SARGENT & LUNDY
ENGINEERS
CHICAGO

ATTACHMENT A

COMMONWEALTH EDISON COMPANY
Byron/Braidwood - Units 1 & 2
Project Nos.: 4391/4392/4683/4684

Moisture Content Analysis For The Air Stream At The Inlet To Auxiliary Building Ventilation Exhaust Charcoal Filters

Prepared by Sargent & Lundy
Chicago

I. Objective

The purpose of this report is to analytically prove that in the air stream entering the Auxiliary Building exhaust system charcoal filters, that:

A. There is no significant entrained moisture present

B. The relative humidity is less than 70 percent

II. Summary of Results

An analysis was performed based on postulated RHR Pump Seal leak of 50 gpm for a thirty minute duration and 1 gpm leak for 720 hours duration during a combined event of loss of coolant accident (LOCA) and loss of off-site power (LOOP) at which time the normal ventilation system is inoperable for two hours and partial ventilation is provided by booster fans in the Auxiliary Building exhaust charcoal filtration system. The details of the analysis are discussed in subsequent sections. The results of the analysis proved that there is no moisture entrainment in the air stream (Table 3) entering the charcoal filters of the Auxiliary Building exhaust system. The relative humidity of the air stream is found to be less than 51 percent (Table 1) for outside air temperatures ranging from 40 - 95°F at 90 percent relative humidity.

III. Input Information

A. Figure 1 is a sketch of the HVAC exhaust configuration for the two RHR pump cubicles for Unit 1. Unit 2's configuration is a mirror image of Unit 1's.

B. The HVAC system flow rates and heat loads for the LOCA plus LOOP scenerio are as given in Figures 2 and 3. These flow rates are due to the operation of the charcoal filter booster fans.

C. The following two cases of RHR pump seal leakage rates are evaluated for the worst case accident scenario of a postulated LOCA with coincidental LOOP for a period of two hours:

1. 50 gpm for a 30 minute duration

2. 1 gpm for a 720 hour duration

III. Input Information (Cont'd)

D. The RHR pump leakage fluid is primary coolant at 250°F. The RHR is placed in the recirculation mode thirty minutes after the LOCA. The sump water temperatures at that time correspond to the saturation temperature for the containment pressure.

E. A range of outside air (supply air) conditions are assessed for their effect on the relative humidity. An outside air relative humidity of 90 percent is used for temperatures from 40°F up to 95°F.

IV. Modeling Assumptions

A. The effects of the passive heat sinks and the area cooler in the effected RHR pump cubicle are not included in the assessment. This constitutes a major conservatism as these two mechanisms would be effective in removing both the flashed water vapor and water droplets. The area cooler will remove water vapor by condensation on its cooling coils and also water droplets due to its internal flow configuration.

B. One dimensional droplet coalescence in the RHR pump cubicle is conservatively assumed. The induced HVAC flow through the cubicle and the area cooler will produce significant mixing and turbulence in the cubicle's air space. Therefore, the actual coalescence process will be multi-dimensional and more effective in removing water droplets.

C. It is assumed that all the leakage that does not flash is removed from the pump cubicle by the floor drain system.

D. It is assumed that airflow mixes properly in the duct system.

V. Method of Analysis

A. Relative Humidity Assessment

The major source of water that can affect the charcoal filters is the RHR pump seal leakage. The leakage is saturated water at 250°F which enters the pump cubicle, which is at atmoshperic pressure. The leakage flashes to water and steam at 212°F. The fraction, x, which becomes steam is calculated from the following enthalpy balance:

A. Relative Humidity Assessment (Cont'd)

$$h_f \text{ @ } 250°F = (1-x)\ h_f \text{ @ } 212°F + x h_g \text{ @ } 212°F \qquad (1)$$

where: h_f @ 250°F = enthalpy of liquid leakage at 250°F
= 218.59 BTU/lb_m [1]

h_f @ 212°F = enthalpy of flashed liquid at 212°F
= 180.16 BTU/lb_m [1]

h_g @ 212°F = enthalpy of flashed vapor at 212°F
= 1150.5 BTU/lb_m [1]

Thus, the leakage flashes such that 4.0 percent becomes vapor and is exhausted from the pump cubicle by the ducted HVAC flow. The balance of the leakage is liquid water which is removed from the pump cubicle by the floor drain system. The flow diagrams shown in Figures 2 and 3 indicate the flow rates of the branches in this HVAC system. The relative humidity and temperature for each of the seven flow paths are calculated. The addition of heat and water vapor to each stream is included in the calculation. The leakage that flashes is the only source of additional moisture to that in the plant supply air.

The required mass and energy balances for each of the HVAC streams utilize the following expressions:

$$\log^{10}\left(\frac{P_{ws}}{218.167}\right) = \frac{-\beta}{T}\left(\frac{a+b\beta+c\beta^3}{1+d\beta}\right) \qquad (2)$$

where: P_{ws} = saturation pressure, atmosphere

β = 647.27-T

T = absolute temperature, Kelvin

a = 3.2437814

b = 5.86826×10^{-3}

c = 1.1702379×10^{-8}

d = 2.1878462×10^{-3}

A. Relative Humidity (Cont'd)

$$W = 0.62198 \frac{p_w}{p-p_w} \tag{3}$$

where: W = humidity ratio, lb_m vapor/lb_m dry air

p = total mixture pressure

p_w = partial pressure of water vapor

$$h = 0.24 + W\ (o.444t) \tag{4}$$

where: h = enthalpy of moist air, BTU/lb_m dry air

t = dry bulb temperature, °F

Two leakage rates (50 gpm and 1 gpm) are assessed and for each leakage rate a range of outside air temperatures (40 - 95°F) are assessed. The heating and dilution effects of merging the RHR pump cubicle exhaust stream (path 3) with the exhaust streams from the balance of the non-accessible areas (paths 4 and 6) on the relative humidity of the charcoal filter inlet stream (path 7) are quantified. The heating of these streams corresponds to the reduced heat load which applies for the LOCA plus LOOP scenario. The calculated relative humidity for path 7 does not allow for any water removal from the HVAC streams such that the entire quantity of leakage which flashes is included in the charcoal inlet stream. The calculated relative humidities are then compared to the upper bound limit of 70 percent.

B. Entrained Leakage Assessment

Sensible moisture, i.e. water droplets, may be formed in the RHR pump cubicle or its ducted exhaust. The water droplets may be entrained by the airflow and thereby transported as droplets (instead of vapor) to the charcoal filter inlet stream. The inherent moisture (vapor and droplet) separation capability of the existing HVAC configuration is investigated.

Initially, the flashed water vapor in the RHR pump cubicle produces super saturated air such that water droplets will form in the cubicle air space at suitable nucleation sites (such as dust in the room air). The drops will interact with each other such that they will collide and coalesce into larger drops. The coalescence process is modeled by using the SPIRT computer code (2) which was developed by

B. Entrained Leakage Assessment (Cont'd)

the NRC for evaluating the performance of containment spray systems. A distribution of drop sizes, their number densities, and their terminal velocities is calculated by SPIRT. The ducted exhaust from the RHR pump cubicle induces a flow through the cubicle and up to the screened inlet to the exhaust duct. The ability of the induced cubicle flow to entrain water droplets is determined by applying Stokes' Law (4) to the droplet motion. Stokes' Law states that the drag force (F_D) on the small droplets is given by the following:

$$F_D = \begin{Bmatrix} \text{drag} \\ \text{force} \end{Bmatrix} = 3\pi\mu u D_p \tag{5}$$

where: μ = viscosity of gas stream

u = velocity of droplet

D_p = diameter of particle or droplet

The droplets terminal velocity is calculated by equating the drag force to the gravitational force on the droplet:

$$3\pi\mu u_t D_p = \frac{\pi}{6} D_p^3 (\rho_L - \rho_g) g \tag{6}$$

This equation is solved for the droplet diameter in terms of the droplets terminal velocity:

$$D_p = \sqrt{\frac{18\mu u_t}{g(\rho_L - \rho_g)}} \tag{7}$$

where: u_t = terminal velocity of droplet

g = acceleration due to gravity

ρ_L = density of liquid droplet

ρ_g = density of gas stream

Droplets with a diameter greater than D_p will not be entrained and will not be removed from the cubicle air space by the ducted exhaust flow.

The initial size and number of the droplets formed by condensation at the different nucleation sites is uncertain. In order to address this uncertainty, a sensitivity study is made on the amount of flashed leakage which condenses into droplets. These results are used to estimate the

B. Entrained Leakage Assessment (Cont'd)

amount of flashed liquid which is removed as condensate (i.e., is collected on surfaces in the cubicle, and flows to the floor drain).

The water that leaves the RHR pump cubicle and enters the HVAC duct may be in the form of droplets or vapor. The exhaust stream is warm and as it cools in the duct the vapor is condensed. The water that condenses on the duct walls or other internal surfaces collects there and is removed from the air stream. However, the vapor that condenses within the air stream will form droplets which will join those droplets already entrained in the flow. The configuration of the HVAC ducts is reviewed to identify mechanisms which will remove entrained water droplets.

The entrained droplets which are removed from the air stream and the vapor which condenses on the internal surfaces will collect in the duct system as liquid water. The water could be removed by evaporation, by leaking from the ducts, or by re-entrainment caused by the airflow past it. Evaporation is addressed by the method described in the previous subsection. Re-entrainment could negate the ducts inherent capability to separate water droplets from the air stream. Re-entrainment for air-water systems requires an air stream velocity of 50-75 fps (4). The air velocity in the RHR pump cubicle exhaust ducts and the ducts which it merges into are calculated based on their volumetric flow rates and cross-sectional areas. The duct velocities are compared to the required re-entrainment velocity to determine if re-entrainment will occur.

VI. Discussion of Results

A. Relative Humidity Calculation

The results of this calculation are summarized in Table 1 for both the 50 gpm and 1 gpm leakage cases. The results show that for the entire range of outside air conditions that the relative humidity of the charcoal filter inlet stream is less than the upper bound limit of 70 percent. Thus, the assumed radionuclide removal efficiencies do not need to be reduced due to postulated high relative humidity effects. The exhaust stream from the affected RHR pump cubicle (path 3) was found to be super saturated for both leakage flows. The mixing of this stream with unsaturated and relatively cooler streams produces a final stream which has less than 70 percent relative humidity. This is the case even for the conservative assumptions used in this calculation. The calculation did

A. Relative Humidity Calculation (Cont'd)

not allow for water removal in the pump cubicle or ducts except for the initially unflashed leakage liquid. Pump cubicle heat and mass removal would result from passive heat sinks (walls and internal obstructions) and from the active area cooler which starts automatically when the RHR pump starts.

B. Entrained Leakage Evaluation

The results of the droplet coalescence parameterization study are summarized in Table 2. The SPIRT code was used to quantify the amount of drop coalescence for a range of initial mean droplet diameters (5 to 30 μm) and "pseudo" spray flow rates which relates to the number density of drops in the room. Droplets form at available nucleation sites such as dust particles. Typical dust particles range in size from about 1 to 100 (7) microns. The low end of the range was selected for the parameterization study since larger droplets would not be entrained by the HVAC flow. The after coalescence number density of a set of 50 droplet sizes was calculated. This result was converted into the corresponding volume of droplets for each of the 50 droplets sizes in the distribution. On this volumetric basis the fraction of the total droplet volume represented by the drop volume of each drop size is calculated. A "running" sum starting with the smallest drop size group is calculated to produce the integrated volumetric droplet fraction as a function of droplet size. Figure 4 is a plot of the result which was obtained for this function for the case of an initial mean drop diameter of 5μm and assuming that 10 percent of the flashed leakage has condensed to form droplets. This set of functions was reviewed and the maximum droplet size entrained by the estimated average room velocity (i.e. 27μm) was used to determine the fraction of coalesced drops with diameters equal to or less than this diameter.

Since the basic issue is an estimate of the amount or mass of water droplets which exit the RHR pump cubicle, the volume fractions rather than the number fraction has been used. For this problem the density of the water droplets is taken as a constant and so the volume fraction of droplets is the same as the mass fraction. These volume fractions define the fraction of droplets which would be removed from the pump cubicle by the HVAC exhaust stream for that given initial mean droplet size. Table 2 shows that for the 50 gpm leakage case that as the initial drop diameter increases for each given condensation fraction, the amount of entrained droplets in the exhaust stream decreases. Also, as the condensation fraction increases, the amount of

B. Entrained Leakage Evaluation (Cont'd)

entrained droplets decreases. For the 1 gpm leakage case, only the dependence on initial drop diameter is observed. For both leakage rates, droplet formation and coalescence in the pump cubicle is an effective mechanism for significantly reducing the amount of leakage which leaves the pump cubicle. The coalescence removal mechanisms will also continue to be operative in the exhaust duct.

The droplets in the HVAC ducts are subjected to several other removal mechanisms due to the existing duct configuration. The exhaust duct from each RHR cubicle consists of a horizontal run of about 105 feet of duct on the same floor (346' elevation) as the RHR pump cubicle before leaving the floor by a vertical duct. The horizontal run is sufficiently long that gravity and turbulent impaction will cause separation of water droplets from the flowing stream.

Additionally, the exhaust duct arrangement in the plant requires from 10 to 18 elbows (5) in its routing depending upon which RHR pump cubicle is assumed to have the leaking seal. Each elbow has turning vanes in it so that the elbow and turning vanes function to remove entrained moisture droplets by centrifugal separation. The Stokes' Law equation (Equation 7 above) was modified to assess the ability of the elbows and turning vanes to separate entrained water droplets. This was accomplished by replacing the gravitational acceleration (g) in Equation 7 by the centrifugal acceleration:

$$v^2/r = \text{centrifugal acceleration} \qquad (8)$$

where: v = linear velocity in duct

r = radius of elbow or turning vane

The revised equation was used to assess the various elbows which are in the duct system and to estimate the fraction of each droplet size or group that could be separated from the flow by each elbow. Thus, settling due to gravity in the straight run of duct approaching each elbow is calculated by applying Equation 7 and separation in each elbow is calculated by substituting Equation 8 into Equation 7. The entire duct system for each RHR pump cubicle starting at the exhaust duct inlet and continuing to the inlet of the mixing plenums upstream of the charcoal filters is treated by this technique. This process is applied for each droplet diameter group equal to or less than 27μm. The result is the mass of water droplets remaining in the exhaust stream for each droplet diameter group. Figures 5

B. Entrained Leakage Evaluation (Cont'd)

and 6 present the distribution of these droplets in terms of the fraction of the total water droplet mass in the stream as a function of droplet diameter. The worst 50 gpm leakage case results in 21.6 and 20.2 pounds per hour (pump rooms 1A and 1B, respectively) of entrained water droplets in the inlet stream to the charcoal filters for the one half hour accident duration. The worst 1 gpm leakage case results in 0.95 and 0.85 pounds per hour (pump rooms 1A and 1B, respectively) of entrained water droplets in the inlet stream to the charcoal filters for the 720 hour accident duration.

Futhermore, the exhaust duct for each cubicle contains a balancing damper which provides additional surface area for droplet impingement and removal. Thus the physical configuration of the existing duct system provides an inherent mechanism for moisture separation.

The ducted flow rate is high enough that the flow is turbulent. The flow turbulence provides another mechanism for droplet deposition within the duct system. The radial velocity fluctuations produced in the turbulent flow cause droplets to migrate toward the duct walls. This removal mechanism results from another physical phenomenon which is inherent in the duct design and applies for both horizontal and vertical ducts.

Once the water droplets have been separated from the air stream, they will collect on the internal duct surfaces. As air continues to flow past these surfaces, the re-entrainment of the collected moisture as dispersed droplets is a possibility that must be considered. A re-entrainment velocity of the order of 70 fps (4) (i.e. 4200 fpm) is required for an air stream flowing over a surface wetted with water. Table 3 displays the air stream velocities that are developed in the RHR pump cubicle exhaust ducts. The last column in Table 3 compares the duct velocities to the re-entrainment velocity. This shows that even in the duct having the highest velocity, that velocity does not exceed 43 percent of that required for re-entrainment of water wetting the duct wall. Consequently, it is concluded that the duct velocities are too low to cause re-entrainment of separated moisture.

Lastly, any water droplets which may remain in the inlet stream of the mixing plenum are directed into the filtering system which is located upstream of the charcoal filters.

B. Entrained Leakage Evaluation (Cont'd)

The filtering system includes HEPA filters which have a removal efficiency of 99.97 percent for particles of 0.3μm and larger (9). The HEPA filters will cause any remaining water droplets (which range between 1 and 27μm) to be absorbed by the filters (which then vaporize off) and thus the charcoal filter will only be exposed to water vapor and not entrained water droplets.

VII. Conclusion

The assessment of the effect of RHR pump seal leakage on the moisture content of the charcoal filter inlet stream demonstrates that the existing system configuration can accommodate such leakage without allowing an excessively high moisture content in the inlet stream. The dilution of the super saturated stream from the affected RHR pump cubicle by the joining (relatively drier) air streams is sufficient to insure that the inlet stream's relative humidity of less than 70 percent.

Additionally, the physical arrangement of the HVAC system provides several inherent means of moisture separation. Multiple phenomena are present and effective in removing entrained water droplets. These include the mechanical processes of centrifugal action, turbulence, coalescence and gravity and the thermal process of condensation on the duct walls. These results have been obtained even when the effects of the cubicle cooler have conservatively been ignored. The operation of the RHR pump room cooler (whose recirculation flow rate is ten times the HVAC flow rate through the cubicle) will mix the room's atmosphere and, thereby, enhance the droplet coalescence mechanism. Furthermore, the cooling coil in the cubicle cooler will remove both heat and water vapor (by condensation) from the pump cubicle. The vapor removed from the cubicle atmosphere is directed to the drain system, and, hence, is removed from the air space.

REFERENCES

1. Steam Tables, J. H. Keenan, F. G. Keyes; John Wiley and Sons, Inc., 1969.

2. NUREG/CR-0009, "Technological Bases for Models of Spray Wash-out of Airborne Contaminants in Containment Vessels," October, 1978.

3. Chemical Engineers' Handbook, ed. J. H. Perry, 4th Edition, 1963, p. 18-83.

4. EPRI CS-2520, "Entrainment in Wet Stacks," Final Report, August, 1982, p.4-27.

5. Sargent & Lundy Drawings:

   Byron 4391/4392 and Braidwood 4683/4684 (latest revision)

   a) M-11
   b) M-216, sheet 2 of 2
   c) M-217, sheet 1 of 2
   d) M-218, sheet 1 of 2
   e) M-315, sheet 1 of 2
   f) M-324
   g) M-343, sheet 1 of 1
   h) M-1310, sheet 1, 9, and 10
   i) M-1311, sheet 1
   j) M-1313, sheet 1 and 2
   k) M-1314, sheet 6
   l) M-1315, sheet 1

6. Byron/Braidwood FSAR, Vol. 7, p. 3.8-1, Amendment #42, 05-31-83.

7. Chemical Engineers' Handbook, ed. J. H. Perry, 4th Edition, 1963, p. 20-66.

8. ASHRAE Handbook of Fundamentals, Chapter 5 (Equations 6, 22 and 32), 1977.

9. ANSI N510, 1980.

TABLE 1

CALCULATED RELATIVE HUMIDITY FOR CHARCOAL FILTER INLET STREAM

Outside Air* Temperature (^{o}F)	RELATIVE HUMIDITY (fraction) 50 gpm Leak Rate	1 gpm Leak Rate
95	0.430	0.407
90	0.430	0.403
85	0.431	0.399
80	0.433	0.395
75	0.435	0.391
70	0.439	0.387
65	0.445	0.383
60	0.452	0.379
55	0.462	0.376
50	0.474	0.372
45	0.490	0.368
40	0.510	0.364

* 90% Relative Humidity

NOTE: The relative humidity trend for decreasing outside air temperature is different for the two leakage rates. The low (1 gpm) leakage rate trend is controlled by the mixing with the downstream flows. The high (50 gpm) leakage rate is so great that this case's trend is reversed by the degree of super saturation experienced by RHR cubicle exhaust stream.

TABLE 2

ESTIMATED DROPLET ENTRAINMENT

FRACTION EXITING CUBICLE

Percent* of Steam Condensed into Droplets	Initial Mean Droplet Diameter (μm) 5	10	20	30
Case A): 50 gpm Leakage				
1%	0.65**	0.30	0.087	0.034
10%	0.47	0.22	0.079	0.032
50%	-	0.09	0.050	0.022
Case B): 1 gpm Leakage				
1%	0.66	0.31	0.088	0.035
10%	0.66	0.31	0.088	0.035
50%	-	0.30	0.087	0.034

*Percent of leakage which as flashed to steam and then condensed in the pump cubicle to form droplets.

**Volume fraction or mass fraction of coalesced droplets (with diameters ≤ 27 μm) which are removed in exhaust steam. This represents the mass fraction of the water droplets that exit the pump cubicle.

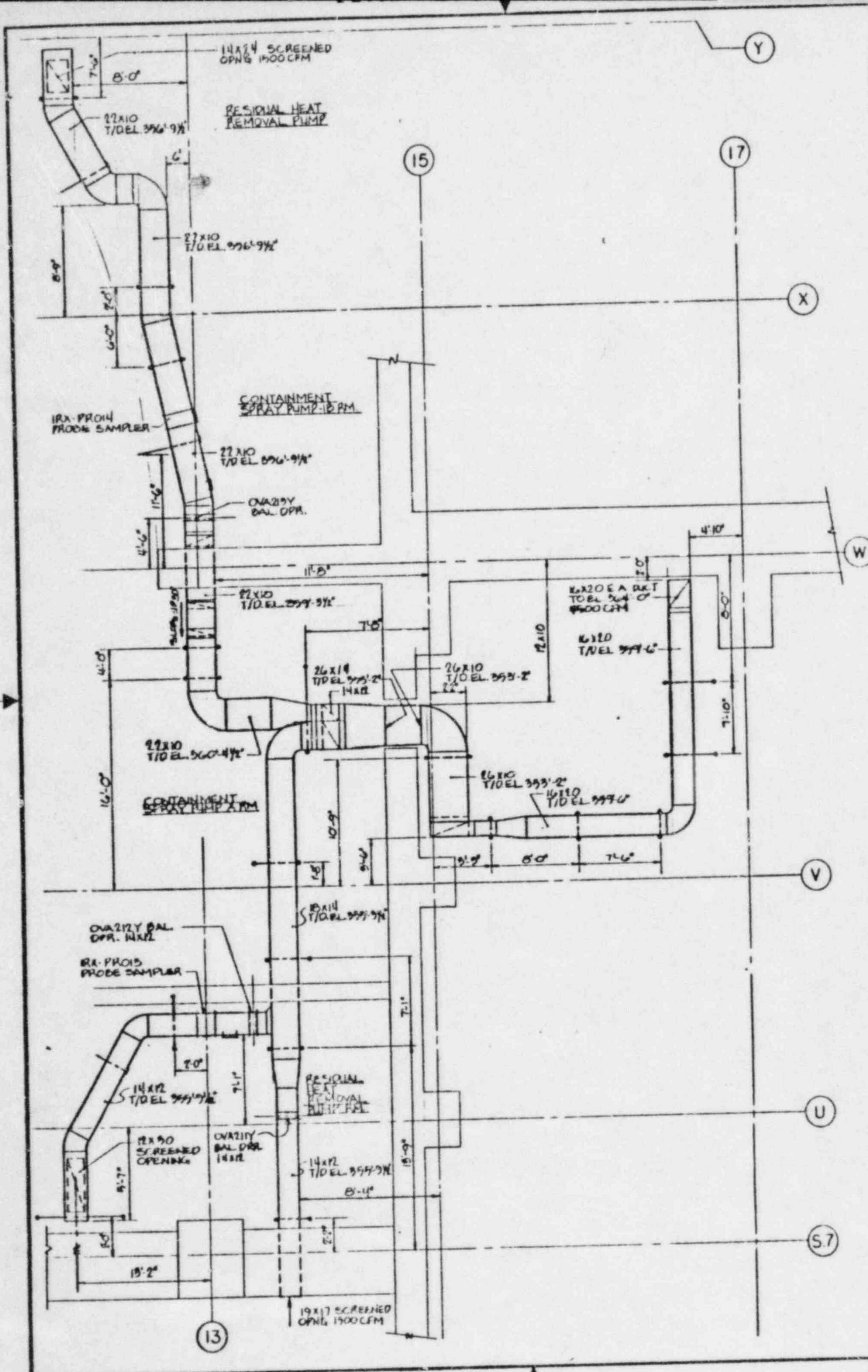
TABLE 3

EXHAUST DUCT VELOCITIES

DUCT SIZE (in x in)*	CROSS-SECTIONAL AREA (ft^2)	FLOW RATE (CFM)	VELOCITY (FPS)	$\frac{\text{VELOCITY}}{V_{re}}$
22 x 10	1.53	1076	11.7	0.17
26 x 10	1.81	3228	29.9	0.43
16 x 20	2.22	3228	24.2	0.34
18 x 14	1.75	2152	20.5	0.29
14 x 12	1.17	1076	15.4	0.22

* (Width x Height)

V_{re} = re-entrainment velocity = 70 FPS


14X14 SCREENED OPNG 1500 CFM
RESIDUAL HEAT REMOVAL PUMP
CONTAINMENT SPRAY PUMP
IRX-PR014 PROBE SAMPLER
IRX-PR013 PROBE SAMPLER
CONTAINMENT SPRAY PUMP RM
12X30 SCREENED OPENING
19X17 SCREENED OPNG 1500 CFM
RESIDUAL HEAT REMOVAL PUMP
Y
X
W
V
U
S.7
13
15
17

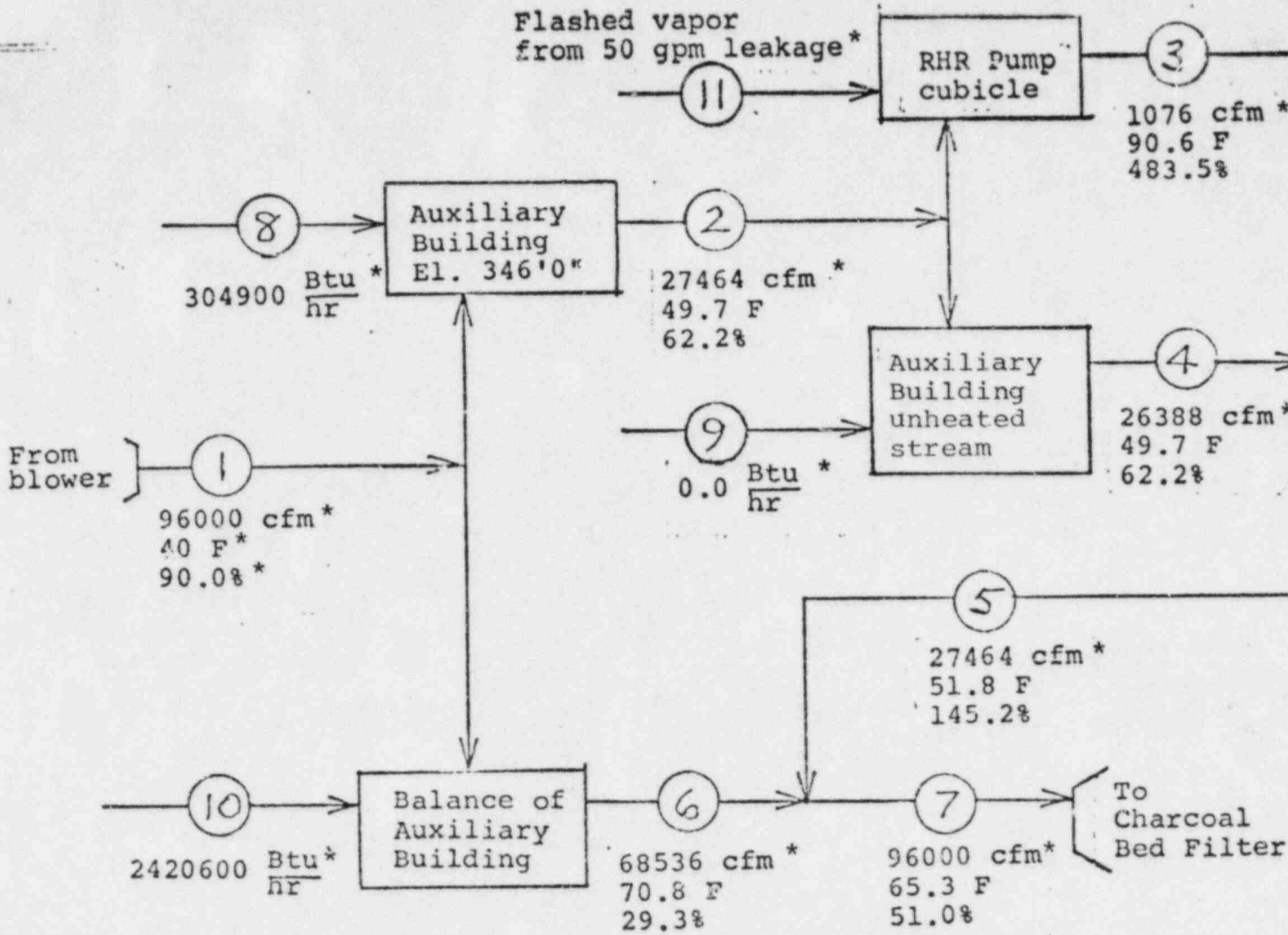


FIGURE 2: Case from Table 1 with Highest Relative Humidity

*These quantities are input data and all the remaining temperatures and relative humidities were calculated as described in Section V.

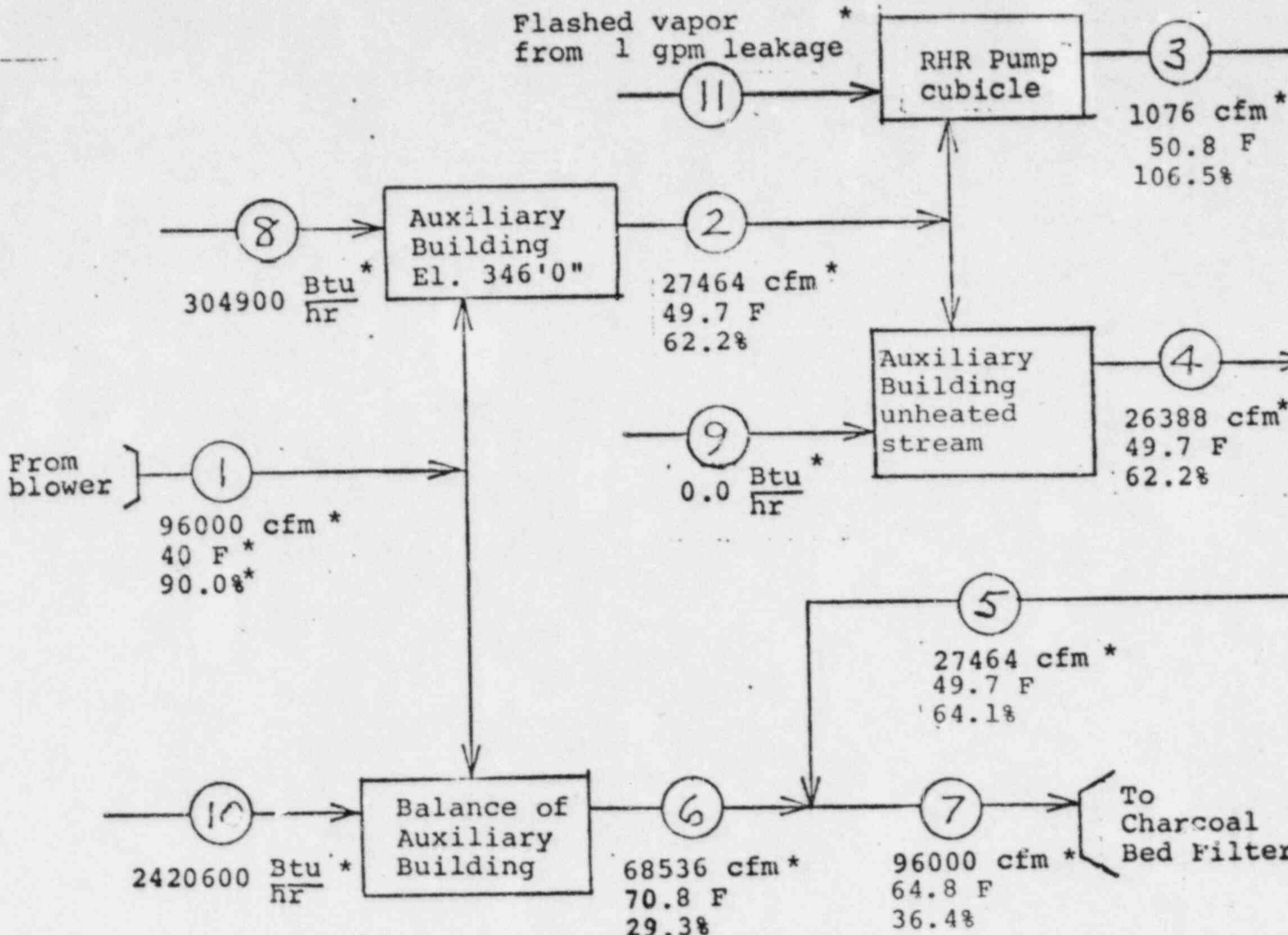


FIGURE 3: Case from Table 1 with Lowest Relative Humidity

*These quantities are input data and all the remaining temperatures and relative humidities were calculated as described in Section V.

FIGURE 4

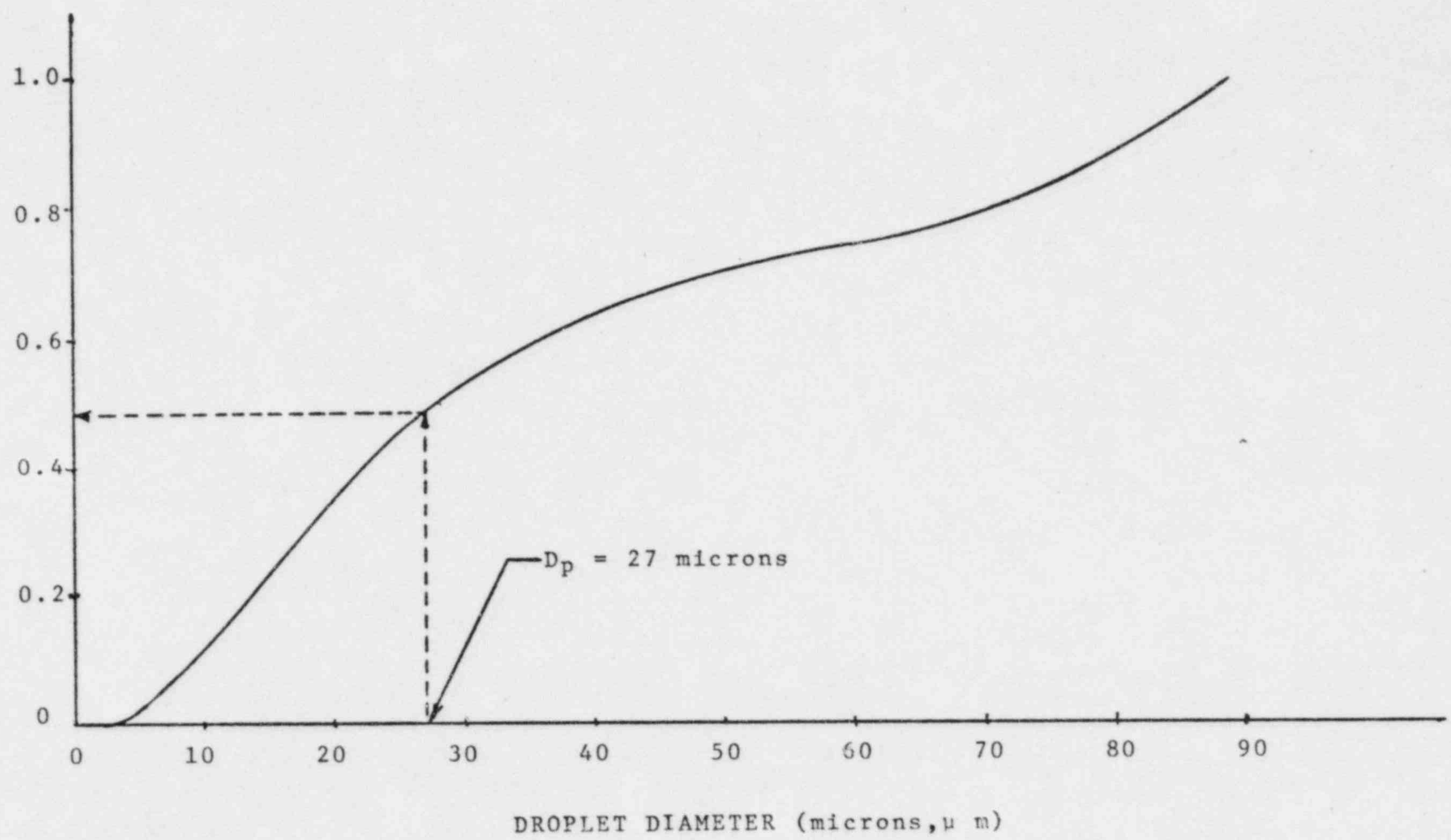

1.0
0.8
0.6
0.4
0.2
0
0
10
20
30
40
50
60
70
80
90
D_p = 27 microns
DROPLET DIAMETER (microns, μ m)

FIGURE 5 DISTRIBUTION OF DROPLET SIZES AT THE PLENUM INLET FOR 50gpm LEAKAGE CASE

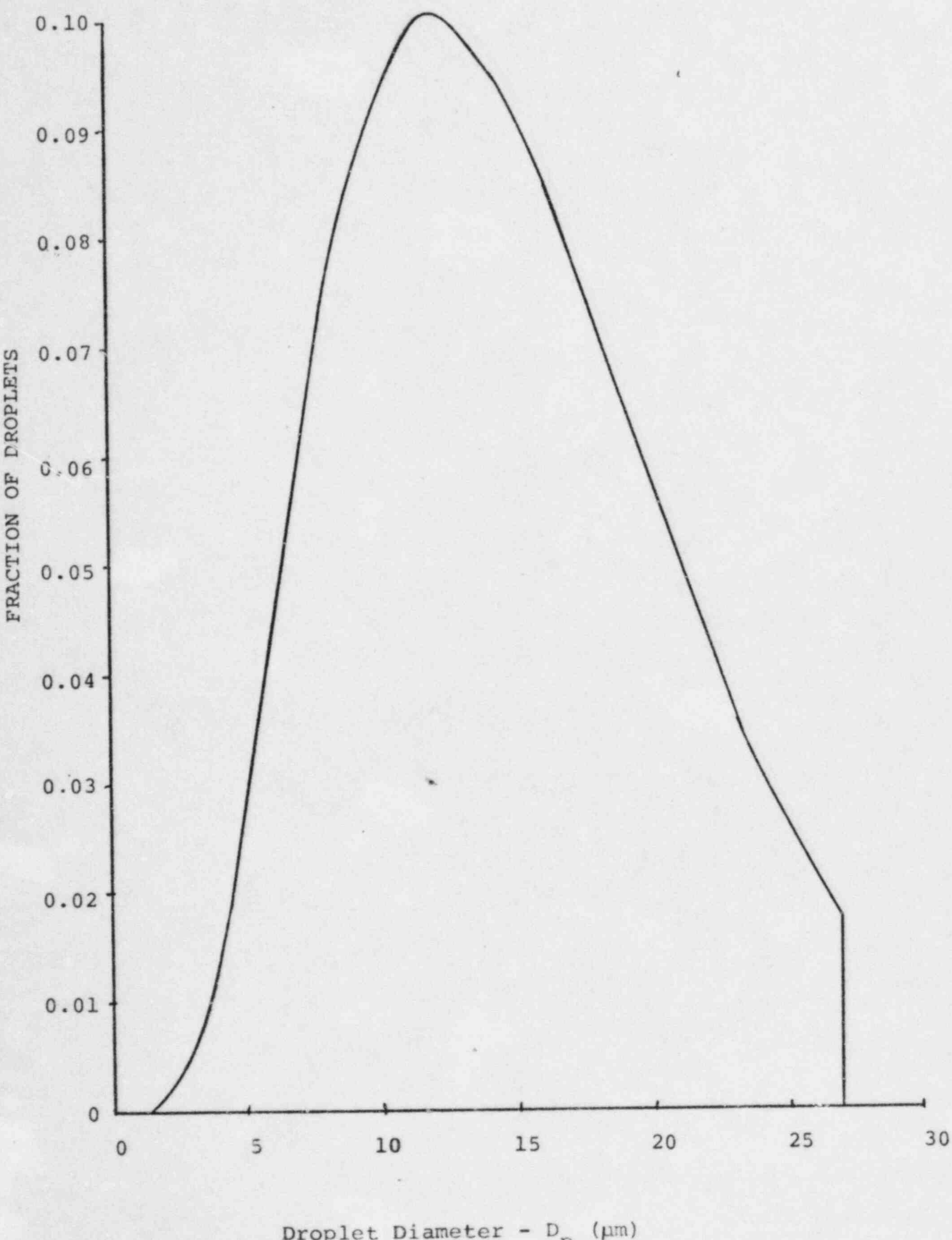
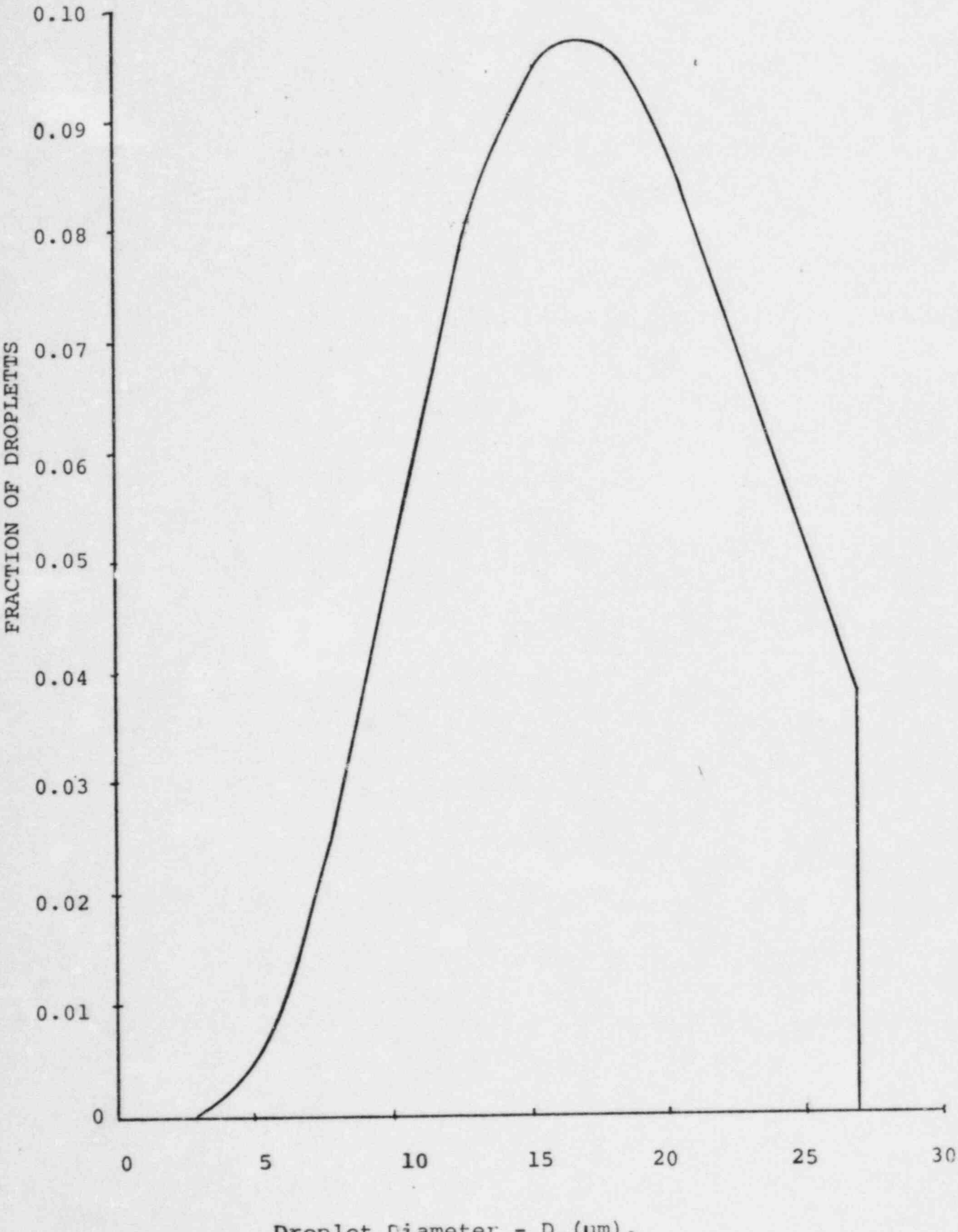


FIGURE 6 DISTRIBUTION OF DROPLET SIZES AT THE PLENUM INLET FOR 1gpm LEAKAGE CASE



NRC QUESTIONS REGARDING

THIS ANALYSIS

QUESTION 1 Some of the flow rates assumed in your analysis (for example, 1076 cfm from the RHR pump cubicle and 26,000 cfm to the charcoal bed filter) do not agree with the FSAR. We understand that this is because the FSAR does not reflect flow rates during accident conditions. If this is so, revise the FSAR to include a discussion which differentiates between the normal operating modes and operation during accident conditions.

Response: FSAR Section 9.4.5.1.1a(1) identifies the Auxiliary Building HVAC System operating modes during normal plant operation and for the two hour period following a postulated loss-of-coolant accident (LOCA) coincident with a loss-of-offsite power (LOOP). The flow rates used in the Moisture Content Analysis for the air stream at the inlet to the Auxiliary Building charcoal filters are those flow rates associated with the system operation during the two hours following a LOCA and LOOP. These values were used since the mixing and dilution is less in this mode of operation. The cubicle flow rate during normal plant operation in the residual heat removal (RHR) cubicle is 39.4% greater than during the accident flow case. The reduction in accident flow is already discussed in FSAR Section 9.5.4.1.1a(7).

QUESTION 2 Paragraph IV.C of the analysis stated that it is assumed that all the leakage that does not flash is removed from the pump cubicle by the floor drain system. We believe this assumption is non-conservative. Revise the analysis to include a conservative assumption for vapor from a seal failure (e.g. 20%)

Response: In paragraph IV.A of the analysis, it is stated that the moisture removal capability of the area cooler in the affected RHR pump cubicle is conservatively not included in the analysis. The conservatism associated with this assumption offsets the non-conservatism suggested in the Nuclear Regulatory Commission's (NRC's) question. The reported analysis only considered the fraction of leakage that flashed (4%) as being suspended in the cubicle air space. As this is the thermodynamic bounding value, it is inferred that the 20% value suggested by the NRC includes both leakage flashing and "spray" from the failed seal. Even if a failed seal could produce this amount of spray, the cubicle's area cooler would effectively remove most of the moisture from the air space. The area cooler flow rate is 10,154 cfm, and the ventilation flow rate through the pump cubicle is 1076 cfm. This is a 9 to 1 ratio. The area cooler suction and exhaust are located between the pump cubicle's HVAC supply and ducted exhaust. This configuration avoids "short circuiting" of the moisture in ventilation and area cooler airflows. The area cooler functions as a highly efficient moisture separator, and coupled with the 9 to 1 flow ratio, it will remove about 90% of the moisture (droplets) that enter the room air space.

QUESTION 2
Response
(Cont'd)

This can be demonstrated by performing a mass balance on the moisture in the RHR pump cubicle (see Equation 1).

$$W_{W1} + H_2 W_{A2} = H_1 W_{A1} + H_1 W_{A2} \qquad (1)$$

Where:

W_{W1} = moisture formation rate in RHR pump cubicle, lb_m moisture/hr.

W_{A1} = airflow rate in RHR pump cubicle due to ventilation system, lb_m air/hr.

W_{A2} = air flow rate in RHR pump cubicle due to area cooler, lb_m air/hr.

H_1 = moisture content in RHR pump cubicle air space, lb_m moisture/lb_m air.

H_2 = moisture content in RHR pump cubicle area cooler exhaust stream, lb_m moisture/lb_m air.

In general, let F be the fraction of moisture removed by the area cooler, and let R be the ratio of the air flow rates due to the area cooler and ventilation system.

$$F = H_2/H_1$$

$$R = W_{A2}/W_{A1}$$

Equation 1 can be rearranged to yield a general expression for the moisture content in the RHR pump cubicle air space,

$$H_1 = \frac{W_{W1}/W_{A1}}{1 + R(1-F)} \qquad (2)$$

For the special case of no area cooler flow (as conservatively assumed in the reported calculation), R equals zero, and Equation 2 reduces to:

$$H_1/_{R=0} = W_{W1}/W_{A1} \qquad (3)$$

Equation 2 divided by Equation 3 yields an expression for assessing the effectiveness of the area cooler as a moisture removal mechanism. Specifically, the fraction of the moisture from the seal leakage that exits the pump cubicle is given by:

$$\frac{H_1}{H_1/_{R=0}} = \frac{1}{1+R(1-F)} \qquad (4)$$

QUESTION 2
Response (Cont'd)

Figure 2-1 displays Equation 4 as a function of F, the area cooler removal fraction, and for a value of R=9 (10,154 cfm/1076 cfm).

Due to the internal configuration of the area cooler, all of the entrained moisture in its inlet stream is removed. Therefore, F is taken as zero (i.e., H_2 = 0), and Equation 4 states that only 10% of the seal failure moisture exits the RHR pump cubicle.

Additionally, the area cooler will condense water vapor and remove moisture by that mechanism as well. Thus, if 90% of the moisture is removed, then only 2% of the 20% suggested in Question 2 would remain. This is less than the 4% used in the reported analysis.

Another aspect of the suggested 20% vapor assumption involves an additional removal mechanism, i.e., spray coalescence. By increasing the number density of the spray drops and realizing that the area cooler will ensure the existence of significant turbulence levels in the RHR pump cubicle, it is observed that coalescence due to gravity and turbulence would be greatly enhanced. It is concluded that the reported analysis includes sufficient conservatism to address the suggested 20% vapor assumption.

QUESTION 3

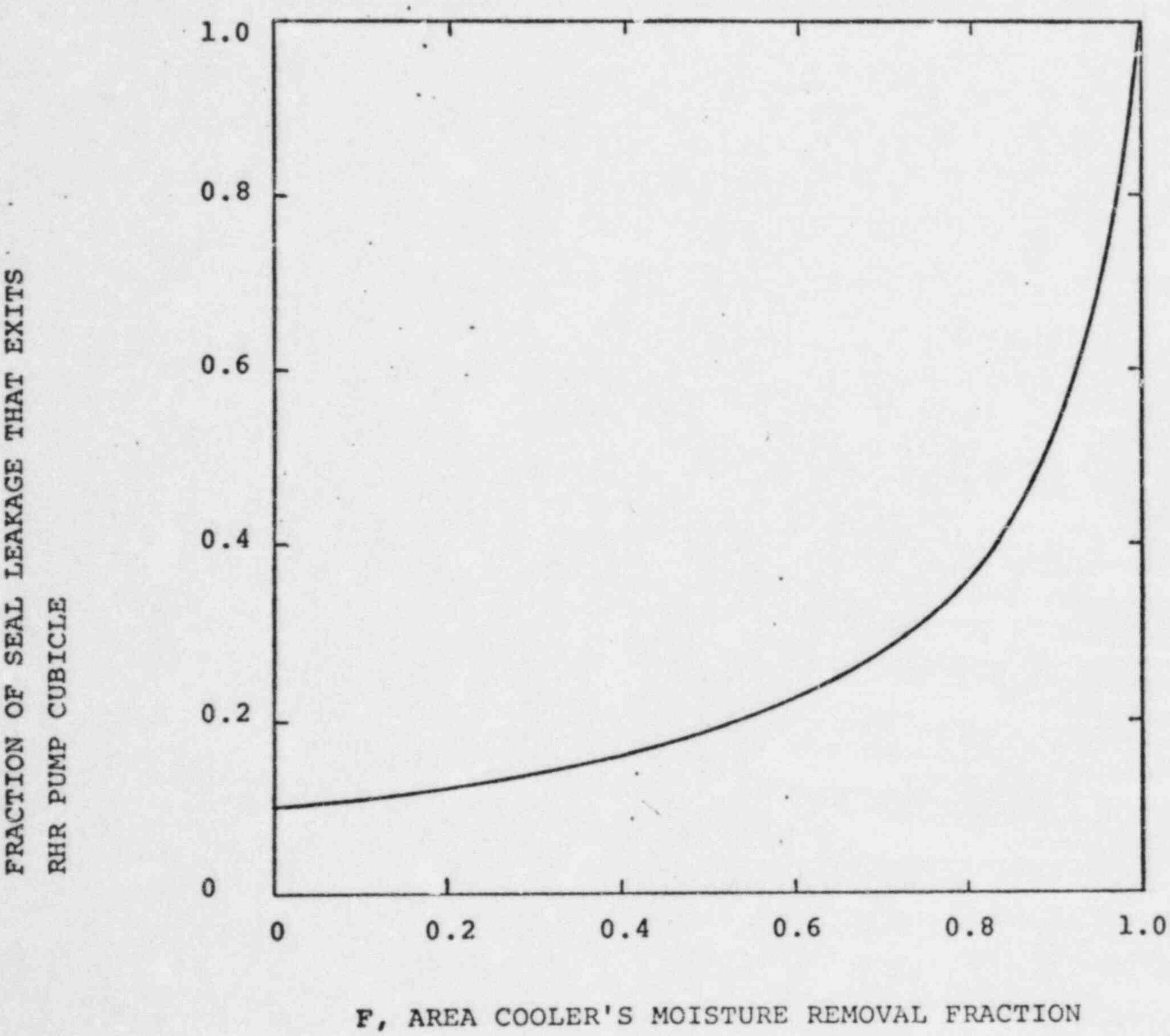
If, as a result of incorporating the comments in Question 2, you decide to include the effects of the area cooler, additional information concerning the cooler and its orientation with respect to the exhaust duct must be provided.

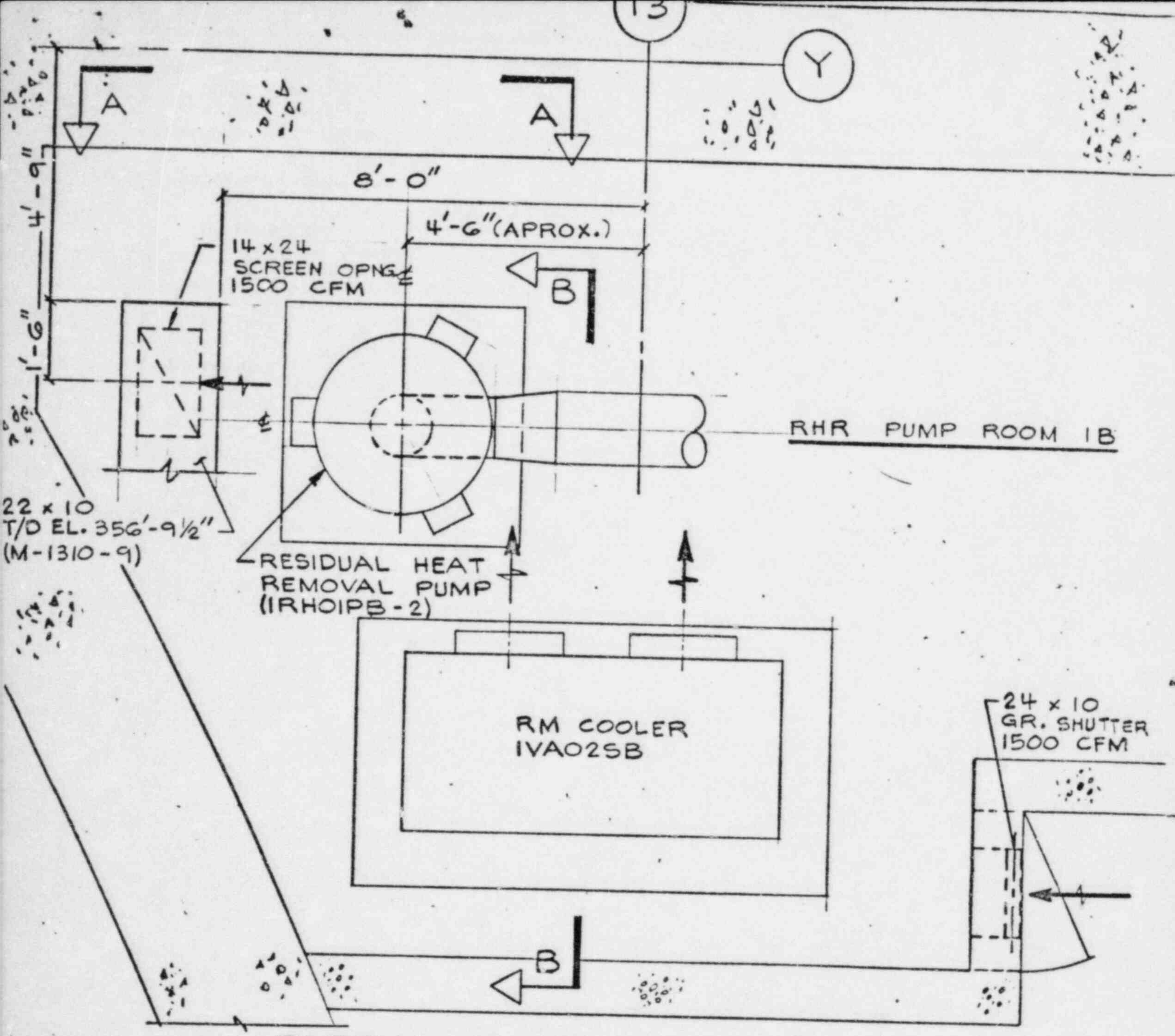
Response:

The attached sketches describe the location of the cubicle area cooler's suction and exhaust, the location of the ventilation exhaust inlet and the RHR pump and motor configuration. The proposed seal leakage would be at least 7'-9" away from the ventilation exhaust duct simply due to the elevation difference. Additionally, the RHR pump motor is located above the RHR pump seal and below the ventilation exhaust duct. The RHR pump motor, therefore, acts as a physical barrier. This physical barrier will inhibit spray from the proposed seal failure from directly impinging on the HVAC ducted exhaust screened opening.

WCM:mnh
4475b

FIGURE 2-1 MOISTURE REMOVAL EFFECTIVENESS FOR RHR PUMP CUBICLE AREA COOLER (R = 9)





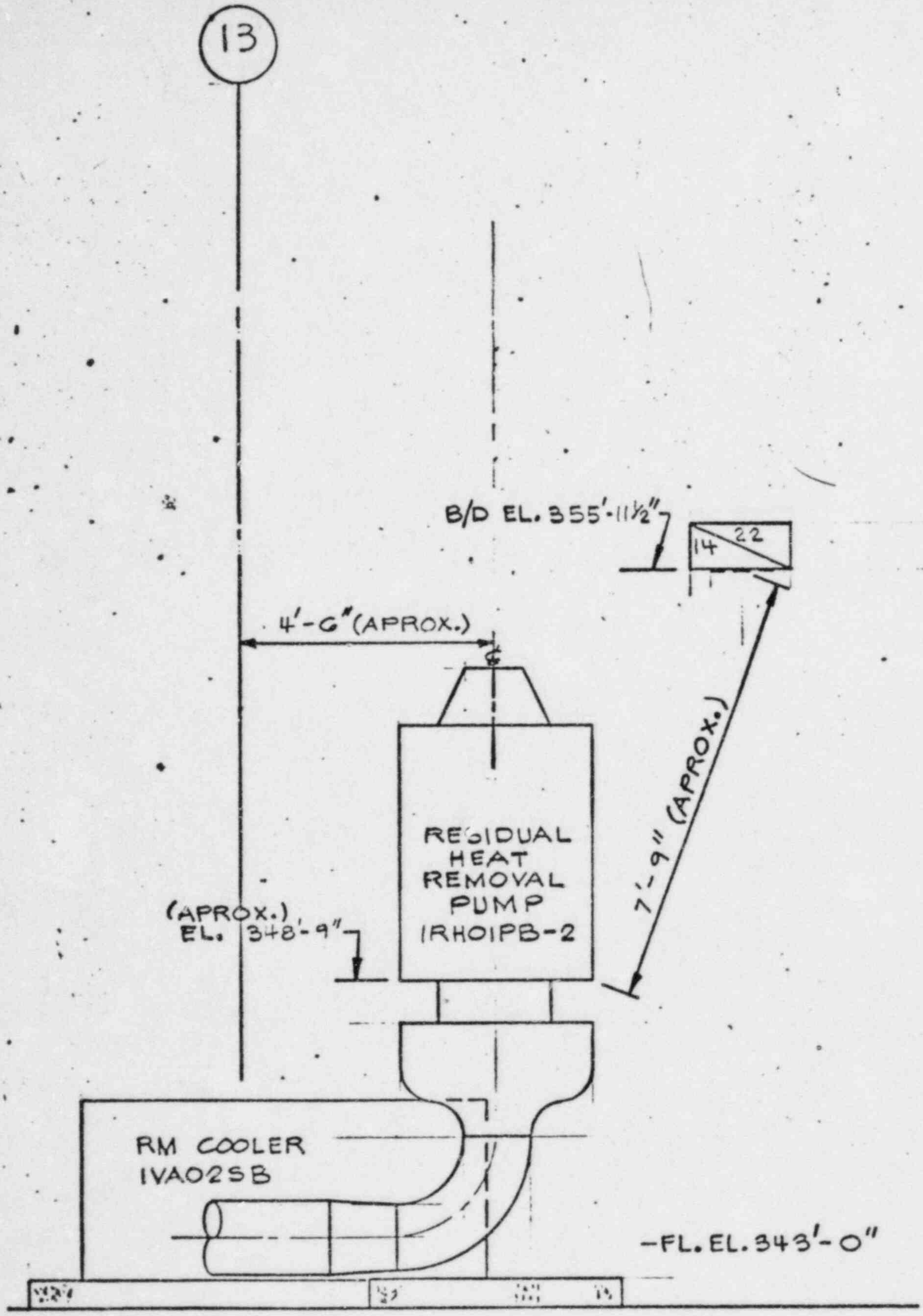
PARTIAL PLAN EL. 343'-0"

SCALE: NONE (M-218-1)

NOTE:

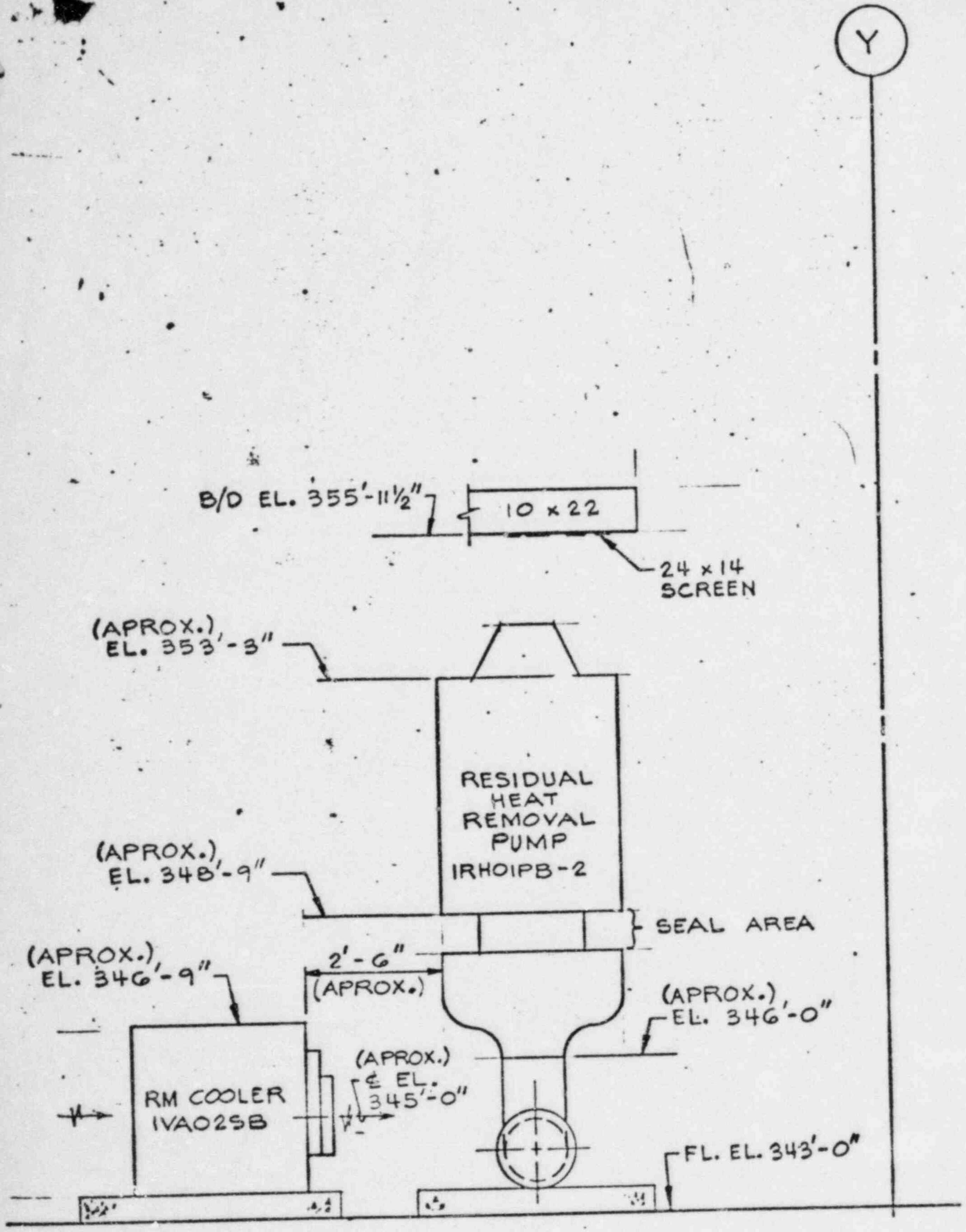
TYPICAL ARRANGEMENT FOR OTHER RHR PUMP ROOMS

PLAN VIEW OF
RHR PUMP,
CUBICLE COOLER
& ASSOCIATED DUCT WORK



SECTION A-A

SCALE: NONE



SECTION B-B
SCALE: NONE

QUESTION 4

Moisture Separator

$$W_{W1} + W_{A1} H_I = W_{A1} H_1 + W_{A2} R_C$$

H_I = moisture content of incoming air, lb. H_2O/lb. air

R_C = removal rate of cooler, $\left(\frac{\text{lb. } H_2O}{\text{lb. air}}\right)$

$$= \left(\frac{\text{lb. } H_2O}{\text{lb. air}}\right)_{\text{inlet}} - \left(\frac{\text{lb. } H_2O}{\text{lb. air}}\right)_{\text{outlet}}$$

$$H_1 WA_1 - H_2 W_{A2}$$

Equation 1 of response to Question 2 did not include moisture content of 1500 cfm ventilation system flow. Only included hot flow and its moisture content.

Response

The analysis presented in response to Question 2 was intended to account for the separation of droplets from the RHR pump cubicle atmosphere exclusive of any mass transfer effects (condensation or evaporation) between the liquid phase (droplets) and the gas phase (humid air). Hence, inclusion of vapor in the incoming air stream was inappropriate. It should be noted that there is no suspended water droplets in the cubicles supply air stream. Nevertheless, in response to the above question, the analysis is extended, below, to include the assumption that the leakage liquid postulated to enter node 1 (the RHR pump cubicle atmosphere) is joined by an additional amount of liquid, namely, a water flow rate corresponding to complete condensation of all vapor in the HVAC airflow entering node 1. This additional liquid flow would, of course, be greatest for the case where the ambient air temperature is the maximum, i.e. 95°F, since an ambient relative humidity of 90% is assumed for all cases. For this case, the absolute humidity is 0.0327 lbm. vapor per lbm. dry air. The corresponding HVAC airflow rate entering node 1 is 4216 lbm. dry air per hour, (1076 cfm for this postulated accident scenario) and the corresponding flow of additional liquid is (4216) (0.0327) = 138 lbm. per hour. Twenty percent of a 50 gpm leakage rate corresponds to a water flow entering the room of 4718 lbm. per hour. The added effect of adding the vapor (as liquid) of the entering room air to this is to increase the entering liquid rate by only 2.9%. Thus, the NRC postulated 20% value would be increased to about 23%. Since the air cooler will remove 90% of this moisture (as shown in the previous response), only one-tenth of 23% value or 2.3% could possibly exit the RHR cubicle. This is also less than 4% used in the reported analysis and so the final conclusions remain valid.