is shown in attached figure.

<u>Can volume be reduced</u>? Yes, as shown in the figure.

c. Elevation of PCCS condensate return line

- Karen Vierow will cover this @ the meeting.

d. <u>IC tube rupture detection system</u>

The leak detection and isolation system (LD and IS) will isolate each IC loop individually on high pool radiation or on high flow (as measured by high differential pressure) in the steam supply line or the condensate return line.

e. Detailed design of the ICS and PCCS modules is shown in the drawings.

4. **RPV**

a. Insulation material and thermal properties given on attached sheet.

b. <u>Steam separator loss coefficients:</u> Given in attached response to NRC Questions

c. Pressure drop data across the lower plenum and the core plate, K values of the core inlet flow restrictors:

Given in attached response to NRC questions.

5. **UPPER AND LOWER DRYWELL CONNECTION DETAILS**

- Detail drawing is attached.
- <u>Flow Area</u> : 14 vents, inside diameter = 0.82m
- <u>Loss coefficients:</u> assumed = 0 (Due to low flow rate through the vents)

6. **ISOMETRIC DRAWINGS OF AUXILIARY SYSTEMS**

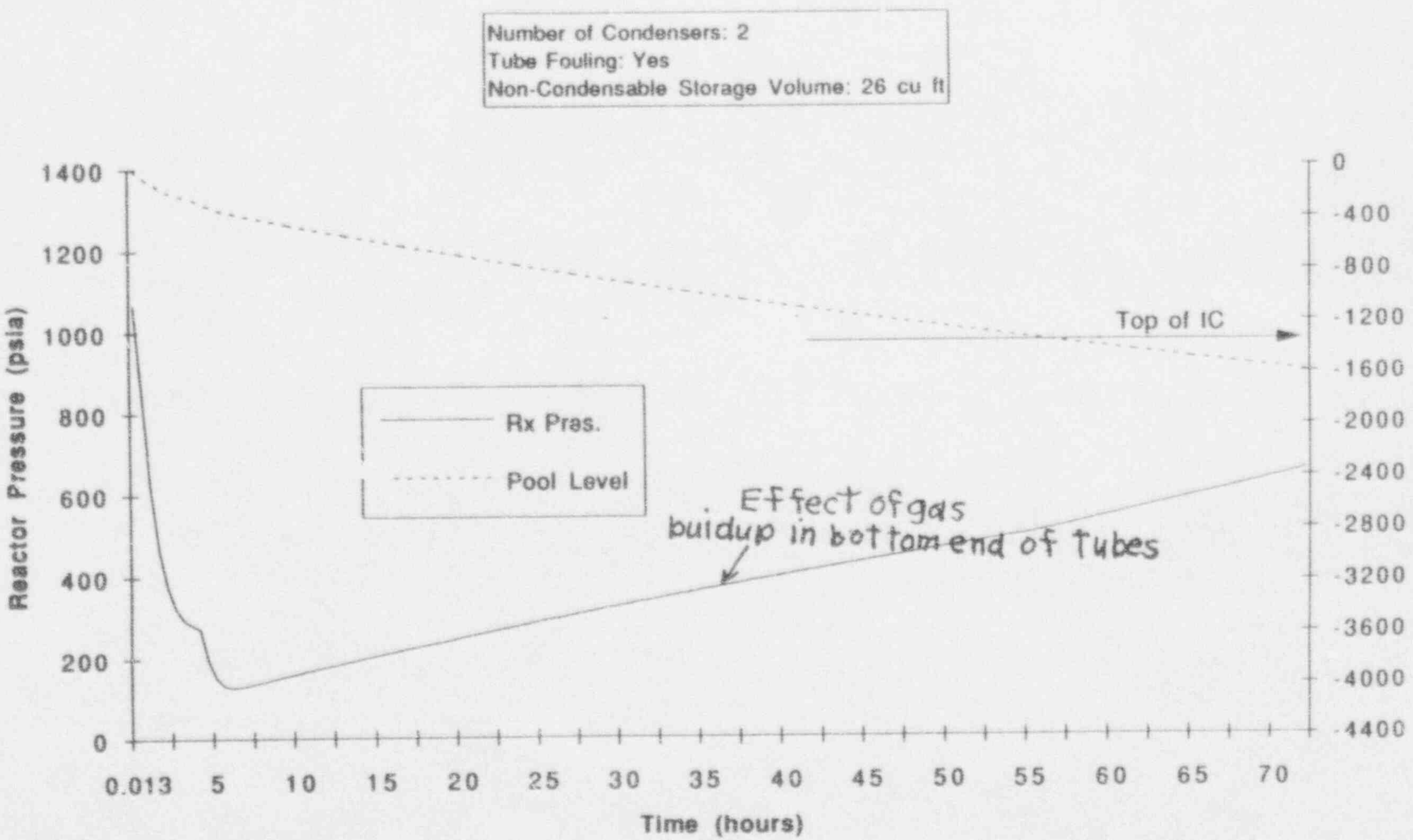
a. RWCU/SDC system drawings attached.

b. CRD system: no isometric drawings available.

(P&ID drawing is included in the SBWR SSAR)

Isolation Condenser Performance with momentary Venting (once @ 4 hrs)

(Response to Question 3b)



-L-

P211-26V

7/21/92

Response to Question 4a

SBWR RPV Insulation:

The RPV insulation is reflective metal type, constructed entirely of series 300 stainless steel. Heat loss from the vessel to the outside surroundings is based on the insulation having an ***average*** heat transfer coefficient of 0.907 W/m^2-°C (0.16 Btu/hr-ft^2-°F) between the vessel surface and the surrounding atmosphere. At operating conditions, the ***average*** maximum heat transfer rates of the outside insulation surface in the refueling bellows region and on the top head are 176 kcal/m^2-hr (65 Btu/ft^2-hr) and 163 kcal/m^2-hr (60 Btu/ft^2-hr) respectively. The ***average*** insulation thickness requirement at all locations is 93 mm or 3.66 inches. Minimum air temperatures outside the vessel and insulation are tabulated as follows.

Vessel Region	Minimum Air Temperature Outside Insulation
Below and outside bottom head insulation and inside vessel support skirt	38°C (100°F)
Outside vessel support skirt	38°C (100°F)
Top head	57°C (135°F)

Response to NRC question, August 24, 1992:
& Purdue questions 4b & 4c

Response to NRC question 2c			
Loaction	Inside Channels	Bypass (outside channels) Rod Position:	
		Inserted	Withdrawn
Flow area (m^2)	7.4	5.6	5.0

Response to NRC question 2e		
Flow Path	Pressure Drop (Pascal)	Loss Coefficient (K,dimensionless)
Across Lower Plenum	5240	K=.9 per CRD guide tube row, 83% area obstructed K=.4 per CRD housing row, 65% area obstructed
Core Plate	6400	$A/\sqrt{K}$=.036 m^2
Core	48200*	Multiple 2 phase losses
Top Guide	600	K=1, associated area=1.7 m^2
Chimney	31700*	K=0.
Steam Separators Response to Purdue Question 4b	26300*	$\Delta P=0.083$ ~~0.036~~ $Q_t^2+8.3$ where: Q_t=2 phase volumetric flow, per separator (ft^3/hr divided by 1000) ΔP=pressure drop, ft of 2 phase mixture
Steam Dryer	2500.	K=165. associated area=28.8 m^2

*Pressure drop includes hydrostatic pressure of 2 phase fluid

Response to NRC RAI 950.13 and Purdue question 4c.

Area (m2)	Irreversible loss coefficient (dimensionless, from TRAC)	Description of loss
FA	FRICP	
2.992000E-03	9.6E-01	(inlet orifice, 3.84 for peripheral channels)
1.011000E-02	8.450000E+00	(lower tie plate)
1.011000E-02	1.244000E+00	(per spacers for 5 spacers)
9.188000E-03	6.290000E-01	(upper tie plate)
5.350000E-04	1.500000E+00	(approximation of channel to bypass flowpath as flow squared loss coefficient)

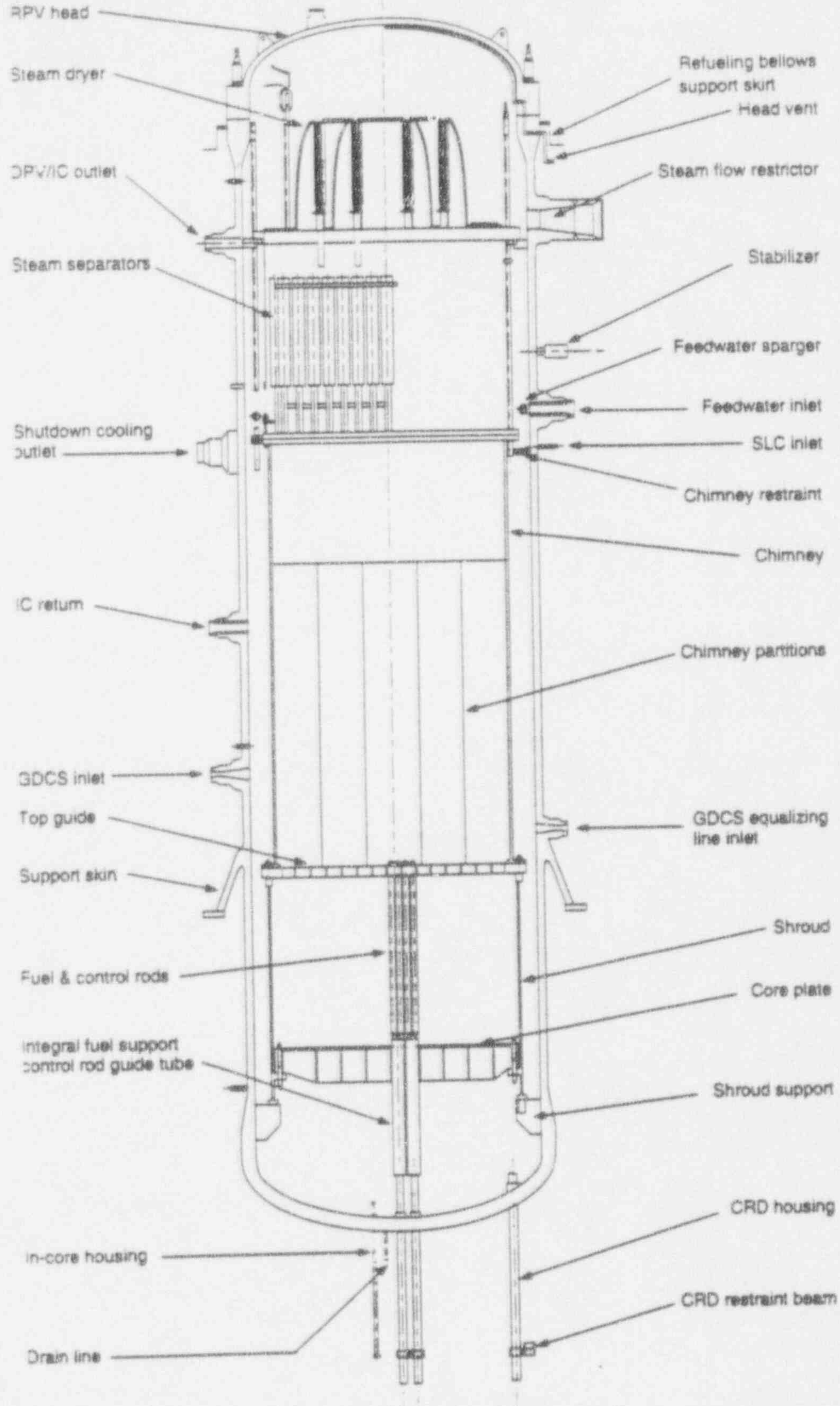
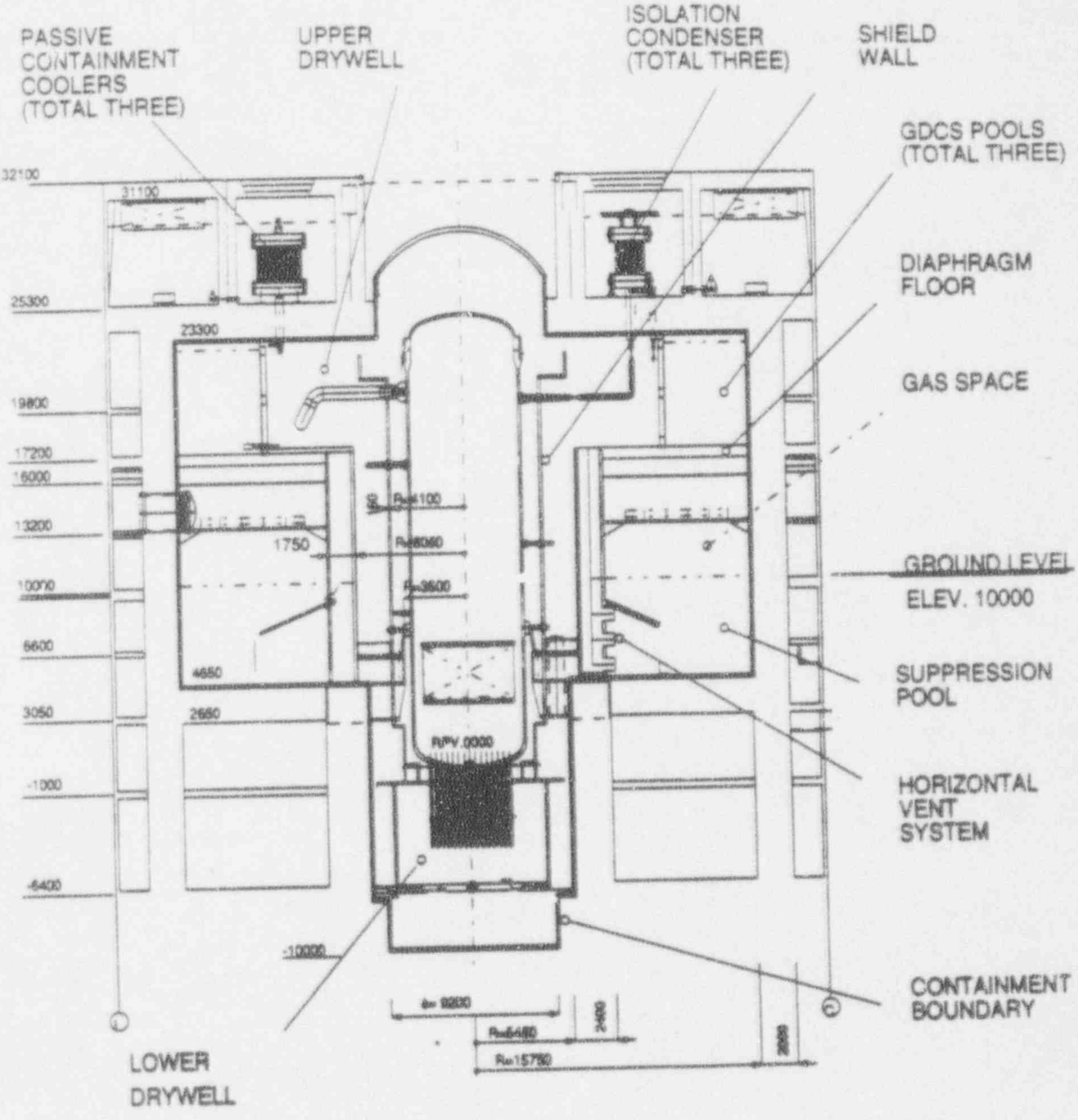


Figure 5.3-3 Reactor Pressure Vessel System Key Features



14 Vents

Figure 6.2-1 SBWR Containment Boundary

6. **Continued**

c. FAPCS: see attached isometric drawings (isometric drawings are only available for portions of this system).

d. FW line: See response to question 1b.

7. **THERMAL HYDRAULIC PARAMETERS @ 150 SECONDS AFTER MSL BREAK INSIDE CONTAINMENT:**

Assume FW pump trip and reactor scram at time zero.

- Water level: (two phase) — Chimney 16.1 m; Downcomer 9.2 m

- Void Fraction:

Lower Plenum	0.24
Channel	0.63
Bypass	0.62
Chimney	0.66
Steam Dome	1.0
Downcomer	0.70

- Vessel Pressure @ Dome: 349.4 psia

- Quality @ Dome: 1.0

- Power @ 150 sec.: 5.78×10^7 watts

(Water level and pressure as a function of time is shown on attached figures.)

8. **DURING INITIAL TRANSIENTS FOLLOWING A LOCA OR BLOWDOWN, AT AND AFTER 150 PSI:**

RWCU/SDC System

- Above RPV water level 3:

  SDC mode can be manually initiated

- Below RPV water level 3 and above level 2:

  RWCU/SDC pump "runsback" to RWCU flow rate (172 gpm) and the regenerative heat exchangers are placed in service. (SDC mode is terminated)

- Below RPV water level 2 or high steam tunnel temperature

  RWCU isolation valves automatically close

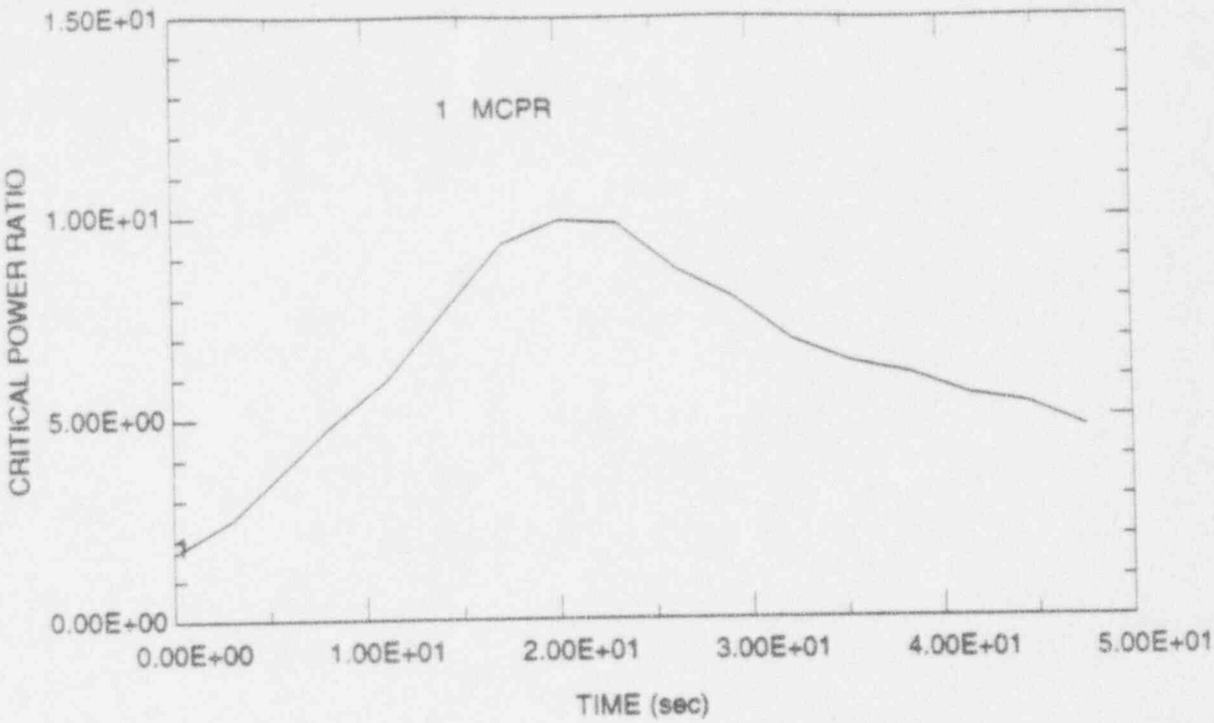


Figure 6.3-17 MCPR, Inside Steam Line Break, 1 DPV Failure

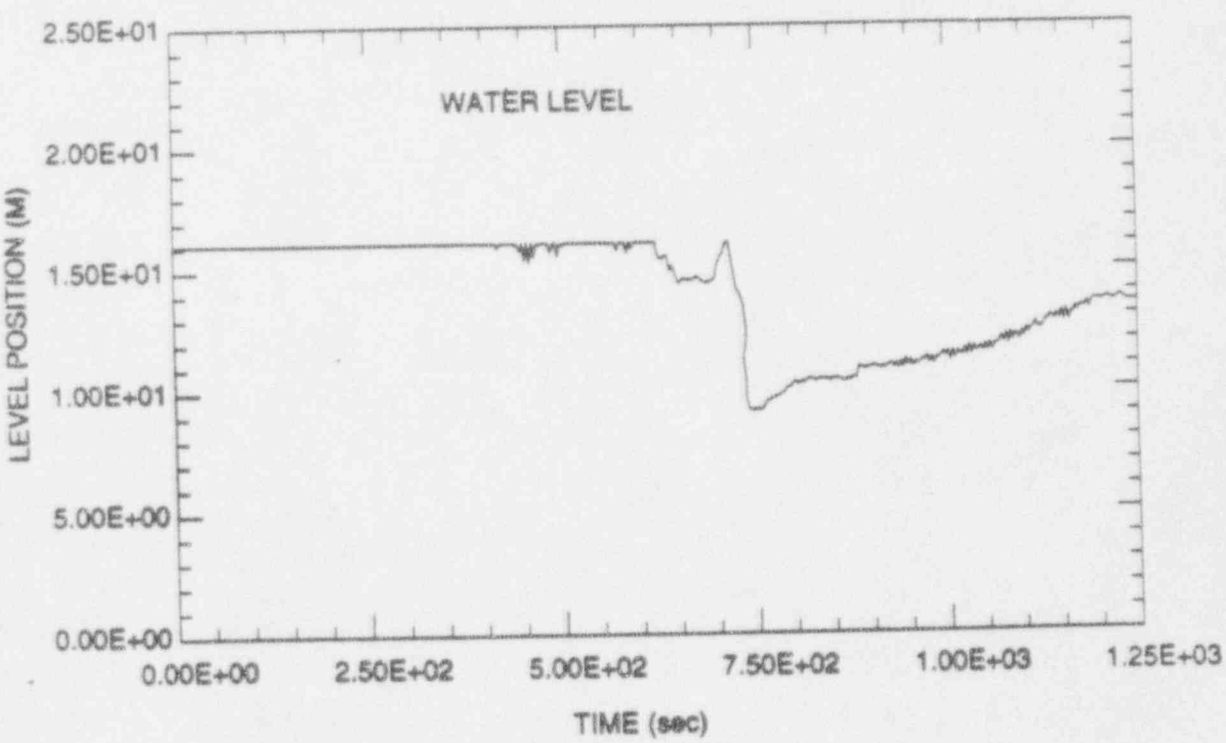


Figure 6.3-18 Chimney Water Level, Inside Steam Line Break, 1 DPV Failure

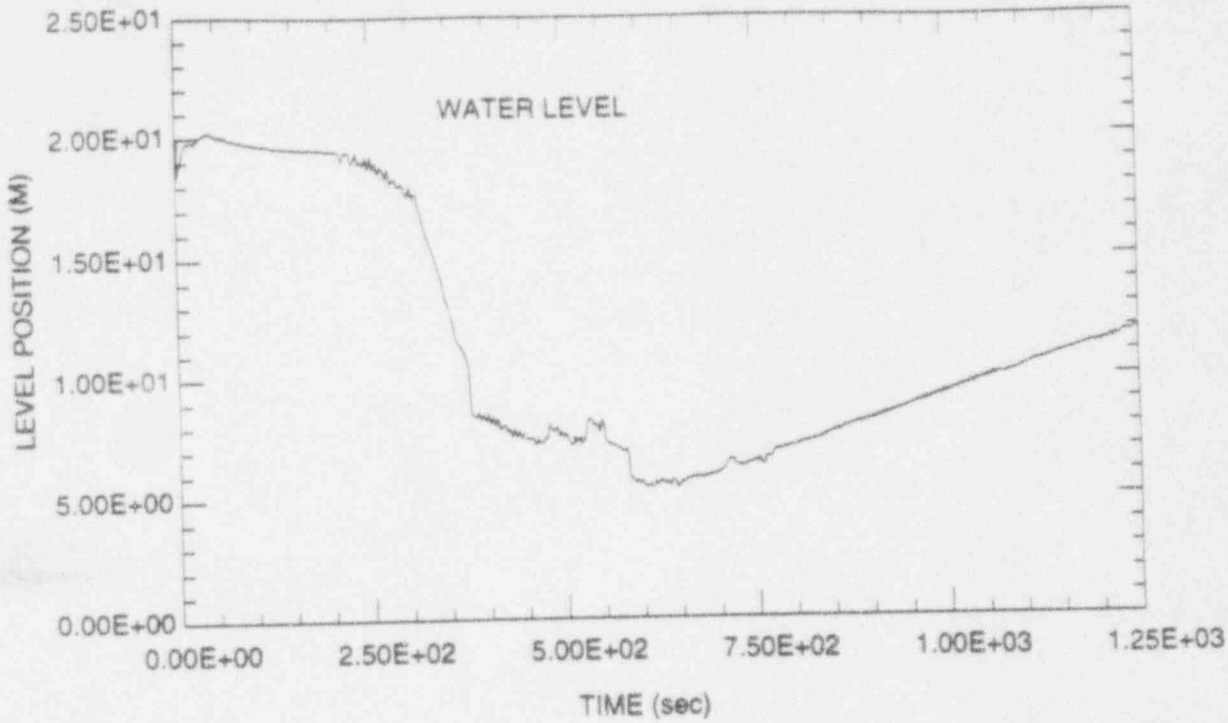


Figure 6.3-19 Downcomer Water Level, Inside Steam Line Break, 1 DPV Failure

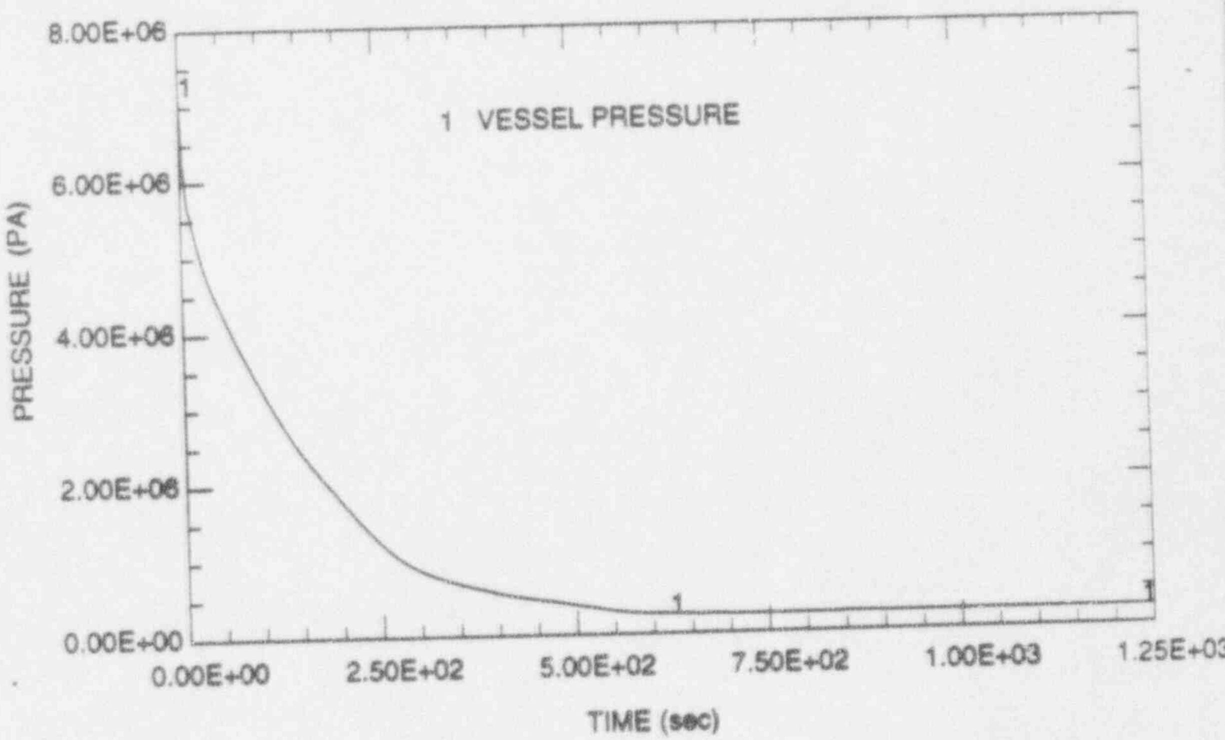


Figure 6.3-20 Vessel Pressure, Inside Steam Line Break, 1 DPV Failure

8. **Continued**

CRD System

- RPV water level 2: High pressure makeup initiates
- RPV water level 8, or low GDCS water level: High pressure makeup shuts off

FAPC System

- Spent fuel pool cooling & cleanup continue if AC power is available. If AC power is not available, the spent fuel pool temperature increases and is allowed to boil. Make up Water is provided from safety-related piping (having no active components) from outside sources.

FWL Pump

- RPV water level 9, (or due to exceedance of pump protection parameters): Pumps tripped
- Motor Operated Valves: Remain open unless power is lost.
- FW Control System: regulates flow to maintain RPV water level.

Vacuum Breakers

- Self actuating
- Full open at $\Delta P = 0.5$ psi

9. **VACUUM BREAKER SET POINT = 0.5 PSI (DIFFERENTIAL PRESSURE BETWEEN DRYWELL AND SUPPRESSION CHAMBER)**

No logic required. Full open at $\Delta P = 0.5$ psi.

10. **OPERATING PROCEDURES AND ACTUATION LOGIC**

- Low Pressure Coolant Injection of FAPCS
  - Manually initiated 72 hours after a LOCA to provide RPV coolant makeup.
  - RPV Pressure ≤ 100 psig to initiate flow. Full flow of at least 1000 gpm when reactor pressure is below 55 psig.
  - Used in conjunction with SRV discharge lines for Decay Heat Removal if RWCU/SDC not available, and the DPV's are not open.

10. **Continued**

- CRD

  - RPV Water Level 2: CRD pump suction filter bypass valves (F014) open, standby CRD pump is actuated, flow control valves (F020) in high pressure makeup lines open, isolation valves in the purge water header (F012) and charging water header (F030) close so all makeup flow is delivered to Reactor through high pressure makeup lines.

  - RPV Water Level 8: Flow control valves (F014) close to stop flow, to prevent flooding of Main Steam lines.

- RWCU/SDC

  - Manually initiated for LOCA recovery to perform Decay heat removal.

  - Above RPV Water Level 3: RWCU/SDC used to remove decay heat.

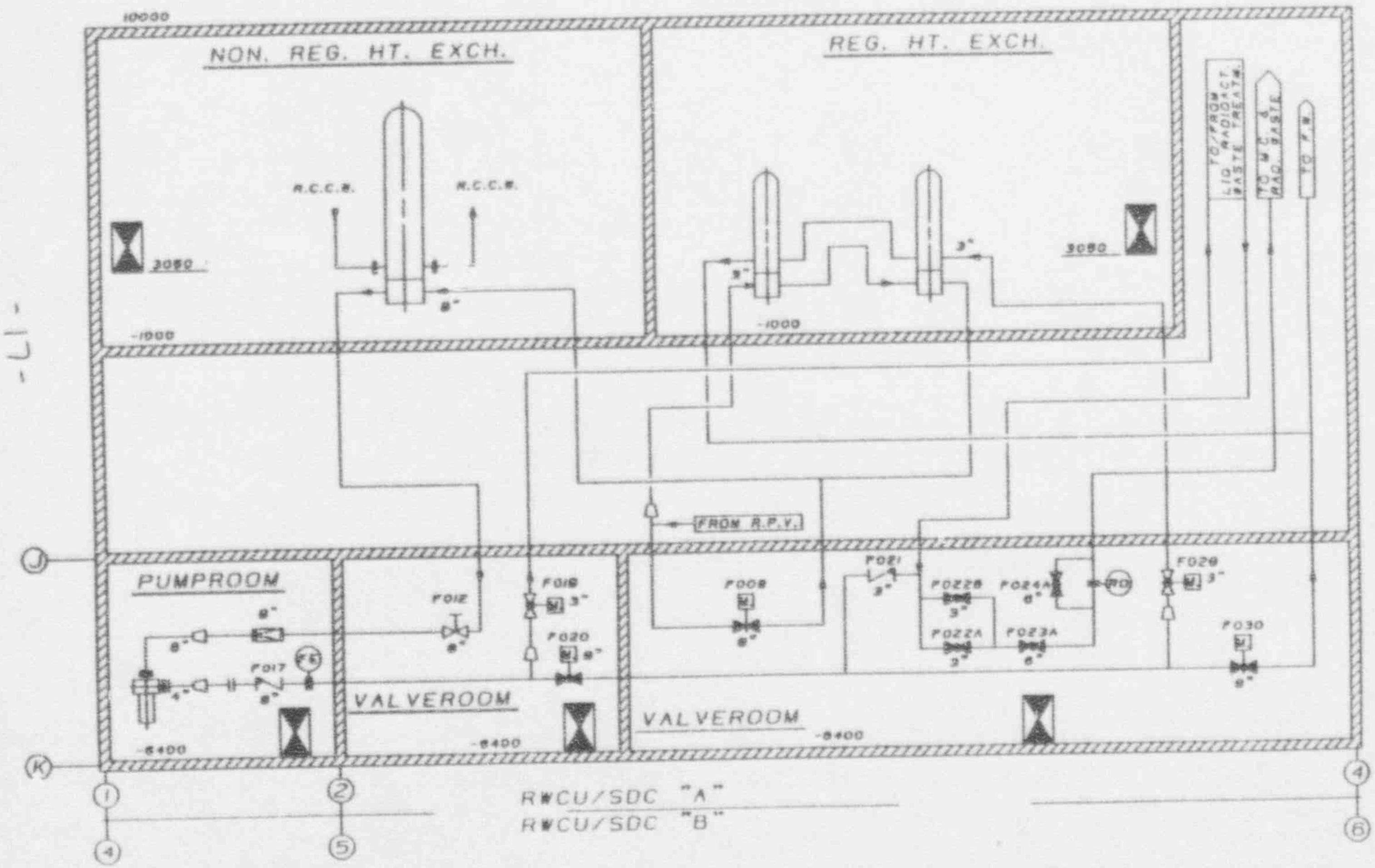
  - At RPV Water Level 3: RWCU/SDC flow rate is reduced to normal cleanup flow rate of 172 gpm, to avoid uncovering the RWCU/SDC RPV nozzle located just below Level 3.

  - At RPV water Level 2 or high MS Tunnel temperature, the RWCU/SDC system is isolated.

11. FAULT TREE ANALYSIS FOR SBWR

GE has already sent Fault Tree's to the NRC.

(For detection of ICS tube rupture and automatic functions to handle tube rupture, see response to Question 3d.)



GENERAL ELECTRIC CO.
PROPRIETARY INFORMATION

WORK IN PROGRESS
OCTOBER 1992

KEYPLAN

GENERAL NOTES

- ALL DIMENSIONS SHOWN ARE IN M/M
- ALL ELEVATIONS ARE FROM RPV 0.000
- VENTS, DRAINS AND FLUSHING CONN. ARE HOLD
- SHIELDING DOOR

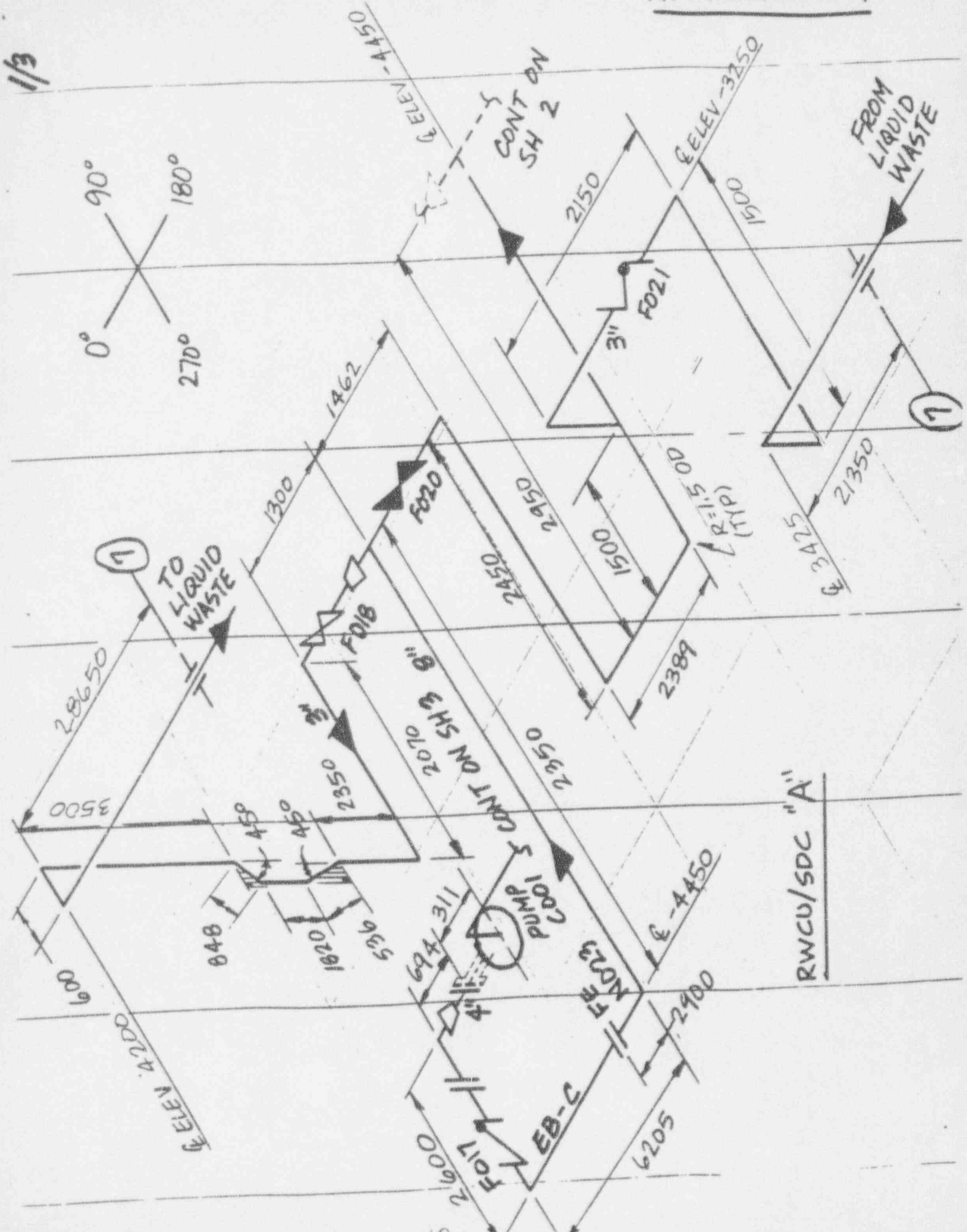
R.W.C.U./S.D.C.

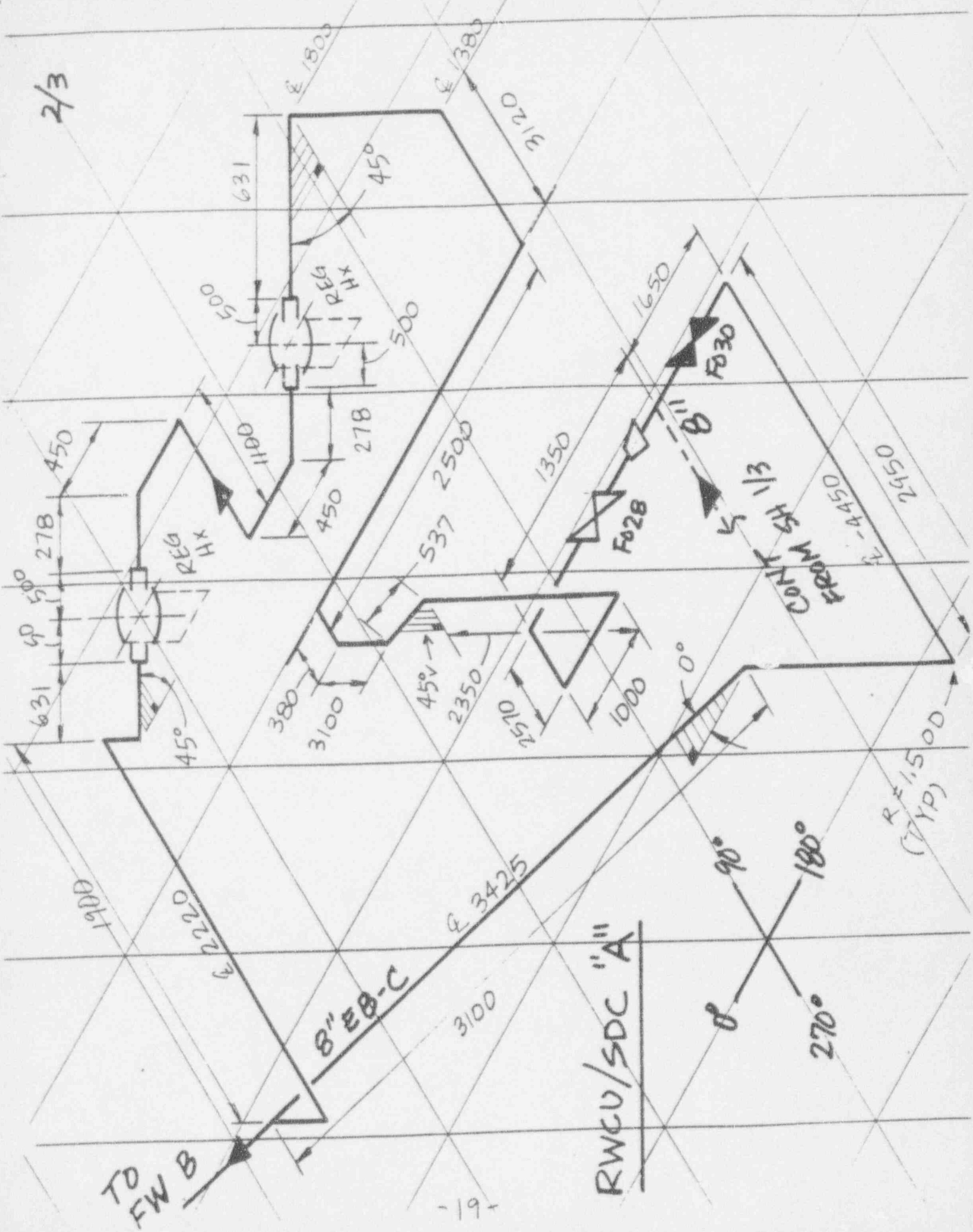
SCALE	
NONE	DEVELOPMENT P&ID MODE: NORMAL OPERATION

WEL595Z-JUN.93

SH. 1 OF 1

ATTACHMENT 1




2/3
RWCU/SDC "A"
8" EB-C
TO FW B
REG HX
REG HX
F028
F030
8"
CONT FROM SH 1/3
R=1.5 OD (TYP)
0°
90°
180°
270°
45°
45°
45°
℄ 3425
℄ 2220
℄ 1800
℄ 1380
℄ -4450
3120
2500
1350
1650
2450
3100
1900
631
631
278
278
500
500
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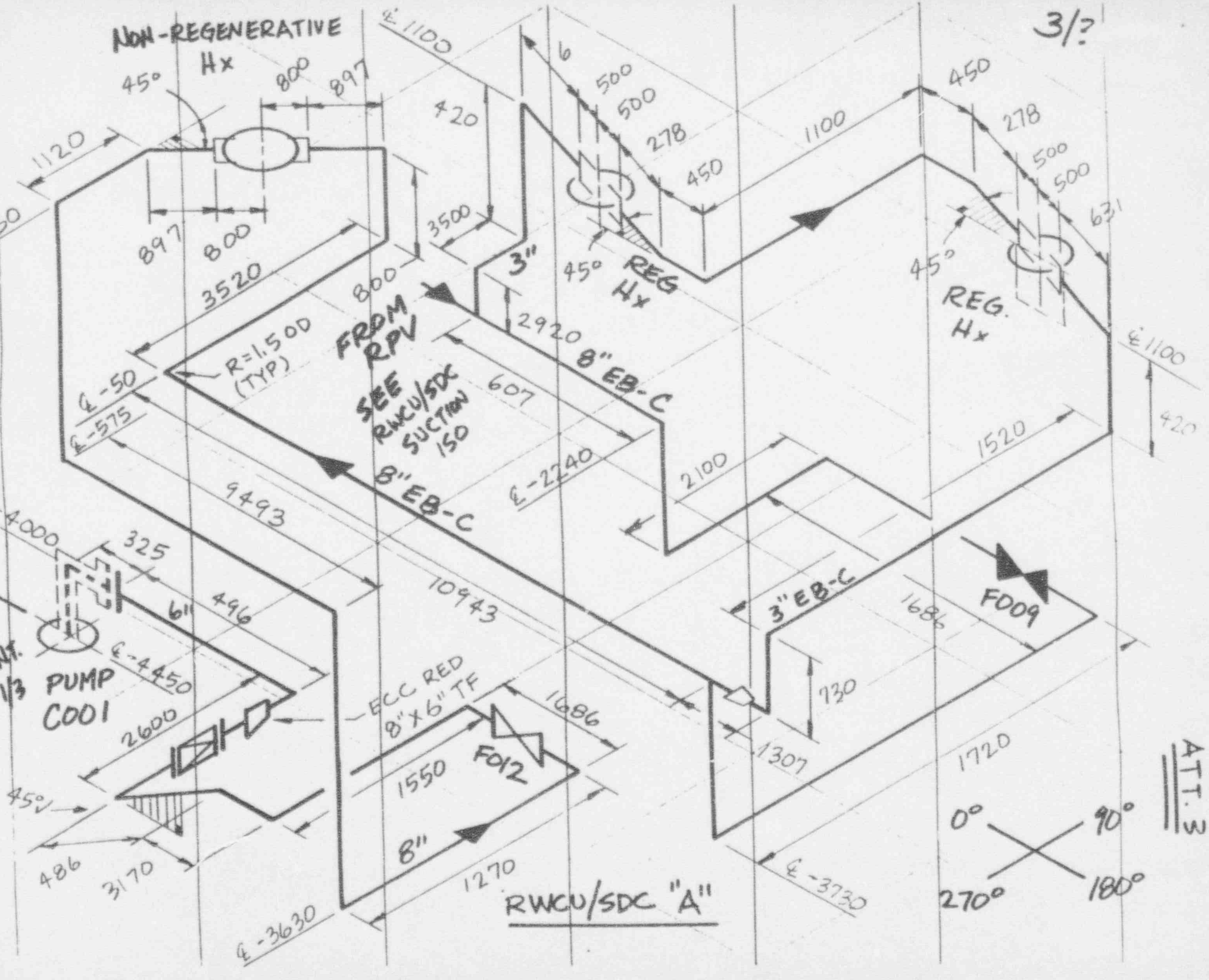
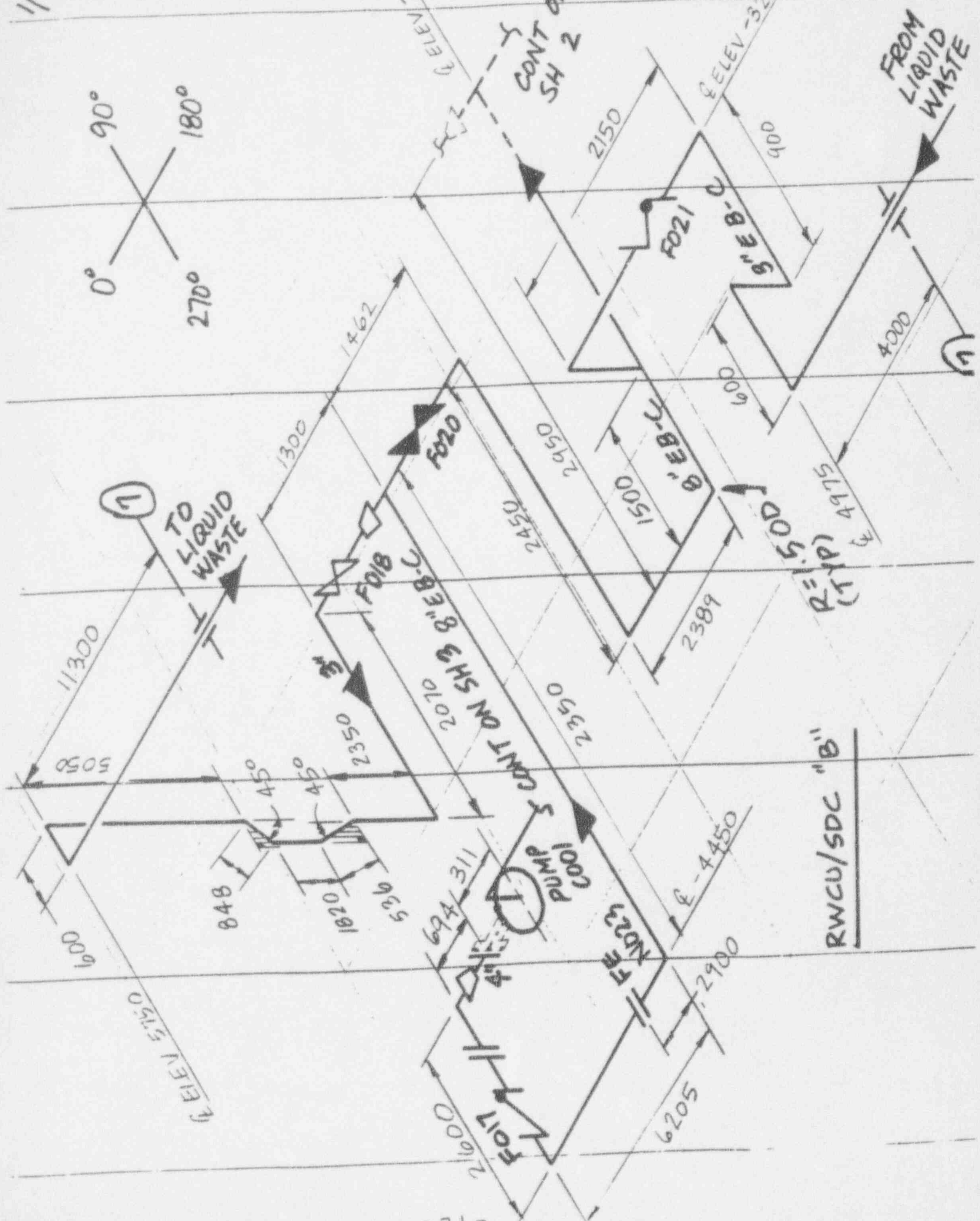
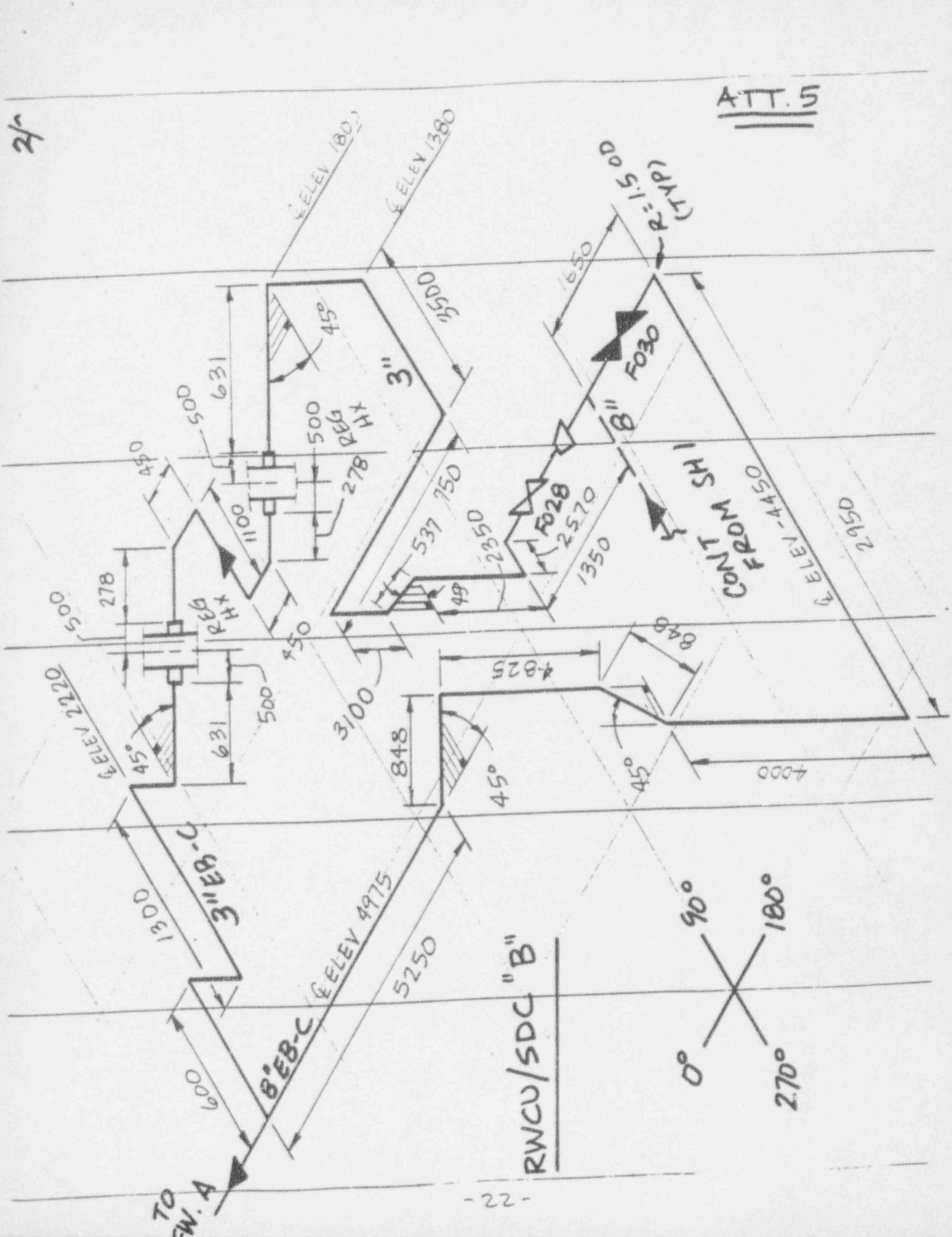
3100
2350
2570
1000

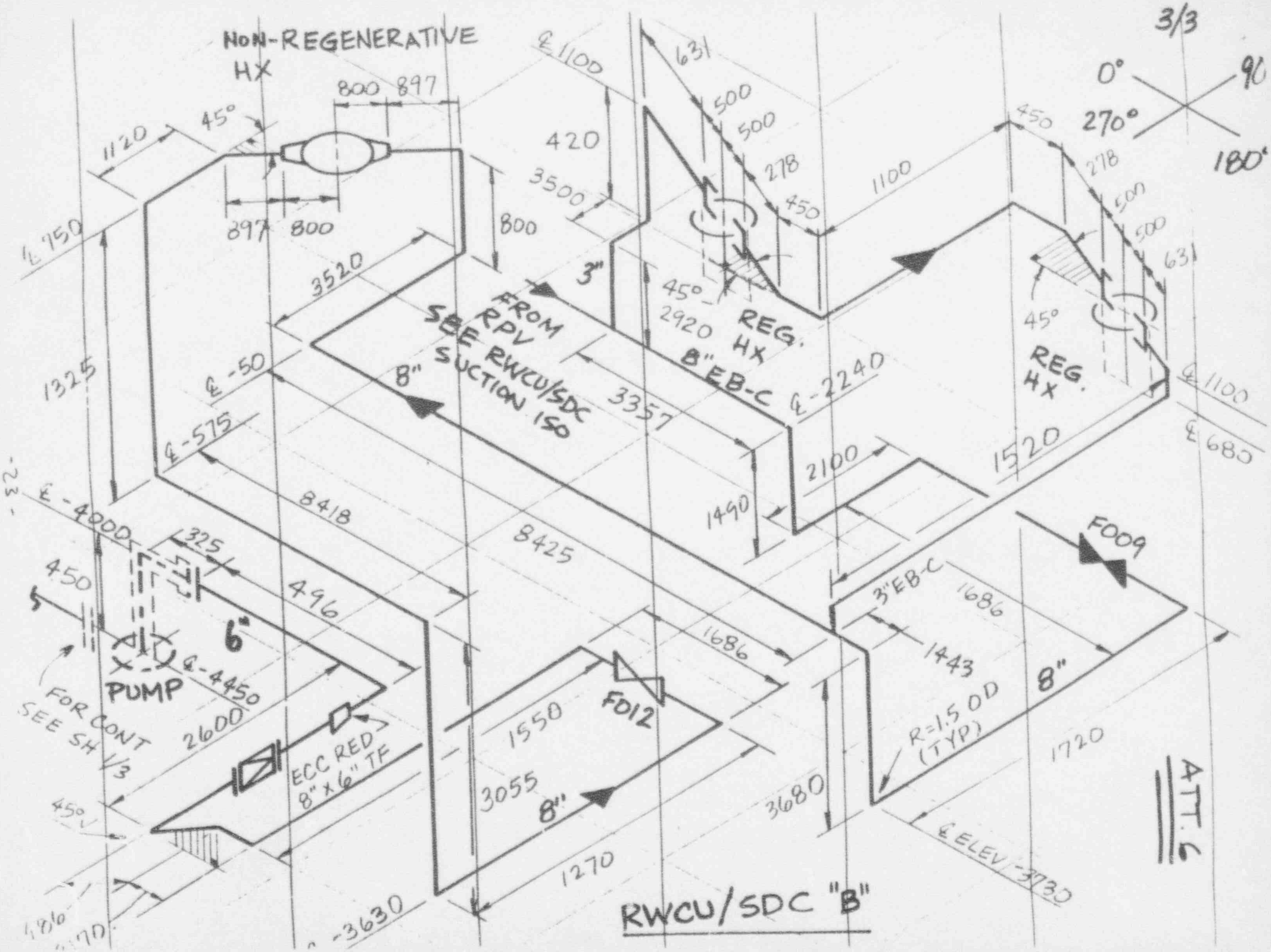

3/?
NON-REGENERATIVE Hx
45°
800
897
1120
℄ 750
897
800
3520
420
3500
800
℄ 1100
6
500
500
278
450
1100
450
278
500
500
631
3"
45°
REG Hx
45°
REG. Hx
℄ 1100
420
1520
FROM RPV
SEE RWCU/SDC SUCTION 150
R=1.5OD (TYP)
℄ -50
℄ -575
2920
8" EB-C
607
℄ -2240
2100
8" EB-C
9493
℄ -4000
325
496
6"
℄ -4450
PUMP C001
10943
3" EB-C
1686
F009
730
ECC RED 8"X6" TF
1686
F012
1550
2600
1307
1720
45°
486
3170
8"
1270
℄ -3630
℄ -3730
RWCU/SDC "A"
0°
90°
180°
270°
ATT. 3

ATT. 4

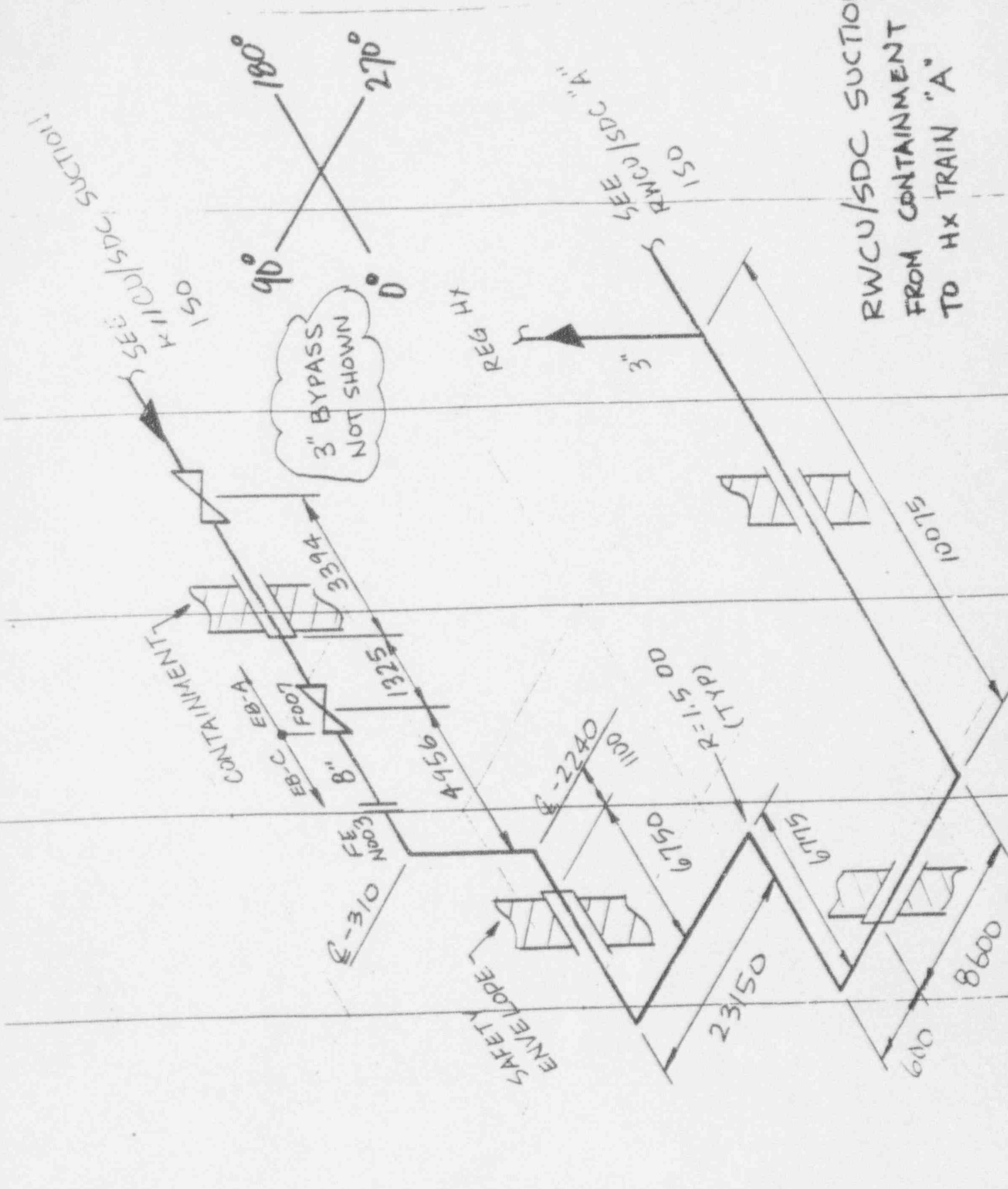

0°
90°
180°
270°
TO LIQUID WASTE
CONT ON SH 2
FROM LIQUID WASTE
CONT ON SH 3 8" EB-C
F017
F018
F020
F021
FE N023
PUMP COOL
8" EB-C
R=1.5 OD (TYP)
℄ ELEV 5150
℄ ELEV -4450
℄ ELEV -3250
℄ 4975
℄ -4450
11300
5058
600
848
1820
536
2350
2070
2350
694
311
2600
6205
2900
1300
1462
2450
2950
1500
2389
2150
900
600
4000
RWCU/SDC "B"

ATT. 5


2/
℄ ELEV 1802
℄ ELEV 1380
R=1.5 OD (TYP)
1650
3500
45°
631
500
500
REG HX
278
3"
F030
8"
450
1100
750
537
49
49
2350
F028
2570
1350
CONT FROM SH 1
℄ ELEV -4450
2950
278
500
REG HX
450
848
4825
3100
500
℄ ELEV 2220
45°
631
848
45°
45°
4000
1300
3"EB-C
℄ ELEV 4975
5250
600
8"EB-C
TO W. A
RWCU/SDC "B"
90°
180°
0°
270°

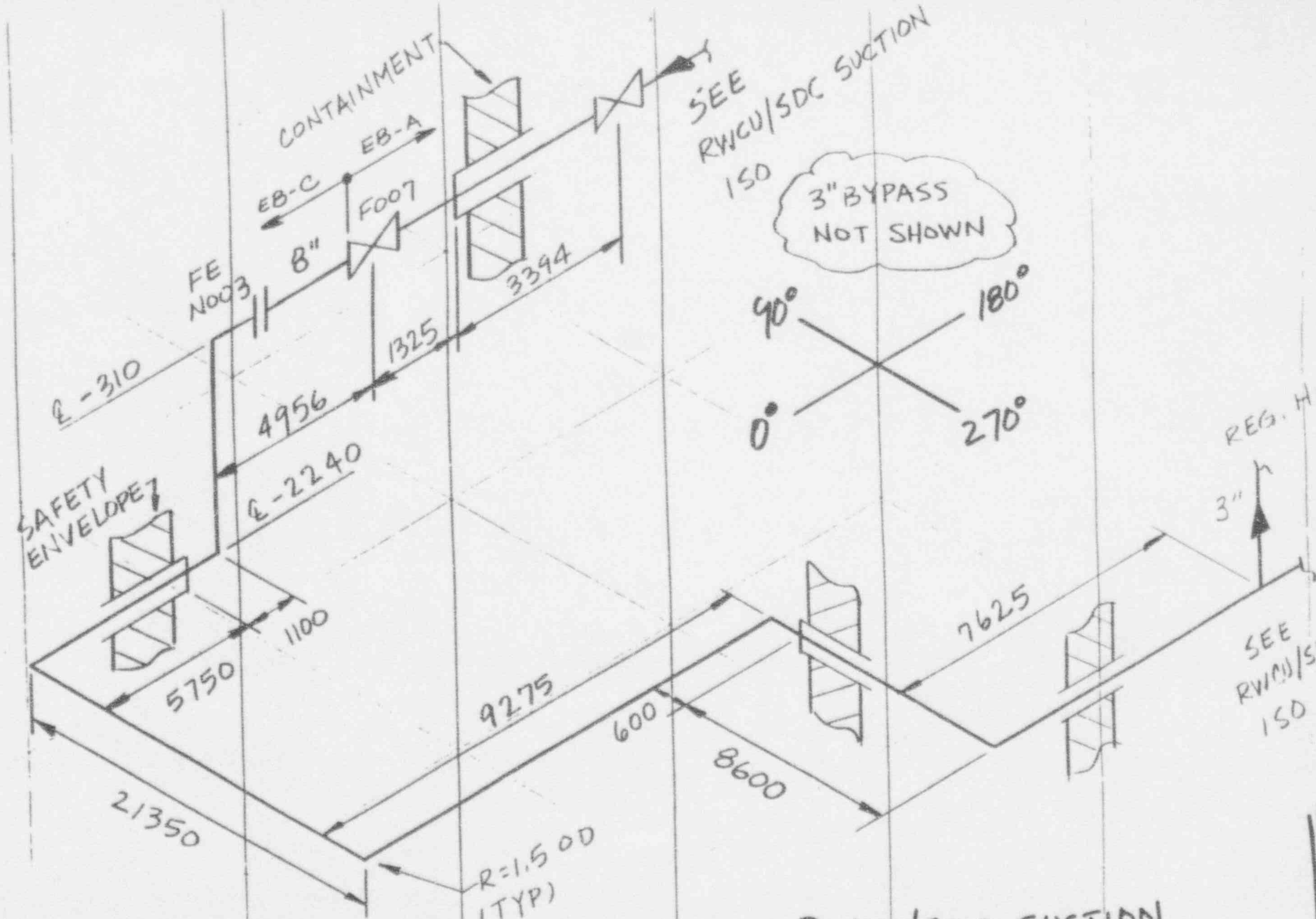

3/3
0°
90
270°
180°
ATT. 6
NON-REGENERATIVE HX
800
897
45°
1120
897
800
℄ 750
1325
800
3520
FROM RPV
SEE RWCU/SDC SUCTION ISO
8"
3"
℄ 1100
420
3500
631
500
500
278
450
45°
2920
REG. HX
8" EB-C
3357
℄ -2240
℄ -50
℄ -575
8418
8425
1100
450
278
500
500
631
45°
REG. HX
℄ 1100
℄ 680
1520
2100
1490
F009
3"EB-C
1686
1443
8"
R=1.5 OD (TYP)
1720
℄ ELEV -3730
℄ -4000
325
450
496
6"
PUMP
℄ -4450
FOR CONT SEE SH 1/3
2600
ECC RED 8" x 6" TF
45°
1686
F012
1550
3055
8"
3680
1270
℄ -3630
RWCU/SDC "B"

ATTACHMENT 7



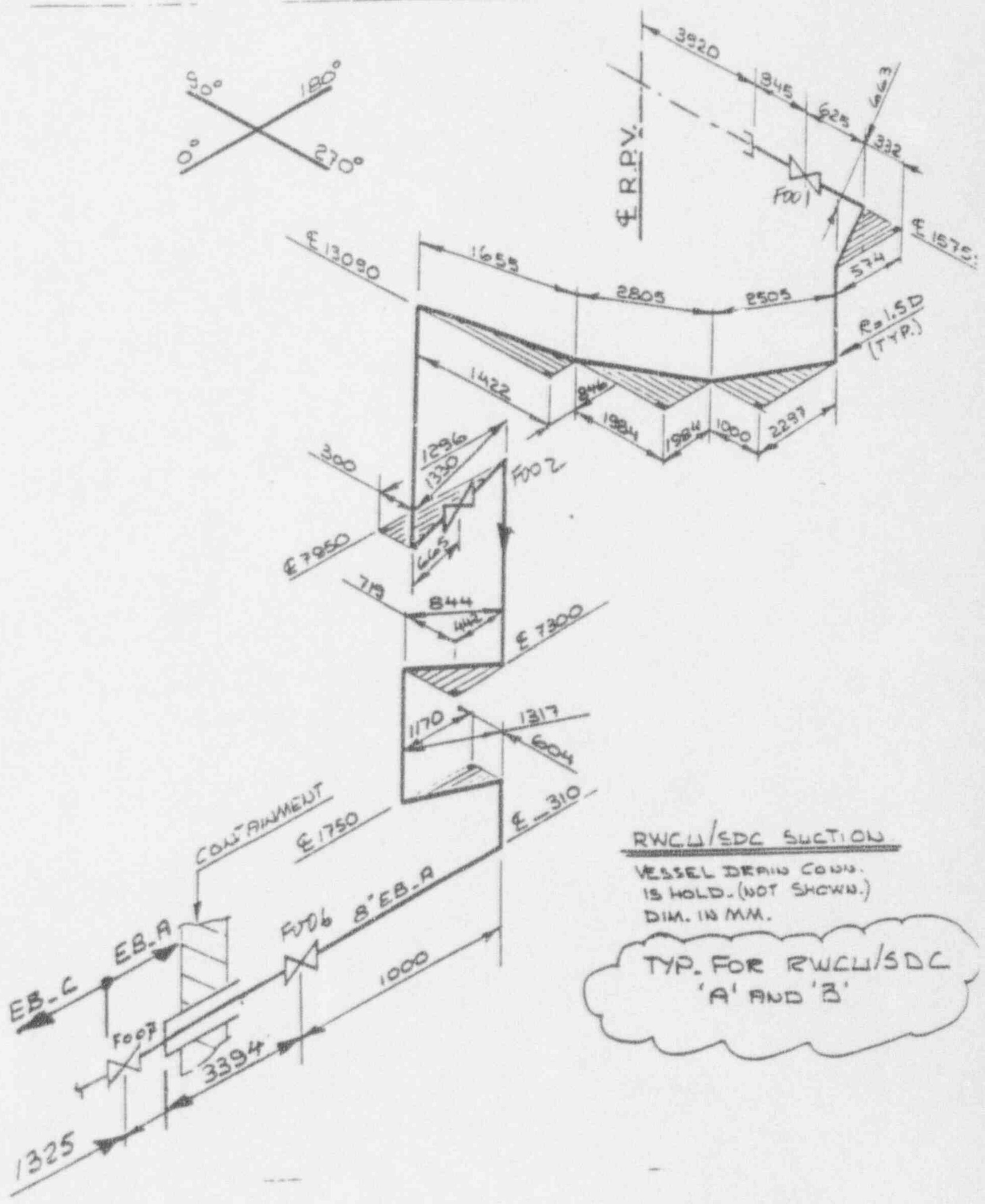
RWCU/SDC SUCTION
FROM CONTAINMENT
TO HX TRAIN "A"

ATT. 8



RWCU/SDC SUCTION
FROM CONTAINMENT
TO Hx TRAIN "B"

ATT. 9

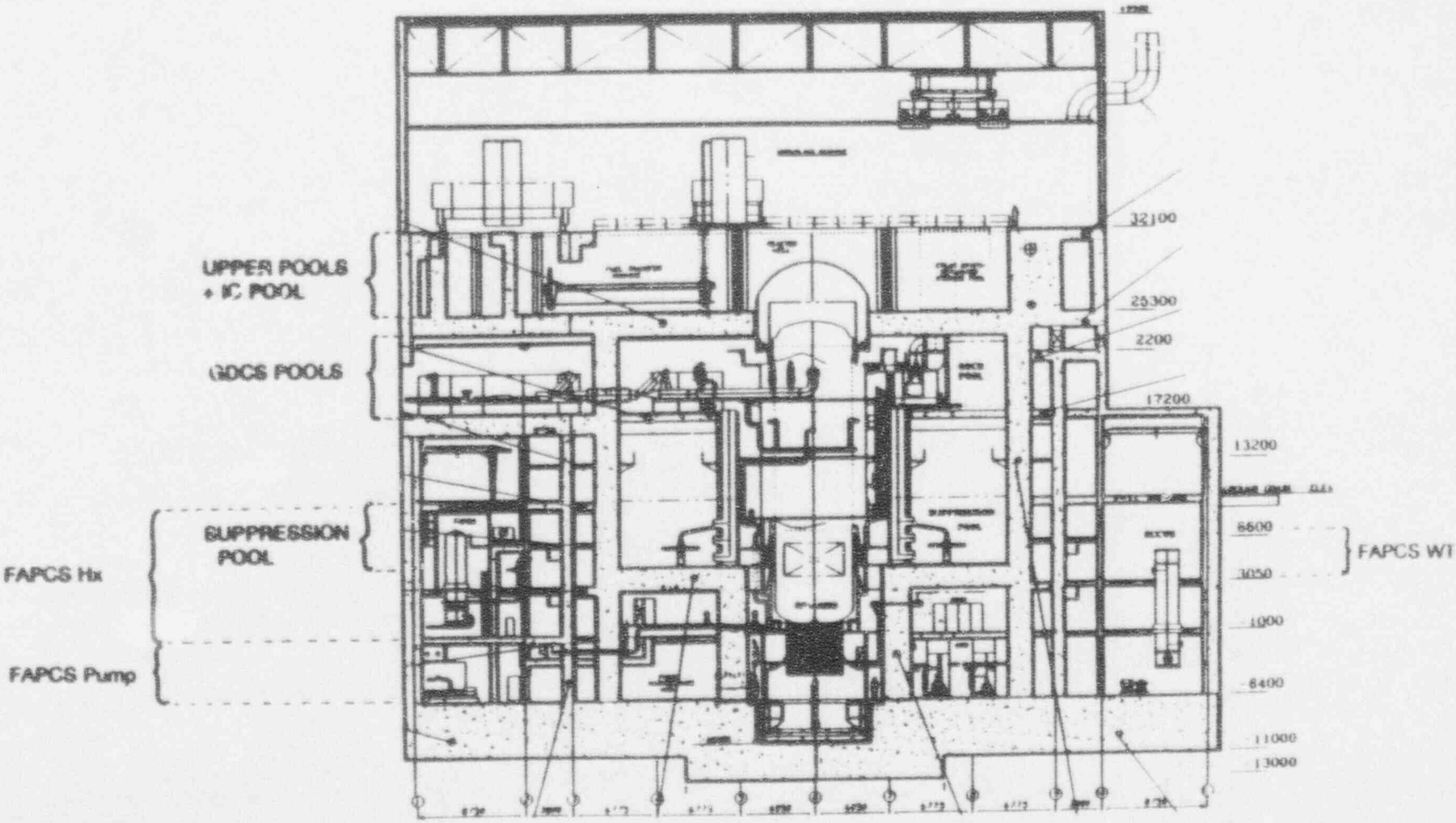


RWCU/SDC SUCTION

VESSEL DRAIN CONN. IS HOLD. (NOT SHOWN.)
DIM. IN MM.

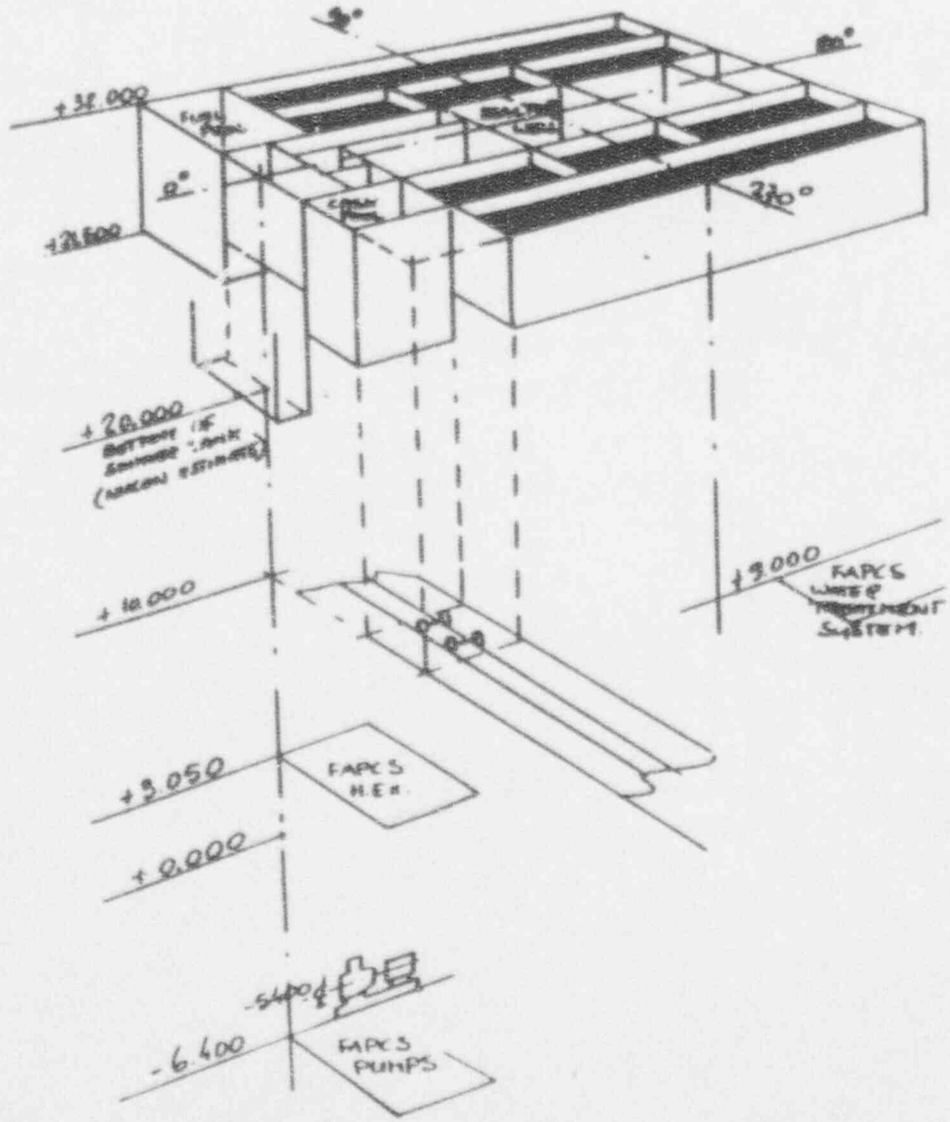
TYP. FOR RWCU/SDC 'A' AND 'B'

REACTOR BUILDING



-27-

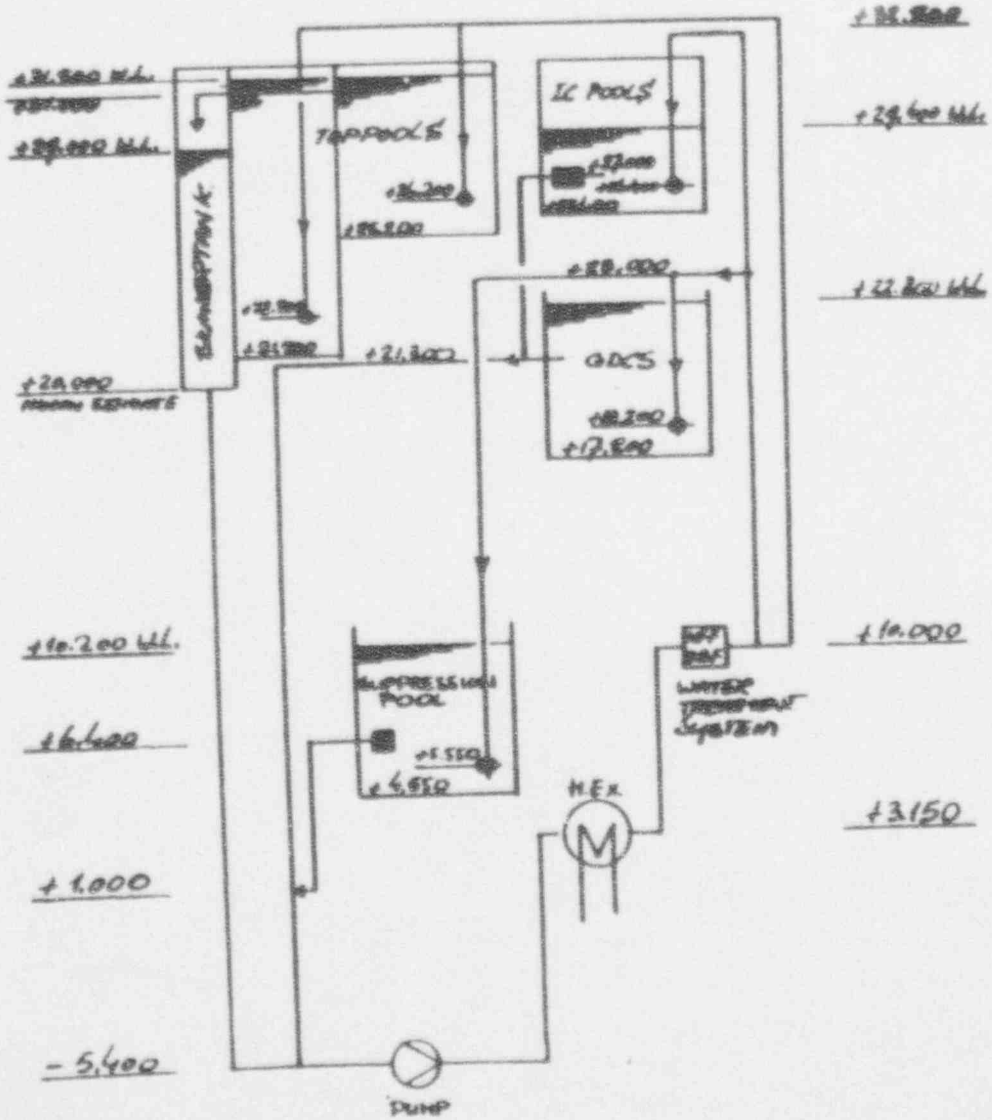
FAPCS — LOCATION OF POOLS AND EQUIPMENT (SKETCH)



-28-

FAPCS

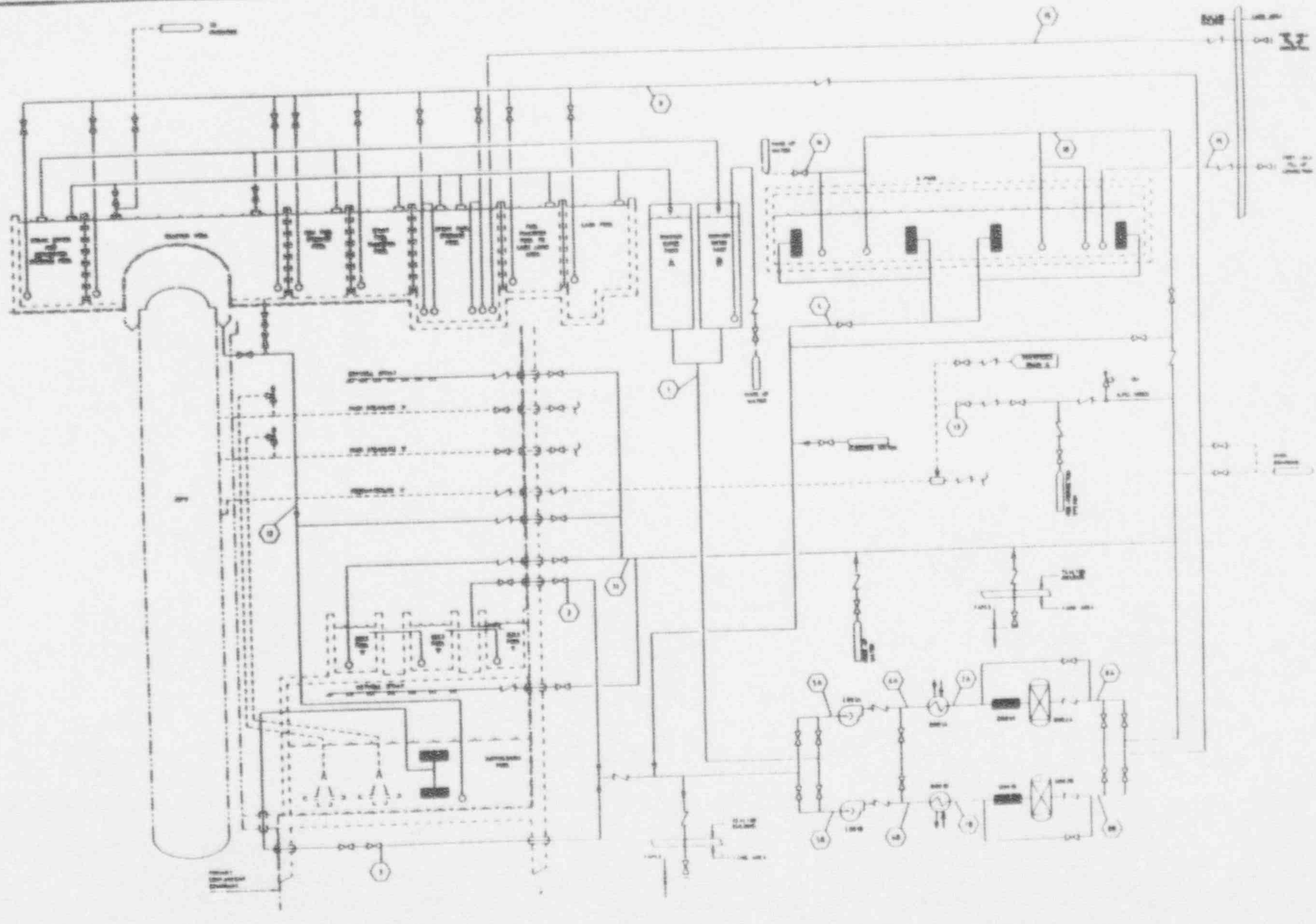
ELEVATION OF POOLS AND EQUIPMENT (SKETCH)



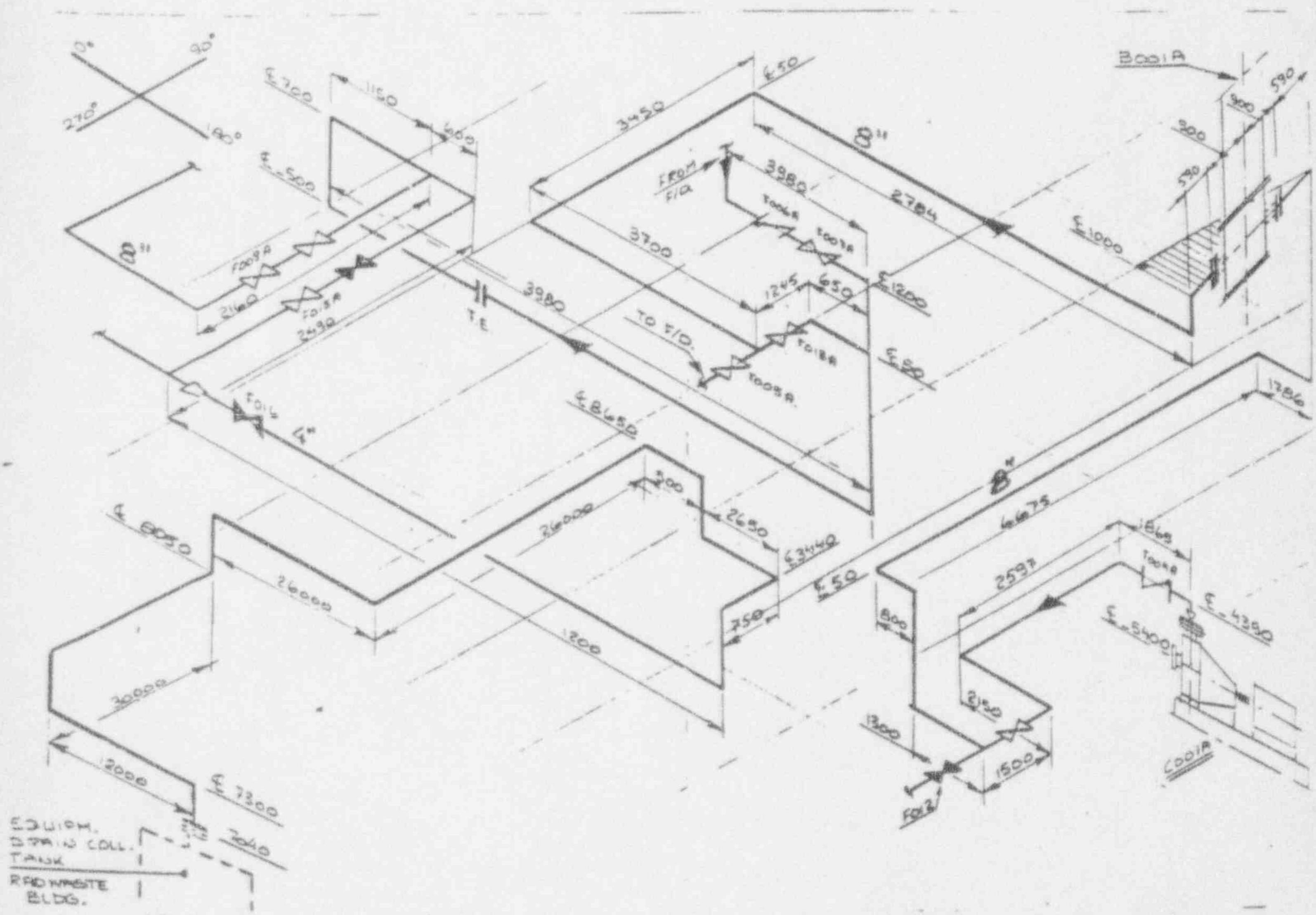
-62-

FAPCS

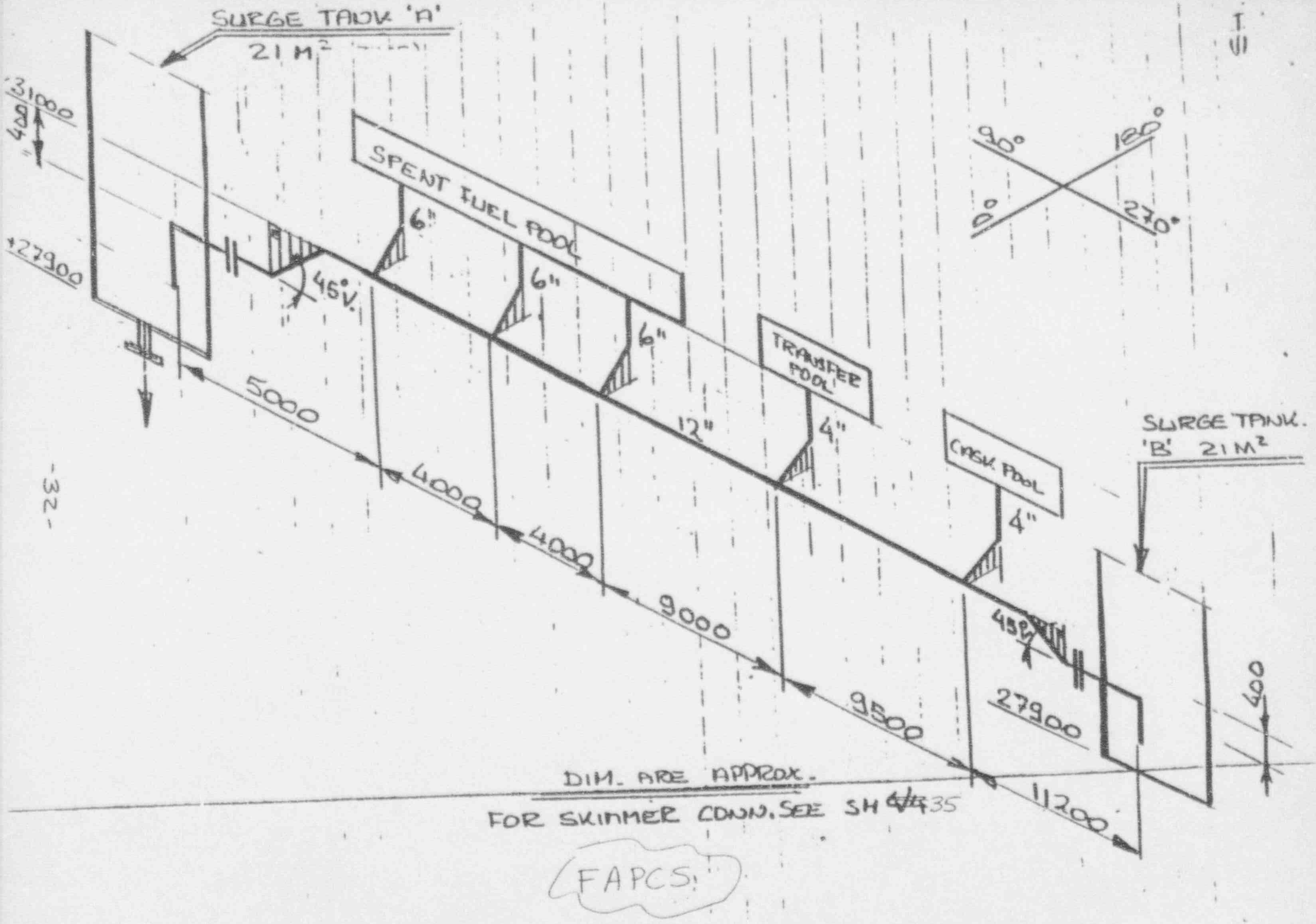
BASIC SYSTEM LAYOUT

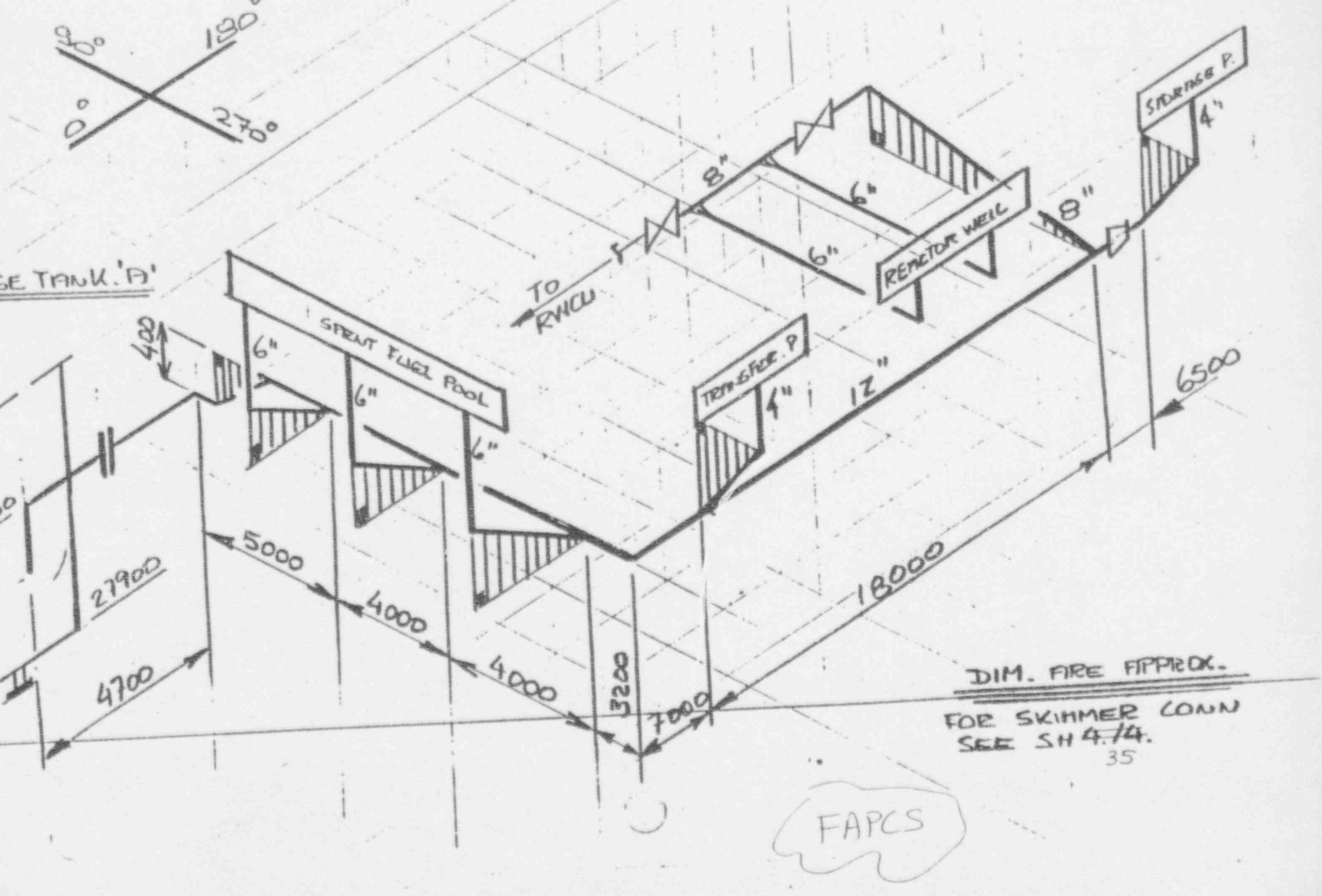


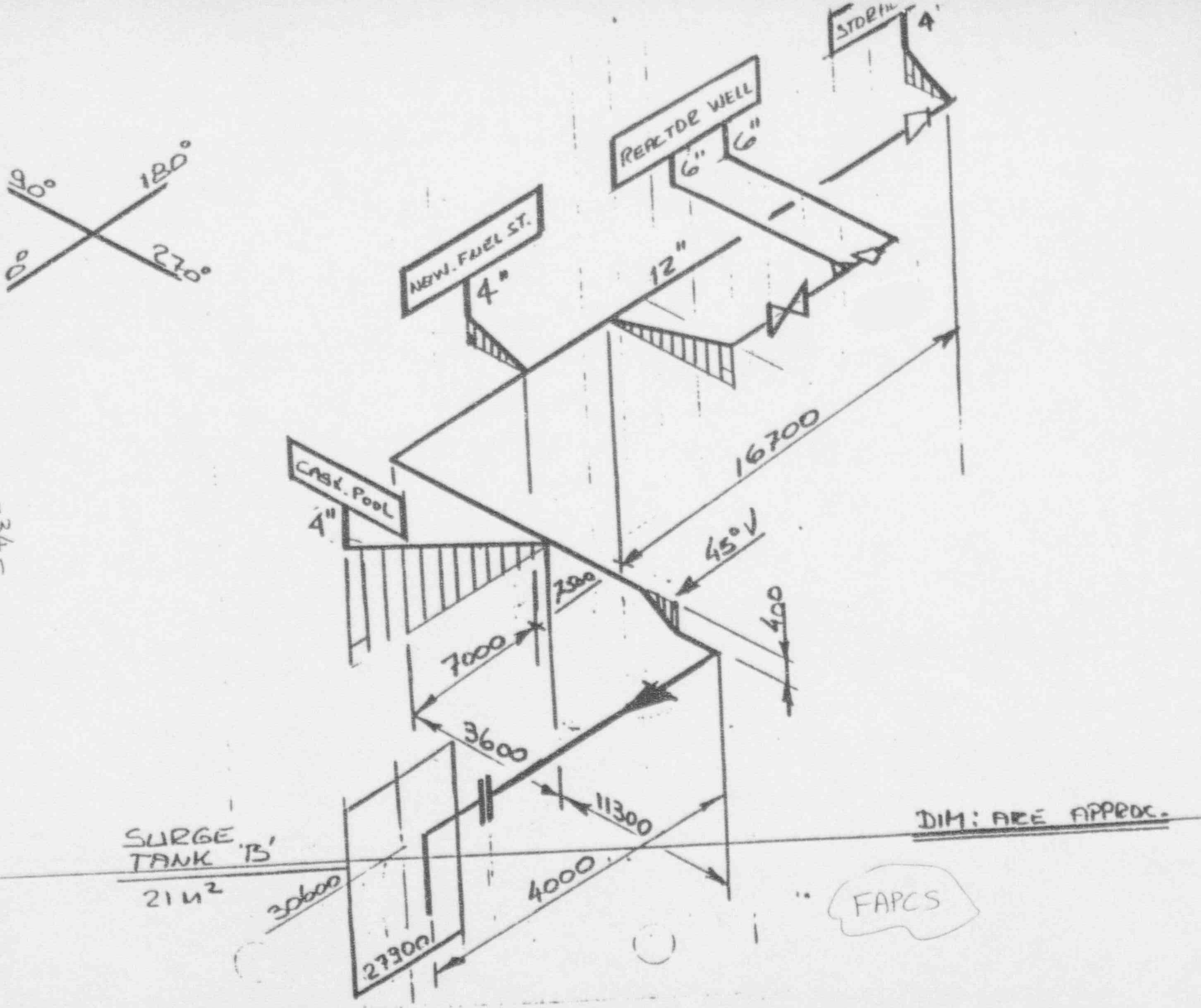
GENUA 92
[illegible]

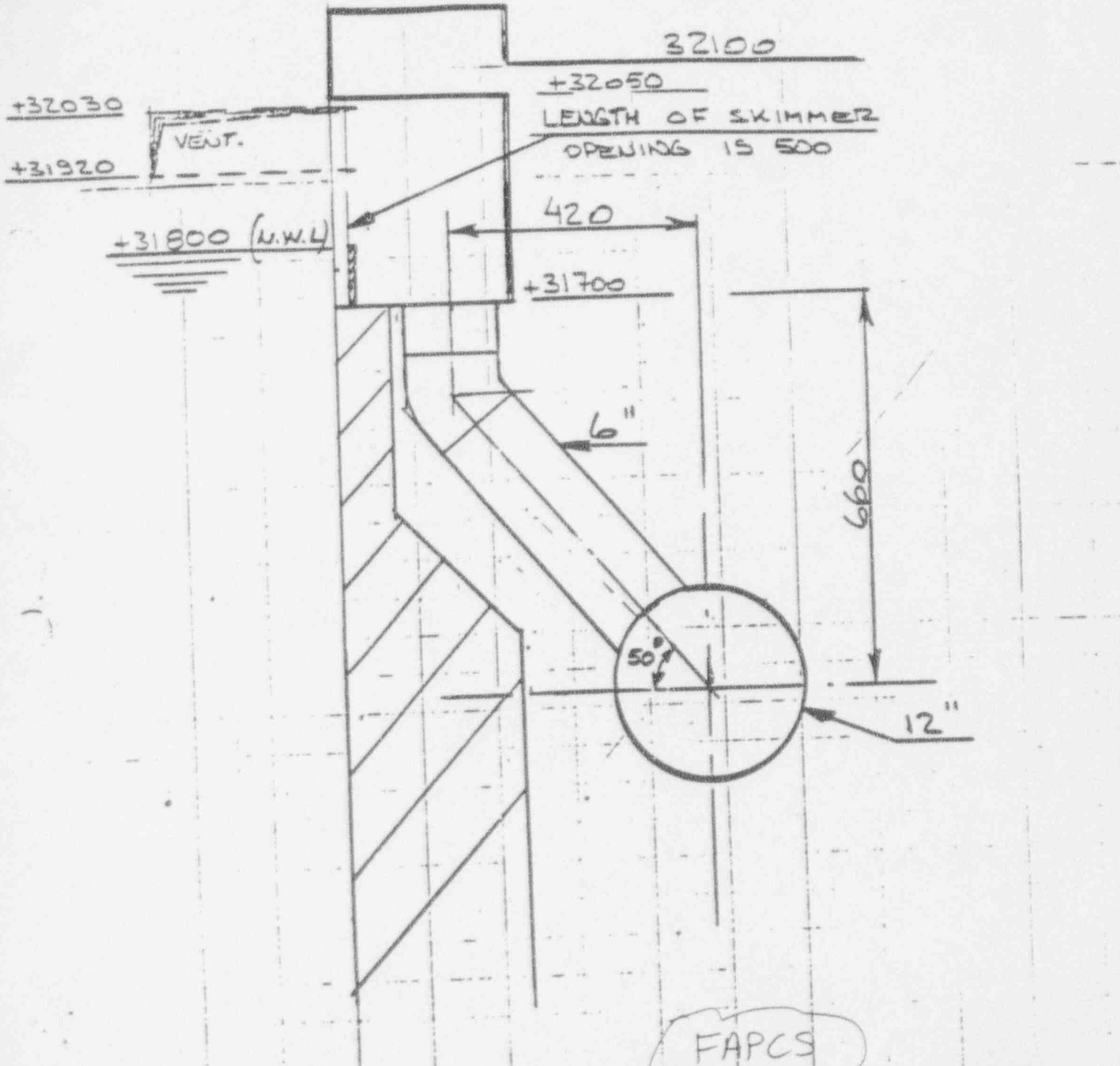


PROPOSED FAPCS & LWS ROUTING.


SURGE TANK 'A'
21 M²
31000
400
+27900
SPENT FUEL POOL
6"
6"
6"
45°V.
5000
4000
4000
9000
12"
TRANSFER POOL
4"
CASK POOL
4"
45°V
9500
11200
27900
400
SURGE TANK. 'B' 21 M²
90°
180°
0°
270°
DIM. ARE APPROX.
FOR SKIMMER CONN. SEE SH 435
FAPCS


90°
180°
0°
270°
SURGE TANK 'A'
SPENT FUEL POOL
6"
6"
6"
48
30600
27900
5000
4000
4000
4700
3200
7000
TO RWCU
8"
6"
6"
REACTOR WELL
8"
STORAGE P.
4"
TRANSFER P.
4"
12"
18000
6500
DIM. ARE APPROX.
FOR SKIMMER CONN
SEE SH 4/4.
35
FAPCS


90°
180°
0°
270°
NEW. FUEL ST.
4"
REACTOR WELL
6"
6"
STORIN
4'
12"
16700
CASK. POOL
4"
45°V
7300
400
7000
3600
11300
4000
SURGE TANK 'B'
21 M²
30600
27900
DIM: ARE APPROX.
FAPCS



TYPICAL SKIMMER CONN.
SPENT FUEL POOL DIM. IN MM
DIM ARE APPROX.

ATTACHMENT C

Additional responses to questions and requests from Attachment A not covered in Attachment B

3. ICS AND PCCS INFORMATION

c. Elevation of the PCCS condensate return line.

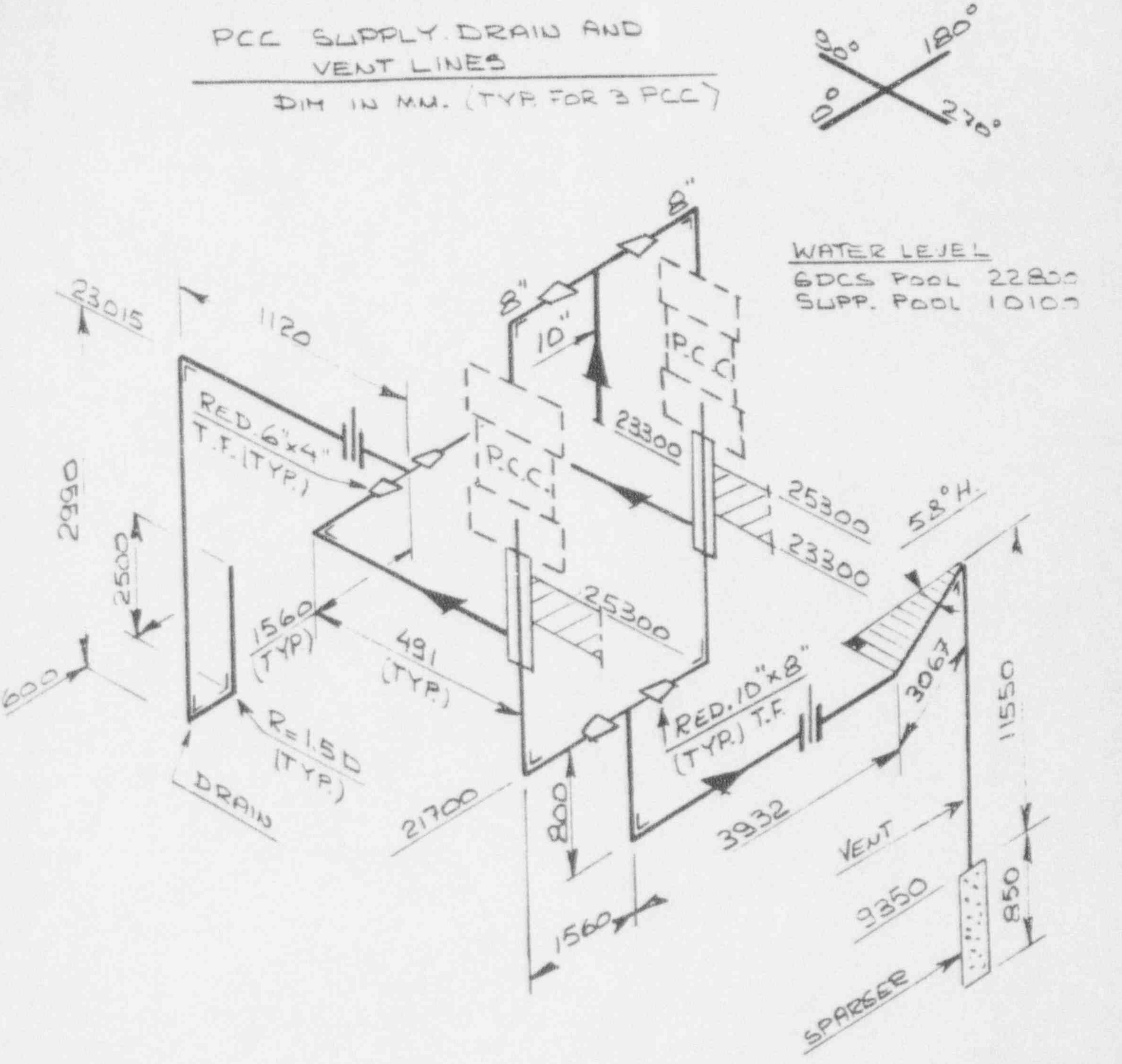
Isometric drawing of the PCCS supply, drain and vent lines is attached.

e. Detailed design of the ICS and PCCS modules.

Enclosed are the drawings of the prototype IC and PCC to be tested in the PANTHERS Test Program. The PCC drawings contain the two modules of the condenser unit. The IC drawings show one module of the two module unit.

PCC SUPPLY, DRAIN AND VENT LINES

DIM IN MM. (TYP. FOR 3 PCC)



Question and Requests on GIST Facility

1. **How were heaters fitted to the vessel? How heater surface temperatures were measured?**

<u>Response</u>

The GIST core heaters are cartridge heaters rated at 3500 Watts at 440V AC single phase. The heat flux is constant from the bottom to the midpoint, decareasing linearly from the midpoint to the top. The cartridges are manufactured by Wellman Thermo Systems and were purchased from Montgomerty Bros. Inc., 1831 Bay Shore Highway, Burlingame, CA 94010. Refer to GE Purchase Order #190-RP614 on August 10, 1987.

The bottom end of each heater cartridge is fitted with a plug which is inserted into and retained by a test vessel flange. The heater cartridge spacing is maintained by spacer collars (washers) and the confines of the vessel internals.

Surface temperatures were measured by Gordon Type T grounded junction stainless steel sheathed thermocouples. The sheath nominal diameter is 0.062" except for a tip with a nominal diameter of 0.04" x 1.5" long. The thermocouples were fixed to a heater rod surface by spot welded stainless steel foil strips during vessel assembly.

2. **Provide the loss coefficients in all the lines of GIST facility.**

<u>Response</u>

Local losses for the important flow path restrictions in the GIST facility are as follows:

	Bottom	Top
Guide Tubes	1.5	1.3
Bypass	1.3	1.2
Channels	1.68	1.273
Downcomer (annulus)	0.8	1.0
Standpipe	0.3	1.36

Response to Question 2 Continued

The local loss for the channel to bypass leakage path is 2.5

The local loss for the SRV orifice is 2.71

The losses for tne GDCS lines should be chosen so that the GDCS system flow matches the design flow.

3. **Need detailed test results and conditions for five GIST tests used for TRACG calculations in order to run similar experiments as required by NRC. Need design of the break simulation using pipe and valve on various lines of GIST facility.**

Response

The initial conditions for each GIST test are given in the GIST final test report GEFR-00850. The key results of the five GIST tests used for TRACG calculations are included on the enclosed diskette. The tests simulated were a 2 inch diameter drainline break in the bottom of the RPV, a GDCS injection line break with a 2 inch diameter flow limiter in the vessel nozzle at 29 ft above vessel "0" and a steam line break with a 13.93 inch diameter flow limiter in the vessel nozzle at 62 ft above vessel "0". The piping for the breaks which directs the flow from the vessel to the containment must be large enough in diameter to insure that the back pressure in the piping has a minimal effect.

4. **How the pressure sense line were connected to the vessel and pressure transducers?**

Response

The pressure sensing lines were connected to 1/2" pipe nipples welded to the vessel and pipes of the test facility. The through holes were flush with the inside diameter and deburred.

5. **What flow meters were used to measure a) water, b) steam and c) two-phase flow in pipe? And what flow meters were used for downcomer liquid flow rate?**

<u>Response</u>

Orifice plates and nozzles were used to measure single and mixed phase flows. Turbine flow meters were used in the GDCS injection lines. The important parameter for this test was water level which was measured throughout the facility. Downcomer liquid flow rate was not important and therefore not measured.

Other Questions

1. **Can GE supply us heaters with built-in surface thermocouples?**

<u>Response</u>

No. See response to question 1 above.

2. **Who made GIST heaters?**

<u>Response</u>

See response to question 1 above.

ATTACHMENT D

Responses to Questions made to GE by Purdue staff
during meeting on October 1, 1993

1. Send paper on heat transfer coefficient correlation for condensation in the presence of noncondensable gases.

Reply

Attached is the paper from the Tsukuba, Japan conference. (Purdue has the less-detailed paper from the ICONE-1 Tokyo, Japan conference.)

2. Is there any bypass flow in the GIRAFFE RPV? If so, how does the GIRAFFE bypass flow compare with that of the SBWR?

Reply

The GIRAFFE testing was not intended to simulate all of the phenomena expected in the SBWR RPV. Since the purpose was to investigate containment performance, the amount of bypass flow is not considered to be a major parameter for the GIRAFFE program.

3. How were thermocouples attached to the PCC tube walls?

Reply

The thermocouples were sheathed, therefore thermocouple junctions were not directly attached to the PCC tube wall.

4. For all three LOCA simulations, how many PCC, IC, and DPV units were operating in GIRAFFE?

Reply

Main Steam Line Break		Bottom Drain Line Break		GDCS Line Break	
SBWR PCC units	3	SBWR PCC units	3	SBWR PCC units	3
IC units	0	IC units	0	IC units	0

One GIRAFFE PCC unit simulated three SBWR PCC units.

Proceedings of The International Conference on

Multiphase Flows '91-TSUKUBA

ICMF'91 TSUKUBA

VOLUME

1

Extended Abstracts

Edited by G. Matsui,
A. Serizawa and Y. Tsuji

in cooperation with the members of
the Conference Committee and
the Scientific Committee

September 24-27
1991

Proceeding of The International Conference on
Multiphase Flows '91 - Tsukuba
September 24-27, 1991,
Tsukuba, Japan

CONDENSATION IN A NATURAL CIRCULATION LOOP WITH NONCONDENSABLE GASES PART I - HEAT TRANSFER

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ABSTRACT

The reduction of condensation heat transfer due to the presence of a noncondensable gas in the vapor is a critical consideration in the design of heat exchangers where such gases are present. Heat transfer coefficients may be so greatly diminished that the exchanger fails to perform its required function. The present paper deals with the effect that a noncondensable gas has upon the condensation within a natural circulation loop. A vertical natural circulation loop was used with the condenser section at the upper part of the downflow side. Steam injected into a lower plenum flowed up the adiabatic side of the loop and the condensate formed on the downflow side drained back to the plenum. Local heat transfer coefficients were measured for ranges of gas content and steam flowrate. The experimental results have been correlated as a correction factor to a heat transfer coefficient calculated from Nusselt theory. When applied to the theoretical value, the correlation provides a local heat transfer coefficient which includes effects of the noncondensable gas and interfacial shear on condensation.

INTRODUCTION

Earlier work by Sparrow and others [1,2] clarified the basic role played by the noncondensable gas through the study of laminar film condensation on a vertical wall, adjacent to a large body of vapor-gas at a uniform ambient state. The gas is carried toward the condensing surface by the flowing vapor. It accumulates there until the diffusion of gas back into the vapor-gas mixture balances the convective flow toward the interface. At steady state, the vapor partial pressure at the condensing surface is therefore lower than in the bulk mixture. Thermodynamic equilibrium dictates that the interface temperature (saturation temperature at the vapor partial pressure) is then lower than in the bulk. For condensation of pure vapor, the thermal resistance of the draining condensate film controls the condensation rate for condensation of pure vapor. With noncondensable gas present, there is a significant, additional thermal resistance on the vapor-gas side associated with the composition boundary layer.

This same physical picture is expected to apply to the present problem of condensation inside vertical heat exchanger tubes. However Sparrow's problem resulted in self-similar boundary layers and a uniform interface temperature. The present problem is clearly nonsimilar. The tube wall temperature varies axially, the vapor-gas composition varies axially as well as radially, and the interfacial shear imposed by the vapor-gas flow has a significant effect upon the liquid film thickness, particularly near the entrance of the condenser tube.

The need for the present study results from a lack of full understanding of the heat transfer mechanisms involved when noncondensable effects and gas-film shear are significant. Earlier experimental studies of forced flow condensation under such conditions have been conducted, however, only length-averaged data are available. Local data and analysis are needed for a full understanding of the phenomena involved.

The present work [3] was carried out in support of the Simplified Boiling Water Reactor (SBWR) which is an advanced light water reactor being developed by an international team led by the General Electric Co., with support from the US Department of Energy, the Electric Power Research Institute, and other participants. In this design, an isolation condenser may be called upon to remove heat from the containment by condensing vapor from a steamnitrogen mixture. The gas mixture would flow by natural circulation from the drywell to the isolation condenser. Successful design of the condenser requires knowledge of the local heat transfer coefficient.

THEORY

The physical situation inside a vertical tube is shown schematically in Figure 1. Axial variations of the cross-section average temperature and species concentration for the internal flow case introduce additional phenomena not considered in previous studies. In contrast to the natural convection case, the bulk vapor saturation temperature decreases with distance along the condenser tube and the bulk noncondensable concentration increases. This produces axial variations in the conditions driving heat and mass transfer. A plausible detailed physical description is as follows.

Steam begins to condense from the gas mixture at the inlet. As steam is drawn to the cooling surface, the gas mixture experiences a force similar to suction through a permeable wall. Noncondensable gas concentration at the film interface becomes higher than in the central core and a gas-vapor boundary layer develops adjacent to the liquid boundary layer. Between the annular gas boundary layer and tube centerline, the steam concentration is constant. However the cross-section average of noncondensable gas concentration increases with distance along the tube axis as the boundary layer thickens. At some axial location, the boundary layer bridges the tube so that there is no longer a central core of inlet composition. Resistance to heat transfer increases with the composition boundary layer thickness.

With steam continuing to condense, but at diminishing rates, a fully-developed composition distribution may not be achieved in the gas phase. Downstream from the point of complete condensation, the gaseous mixture contains steam in equilibrium

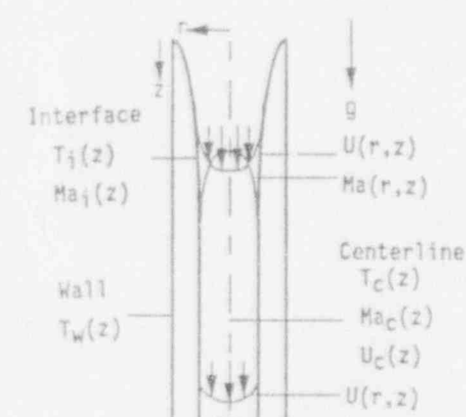


Figure 1 Developing Boundary Layers

with the condensate and noncondensable with a partial pressure which maintains tube total pressure at nearly the loop pressure.

Another distinguishing feature of internal condensation is the presence of interfacial shear. The gas phase has a higher velocity than the condensate film, producing interfacial shear which, in the case of downflow, tends to decrease the liquid film thickness and reduce the film Reynolds number for transition from laminar to turbulent film flow. The thermal resistance of the liquid film is reduced by this thinning effect and also by turbulence when it is present. These concepts have been employed in the present work to develop a suitable correlation form. Theorectical analysis along these lines is being pursued in a follow-on program at the University of California, Berkeley.

EXPERIMENTAL DESCRIPTION

A natural circulation loop, with a vertical condenser tube 22 mm I.D. and 2.1 m in length, provided the experimental data for calculation of localized heat transfer coefficients. The closed loop consisted of a lower plenum, an adiabatic vertical riser, the condenser leg, and an adiabatic downcomer returning to the plenum. The entire system was insulated, with connections to the plenum for the steam supply line and condensate drain line. As part of the startup procedures, the closed loop was brought down to a vacuum and then given an initial charge of noncondensable gas (air). The quantity of air remained fixed throughout a test run, enabling determination of noncondensable concentrations in the loop. Steam was then injected into the lower plenum where it mixed well with the air. Upon condensing in the test section, the condensate (and the air) returned to the lower plenum via the downcomer. Condensate was removed at a rate to maintain a constant liquid level in the plenum as measured using a sight glass. Recirculating air mixed with the incoming steam in the lower plenum.

Fitted with an annular cooling jacket, the condenser tube was cooled by single-phase heat transfer to cooling water. The coolant flow rate was maintained so as to provide essentially complete steam condensation on the primary side, yet obtain an accurate determination of the secondary-side temperature rise along the test section (approximately 11°C).

The system was instrumented with pressure transducers and thermocouples in the lower plenum and at the top of the loop. Coolant and test section outer wall temperature profiles were measured for local determination of heat transfer parameters. When at a steady state, the condensate drainage rate was measured. The coolant flow rate, as measured through an orifice flow meter, and the steam inlet flow rate were continuously monitored to prevent deviations from the approach to steady-state conditions. The rate of steam supply was determined by the electric power supplied to the boiler and the heat of vaporization at the system pressure. Using flow measurements, in conjunction with heat loss data, heat balances were performed to ensure that all energy in the system could be accounted for.

A steady state was deemed to exist when signals from all instrumentation had been constant for a period of at least ten minutes. The operating pressure and temperatures were determined by the ability of the system to circulate the gas mixture and remove heat in the test section. A process sensitive to changes in steam and cooling water flow rates and plenum water level, the approach to a steady state was observed to be very gradual. As described in Part II of this paper, oscillations occurred with higher air concentrations and prevented attainment of a steady state. The operating parameters were as below:

Parameter	Operating Range
Heater power input	6 - 18.9 kW
Vapor flow rate	5.9 - 25 kg/hr
System pressure	30 - 452 kPa
System temperature	72 - 146 C
Inlet air mass fraction	0.0 - 0.14
Coolant inlet temperature	9 -12 C
Coolant outlet temperature	17 - 23 C
Coolant flow rate	364 - 1432 kg/hr

For this range of conditions, the condensing length varied from 0.4 to 1.25 m.

RESULTS AND DISCUSSIONS

For test runs in which a steady state was achieved, two types of tube wall temperature profiles were observed. The majority showed a momatonically decreasing temperature along the condensing length. Cases with a low air content revealed an anomolous temperature profile which increased from the tube entrance before decreasing, herein referred to as a "temperature inversion". Some conjecture is provided in reference 3 for this behavior but it remains to be adequately explained. A thermosyphon mode of operation was considered, but this would appear to violate flooding limits for countercurrent flow in the downcomer. A similar, although less pronounced, effect was observed in low head forced convection tests at Toshiba [4] in Japan.

From the majority of the runs, data were used to obtain local condensation heat transfer coefficients. To obtain the air mass fraction at the condenser entrance, the air holdup in the condenser and downcomer was found from approximate calculations. This amount of air was subtracted from the known loop air inventory and the remainder was assumed to be uniformly distributed within the remaining system volume. The axial profiles of the primary-side and secondary-side fluid temperatures, bulk air mass fraction, condensate flow rate, and bulk gas-vapor mixture Re_m, among other parameters were obtained. From a high value at the inlet, the heat flux decreased as an exponential or as a power function of distance from the entrance. The air mass fraction gradually increased, and the mixture Re_m gradually decreased, before undergoing rapid change to nearly 1.0 and 0.0 respectively, at the end of the condensation zone.

The data have been correlated as a correction factor to the local heat transfer coefficient based on Nusselt theory, i.e., liquid thermal conductivity divided by the local liquid film thickness. The "Nusselt" film thickness was calculated from

$$\delta = \left(\frac{3\mu_l \Gamma}{g\rho_l(\rho_l - \rho_g)} \right)^{1/3} \qquad (1)$$

where Γ is the film flowrate per unit circumference. This equation is for laminar film flow in the absence of interfacial shear. It was confirmed that the film was always laminar in the present experiments. The correction factor is defined as the ratio of the local experimental condensation heat transfer coefficient to the local theoretical Nusselt value. Correlated in terms of the bulk local air mass fraction and steam-air Reynolds number, Re_m, this factor is based on the data from runs without temperature inversions. The result is

$$f = (1 + 2.88\times10^{-5} Re_m^{1.18})(1 - C M_a^{b}) \qquad (2)$$

where M_a is the bulk air mass fraction and

$C = 10$,	$b = 1.0$	for	$M_a < 0.063$
$C = 0.938$,	$b = 0.13$	for	$0.063 < M_a < 0.60$
$C = 1.0$,	$b = 0.22$	for	$M_a > 0.60$.

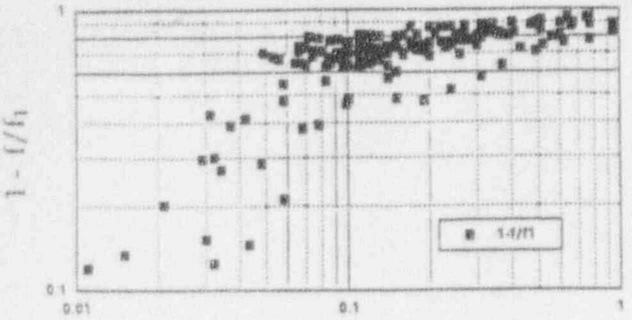
The experimental results are shown in the form of the correlation in Figure 2. The data scatter may be due in part to the relatively large uncertainty in the air mass fraction.

The correction factor accounts for two competing effects. First, the Re_m factor introduces the effect of gas flow causing interfacial shear which enhances condensation rates. This is the first bracketed term in Equation 2. It tends to unity as Re_m tends to zero. The interfacial shear is predominant near the tube entrance where Re_m is maximum and noncondensable mass fractions are minimum. The second bracketed term, which accounts for the presence of noncondensable gas, ranges from unity for $M_a = 0$ to zero for $M_a = 1$.

A preliminary version of the correlation has been used in the TRAC-G code at G. E. Nuclear Energy to analyze the Toshiba tube-average data. This resulted in underpredicting the data by as much as 30%.

CONCLUSIONS

Condensation of steam in a natural circulation loop was experimentally studied to investigate the effects of a noncondensable gas on condenser performance. Steady-state operating conditions depended strongly on air content and inlet steam flow rate. Local heat transfer coefficients decreased as bulk air mass fraction increased and increased with mixture



Local Air Mass Fraction

Figure 2 Correlation of Heat Transfer Degradation Factor
Note: $f_1 = 1 + 2.88x10^{-5}Re_m^{1.18}$

Reynolds number A localized correlation has been developed which accounts for the effects of heat transfer degradation due to noncondensable gas mass fraction and condensation rate enhancement due to interfacial shear (gas-vapor Reynolds number effect).

For low air contents, a temperature inversion phenomenon occurred which indicated low heat fluxes and heat transfer coefficients at the test section inlet. However the locally reduced heat transfer rates did not prevent complete steam condensation. Further work is needed to clarify the temperature inversion phenomon.

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2. Minkowycz, W. J., E. M. Sparrow, "Condensation Heat Transfer in the Presence of Noncondensables, Interfacial Resistance, Superheating, Variable Properties, and Diffusion", Int. J. Heat Mass Transfer, 1966, Vol. 9, pp. 1125-1144.

3. Vierow, K. M.,"Behavior of Steam-Air Systems Condensing in Cocurrent Vertical Downflow", M.S. thesis, U. of CA at Berkeley, Aug. 1990.

4. Nagasaka, H., Private Communication, October 1990.