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ATTACHMENT 4

EVALUATION OF THE DOSE RATE AND SHIELDING REQUIREMENTS FOR THE POST ACCIDENT SAMPLE SYSTEM

Prepared by

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1.0 INTRODUCTION

Sentry Equipment Corp. (SEC) has evaluated the shielding design for the Post Accident Sample System (PASS) equipment being provided by SEC for use in nuclear power stations. The PASS equipment consists of the following:

Grab Sample Panel (GSP)
Containment Air Sample Panel (CASP)

This equipment is designed to enable an operator to obtain samples of primary reactor coolant or containment atmosphere, which may be highly radioactive in the event of a reactor accident involving substantial fuel failure.

The results of the shielding analyses c[illegible]fies t[illegible] the maximum integrated dose to an operator performing any sampling operation using the GSP or CASP is approximately 400 mrem.

2.0 SHIELDING EVALUATION METHODS

2.1 Introduction

The dose rates due to direct radiation emitted from the process piping behind the GSP and CASP were determined by the SEC radiation shielding design system computer codes. The methods used are discussed in section 2.2 and are based on the equations given in volume 1, section 6.2 of the Engineering Compendium on Radiation Shielding (Springer-Verlag New York Inc., 1968).

The dose rate contributions to the front of the GSP and CASP due to backscatter from the walls and floor behind the panels is not considered. There are no "thin" sections or ducts in the shielding that would make scattered radiation of more concern than direct radiation.

The dose rate contributions due to various shield penetrations are discussed in section 2.3

2.2 Discussion of Methods

The dose rates were calculated using the equations for shielded line sources. Modeling was simplified by not considering shielding contributions of the piping walls or self absorption in the process fluid. Obviously, this will result in a more conservative dose rate than if they had been considered.

The equations used for the geometries shown in Figure 2-1 are:

At P_1:

$$\text{D.R. (mrad/hr)} = \frac{B\ S_v\ A_x}{4\pi\ z\ C}\left[F(\theta_1,X)+F(\theta_2,X)\right]$$

At P_2 & P_3:

$$\text{D.R. (mrad/hr)} = \frac{B\ S_v\ A_x}{4\pi\ z\ C}\left[F(\theta_2,X)-F(\theta_1,X)\right]$$

where:

B = scattered buildup factor as discussed in section 2.2.1.

S_v = volumetric source strength (photons/sec/cm^3) as discussed in section 3.2.1

A_x = cross-sectional area of source material

$$F(\theta,x) = \int_0^{\theta} \exp\left[-x \sec \theta'\right] d\theta'$$ R2

$$X = \sum_{i=1}^{n} \mu_i t_i$$

C = flux to dose conversion $\dfrac{\text{photons/cm}^2\text{/sec}}{\text{mrad/hr}}$

t_i = shield laminate thickness (cm)

μ_i = linear attenuation coefficient of shield laminate (cm^{-1}) (Table 2-1)

[illegible].1 Scattered Dose Buildup Factors

The scattered buildup factor for multiple shields was determined by Broder's method discussed in chapter 3 of Weapons Radiation Shielding Handbook (DNA-1893-3, Rev. 1; March 1972). This method is based on a buildup factor being calculated at each shield interface; once for each laminate material as if the entire shield consists of that material. These buildup factors are then combined by Broder's recurrence equation:

$$B\left(\sum_{i=1}^{N} \mu_i t_i\right) = B\left(\sum_{i=1}^{N-1} \mu_i t_i\right) + B_N\left(\sum_{i=1}^{N} \mu_i t_i\right) - B_N\left(\sum_{i=1}^{N-1} \mu_i T_i\right)$$

where B ( ) indicates a function not a product.

Thus, the formula for total buildup is:

$$B\left(\sum_{i=1}^{N} \mu_i t_i\right) = \sum_{n=1}^{N} B_n\left(\sum_{i=1}^{n} \mu_n t_i\right) - \sum_{n=2}^{N} B_n\left(\sum_{i=1}^{n-1} \mu_n t_i\right)$$

Each individual buildup factor was calculated using Capo's point source polynomial approximation:

$$B = \sum_{i=0}^{3} \beta_i (ut)^i$$ (after Engineering Compendium on Radiation Shielding, Vol. 1)

where β_i are the coefficients listed in Table 2-2

2.2.2 Gamma Scurce Definition

The source terms were divided into nine groups as follows:

Representative Energy (MeV)	Energy Range (MeV)
0.4	0.1 - 0.5
0.8	0.5 - 0.9
1.3	0.9 - 1.35
1.7	1.35 - 1.8
2.2	1.8 - 2.2
2.5	2.2 - 2.6
2.8	2.6 - 3.0
4.0	3.0 - 5.0
6.1	6.1

2.2.3 Flux to Dose Conversion

The gamma flux calculated at the dose point is quantified in units of photons/sec/cm^2. These are converted to dose rates in mrad/hr for each energy group as follows:

Energy Group (MeV)	Conversion Factor (photons-hr/sec/cm^2/mrad)
0.4	1357
0.8	696.9
1.3	467.2
1.7	380.6
2.2	320.4
2.5	297.7
2.8	275.8
4.0	210.4
6.1	157.0

(after Nuclear Engineering Handbook, Section 7; McGraw-Hill)

2.3 Shield Penetration

All penetrations passing through the shield are offset to minimize the dose due to radiation streaming and have negligible contribution to the dose rate. However, the shielding evaluation for Sentry Equipment Corp. High Radiation Sample System considered the valve stem penetrations (which are identical to those used on the PASS) to have no offset. Therefore, the evaluation of the valve stem penetrations will be included, realizing this will provide a conservative analysis.

Table 2-1: Linear Attenuation Coefficients

Energy (MeV)	Lead (cm^{-1})	Iron (cm^{-1})
0.4	2.4948	0.7165
0.8	0.9707	0.5174
1.3	0.6430	0.4139
1.7	0.5477	0.3571
2.2	0.5012	0.3182
2.5	0.4888	0.3026
2.8	0.4785	0.2894
4.0	0.4695	0.2575
6.1	0.4933	0.2373

(after Nuclear Engineering Handbook, Section 7; McGraw-Hill)

Table 2-2: Coefficients Used in Capo's Form of the Buildup Factor

LEAD

Energy (MeV)	B0	B1	B2	B3
0.4	0.99993E+00	0.24413E+00	-0.17836E-01	0.59319E-03
0.8	0.10118E+00	0.30992E+00	-0.14248E-01	0.48683E-03
1.3	0.10179E+01	0.36963E+00	-0.78522E-02	0.26797E-03
1.7	0.10152E+01	0.38419E+00	-0.28531E-02	0.11143E-03
2.2	0.10076E+01	0.37505E+00	0.26969E-02	-0.30058E-05
2.5	0.10026E+01	0.36026E+00	0.54705E-02	-0.11432E-04
2.8	0.99805E+00	0.34141E+00	0.77384E-02	0.31761E-04
4.0	0.99061E+00	0.25870E+00	0.11135E-01	0.719[illegible]2E-03
6.1	0.10044E+01	0.19172E+00	-0.14075E-02	0.29838E-02

IRON

Energy (MeV)	B0	B1	B2	B3
0.4	0.10025E+01	0.86091E+00	0.97034E-01	-0.15664E-03
0.8	0.96274E+00	0.80173E+00	0.10918E-00	-0.15172E-02
1.3	0.10160E+01	0.73677E+00	0.57451E-01	-0.48387E-03
1.7	0.10141E+01	0.[illegible]360E+00	0.42602E-01	-0.45168E-03
2.2	0.10074E+01	0.62416E+00	0.33554E-01	-0.45419E-03
2.5	0.10043E+01	0.58796E+00	0.30177E-01	-0.43507E-03
2.8	0.10019E+01	0.55378E+00	0.27590E-01	-0.40323E-03
4.0	0.99786E+00	0.44092E+00	0.21099E-01	-0.22404E-03
6.1	0.99809E+00	0.31496E+00	0.15465E-01	0.69837E-04

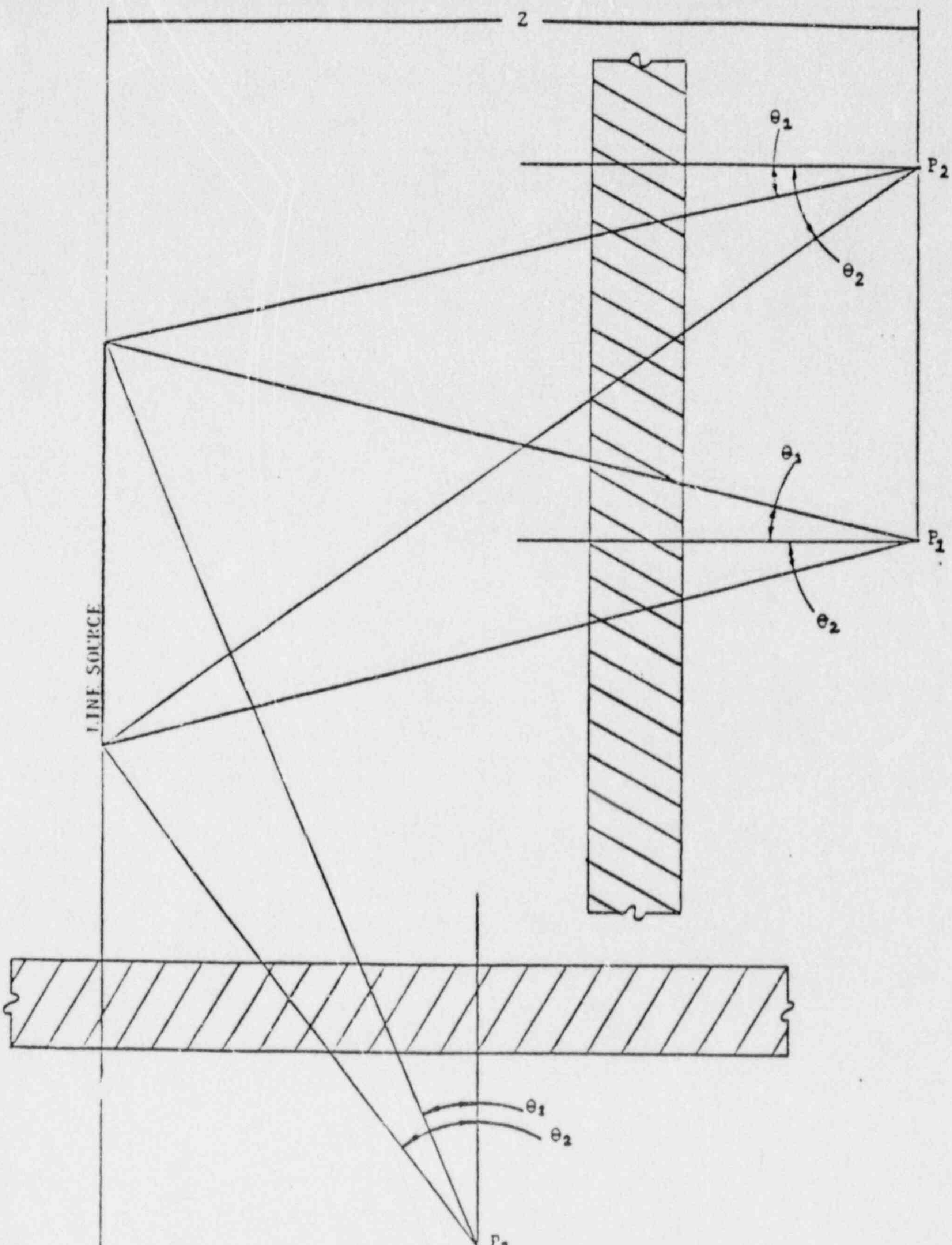

FIGURE 2-1

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3.0 SHIELDING EVALUATION RESULTS

3.1 Design Criteria

The shielding provided on the Grab Sample Panel (GSP) and the Containment Air Sample Panel (CASP) is designed to limit the integrated dose to an operator standing one (1) meter in front of the panel to 3 rem whole body and 18.75 rem extremities from a single exercise. R2

3.2 GSP Shielding Evaluation

3.2.1 Source Terms

The radiation source terms used in the GSP shielding evaluation are based on:

* an equilibrium core operating at a power level of 2561 MW_t
* release of 100% of the noble gas, 50% of the halogen, and 1% of the solid radionuclides to the reactor coolant
* reactor coolant volume of 9500 cubic feet

These source terms are listed in Table 3-1.

3.2.2 The shielding evaluation is based on the "worst case" accident defined by the source terms above. The types of samples which can be obtained during accident conditions are:

* 30 ml in-line pressurized reactor coolant sample from which the gases are stripped
* 3 ml sample of undiluted, gas-stripped reactor coolant
* 1000:1 diluted, gas-stripped reactor coolant sample
* 15,000:1 diluted, stripped gases

A purge of all lines connecting the GSP to the reactor coolant system precedes the acquisition of each sample. After the purge is complete, the 30 ml in-line pressurized reactor coolant sample is isolated. At this time, any lines in the panel containing reactor coolant would be flushed with demineralized water to reduce the total active volume. Then the in-line sample is stripped, separating the gases from the liquid. Now, any or all of the remaining samples may be taken. Upon completion of the sample acquisition, the entire panel is flushed with demineralized water to remove the remaining active liquids and gases.

The process piping and component data used for this evaluation is:

* all lines in the panel are either 1/4 inch diameter by 0.166 inch bore tube or 1/8 inch diameter by 0.067 inch bore tube.
* the volume of all 1/4 inch tube rising stem valves is 1 ml
* the volume of the thermocouple is the same as an equal length of 1/8 inch tube
* the volume of the VREL is the same as an equal length of 1/4 inch tube
* the flow element is 3/8 inch diameter by 0.315 inch bore tube
* all ball valves have the same bore as their connecting tubing
* the volume of all 1/8 inch tube rising stem valves is 0.1 ml
* the volume of SF1 is 30 ml
* the volume of EV1 and EV2 is 300 ml (150 ml each)

The total source volumes are listed in Table 3-2.
Specific details on GSP operation are given in the Operation and Maintenance Manual.

3.2.3 GSP Shielding

The GSP shielding design consists of a main panel shield and a shield surrounding the opening for the undiluted sample cask. The main panel shield is comprised of 7 inches of lead shot held between two 1/2 inch steel plates and runs from the floor to the top of the panel. The shield surrounding the opening for the undiluted sample cask is comprised of 4 inches of solid lead between two 1/2 inch steel plates. This shield is connected to the opening in the main panel shield and covers the interior side wall, rear wall, and ceiling of the opening. Refer to Figure 3-1 for an illustration of the shielding.

The lead shot density used in the analysis was 7.14 g/cm^3. This value corresponds to 63% of the theoretical lead density of 11.34 g/cm^3 and is based on mechanical and radiometric measurements made by Sentry Equipment Corp.

The maximum whole body and extremity dose rates are considered to be one and the same since use of the reach rod requires that the hands be close to the body. These dose rates are listed in Table 3-3. The line source geometries are shown in Figures 3-2 through 3-4. The dose point considered was directly in front of SF1 at a distance of one (1) meter from the front of the panel. No other points were considered as SF1 will always contain the greatest concentrated active volume during sampling.

3.2.4 Valve Stem Penetrations

The valve stem penetrations used on the PASS are identical to those used on the HRSS. Therefore, the results from the HRSS study were used in this study. It should be understood that the radiation streaming from one penetration is so highly collimated that it will not be additive to the exposure from any other penetration. Therefore, the dose rate of 10 mrem/hr was used for valve stem penetrations based on "Evaluation of the Dose Rate and Shielding Requirements for the HRSS Equipment", NUS 3872; October 1981.

3.2.5 GSP Integrated Dose Results

The integrated dose results are compiled in Table 3-4. These results are well below the requirements of 3 rem whole body and 18.75 rem for R2
extremities specified by the integrated dose criteria.

3.3 <u>CASP Shielding Evaluation</u>

3.3.1 Source Terms

The radiation source terms used in the CASP shielding evaluation are based on:

* an equilibrium core operating at a power level of 2561 MW_t R1
* release of 100% of the noble gas and 25% halogen radionuclides to the containment atmosphere
* containment free volume of 158,562 cubic feet

These source terms are listed in Table 3-1.

3.3.2 The shielding evaluation is based on the "worst case" accident defined by the source terms above. The type of sample obtained during accident conditions is:

* 624:1 sample of the containment atmosphere (the volume of the sample before dilution is 24 μl).

A purge of the sample lines in the CASP and its interconnecting lines to the containment precedes the acquisition of the sample. After the purge is complete, the sample is trapped in the diluter valve and swept into the sample vial. Upon completion of the sample R1
acquisition, the entire panel is flushed with nitrogen to remove the remaining active gas.

The process piping and component data used for this evaluation is:

* all lines in the panel are either 1/4 inch diameter by 0.166 inch bore tube or 1/8 inch diameter by 0.067 inch bore tube.
* the eductor exhaust line has a 0.166 inch bore containing radioactive gas the remainder of the bore is nonradioactive nitrogen.
* the flow element is 1/4 inch diameter by 0.166 inch bore tube.
* all ball and plug valves have the same bore as their interconnecting tubing.

The total source volume is listed in Table 3-2. Specific details on CASP operation are given in the Operation and Maintenance Manual.

3.3.3 CASP Shielding

The CASP shielding design consists of a front panel shield and two side panel shields. The front panel shield is comprised of seven inches of lead shot held between two 1/2 inch steel plates and runs from the floor to the top of the panel. The side shields are five inches of lead shot held between 2 1/2 inch steel plates and run from the floor to the top of the panel.

Refer to Figure 3-5 for an illustration of the shielding.

The lead shot used in the analysis was 7.14 g/cm^3. This value corresponds to 63% of the theoretical lead density of 11/34 g/cm^3. The maximum whole body and extremity dose rates are considered to be one and the same since use of the reach rod requires that the hands be close to the body. These dose rates are listed in Table 3-3. The line source geometry is shown in figure 3-6. The dose point considered is one meter from the panel face, 0.8128 meter above the floor, and 0.2032 meter from the panel's right side. R1

3.3.4 Valve Stem Penetrations

See Section 3.2.4.

3.3.5 CASP Integrated Dose Results

The integrated dose results are compiled in Table 3-5. These results are well below the requirements of 5 rem whole body and 18.75 rem extremities specified by the integrated dose criteria. R2

Table 3-1: Source Terms

Liquid Sources for a Non-Linebreak Accident

Representative Energy (MeV)	Production Rate @ 1 Hour (photons/sec/cm^3)
0.4	0.3379E+11
0.8	0.4225E+11
1.3	0.1403E+11
1.7	0.6152E+10
2.2	0.3334E+10
2.5	0.2544E+10
2.8	0.1511E+10
4.0	0.3101E+10
6.1	0.9508E+09

Degased Liquid Sources (30cm^3 total volume)

Representative Energy (MeV)	Production Rate @ 1 Hour (photons/sec/cm^3)
0.4	0.3171E+11
0.8	0.4108E+11
1.3	0.1363E+11
1.7	0.5915E+10
2.2	0.3117E+10
2.5	0.2290E+10
2.8	0.1511E+10
4.0	0.3098E+10
6.1	0.9508E+09

Gas Sources (270 cm^3 total volume)

Representative Energy (MEV)	Production Rate @ 1 Hour (photons/sec/cm^3)
0.4	0.2084E+10
0.8	0.1174E+10
1.3	0.3970E+09
1.7	0.2371E+09
2.2	0.2175E+09
2.5	0.2538E+09
2.8	0.2488E+06
4.0	0.3374E+06
6.1	0.2492E+01

Table 3-1: Source Terms (Con't)

Containment Atmosphere Sources for a Linebreak Accident

R1

Representative Energy (MeV)	Production Rate @ 1 Hour (photons/sec/cm^3)
0.4	0.2709E+10
0.8	0.1253E+10
1.3	0.4237E+09
1.7	0.2028E+09
2.2	0.1450E+09
2.8	0.2528E+08
4.0	0.2606E+07
6.1	0.1357E+02

(Source terms were prepared by Sargent & Lundy Engineers)

Table 3-2: Source Volumes

GSP

Operation	Volume (cm^3)
Purge	86.4
Capture in-line flask	116.4
Diluted or undiluted liquid sample	36.0
Diluted gas	303.4 (gas) 30.0 (liquid)

CASP

Operation	Volume (cm^3)
Purge & Sampling	12.4

R1

Table 3-3: Dose Rates

GSP

Operation	Dose Rate (mrem/hr)
Purge	1907
Capture in-line flask	2532
Diluted or undiluted liquid sample	554.7
Diluted gas	331.6

CASP

Operation	Dose Rate (mrem/hr)
Purge & Sampling	15.6

R1

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Table 3-4: CSP Integrated Doses

Operation	Time in field (min)	Dose (mrem)	
Purge	5	158.9	
Capture in-line flask	3	126.6	
Strip gas	6	62.5	
Subtotal for initial operations		348	
To obtain undiluted or diluted liquid sample	5	46.2	R2
Total		394.2	R2
To obtain diluted gas	5	27.6	
Total		375.6	

Table 3-5: CASP Integrated Dose R1

Operation	Time in field (min)	Dose (mrem)
Purge	3	0.8
Sampling	1	0.3
	TOTAL	1.1

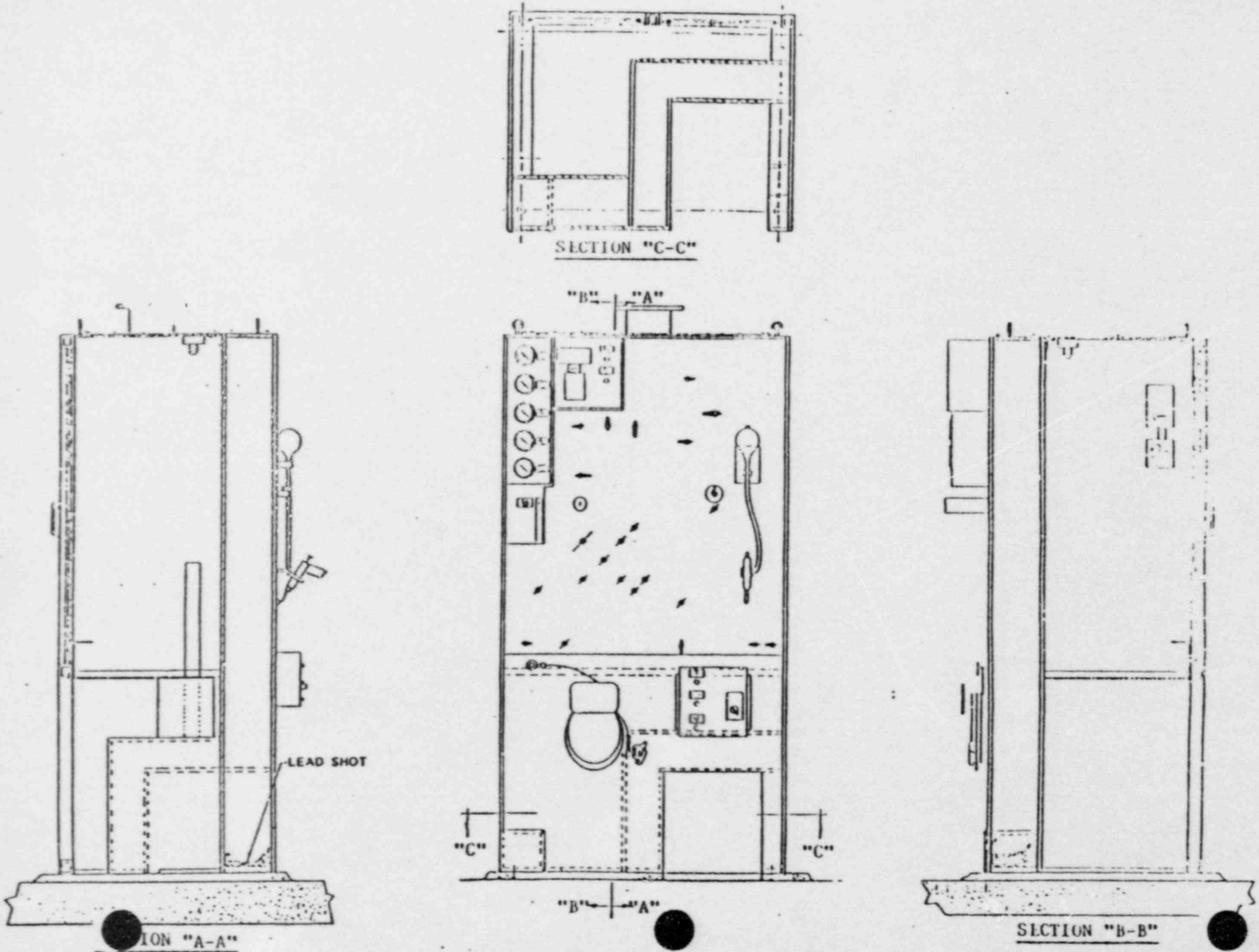


FIGURE 3-1

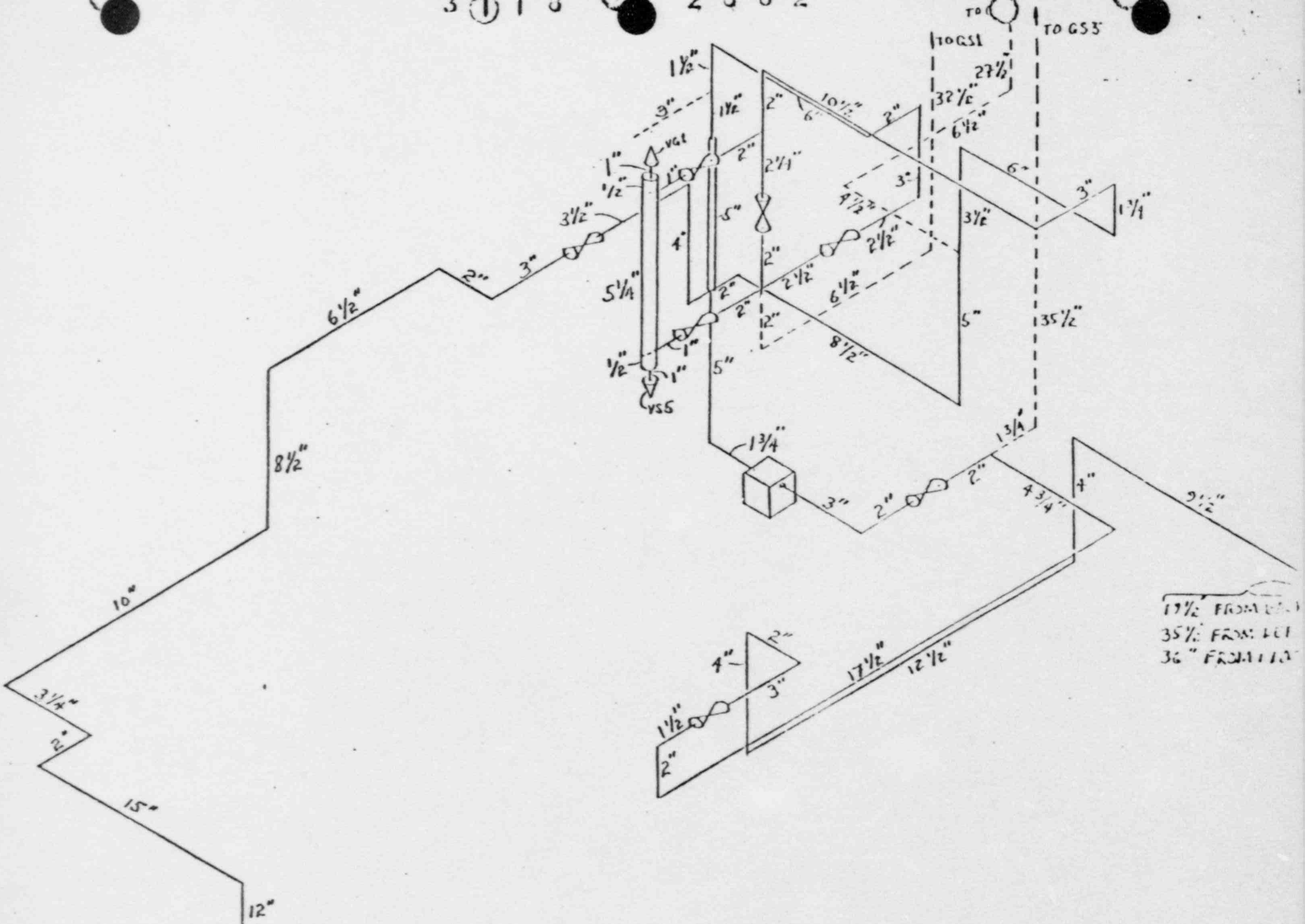


FIGURE 3-2

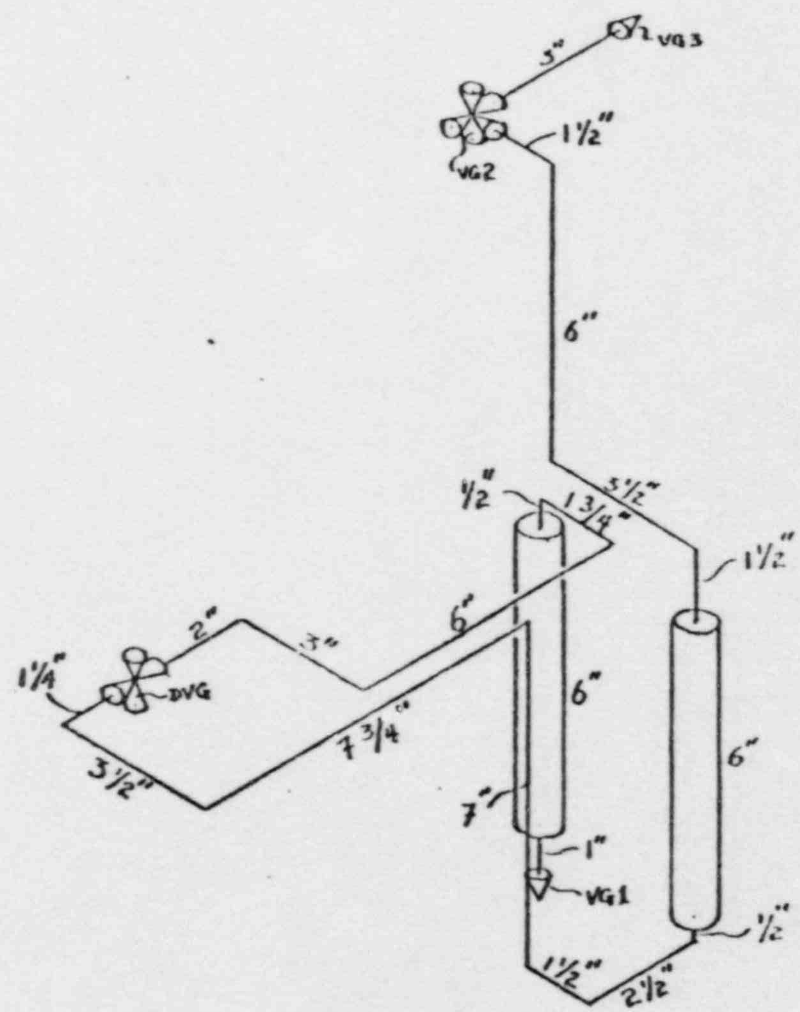


FIGURE 3-3

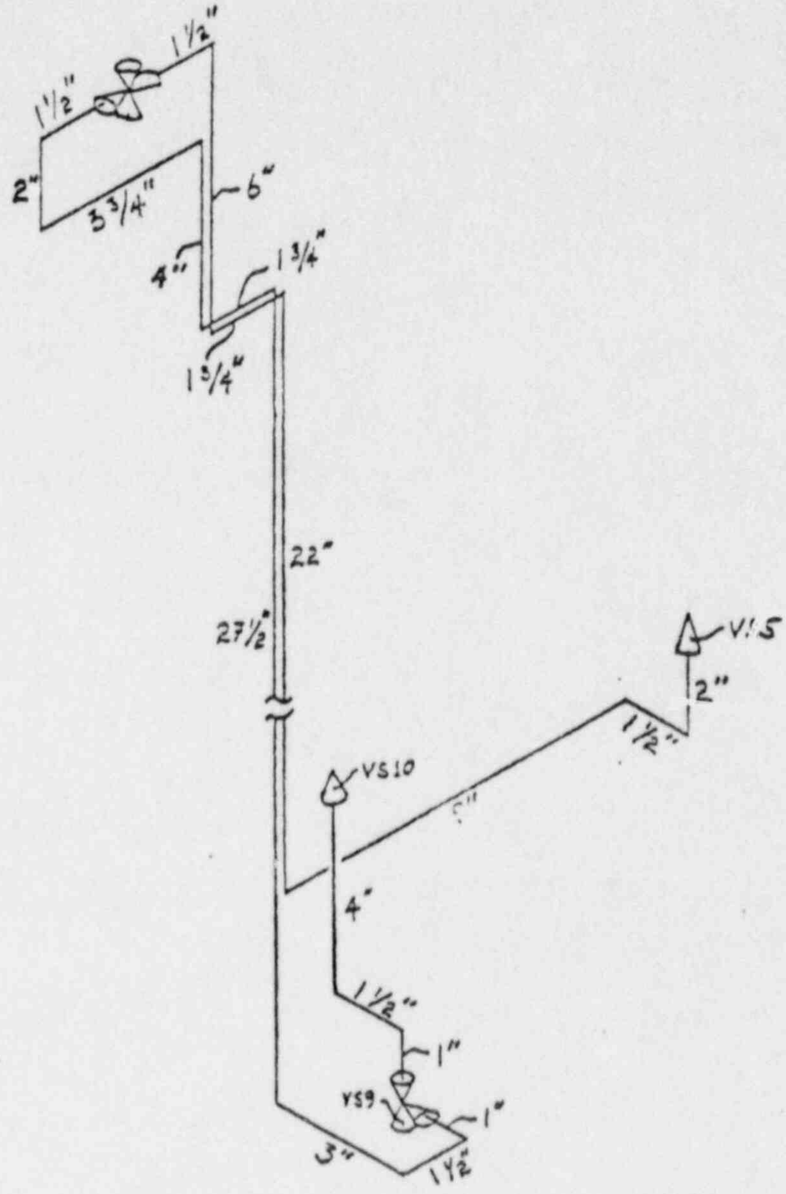
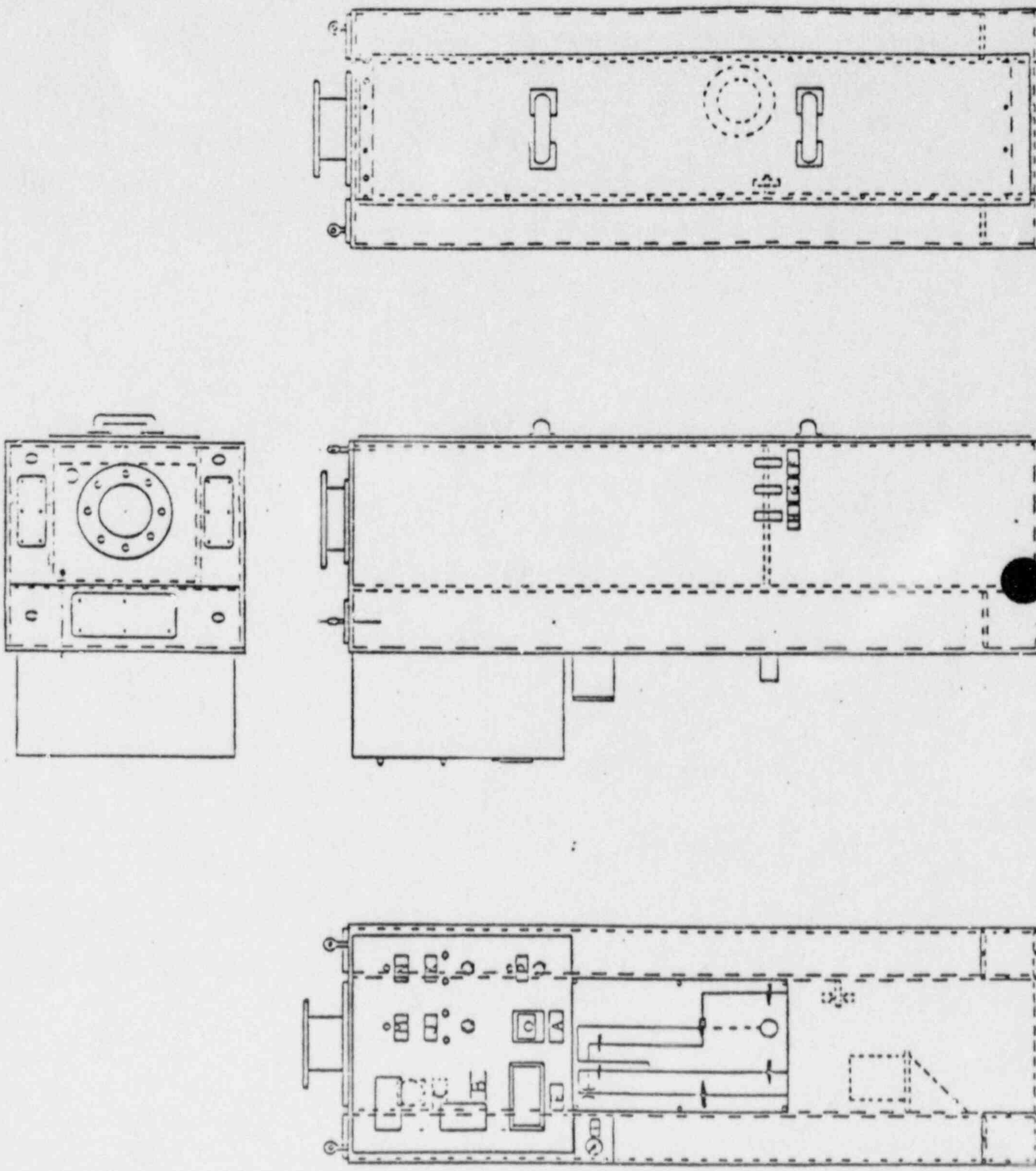
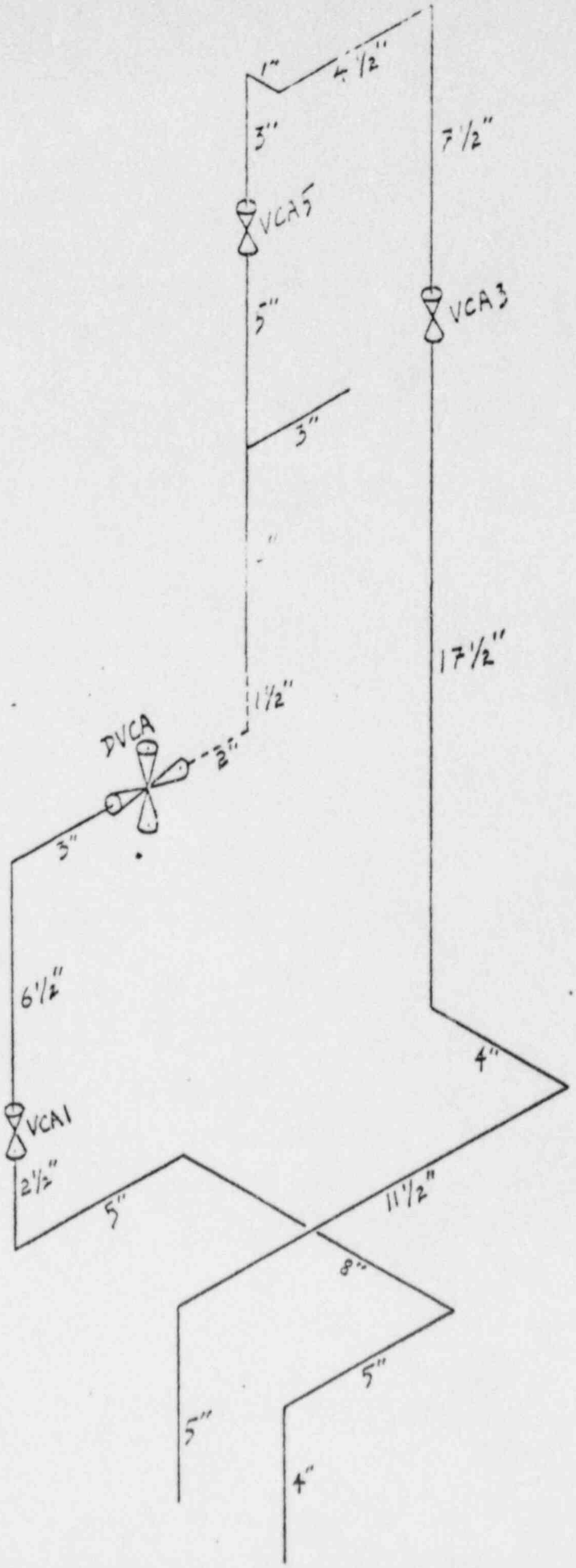


FIGURE 3-4

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DVCA
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6 1/2"
VCA1
2 1/2"
5"
4"
11 1/2"
8"
5"
5"
4"

FIGURE 3-6

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