Enclosure 2

Redacted version of

ANALYSIS OF CONTAINMENT MIXING RATE DURING A DESIGN BASIS LOCA
by Stone & Webster Engineering Corporation
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ANALYSIS OF CONTAINMENT MIXING RATE DURING A DESIGN BASIS LOCA

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Introduction

At Millstone 3, containment mixing following a DBA is promoted by the quench and recirculation spray systems. The quench spray system becomes effective at about 70 sec after start of the accident and the recirculation spray system becomes effective at about 11 min after the start of the accident. Spray coverage for the recirculation spray system has not been calculated and therefore is not credited for removal of fission products from the containment atmosphere in the dose calculation. The containment cooling rate calculation includes heat removal by both the quench and recirculation spray systems. Therefore, heat removal by both systems is considered when calculating containment mixing rates. However, the containment mixing rate is based solely on the buoyancy force that arises from density and elevation differences between the sprayed regions and the unsprayed regions within the containment. Note that equations 2 and 3 in the following development of mixing rates are in the form of Bernoulli's equation as it applies here. The Bernoulli equation is frequently used to solve steady flow problems in engineering. The mixing calculation is extremely conservative because momentum transfer from the spray droplets to the containment atmosphere and the small pressure differences between the sprayed and unsprayed regions that are induced by operation of the spray systems are not considered in the mixing analysis.

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Derivation of the Containment Mixing Model

As stated above, only buoyancy forces are assumed when calculating the mixing rate between the effectively sprayed and unsprayed volumes of containment. This assumption is highly conservative. In reality, momentum transfer between spray droplets and the surrounding gases and small pressure variations due to containment cooling in the containment would result in significantly higher mixing rates than calculated here.

In deriving the mixing model, it is assumed that over short time intervals the mass of gas in the effectively sprayed and unsprayed volumes remains constant (i.e. the rate of change of the mass in each volume is slow compared to the mixing rate). Early in the transient, a net transfer of mass may be expected before this quasi-steady state condition is reached; however, the mixing rates are not calculated using this methodology until a time by which the quasi-steady state condition is expected to be attained.

The mixing rate between the effectively sprayed and unsprayed volumes can be determined by simultaneous solution of the energy, mass, and momentum conservation equations. The model is illustrated in Figure 1. The parameters shown in Figure 1 are used to derive the buoyancy-driven mixing model during containment cooling. [Stone & Webster Proprietary Information]

The Energy Equation

The energy equation is based on the steady state condition when the cooling rates in the effectively sprayed and unsprayed volumes are equal, with a constant temperature difference (δT) between the two volumes. The energy contained within the unsprayed volume at the end of any small time interval equals the energy in the volume at the start of the time interval, plus the energy entering during the time interval minus the energy leaving during the time interval:

$$E_u(t+dt) = E_u(t) + dE_{in} - dE_{out}$$

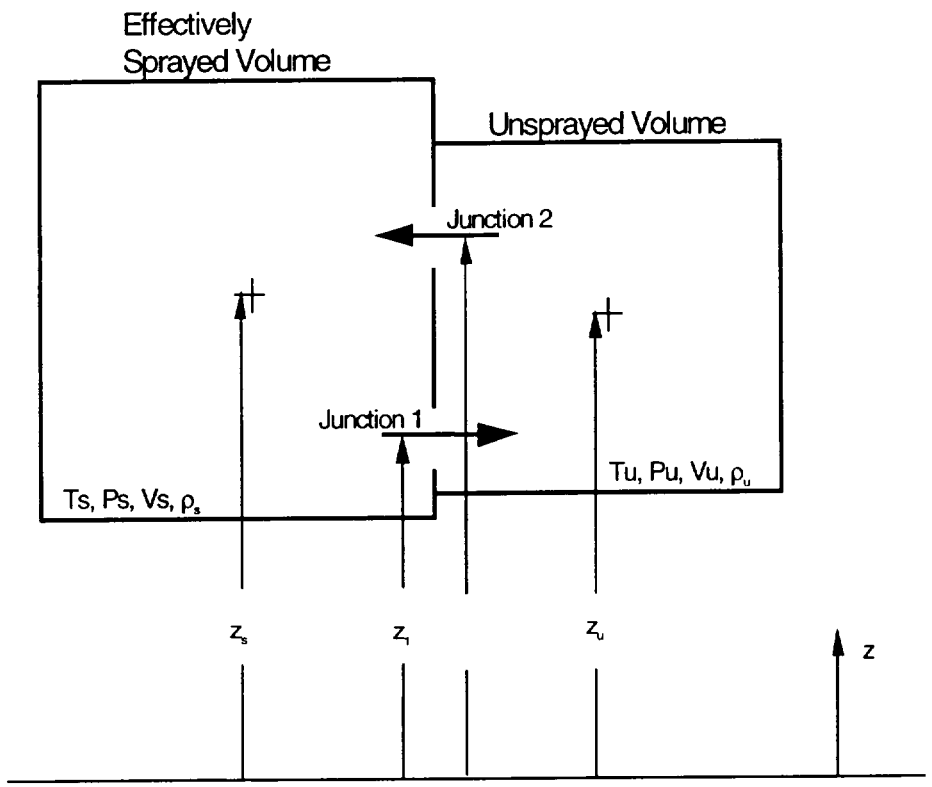

Figure 1: Mixing Model Parameter Illustration

The variable m_u is used to denote the mass of gas within the unsprayed volume. Define λ_{mix} as the number of turnovers of the unsprayed volume per unit time. Then the mass that flows through the junction from the unsprayed volume to the effectively sprayed volume during the time interval is $\lambda_{mix} m_u dt$. Since the mass in each volume is assumed to remain constant, this is the flow rate through each junction. For a gas with specific heats c_v and c_p the energy at the end of the time interval can now be written as:

$$m_u c_v T_u(t+dt) = m_u c_v T_u(t) - \lambda_{mix} m_u c_p T_u(t)\, dt + \lambda_{mix} m_u c_p T_s(t)\, dt.$$

Rearranging this equation leads to:

$$\lambda_{mix} = \frac{1}{T_s(t) - T_u(t)} \frac{T_u(t+dt) - T_u(t)}{dt} \frac{C_v}{C_p} = -\frac{1}{\delta T} \frac{dT}{dt} \frac{C_v}{C_p}$$ **Equation 1**

where:

δT = the temperature difference between the unsprayed and effectively sprayed volumes (T_u - T_s), and

dT_u/dt = the rate of temperature change in the unsprayed volume.

A second relationship, which describes the buoyancy-driven flow through a limiting flow area, is derived from solving the equations of conservation of mass and momentum simultaneously.

Conservation of Mass

Since the mass in each volume remains constant, the mass flow rate through junction 1 must equal that through junction 2:

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

where:

ρ_j = density of flow through junction j (In Figure 1, the density in junction 1 would be the same as the density in the sprayed volume ρ_s, and the density in junction 2 is the same as that in the unsprayed volume, ρ_u)

A_j = area of junction j,

v_j = velocity through junction j, and

j = subscript for the junction number.

Conservation of Momentum

The conservation of momentum equation is:

$$I_j \frac{d(\rho_j A_j v_j)}{dt} = (P_K + P_{K,gj}) - (P_L + P_{L,gj}) - \frac{K_j}{2\rho_j}\left(\frac{\rho_j A_j v_j}{A_j}\right)^2$$

where I_j = geometric "inertia" for junction j,
P_K = total static pressure in volume K,
$P_{K,gj}$= gravity pressure difference from junction j to the center of volume K,
P_L = total static pressure in volume L,
$P_{L,gj}$= gravity pressure difference from junction j to the center of volume L,
and
K_j = loss factor through junction j.

The gravity pressure difference term is expressed by:

$$P_{K,gj} = (z_K - z_j)\, \rho_K\, g$$

For the steady state, the inertia term is zero and the difference between the total pressure terms for volumes K and L equals the loss factor term. For the geometry shown in Figure 1, this results in separate equations for each junction:

$$[P_s + (z_s - z_1)\rho_s g] - [P_u + (z_u - z_1)\rho_u g] = \frac{\rho_s K_1}{2} v_1^2 \qquad \textbf{Equation 2}$$

$$-[P_s + (z_s - z_2)\rho_s g] + [P_u + (z_u - z_2)\rho_u g] = \frac{\rho_u K_2}{2} v_2^2 = \frac{\rho_s K_2}{2} \frac{\rho_s A_1^2}{\rho_u A_2^2} v_1^2 \qquad \textbf{Equation 3}$$

In the latter equation, the loss factor term has been rewritten in terms of the velocity through junction 1 using the conservation of mass equation. In this analysis, the lower junction with flow from the effectively sprayed volume to the unsprayed volume (corresponding to junction 1) is the junction that is most limiting to the mixing flow. Deriving the equations in terms of the flow through this junction makes explanations of the final equations simpler.

Adding the two equations for conservation of momentum and rearranging yields:

$$(z_2 - z_1)(\rho_s - \rho_u)\, g = \left(1 + \frac{\rho_s A_1^2 K_2}{\rho_u A_2^2 K_1}\right) \frac{\rho_s K_1}{2} v_1^2$$

Solving for v_1 results in:

$$v_1 = \sqrt{\frac{2g}{K_1} x \frac{\rho_s - \rho_u}{\rho_s} x \frac{z_2 - z_1}{\left(1 + \frac{\rho_s A_1^2 K_2}{\rho_u A_2^2 K_1}\right)}}$$

The mixing rate λ_{mix} is defined as number of turnovers of unsprayed volume per unit time. Thus:

$$\lambda_{mix} = \frac{\rho_u A_2 v_2}{\rho_u V_u} = \frac{\rho_s A_1 v_1}{\rho_u V_u}$$

where V_u = unsprayed volume.

Using the expression developed for the velocity through junction 1 yields:

$$\lambda_{mix} = \frac{\rho_s A_1}{\rho_u V_u} \sqrt{\frac{2g}{K_1} x \frac{\rho_s - \rho_u}{\rho_s} x \frac{z_2 - z_1}{\left(1 + \frac{\rho_s A_1^2 K_2}{\rho_u A_2^2 K_1}\right)}}$$

Bringing the ratio ρ_s/ρ_u inside the radical and rearranging results in:

$$\lambda_{mix} = \frac{A_1}{V_u} \sqrt{\frac{2g}{K_1} x \frac{\rho_s - \rho_u}{\rho_u} x \frac{z_2 - z_1}{\left(\frac{\rho_u}{\rho_s} + \frac{A_1^2 / K_1}{A_2^2 / K_2}\right)}}$$

For an ideal gas, the second term under the radical can be rewritten:

$$\frac{\rho_s - \rho_u}{\rho_u} \approx \frac{\frac{1}{T_s} - \frac{1}{T_u}}{\frac{1}{T_u}} = \frac{T_u - T_s}{T_s} = \frac{\delta T}{T_s}$$

Then,

$$\lambda_{mix} = \frac{A_1}{\sqrt{K_{eff}}} x \sqrt{2g H_d \frac{\delta T}{T_s}} x \frac{1}{V_u}$$ **Equation 4**

where $H_d = z_2 - z_1$

$K_{eff} = K_1 \{(\rho_u / \rho_s) + (A_1^2 / K_1)/(A_2^2 / K_2)\}$

Mixing Rate

Equation (1) can be solved for δT and substituted into equation (4), which results in:

$$\lambda_{mix} = \left(A_1 \sqrt{2g \frac{H_d}{K_{eff}}} \right)^{2/3} \left(\frac{-dT_u/dt}{T_s} \right)^{1/3} \left(\frac{1}{V_u} \right)^{2/3} (\gamma)^{-1/3}$$

or,

$$\lambda_{mix} = 841.6 \left(\frac{A_1}{V_u} \sqrt{\frac{H_d}{K_{eff}}} \right)^{2/3} \left(\frac{-dT_u/dt}{T_s} \right)^{1/3}$$ **Equation 5**

where:

λ_{mix}= the mixing rate (hr^{-1}),
A_1 = the limiting flow area along the entire flow path(ft^2),
H_d = the driving head for the buoyancy flow (ft),
K_{eff} = the effective loss factor along the entire flow path based on the limiting flow area,
g = the acceleration due to gravity (32.174 ft/s^2),
dT_u/dt = the rate of temperature change in the unsprayed volume ($^oF/hr$),
T_s = the average temperature (^oR) of effectively sprayed volume for a time period,
V_u = the unsprayed volume (ft^3),
γ = the ratio of specific heats (c_p/c_v): (= 1.4)

The numerical constant 841.6 results from using the units of hr^{-1} for λ_{mix}, while using a gravity constant with units of ft/sec^2. Similarly, the mixing rate during containment heating is:

$$\lambda_{mix} = 841.6 \left(\frac{A_1}{V_u} \sqrt{\frac{H_d}{K_{eff}}} \right)^{2/3} \left(\frac{dT_u/dt}{T_s} \right)^{1/3}$$ **Equation 6**

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Conclusion

The Millstone 3 modeling of the effectively sprayed volume is conservative for the following reasons:

- Mixing rates are conservative because 1) momemtum transfer from the spray droplets to the containment atmosphere is neglected, 2) small pressure variations that are induced by the containment cooling systems are neglected, and 3) a minimum mixing rate envelope for several accident scenarios is used.
- The recirculation spray system is not credited for fission product removal
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Attachment 3

Millstone Nuclear Power Station, Unit No. 3

License Amendment Related to the Supplementary Leakage Collection and Release System (PLAR 3-98-5), Supplemental Information
Replacement FSAR Table 15.0-11

TABLE 15.0-11

ATMOSPHERIC DISPERSION DATA USED FOR DESIGN BASIS ACCIDENT ANALYSIS

EAB X/Qs (sec m^{-3})	
Ground level release-containment 0-2 hr.	5.42×10^{-4}
Ground level release-ventilation vent 0-2 hr.	4.3×10^{-4}
Elevated release-Unit 1 Stack 0-2 hr.	1.0×10^{-4} ~~7.0×10^{-6}~~
LPZ X/Qs (sec m^{-3})	
Ground level release-containment 0-8 hr.	2.91×10^{-5}
Ground level release-ventilation vent	
0-8 hr.	2.91×10^{-5}
8-24 hr.	1.79 ~~2.0~~ $\times 10^{-5}$
1-4 days	8.66 ~~8.7~~ $\times 10^{-6}$
4-30 days	2.63×10^{-6}
Elevated release-Unit 1 stack	
~~40~~-8 hr. 0-4 hr	2.69×10^{-5} ~~3.30×10^{-6}~~ 1.07×10^{-5}
8-24 hr.	6.72 ~~2.30~~ $\times 10^{-6}$
1-4 days	2.46 ~~1.05~~ $\times 10^{-6}$
4-30 days	5.83 ~~3.39~~ $\times 10^{-7}$

	Millstone 1	Millstone 2	Millstone 3
Control room X/Qs[4] (sec m^{-3})			
a. Ground level release-containment			
0-8 hr.	1.9×10^{-3}	1.4×10^{-3}	1.52×10^{-3} ~~8.08×10^{-4}~~
8-24 hr.	1.3×10^{-3}	9.7×10^{-4}	8.53 ~~5.49~~ $\times 10^{-4}$ (92-22)
1-4 days	4.2×10^{-4}	3.4×10^{-4}	2.59 ~~1.95~~ $\times 10^{-4}$ 6/92
4-30 days	3.8×10^{-5}	2.7×10^{-5}	3.21 ~~2.75~~ $\times 10^{-5}$
0-24 hr[1]	NA	8.7×10^{-5}	NA
24-36 hr[1][3]	NA	5.2×10^{-5}	NA
b. Elevated release-Unit 1 Stack[2]			
0-4 hr.	1.6×10^{-4}	1.6×10^{-4}	~~NA~~ 1.39×10^{-4}
4-8 hr.	4.4×10^{-6}	4.4×10^{-6}	~~NA~~ 3.23×10^{-5}
8-24 hr.	2.4×10^{-6}	2.4×10^{-6}	~~NA~~ 1.56×10^{-5}
1-4 days	6.3×10^{-7}	6.3×10^{-7}	~~NA~~ 1.92×10^{-6}
4-30 days	9.3×10^{-8}	9.3×10^{-8}	~~NA~~ 1.32×10^{-7}
0-24 hr.[1]	NA	2.0×10^{-8}	NA
24-36 hr.[1][3]	NA	1.2×10^{-8}	NA
c. Ground level release-ventilation vent			
0-8 hr.	NA	NA	3.75 ~~2.24~~ $\times 10^{-3}$
8-24 hr.	NA	NA	2.28 ~~1.40~~ $\times 10^{-3}$ (92-22)
1-4 days	NA	NA	7.43 ~~5.08~~ $\times 10^{-4}$
4-30 days	NA	NA	9.69 ~~9.68~~ $\times 10^{-5}$

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Docket No. 50-423
B18209

Attachment 4

Millstone Nuclear Power Station, Unit No. 3

License Amendment Related to the Supplementary Leakage Collection and Release System (PLAR 3-98-5)
Response to NRC Questions from May 24, 2000 Facsimile

License Amendment Related to the Supplementary Leakage Collection and Release System (PLAR 3-98-5)
Response to Requests for Additional Information

Question 1

The sprayed region of Zone 3 is added to the "effectively sprayed volume" of Zones 1 and 2 for the mixing model. What fraction of the total containment volume is the unsprayed region in Zone 3? It is our understanding that this unsprayed region in Zone 3 is a slow mixing region due to structural interferences in the region. Assuming the volume of the unsprayed region in Zone 3 is not negligible or even substantial, was a qualitative or quantitative estimation or actual calculation of the mixing rate for this region done?

Response

The unsprayed region in Zone 3 represents approximately 47 percent of the containment net volume. The mixing rate for this region was obtained by actual calculation.

Question 2

Do the final mixing rates (time-dependent) include any correction(s) contributed by the Zone 3 unsprayed region for its slow mixing rate(s)? If not, please provide a brief discussion.

Response

This question was withdrawn per the telephone conference conducted on June 13, 2000, between the Nuclear Regulatory Commission (NRC) staff, Northeast Nuclear Energy Company (NNECO) staff, and Stone and Webster (S&W) staff.

Question 3

Is there any qualitative relationship or a discussion representing a relationship between the mixing rate and other removal coefficients by spray for first order elemental Iodine? Please provide a brief discussion.

Response

This question was withdrawn per the telephone conference conducted on June 13, 2000, between the NRC staff, NNECO staff, and S&W staff.

Question 4

Insert G in the submittal dated April 19, 2000, contains a list of parameters used in determining removal rates of elemental and particulate iodine from the post-accident containment atmosphere. We would like to know how did you arrive at the values of the following iodine removal coefficients (λ). Please, provide a description of the method and the values of input parameters used in calculation:

- **Elemental iodine coefficient by plate out in the sprayed region of containment**
- **Particulate iodine removal coefficients by sprays in the sprayed region of containment**

Response

This question was withdrawn per the telephone conference conducted on June 13, 2000, between the NRC staff, NNECO staff, and S&W staff.

Question 5

Stone and Webster calculation dated May 27, 1998, on X/Qs from the Unit 3 main steam building (MSVB) states that the postulated effluent release for the MSVB bypass scenario does not meet the Murphy-Campe criteria for using the diffuse source equation. However, a general statement is made that because of multiple flow disruptions due to buildings both upwind and downwind of the release, it is reasonable to assume that this equation may be used to estimate resultant X/Q values. The calculation assumes that the release occurs from the vent closest to the control room intake and mixes in the wake of the MSVB.

Response

S&W calculation WM(B)-01, dated May 27, 1998, calculates the X/Q from the Unit No. 3 Main Steam Valve Building (MSVB) to the MP3 control room using the diffuse source equation of Murphy-Campe. The diffuse source equation was used to estimate the X/Q even though the elevation difference between the MSVB release point and the control room intake meet the criteria of the point source - point receptor technique of Murphy - Campe. The justification for using the diffuse source equation is based upon the aerodynamic obstacles encountered by the plume in the straight line pathway between the two points. Figures 1 and 2 depict the postulated flow path that the plume would have to travel from the MSVB to the Unit 3 control room intake.

The MSVB has two exhaust vents as shown in Figure 2. These vents (elev. 85.9') are physically located between the containment structure and the Auxilliary Bay/Ventilation Enclosure structures. The MSVB vents discharge downward. The closest vent to the

control room intake is considered in the X/Q calculation. The prevailing wind necessary to transport postulated radioactivity released from the MSVB to the control room intake would need to flow around the containment structure, entrain the MSVB effluent discharged downward, flow up and over the Ventilation Enclosure roof (elev. 100'), be effected by the turbulent flow created by skirting the turbine building corner (elev. 132') at approximately a 45 degree angle, then decrease in elevation to the control room intake (elev. 94.6'). The accumulated affect of containment structure building wake and complex aerodynamic forces and obstacles encountered in the pathway between the source point and receptor, were justification for using the diffuse source equation of Murphy-Campe for this pathway.

Figure 1 - Plant Isometric

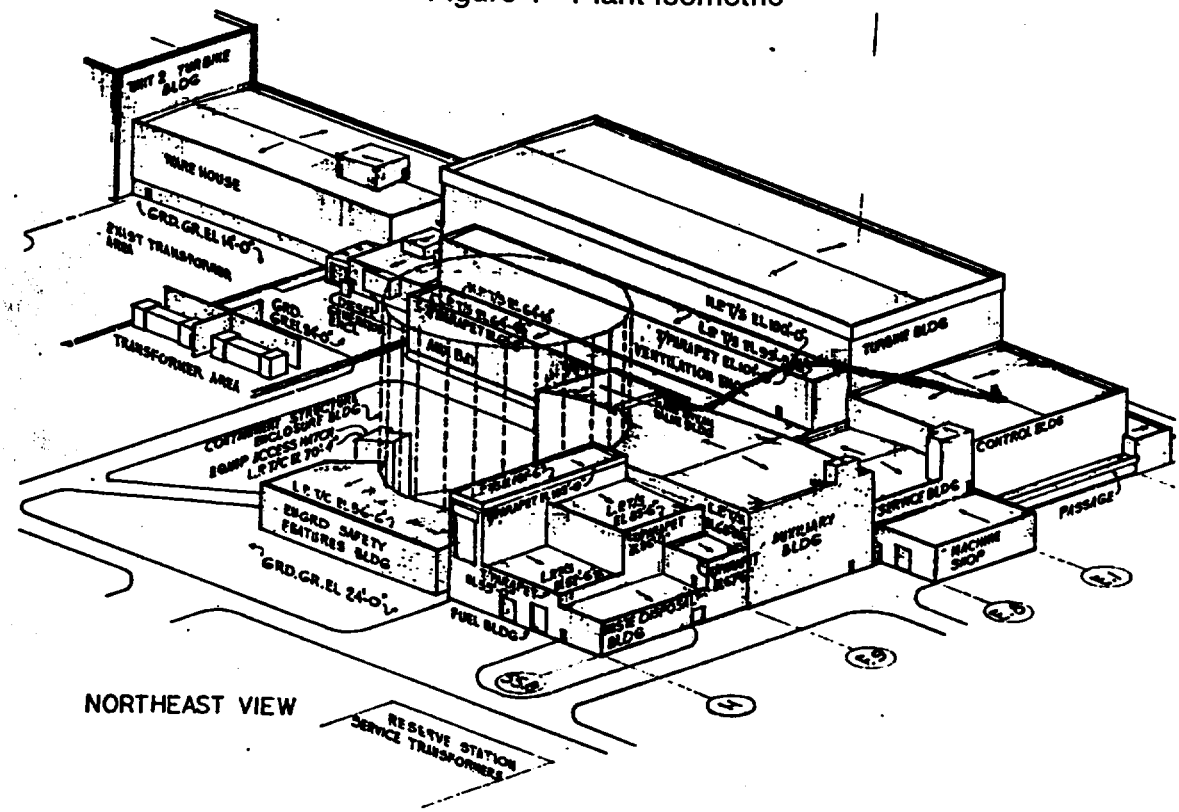
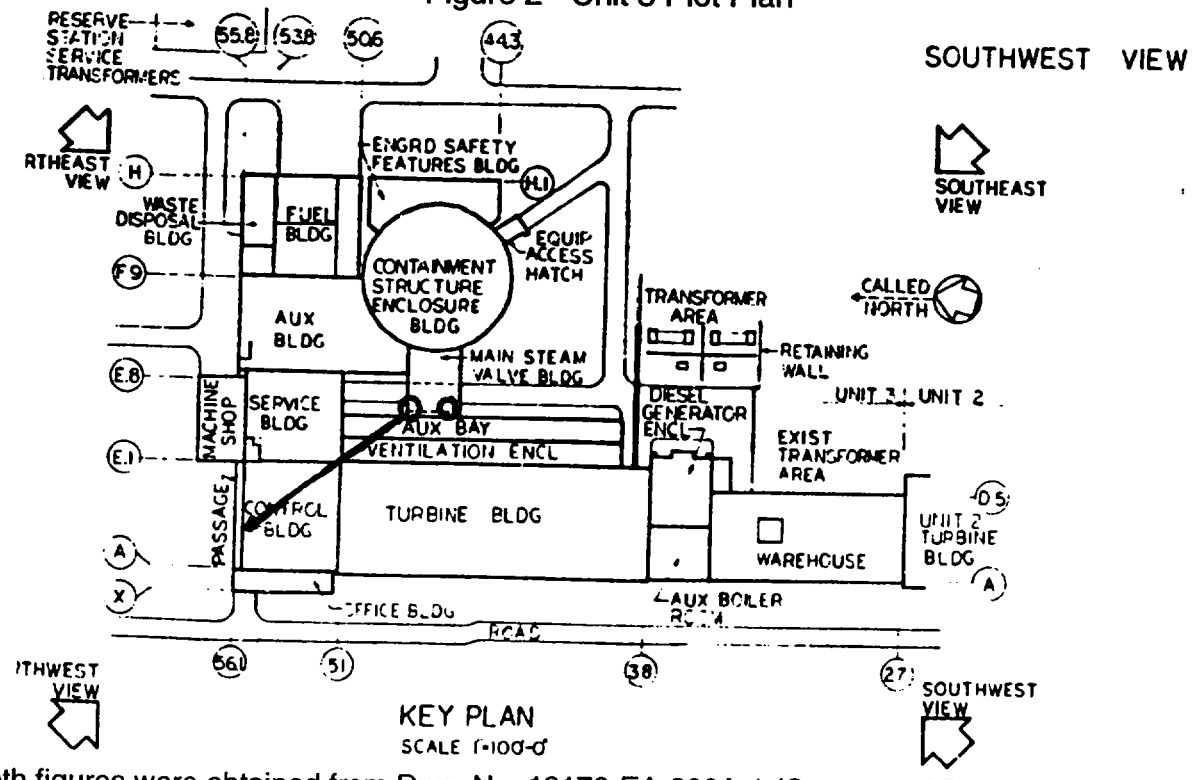


Figure 2 - Unit 3 Plot Plan



Both figures were obtained from Dwg. No. 12179-EA-200A-1 (Conceptual Design)