TENNESSEE VALLEY AUTHORITY

Watts Bar Nuclear Plant

Rhea County, Tennessee

EVALUATION OF SONIC VELOCITIES IN LOWER COMPARTMENT

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WATTS BAR NUCLEAR PLANT

EVALUATION OF SONIC VELOCITIES IN LOWER COMPARTMENT

Supplement No. 1 to the staff's safety evaluation for the Watts Bar Nuclear Plant recommends: "To allow further margin for uncertainties in describing the transient flow characteristics of the steam-air water mixtures that flow past major flow obstruction (e.g., steam generators) or through the major relief paths from a subvolume or subcompartment, it is recommended that mixture flow velocities projected to occur in these restricted flow regions be maintained at levels less than approximately three-fourths of the sonic velocity for the flowing mixture." This report addresses the recommendation by describing the location and time duration for which sonic flow exists in the present design, and explaining why sonic flows are acceptable, and, therefore, not necessary to comply with the staff's 75 percent of sonic velocity recommendation. Essentially, it is shown that flow choking does not represent a threshold beyond which sharper increase in compartment pressure could be expected.

The Watts Bar containment pressure transients for the design basis LOCA have been determined by the TMD computer code. The TMD Code is described in Report WCAP-8078, which was submitted to the AEC with D. C. Cook Plant Amendment 39, Appendix N. Briefly, modeling in TMD is developed by considering the conservation equations of mass, momentum, and energy and the equation of state together with the control volume technique for simulating spatial variation in the containment. To represent the containment pressures and flows of interest, the Watts Bar containment has been divided into 49 elements. Division of the containment and interconnection between elements is shown in figures 1 through 5. The momentum equation is used to calculate the flow rate between elements. A critical flow routine assures that the maximum possible calculated flow rate between restricted vent paths does not exceed choked flow conditions. Also, choked flow is described in terms of critical mass flux (G^*) rather than sonic velocity. Between any two elements connected by a flow path, the mass flux (G) calculated is compared to G^* as determined by upstream element conditions. The minimum of these two values is used to determine mass flow rate, and the conditions in the elements are updated accordingly.

For this evaluation, then, a special TMD run was made to define a 75 percent sonic condition in terms of critical mass flux. The procedure used was as follows (see figure 6). For a given set of upstream conditions, critical mass flux was calculated using the existing TMD critical flow routine. This value of critical mass flux defined sonic velocity (V^*) for the flow path in question under these conditions. Further iterations were then made to search for the value of downstream pressure that would establish a fluid velocity which was 75 percent of this sonic value. With a downstream pressure established, mass flux through the flow path was then calculated. This mass flux would correspond to a 75 percent sonic condition. Results of the analysis for a range of upstream conditions indicate a mass flux of approximately 90 percent of the critical mass flux which is representative of a 75 percent sonic condition. That is:

$$\frac{G}{G^*} = 0.9 \quad \text{for 75 percent sonic conditions}$$

The break considered, which gives the worst flow condition because of the longer sustained blowdown rate, is the DECL break in compartment 1. Results of this analysis, which used the present Watts Bar plant geometry, show flow choking to occur for approximately 0.5 second past the first two steam generators. In addition, for 1.5 seconds, some flow paths remain at 90 percent of the critical mass flow which corresponds to a maximum velocity of approximately 75 percent of sonic velocity. Figure 7 shows the critical mass flux ratio versus time for the major vent area (past the steam generator) where flow choking occurs. Flow choking past other steam generators and pressurizer does not occur.

Another matter investigated was to determine the increase in flow area required if the 75 percent sonic velocity recommendation was met. To determine the effect of flow area changes past major flow obstructions on velocity in the lower compartments, a series of sensitivity runs were made using TMD. Specifically, the areas of flow paths from TMD elements 1 to 2, 2 to 3, 3 to 4, 4 to 5, and 5 to 6 were uniformly increased until peak velocity in these flow paths was less than 75 percent of sonic velocity, i.e., until G/G^* was less than .9 for all five flow paths. For the worst case, a double-ended guillotine cold leg break in element 1, approximately a 30 percent increase in flow areas was required to meet the 90 percent choked flow limitation. In terms of plant parameters, this means a 7-foot increase in plant diameter is required to obtain this added vent flow area. This increase in containment diameter would mean an extensive reanalysis and redesign of the containment including ice condenser components. It can be shown, as follows, that sonic velocity and choked flow do not represent a limiting situation beyond which additional increases in mass flow and pressure relief are not obtained.

Consequently, establishment of an arbitrary upper bound on velocity in terms of sonic velocity is not meaningful.

The phenomenon of flow choking is frequently explained by assuming a fixed upstream pressure and examining the dependence of flow rate with respect to decreasing downstream pressure. This approach is illustrated for an assumed upstream pressure of 30 psia as shown in the upper plot of figure 8 with the results plotted versus downstream pressure in the lower plot of figure 8. For fixed upstream conditions, flow choking represents an upper limit flow rate beyond which further decreases in back pressure will not produce any increase in mass flow rate. The data in figure 8 illustrates the behavior of mass flow rate as a function of upstream and downstream pressures, including the effects of flow choking. The upper plot shows mass flow rate as a function of upstream pressure for various assumed values of downstream pressure. For zero back pressure ($P_d = 0$), the entire curve represents choked flow conditions with the flow rate approximately proportional to upstream pressure, P_u. For higher back pressure, the flow rates are lower until the upstream pressure is high enough to provide choked flow. After the increase in upstream pressure is sufficient to provide flow choking, further increases in upstream pressure cause increases in mass flow rate along the curve for $P_d = 0$. The key point in this illustration is that flow rate continues to increase with increasing upstream pressure, even after flow choking conditions have been reached. Thus, choking does not represent a threshold beyond which dramatically sharper increases in compartment pressure could be expected because of limitations on flow relief to adjacent compartments.

To demonstrate the flow choking effect on peak pressure in the actual plant, sensitivity runs were made on the blowdown rate for the present Watts Bar geometry. Blowdown rates from 50 to 120 percent of the double-ended cold leg were studied for the worst break location. Blowdown rates 80 percent and higher produced choking past major flow areas of the lower compartment. Below this blowdown rate, no flow choking occurred. Figure 9 is a plot of peak break compartment pressure versus blowdown rate. As can be seen from this curve, the rate of pressure rise is essentially linear before and after flow choking occurs.

In summary, it has been shown that even though velocities in the present Watts Bar design exceed the staff's 75 percent of sonic velocity recommendation, this is of no consequence since flow choking in major vent areas does not represent a threshold in the rate of pressure increase.

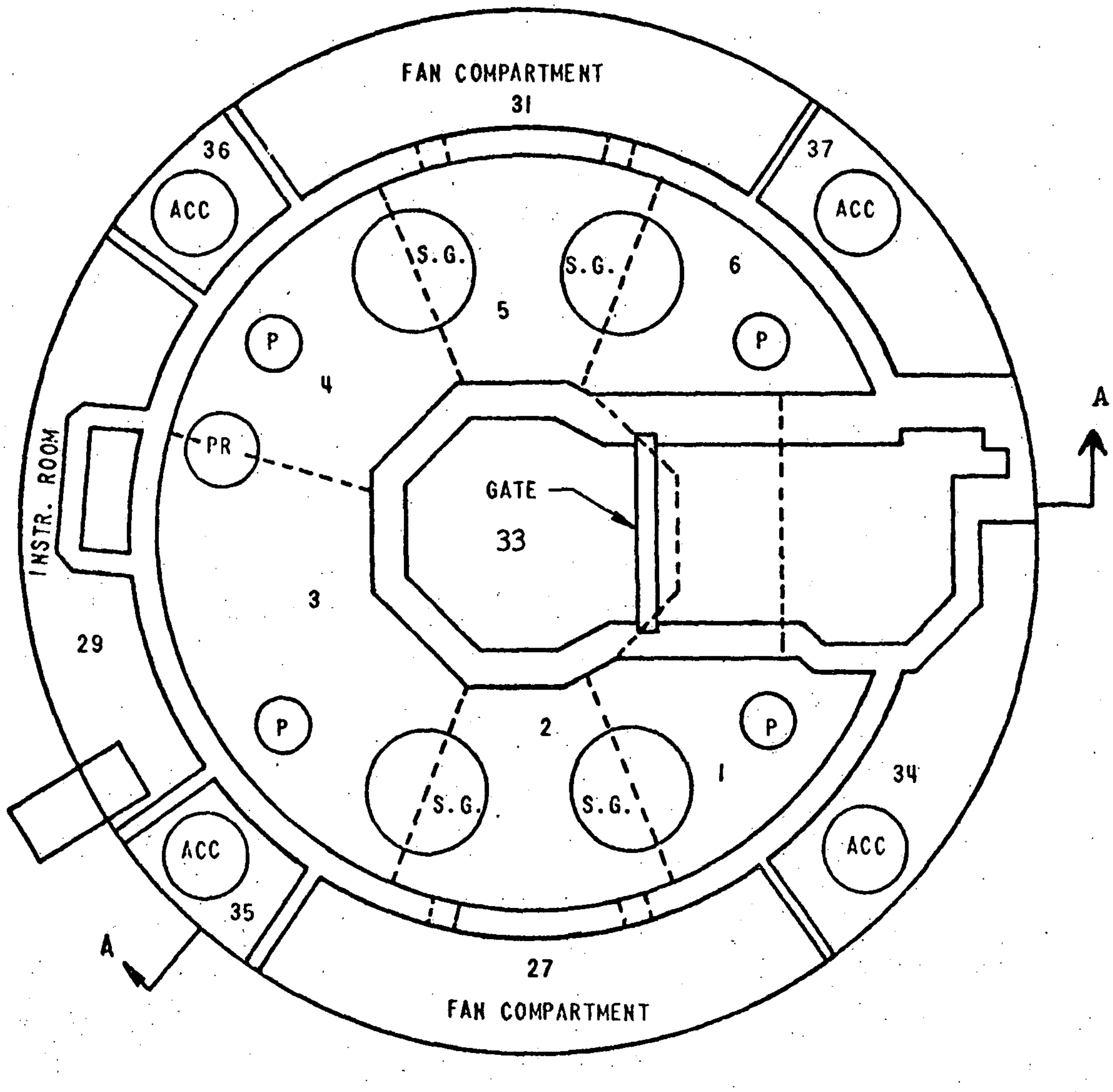
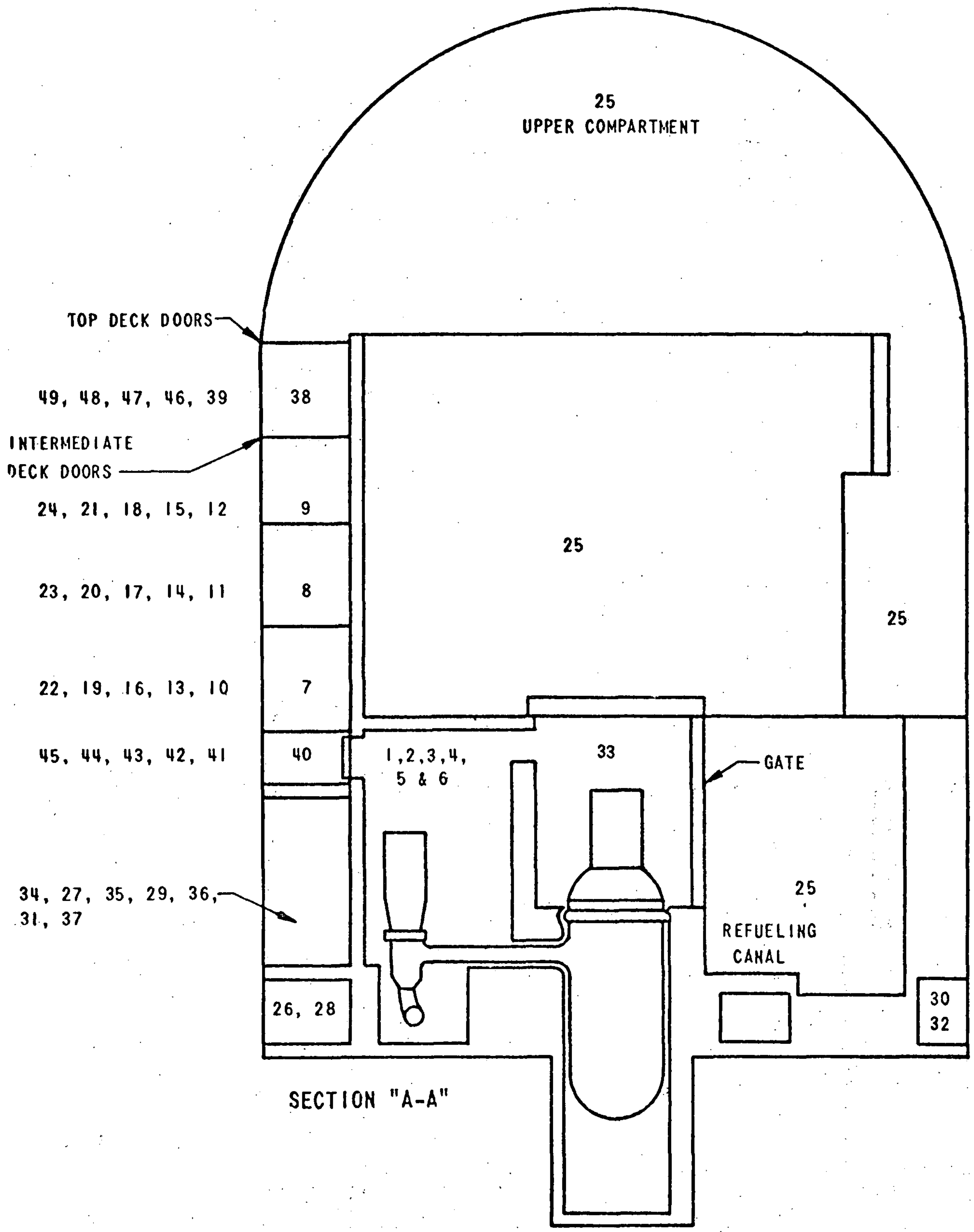


Figure 1 Plan at Equipment Rooms Elevation



SECTION "A-A"

Figure 2 Containment Section View

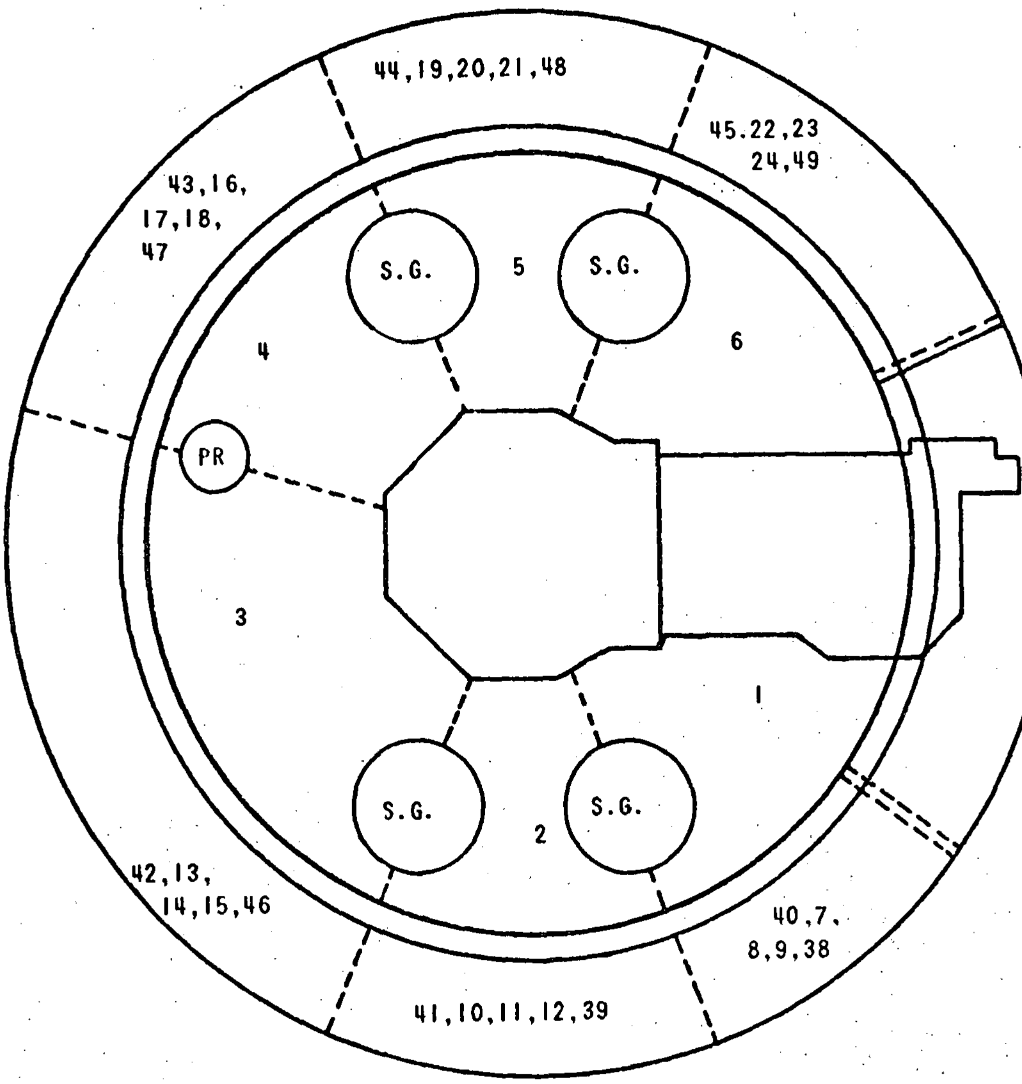


Figure 3 Plan View at Ice Condenser Elevation-Ice Condenser Compartments

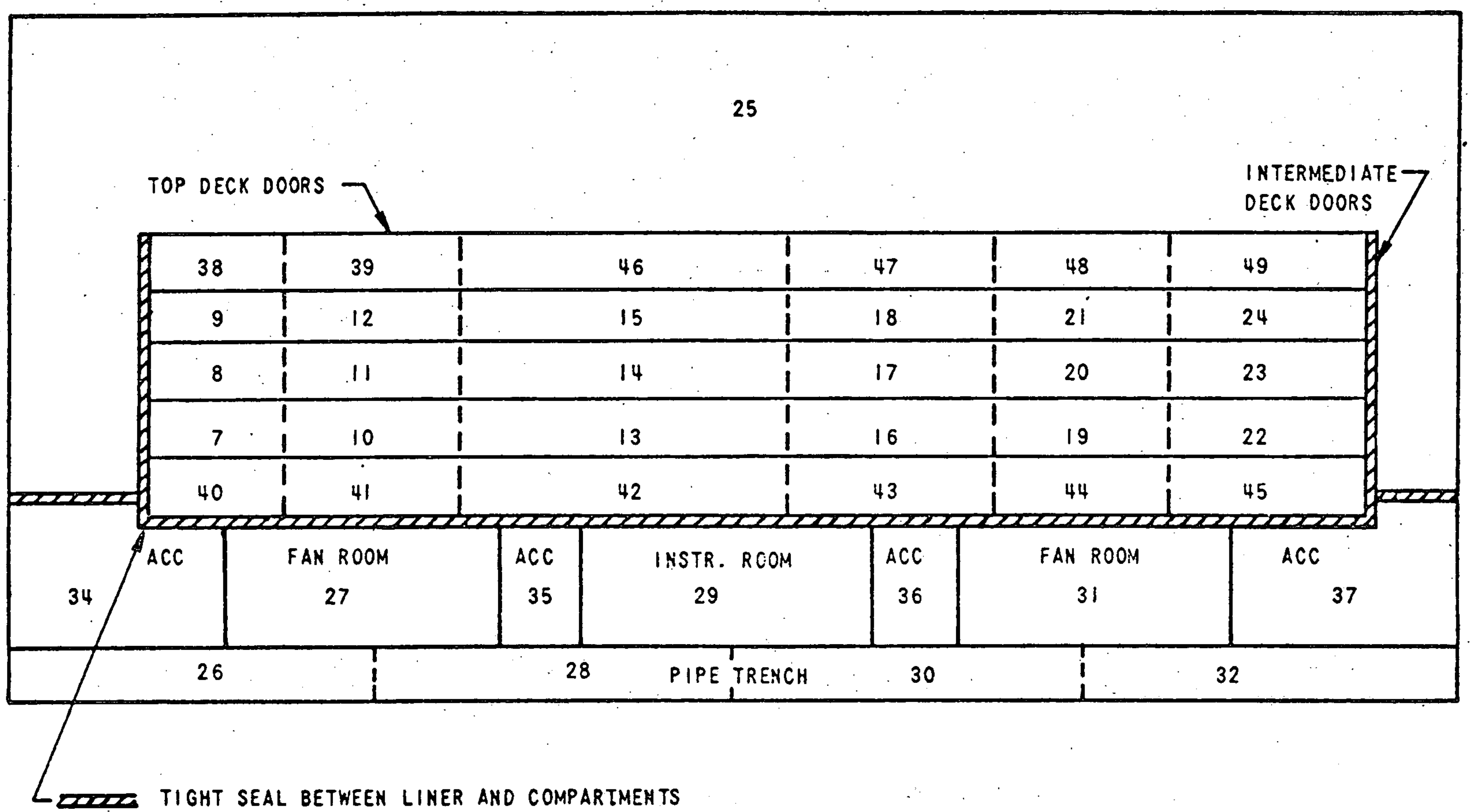


Figure 4 Layout of Containment Shell

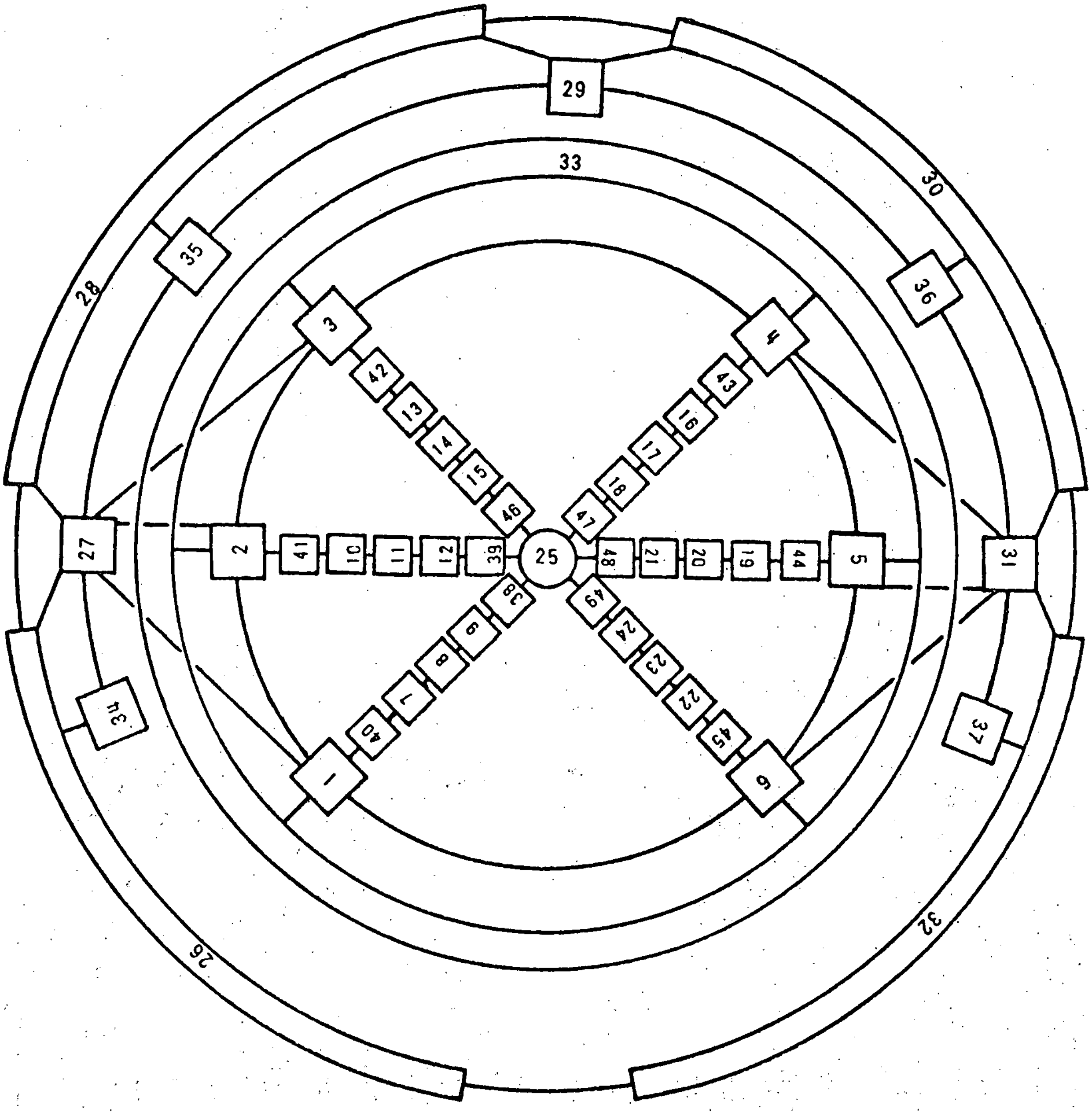


Figure 5 TMD Code Network

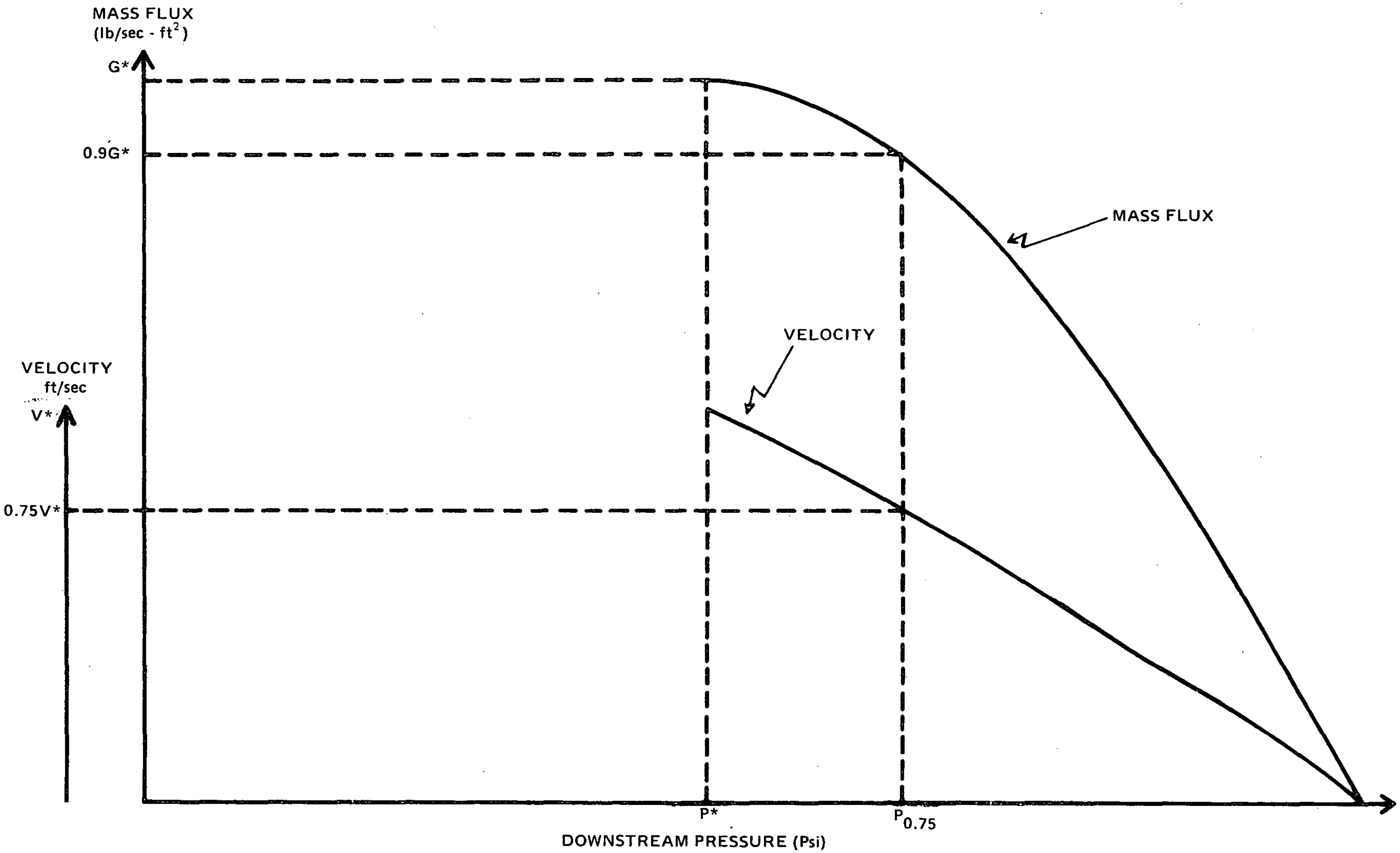


FIGURE 6 DETERMINATION OF MASS FLUX CORRESPONDING TO 75 PERCENT OF SONIC VELOCITY (ILLUSTRATIVE)

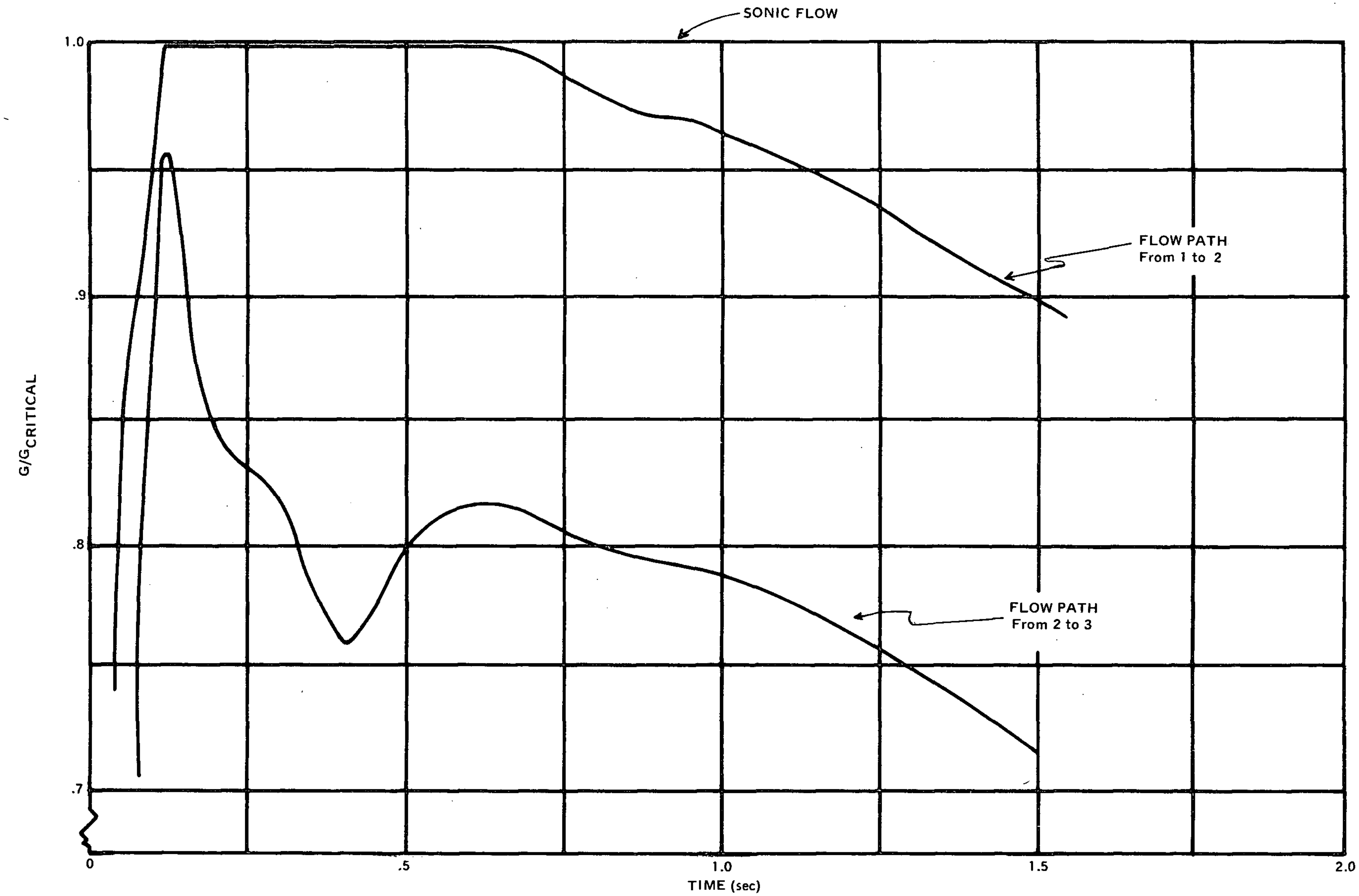


FIGURE 7 CRITICAL MASS FLUX RATIO PAST STEAM GENERATORS VS TIME

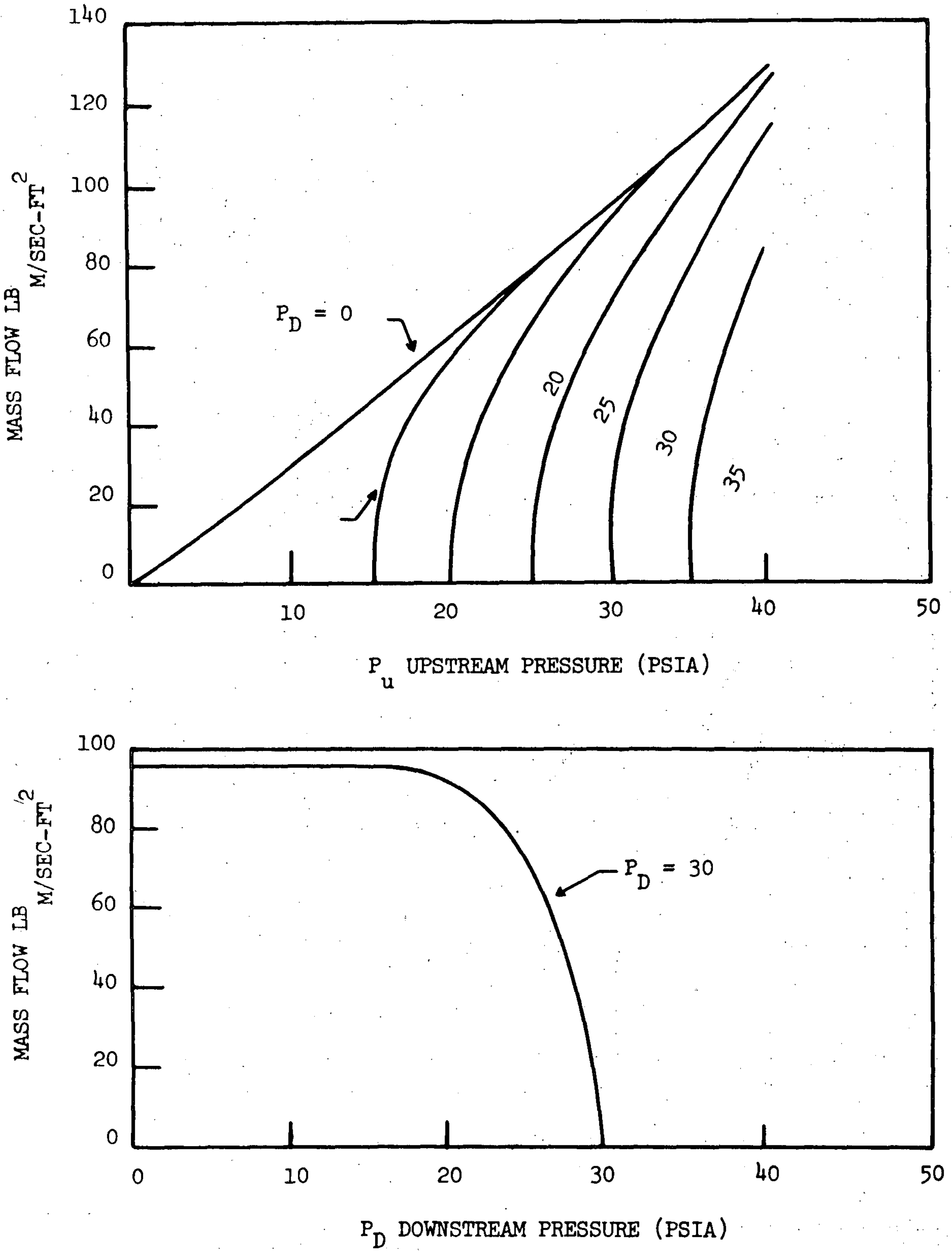


FIGURE 8 ILLUSTRATION OF CHOCKED FLOW CHARACTERISTICS

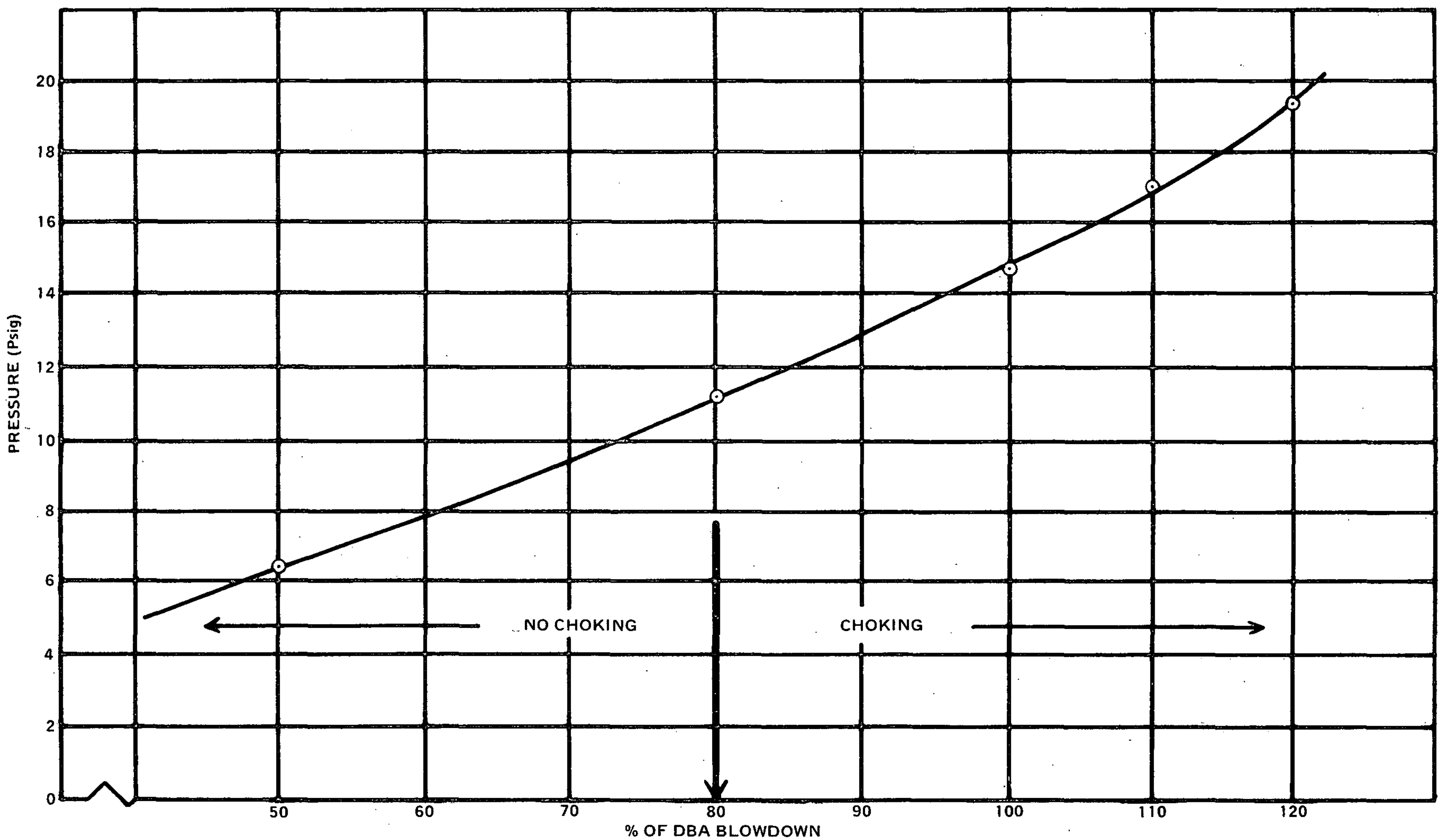


FIGURE 9 COMPARTMENT PEAK PRESSURE FOR DECL BREAK
IN COMPARTMENT I VS % DBA