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Technical Description: Annulus Pressurization Load Adequacy Evaluation,"

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TECHNICAL DESCRIPTION ANNULUS PRESSURIZATION LOAD ADEQUACY EVALUATION

D.K. SHARMA

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ANNULUS PRESSURIZATION LOAD ADEQUACY EVALUATION

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1. TECHNICAL INFORMATION AND DATA REQUIREMENTS

1.0 OBJECTIVE

The objective of this document is to: (1) describe the method by which short term mass release rates are calculated, and (2) provide a definition of the customer data input requirements necessary to perform the loads adequacy evaluation. These requirements are already specified in NEDO-24547 and are given here only for sake of completeness.

1.1 BACKGROUND INFORMATION

Annulus pressurization, jet impingement, pipe whip restraint and jet thrust are phenomena related to postulated pipe ruptures. A postulated pipe rupture at the weld between recirculation, or feedwater piping and a reactor nozzle safe end (see Figure 1), will lead to a high flow rate of flashing water/steam mixture into the annulus between the reactor pressure vessel and the biological shield wall. The total effect of the vessel and pipe inventory blowdown from the break being postulated must be accounted for in the evaluation. A recirculation line break will give rise to an angular dependent short term pressure differential (of approximately 0.025 second duration) around the vessel, followed by a longer term pressure buildup in approximately 0.2 second duration in the annulus. A recirculation line postulated rupture may not produce worst case conditions and reference to time intervals for only the recirculation break should be treated superficially. A postulated rupture of the feedwater piping may produce the extreme case for determining: 1) the shield wall and reactor vessel to pedestal interactions, 2) loading on the reactor vessel internals, or 3) responses for the balance of piping attached to the vessel.

The pressure (force) time-history data for annulus pressurization can be obtained using the RELAP-4 computer code or equivalent. This computer code is described in detail in the User's Manual ANCR-1335*,

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*The RELAP-4 Code along with Aerojet Nuclear Company Report (ANCR-NUREG-1335, Sept. 1976) is available through the Argonne Code Center, Argonne National Lab., 9700 S. Cass Avenue, Argonne, IL 60439.

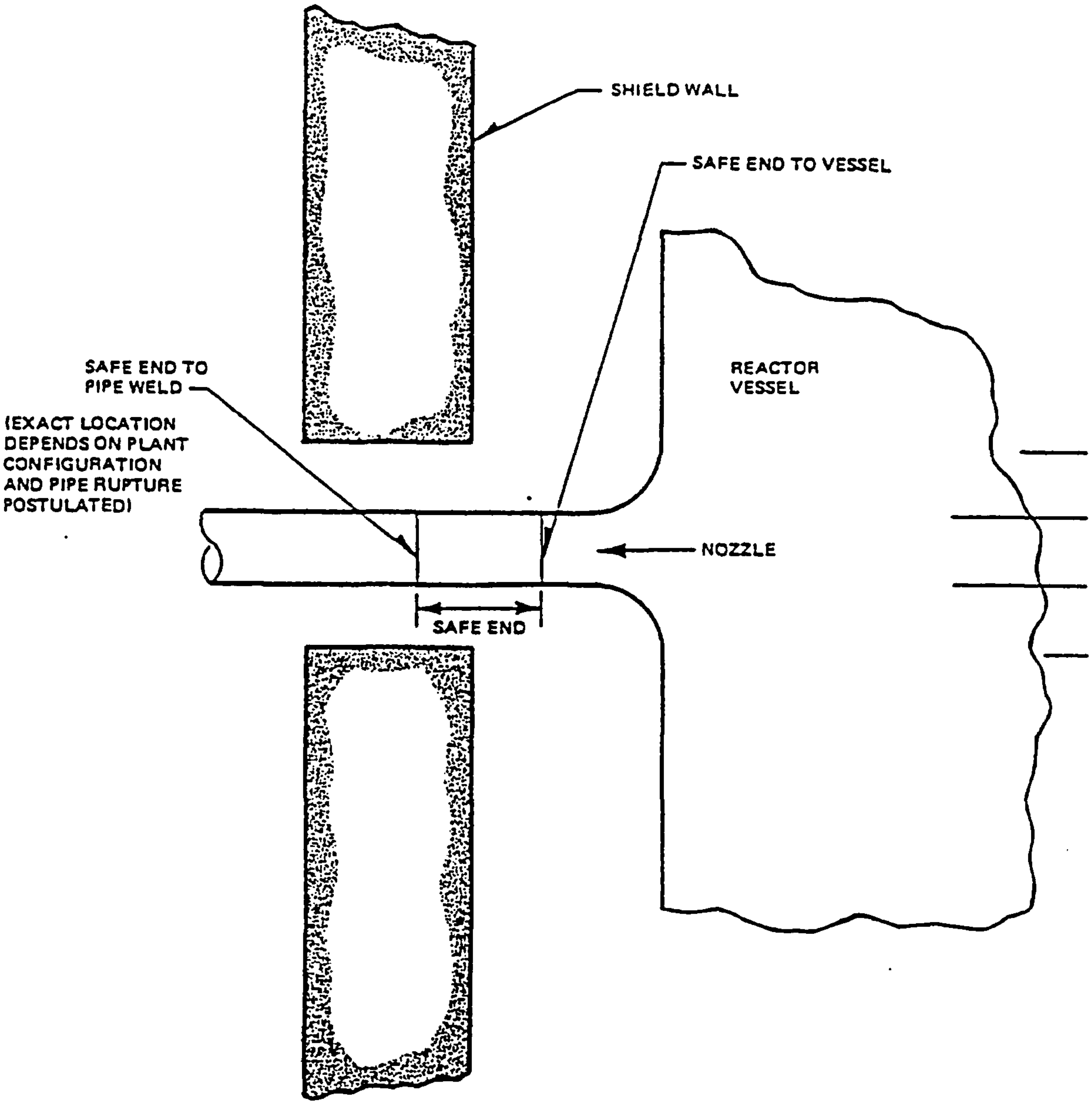


Figure 1. Safe End Break Location

1.2 ENGINEERING DATA FROM PRESSURIZATION OF THE ANNULUS

Engineering data are needed from the purchaser for NSSS equipment evaluations from sub-compartment pressurization for recirc break and from subcompartment pressurization, jet reaction, jet impingement and pipe whip restraint loads for feedwater break. These forces are shown schematically in Figure 2. If any other break is found governing, engineering data for the above four loads is needed for that break. The load data shall be supplied in computer decks. Format requirements are given in Table 1. The subcompartment pressurization data shall be supplied as a pressure time history for each subcompartment zone as typically shown in Figure 3. The jet reaction, jet impingement and pipe whip restraint loads shall be supplied as a force time history at a node. Written description shall be supplied of time step and nodal point location where jet reaction, jet impingement and pipe whip restraint loads are acting on the reactor pressure vessel or shield wall.

In addition to pressure time histories, the purchaser shall provide the following:

(I) A plot for each pressure time-history. (These plots will be used as a data check of card deck arrangement and completeness.)

(II) Detailed description of structural math model showing nodalization of biological shield wall, shield wall to pedestal connection, pedestal, diaphragm floor and other pertinent structures or restraints which could influence or resist annulus pressurization or related phenomena forces (See Figure 2). All necessary details to construct a dynamic model (including mass, stiffness, structural damping parameters and nodal coordinates) should be inlcuded. Applicability of shield wall and pedestal model to the frequency response inherent to annulus pressurization should be demonstrated. The horizontal model supplied for use with seismic analyses could apply with slight modifications (if needed) or refinement of nodal points in the biological shield wall region. An equivalent beam model is to be supplied for BWR 4 and 5 and a shell model for BWR 6.

(III) Detailed engineering drawings of RPV support pedestal and biological shield wall together with material properties of steel and concrete portions.

(IV) All other data requirements of NEDO-24547 shall be met.

1.3 PRESSURE (FORCE) TIME-HISTORY

In order to evaluate the effects from these pressures on the vessel internals, vessel skirt, piping attached to the vessel, vessel to pedestal and shield wall interface connections, the computer code RELAP-4 can be used to generate the pressures within the annulus. User specified maximum and minimum

Table 1

STANDARDIZATION OF DATA FOR NSSS DESIGN ADEQUACY EVALUATIONS

To minimize conversion work and additional verification, the data received for NSSS design adequacy evaluations are desired on cards or tapes* using the following format:

1. Heading of input time history (optional)
2. Heading of the following volume pressure time history (optional)
3. T1 P1 T2 P2 .... 8F10.0
4. Heading of next volume pressure time history (optional)
5. T1 P1 T2 P2 8F10.0
6. Repeat for all volume pressure time histories

*If magnetic tapes are used the following restrictions apply:

- No header labels or record control words.
- Data blocks are to be separated by inter record gaps.
- Multiple files with intermittent file marks separating each of the files may be used.
- Tape format is to be 7 track with 800 BPI or 9 track with 1600 BPI. (9 track preferred; with 800 BPI - even parity is required).
- Data to be EBCDIC or BCD format.
- Data to be presented in 80 character (Card Image) logical records.

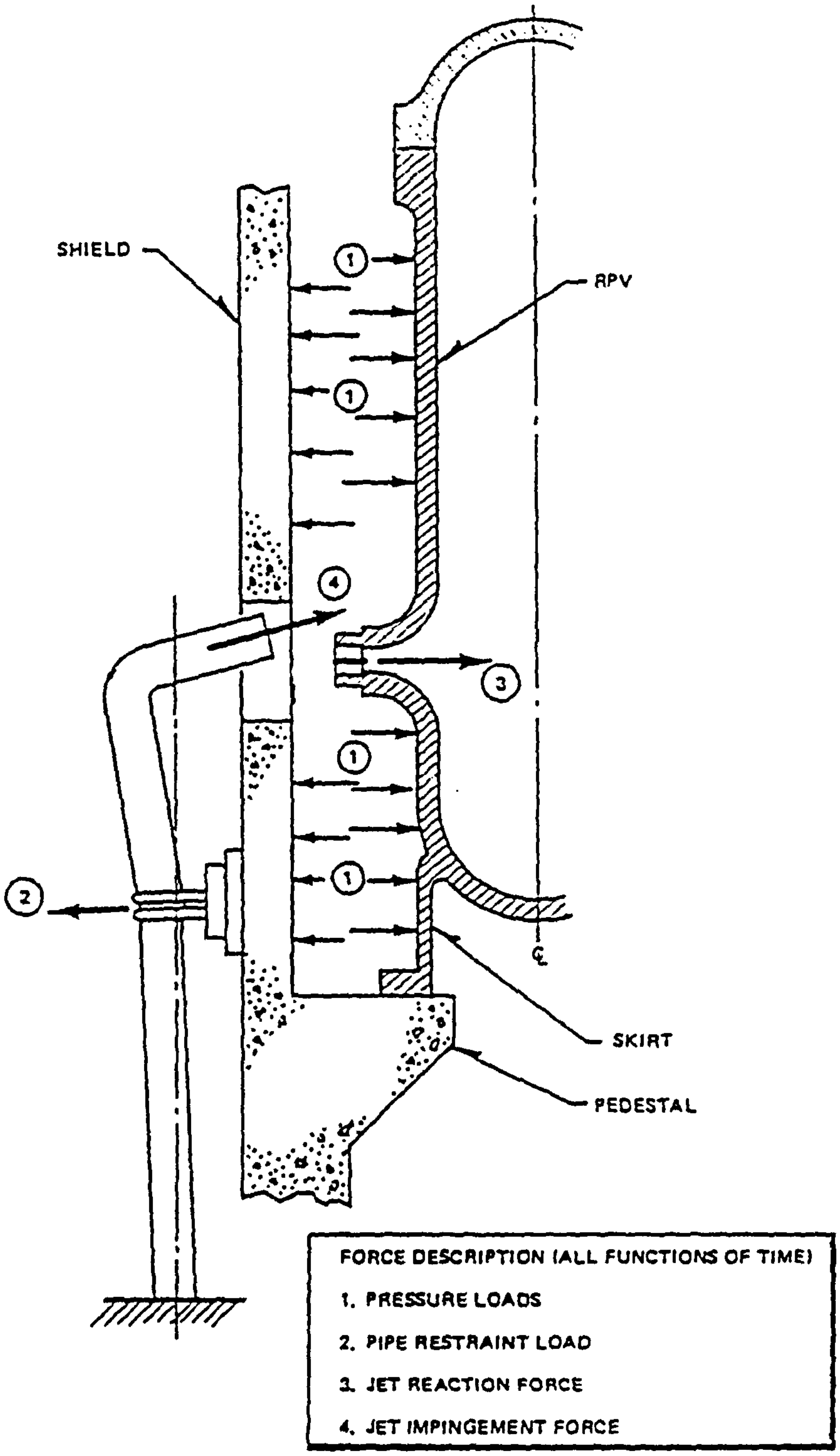


Figure 2. Loading Description

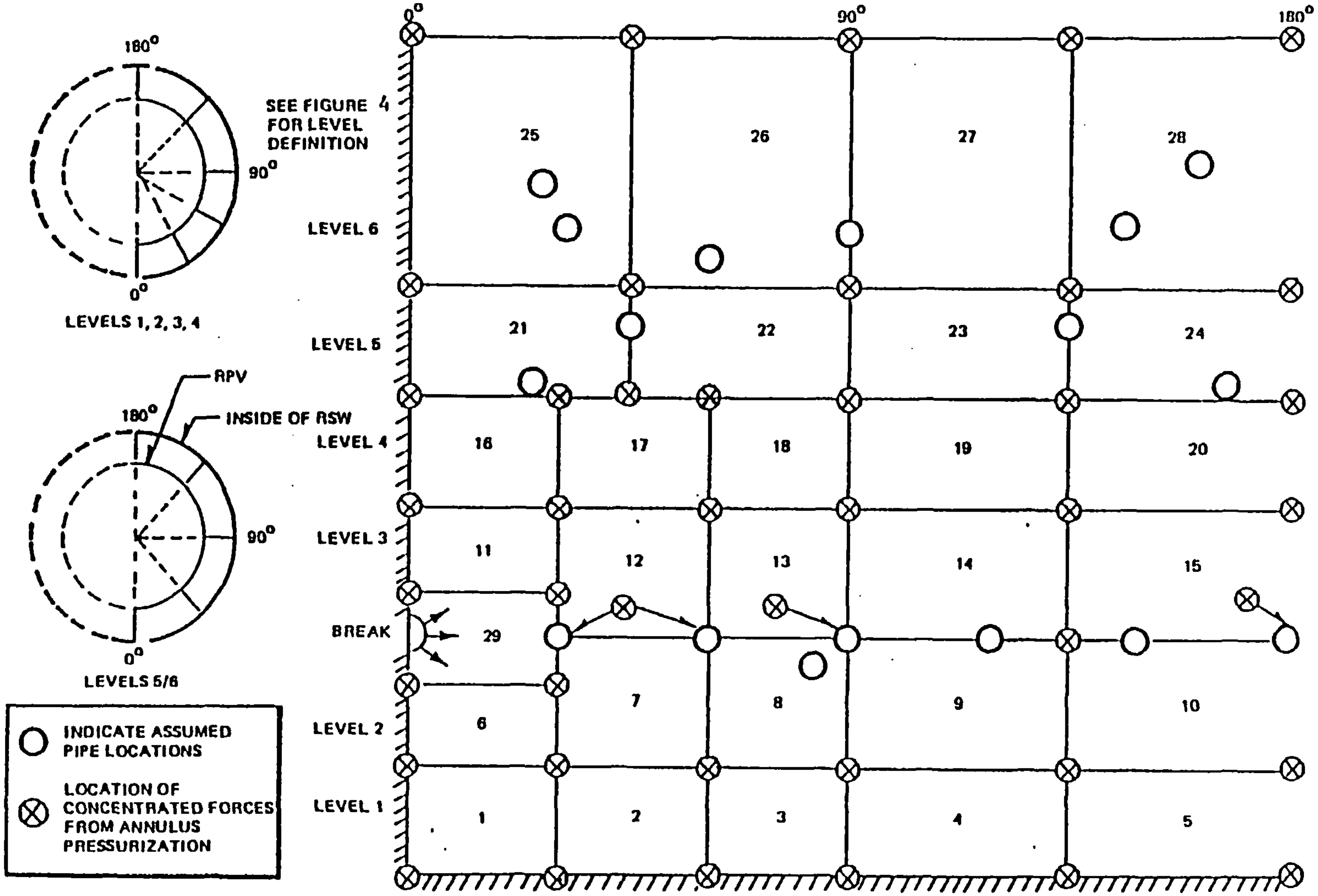
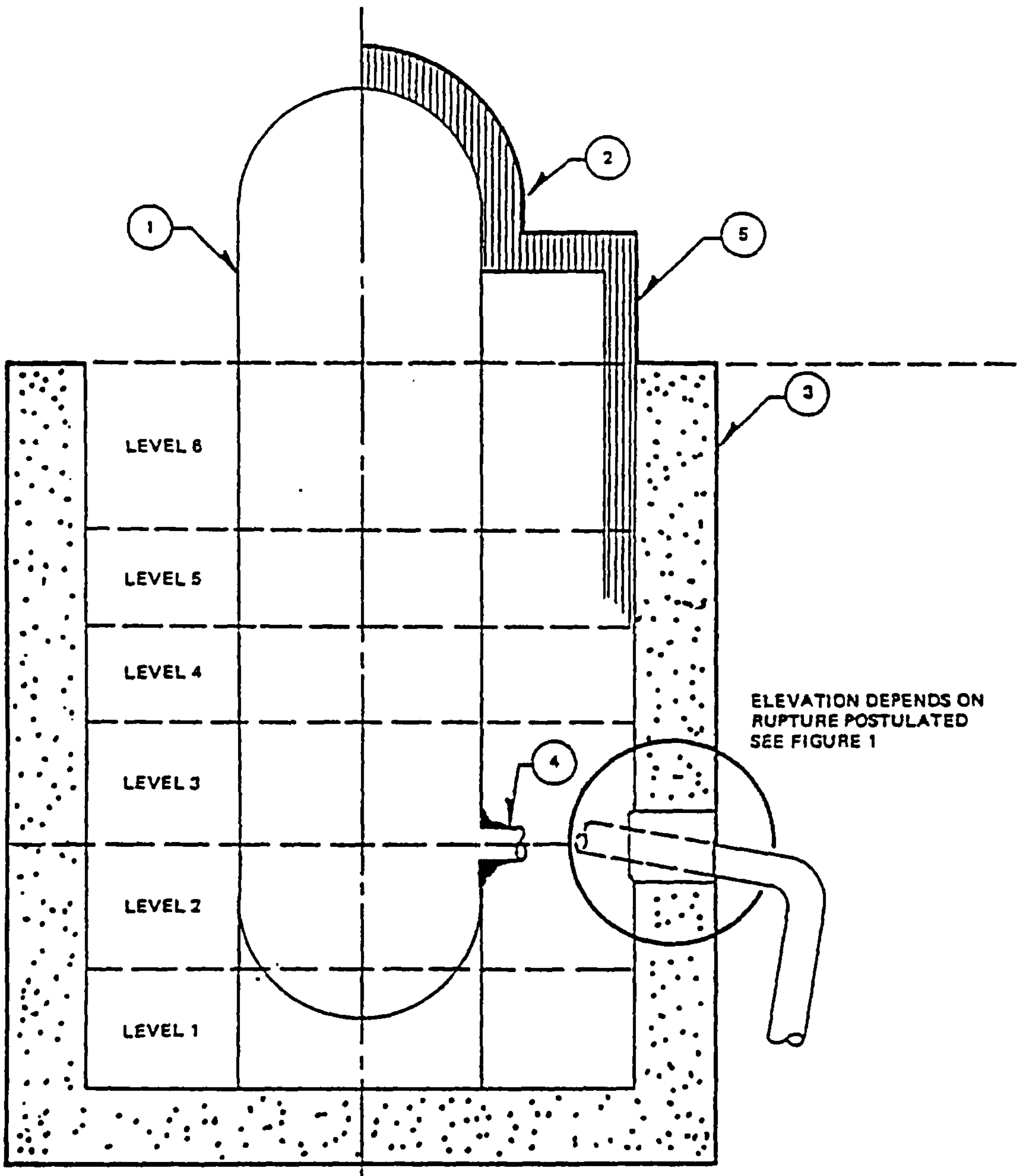


Figure 3. Typical Subcompartment Zones



① REACTOR PRESSURE VESSEL

② INSULATION

③ REACTOR SHIELD WALL

④ BREAK NOZZLE LOCATION DEPENDS ON
PLANT CONFIGURATION (SEE FIGURE 1)

⑤ ACCESS PANELS

Figure 4. General Arrangement

time steps as well as time duration should be so chosen as to avoid instability and large fluctuations in calculated time step. The user should comply with the recommendations for time step limits described in the RELAP documentation. A nodal sensitivity study should be performed for each analysis to ensure convergence. The RELAP-4 user is required to define a nodalized model of the subcompartment to be analyzed and to provide certain information about both the nodes and the internodal flow paths as well as the mass and energy release consequent to a pipe break. In addition, the code provides certain options concerning the manner in which a particular calculation is performed (e.g., compressible versus incompressible flow) and it is the user's responsibility to make the selection. As indicated on Figure 3, only one-half of the annulus is shown because of the circumferential symmetry of the annulus. Any symmetry assumption is the responsibility of the A/E. It should be noted that the insulation could be conservatively considered to remain in place for volume and flow area calculations. The wall friction loss may be calculated internally by the RELAP-r code and is determined as shown in the RELAP-4 manual. Because there is two-phase flow present, the option to multiply this loss by a two-phase loss coefficient index might be used. The magnitude of this multiplier is determined by the code as explained in the RELAP-4 manual.

In order to account for flow losses due to pipes crossing the annulus, the nodal/junction network may be laid out so that a maximum number of pipes would fall on the junctions. If a pipe does not fall on a junction, then it might be projected to the nearest junction. Pipes which could influence flow in both vertical and horizontal directions might be projected in both directions to two different junctions. The areas of junctions on which pipes project should be reduced by the cross-section area of the pipe (width of annulus times diameter of the pipe).

For fluid traveling horizontally around the vessel, an additional flow loss might be considered because of flow direction changes. These values could then be added to pipe loss values and input to RELAP-4 via input variables "FJUNF" and "FJUNR".

Note the above code comments are only recommendations, and the user must use judgements to develop the methods required to obtain the pressure data.

To completely address structural loads on the vessel skirt, and interface of pedestal to vessel connection, RPV internals and other piping systems, the jet reaction, jet impingement and pipe whip restraint loads must be considered in conjunction with the above described pressure loads. These additional loads should also be incorporated in the biological shield wall and interface of pedestal to shield wall connection evaluations. These loads are graphically illustrated in Figure 2.

2. SHORT TERM MASS ENERGY RELEASE

2.1 GENERAL

The purpose of this procedure is to document the method by which short term mass release rates are calculated. The flowrates which could be produced by a primary system line break for the first five seconds include the effects of inventory and subcooling. Optionally, credit may be taken for a finite break opening time.

2.2 ASSUMPTIONS

a. The initial velocity of the fluid in the pipe is zero. When considering both sides of the break, the effects of initial velocities would tend to cancel out.

b. Constant reservoir pressure.

c. Initially fluid conditions inside the pipe on both sides of the break are similar.

d. Wall thickness of the pipe is small compared to the diameter.

e. Subcompartment pressure ≈ 0.

f. Quasi-steady mass flux is calculated using the Moody steady slip flow model with subcooling.

2.3 NOMENCLATURE (See Figure 5)

A_{BR} - Break area

A_L - Minimum cross-sectional area between the vessel and the break. This is the sum of the areas of parallel flow paths.

c - Sonic speed in the fluid (see Figure 6)

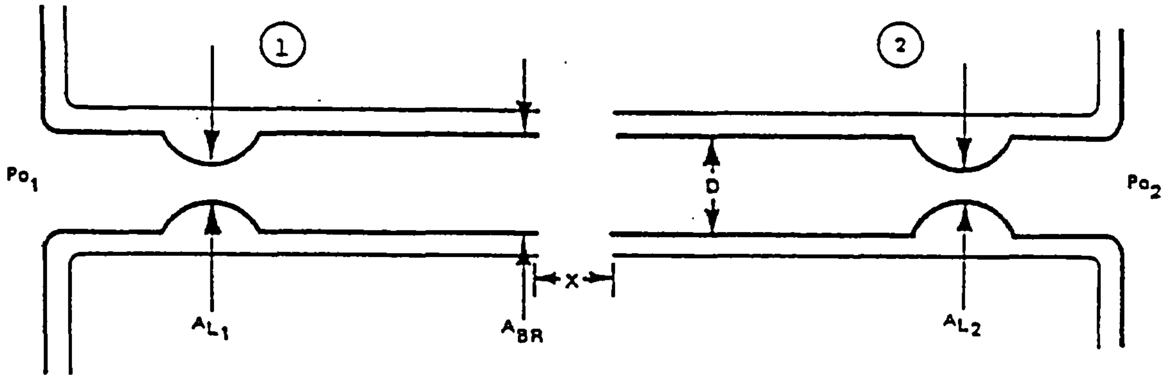


Figure 5. Geometry

D - Pipe inside diameter at the break location

F_I - Inventory flow multiplier

$F_I = 0.75$ for saturated steam

$F_I = 0.50$ for liquid

g_c - Proportionality constant ($= 32.17$ lbm-ft/lbf-sec^2)

G - Mass flux

G_c - Maximum mass flux (see Figure 7)

h_o - Reservoir or vessel enthalpy

h_p - Initial enthalpy of the fluid in the pipe

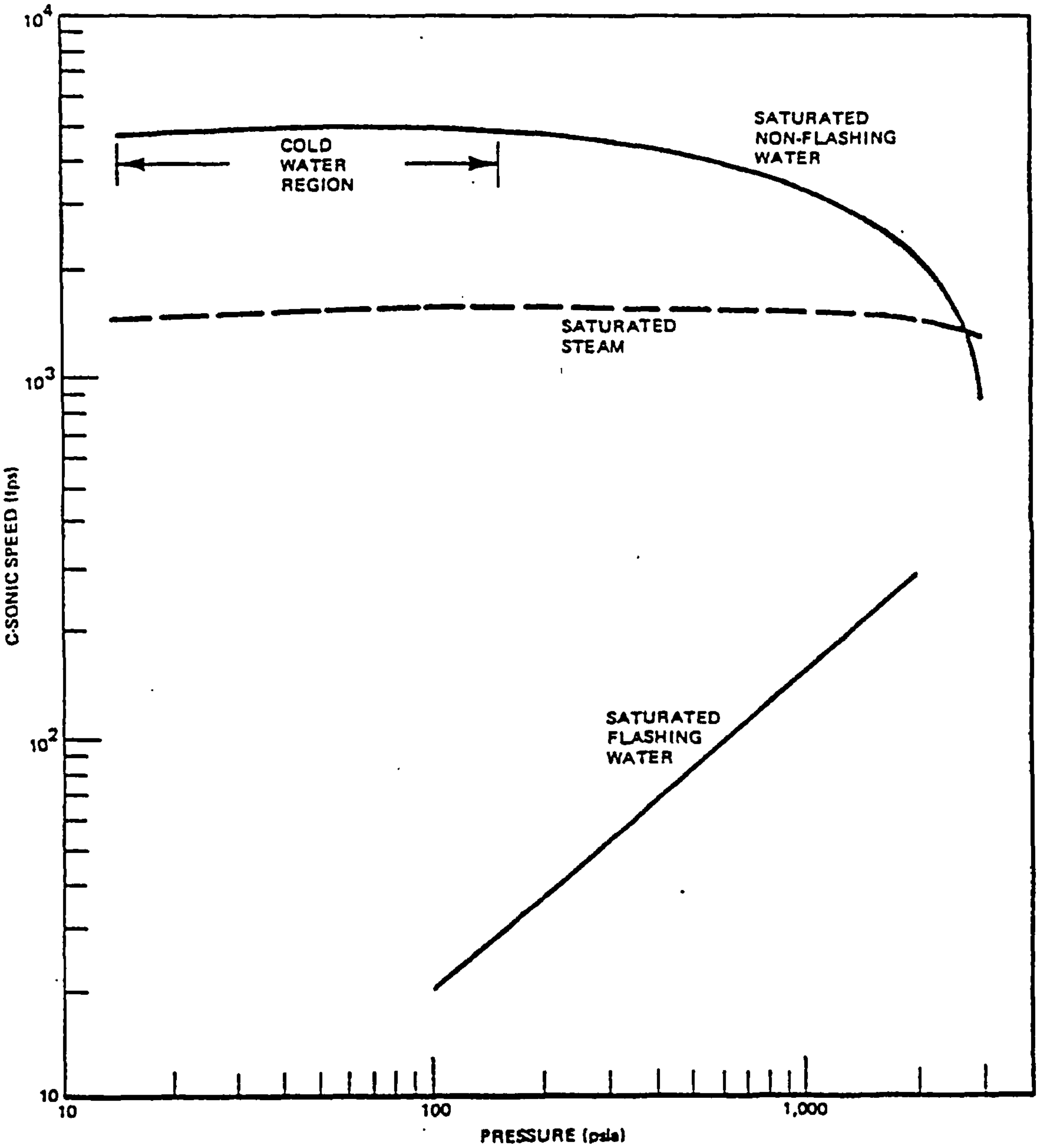


Figure 6. Wave Speed

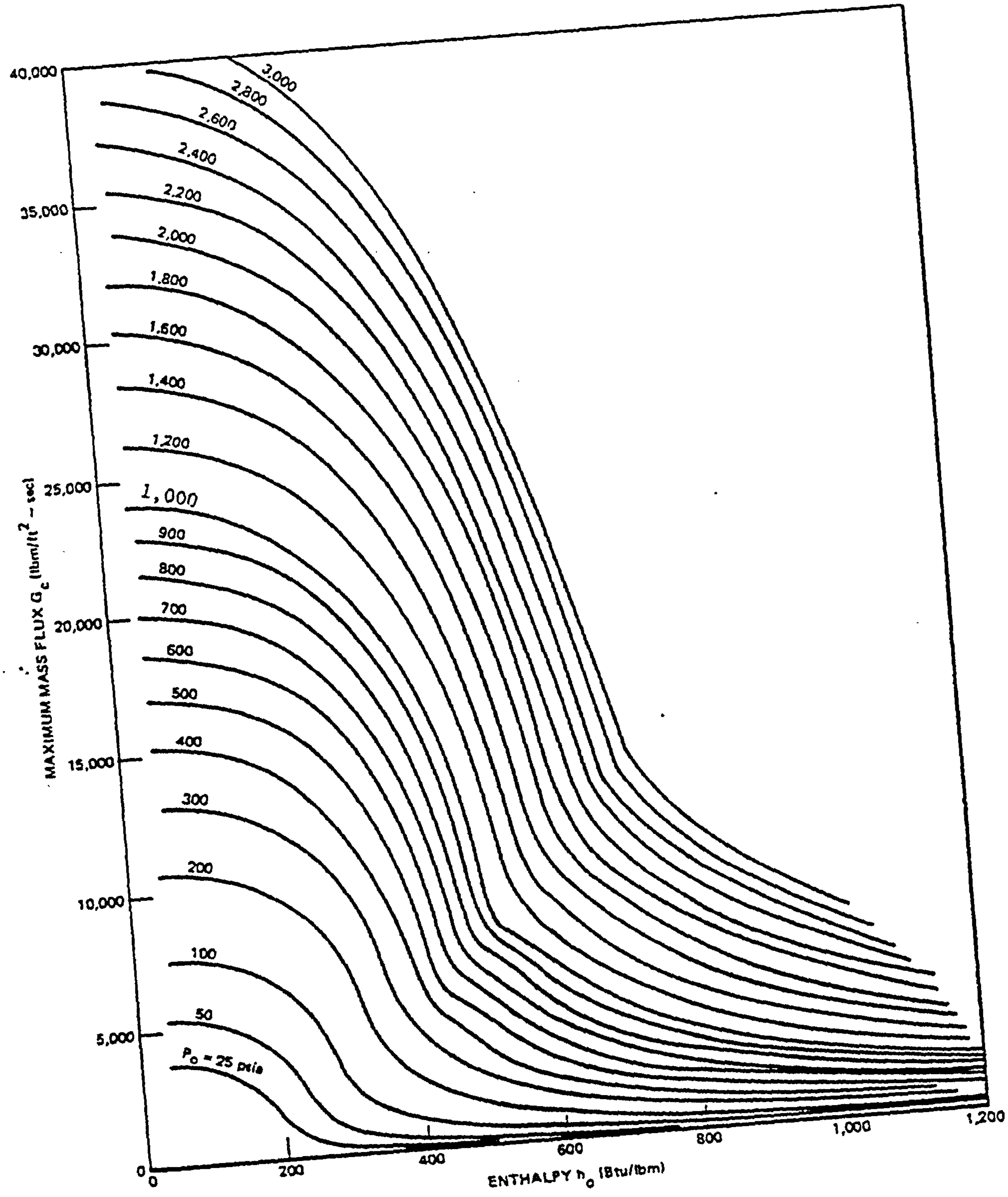


Figure 7. Mass Flux, Moody Steady Slip Flow

L_I - Inventory length. The distance between the break and the nearest area increase or A_L whichever distance is less.

$\dot{M}$ - Mass flowrate

$\dot{M}_I$ - Mass flowrate during the inventory period

P_o - Reservoir or vessel pressure

P_{sat} - Saturation pressure for liquid with an enthalpy of h_p

t - Time

t_I - Length of the inventory period

v - Specific volume of the fluid initially in the pipe

V_I - Volume of the pipe between the break and A_L

X - Separation distance of the break

2.4 INSTANTANEOUS GUILLOTINE BREAK

The following method should be applied to each side of the break and the results summed to determine the total flow.

2.4.1 Inventory Period

Prior to a pipe break, the fluid in the pipe is moving at a relatively low velocity. After the break occurs, a finite time is required to accelerate the fluid to steady state velocities. The length of this time period is conservatively estimated as follows:

a. If $A_L/A_{BR} > F_I$,

the discharge rate will increase from its initial value for each wave round trip from the break. Therefore, the minimum time for the initial discharge rate is obtained conservatively as

$$t_I = \frac{2L_I}{c} \tag{1}$$

b. If $A_L/A_{BR} < F_I$,

the discharge rate will decrease from its initial value. Therefore, it is conservative to permit the initial flow rate until the inventory pipe section is purged, or

$$t_I = \frac{V_I}{A_{BR}\ G\ F_I\ v} \tag{2}$$

where G is calculated as shown in Section 2.7(b) for a large separation distance and $t < t_I$

During this time period, the mass flowrate is calculated as

$$\dot{M}_I = G\ A_{BR}\ F_I \tag{3}$$

2.4.2 Steady State Period

Following the inventory period, the flow is assumed to be choked at the limiting cross sectional flow area.

For $t_I < t < 5.0$ seconds,

$$\dot{M} = A_L\ G \tag{4}$$

2.5 BREAK OPENING FLOWRATE

To calculate flowrate, plant unique computer printout of pipe displacement time histories for postulated recirculation suction pipe ruptures can be obtained from GE.

2.5.1 Inventory Period

The inventory period is determined as described in Section 2.4.1. The flowrate as a function of pipe separation distance is given by

$$\dot{M} = G \pi D X \qquad (5)$$

Where G is obtained by using the methods of Sections 2.7(a) or 2.7(b).

2.5.2 Flowrate

Following the inventory period, equation (5) is used to determine the flowrate where the mass flux, G, is determined from Sections 2.7(a), 2.7(b).

2.6 COMBINED BREAK FLOW

To determine the total flowrate released from the break, the results of Sections 2.4 and 2.5 are compared and whichever produces the smallest flowrate at any time is used (see Figure 8). Both methods produce maximum flowrates based on different limiting areas. The transfer from one curve to the other represents a change in the point where the flow is choked.

2.7 DETERMINATION OF THE MASS FLUX, G

Depending on the time period, fluid conditions, and break separation distance, the mass flux is determined as follows:

$$X_B = \sqrt{1 - (P_{sat}/P_o)}\ (D/2)$$

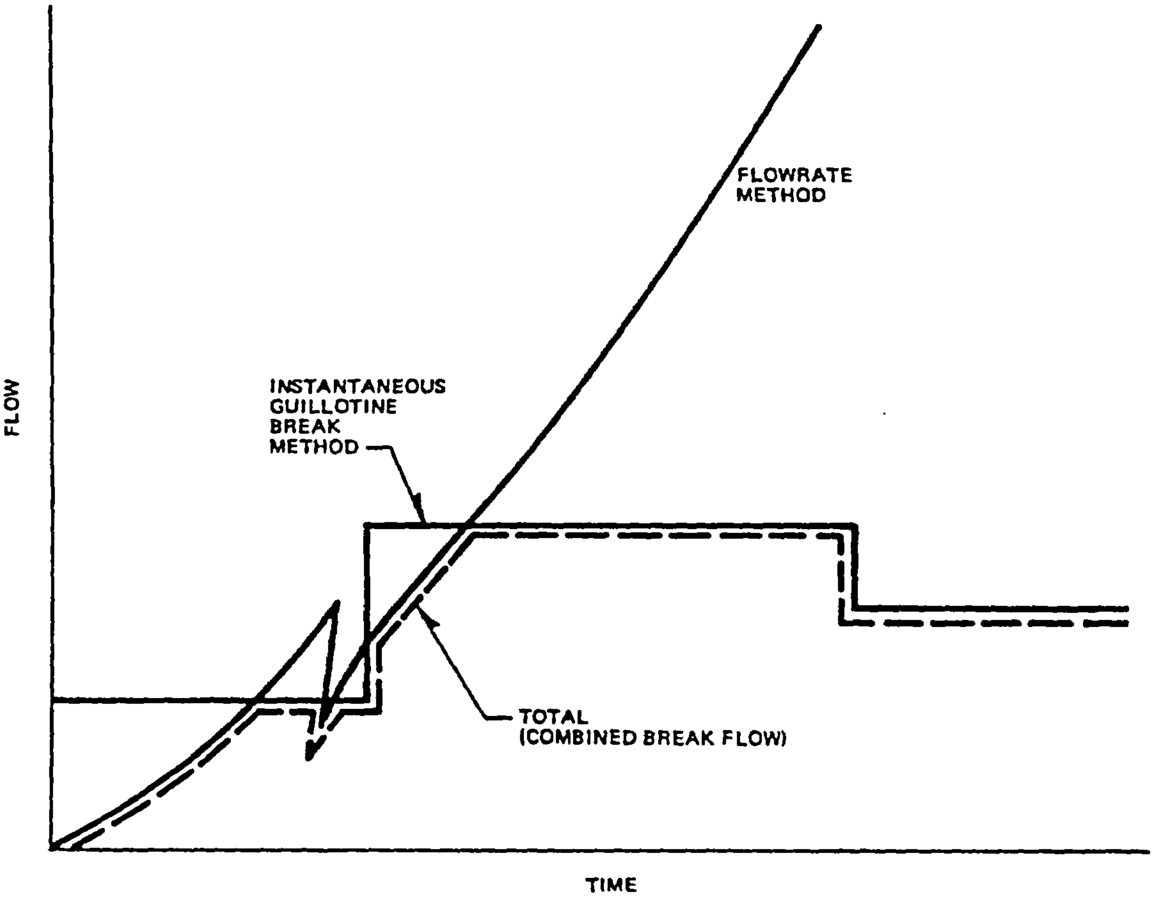


Figure 8. Break Flow vs. Time

a. If $X < X_B$ (see Table 2)

$$G = \sqrt{2g_c\ P_o/v}$$

b. If $X > X_B$ and $t < t_I$ (see Table 2)

$$G = G_c(P_o,\ h_p) \qquad \text{from Figure 7}$$

c. If $X > X_B$ and $t > t_I$ (see Table 2)

$$G = G_c(P_o,\ h_o) \qquad \text{from Figure 7}$$

Note that for complete break separation (Section 2.4) X is always greater than X_B and for saturated water X_B is equal to zero.

2.8 FLOW INTO ANNULUS

For the purpose of analyzing the flow into annulus, credit may be taken for flow which escapes through the wall penetration. If the initial break location is in the annulus region between the wall and the vessel, no flow is assumed to escape through the penetration. If however, it is located within the penetration itself, some of the flow may be assumed to escape. It is recommended that the fraction of the flow which escapes be calculated based on the ratio of the minimum annular flow area between the penetration and pipe surface and between the penetration and the safe-end nozzle.

Table 2

TYPICAL BLOWDOWN INTERVALS

	Time	Area (ft^2) Vessel	Area (ft^2) Pipe	Notes
Break Opening	0-20 msec	0 to 1.798	0 to 1.755	break opens under restraint
Inventory Depletion	0-1.5 sec	1.798	1.755	pipe inventory depletion
Quasi-steady Blowdown	1.5+ sec	1.798	0.440	vessel depressurizes

2.9 RECOMMENDATIONS

Since P_o and h_o vary within the vessel, the mode of selecting P_o and h_o is described below. These are GE recommendations only and the user has the responsibility of calculating G in a conservative manner.

In the case of a recirculation line break, the value of P_o is the steam dome pressure plus the hydrostatic head at the recirculation line nozzle, and h_o is the enthalpy at the core inlet. For containment calculations, GE normally uses P_o and h_o at 102% maximum licensed thermal power. The method of choosing A_{BR}, the break area, and A_R, the limiting area is outlined in Section 3.

In the case of a feedwater line break, the value of P_o to be chosen is the steam dome pressure plus the hydrostatic head at the feedwater sparger. h_o is the core inlet enthalpy while calculating the flow from the vessel side of the break and feedwater line enthalpy while calculating the flow from the pump side of the break. While calculating the quasi steady flow from the vessel side it should be borne in mind that the limiting area occurs in the feedwater sparger.

The following section contains sample calculation for mass and energy release consequent to a recirculation line break following the methodology outlined.

3. ANNULUS PRESSURIZATION MASS ENERGY RELEASE (SAMPLE CALCULATIONS)

3.1 SAMPLE CALCULATION FOR RECIRCULATION LINE BREAK

The assumed geometry for a recirculation line break is shown in Figure 9. The break is assumed to be on the suction side.

3.2 INSTANTANEOUS OPENING TIME

3.2.1 Vessel Side

a. Determination of inventory time. For subcooled liquid, $F_I = 0.5$

$$A_L/A_B = 1.798\ \text{ft}^2/1.798\ \text{ft}^2 = 1.0 > F_I$$

Therefore

$$t_I = \frac{2L_I}{C} = \frac{2(38\ \text{in})}{3200\ \text{ft/sec}} \times \frac{\text{ft}}{12\ \text{in}} = 0.00198\ \text{sec}$$

b. Inventory Flow Rate

$$\dot{m}_I = G\ A_{BR}\ F_I = \left(9020\ \frac{\text{lbm}}{\text{sec/ft}^2}\right) (1.798\ \text{ft}^2)\ (0.5)$$

$$= 8110\ \text{lbm/sec}$$

c. Steady State Flow

$$\dot{m}_{ss} = G\ A_L = \left(9020\ \frac{\text{lbm}}{\text{sec-ft}^2}\right) (1.798\ \text{ft}^2)$$

$$= 16200\ \text{lbm/sec}$$

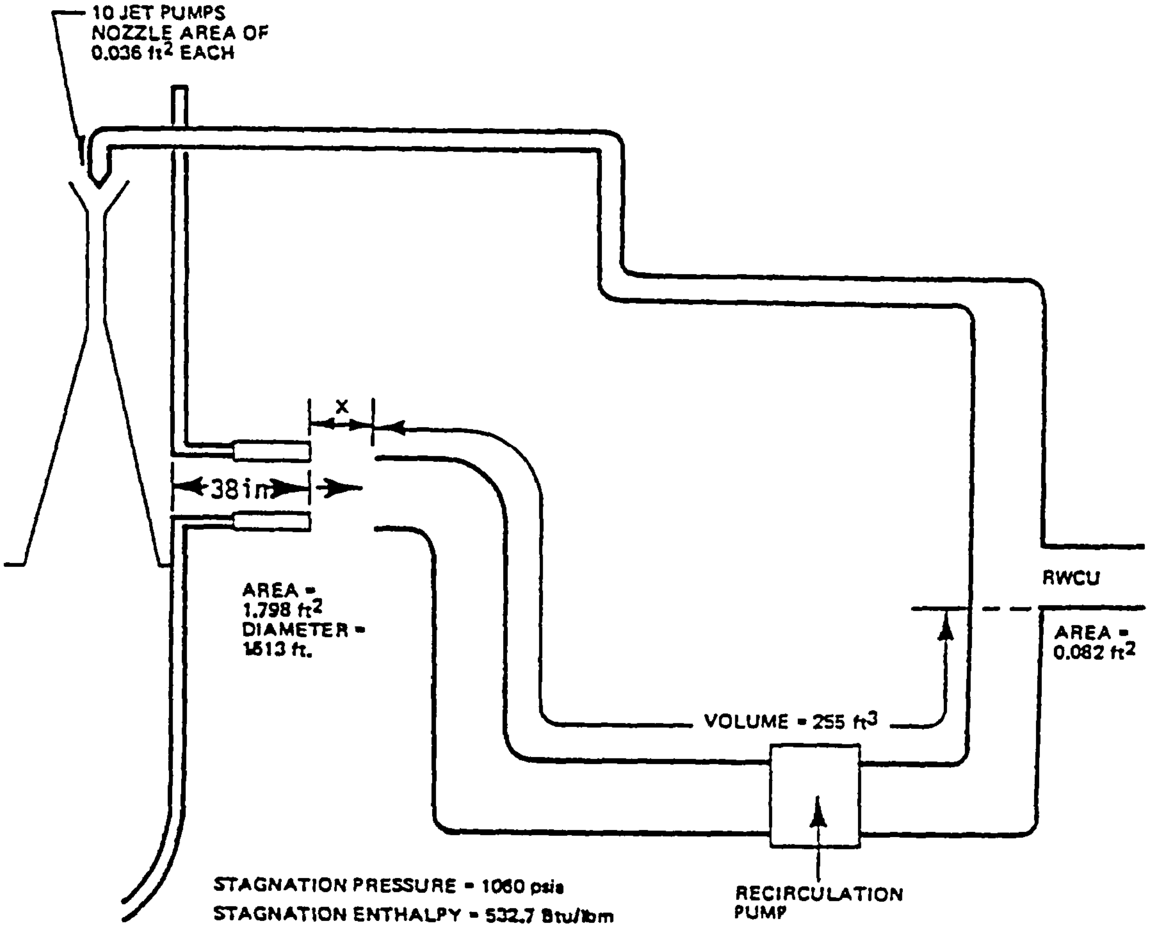


Figure 9. Assumed Geometry

3.2.2 Discharge Side

a. Inventory time. The limiting area between the break and the vessel is either the break area or the summation of the jet pump throat areas and the RWCU line area. The total area of the jet pumps is

$$A_{PUMPS} = 10(0.036\ ft^2) = 0.36\ ft^2$$

$$A_{RWCU} = 0.082\ ft^2$$

$$A_{TOTAL} = 0.442$$

Therefore,

$$AL/A_{BR} = 0.442\ ft^2/1.798\ ft^2 = 0.25 < F_I$$

$$t_I = \frac{V_I}{A_{BR}\ G\ F_I\ v}$$

$$= \frac{255\ ft^3}{(1.798\ ft^2)\left(9020\ \frac{lbm}{ft^2\text{-}sec}\right)(0.5)\left(0.021\ \frac{ft^3}{lbm}\right)}$$

$$= 1.50\ \text{seconds}$$

b. Inventory Flow Rate

$$\dot{m}_I = G\ A_{BR}\ F_I = \left(9020\ \frac{lbm}{sec\text{-}ft^2}\right)(1.798\ ft^2)\ (0.5)$$

$$= 8110\ lbm/sec$$

c. Steady State

$$\dot{m}_{ss} = \left(9020\ \frac{lbm}{sec\text{-}ft^2}\right)(0.442\ ft^2) = 3990\ lbm/sec$$

3.2.3 Total Flow

The results of sections 3.2.1 and 3.2.2 are summed to determine the total flow rate. (See Figure 10)

3.3 FINITE BREAK OPENING TIME

3.3.1 Determination of Inventory Time

For this case, it is assumed that the stagnation enthalpy in the pipe is the same as that in the vessel. Therefore, the inventory time has no effect on this portion of the analysis.

3.3.2 Mass Flow Rate

The saturation pressure for fluid at an enthalpy of 532.7 Btu/lbm is 938 psia. Therefore,

$$X_B = \sqrt{1 - (938/1060)}\ (D/2)$$

$$= \sqrt{1 - (938/1060)}\ \frac{1.513\ \text{ft}}{2}$$

$$= 0.257\ \text{ft} = 3.08\ \text{in}$$

From the data in Table 3, this occurs at about 0.0151 seconds. During this time, the mass flux will be,

$$G = \sqrt{\frac{2g_c\ P_o}{v}}$$

$$= \sqrt{\frac{(2)(32.17\ \text{lbm-ft/lbf-sec}^2)(1060\ \text{lbf/in}^2)(144\ \text{in}^2/\text{ft}^2)}{(0.021\ \text{ft}^3/\text{lbm})}}$$

$$= 21600\ \text{lbm/sec-ft}^2$$

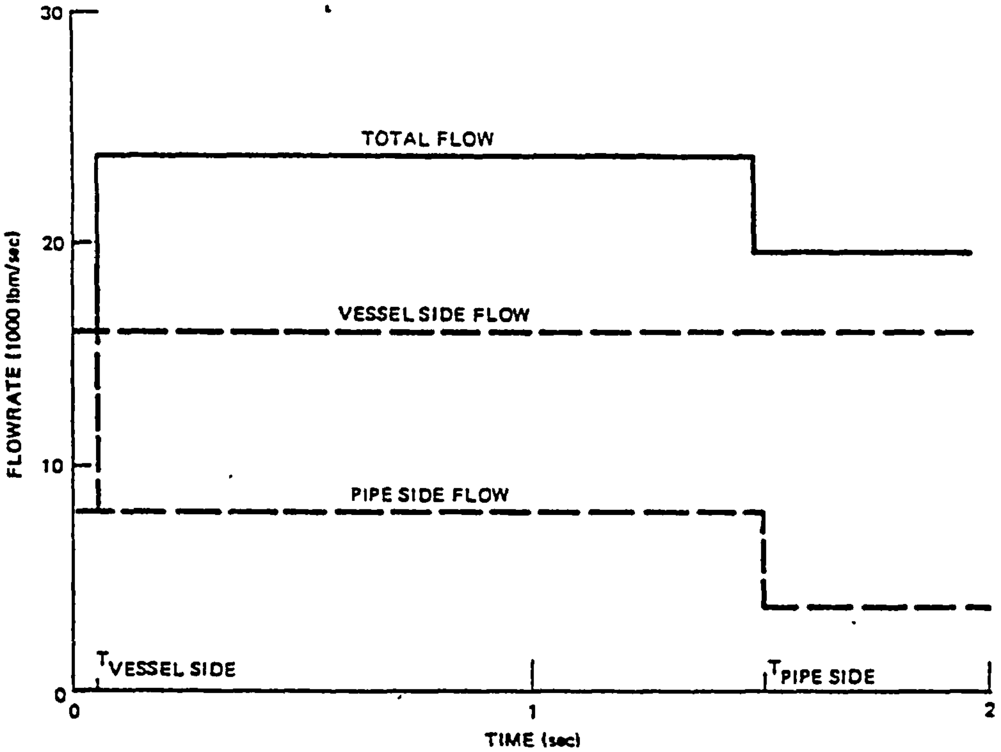


Figure 10. Breakflow with Instantaneous Complete Pipe Separation

Therefore, the mass flowrate is

$0 < t < 0.0151$ sec,

$$\dot{m} = G\pi DX = \pi \left(\frac{21600 \text{ lbm.}}{\text{sec-ft}^2}\right) (1.513 \text{ ft}) \left(\frac{\text{ft}}{12 \text{ in}}\right) X$$

$$= 8560X \text{ lbm/sec}$$

Where X is in inches.

Table 3

PIPE DISPLACEMENTS
(Data Used in Sample Calculations)

```
EFFECTIVE                 LENGTH FROM               RESTRAINT
CLEARANCE                 RESTRAINT TO              LOADING
(INCHES)                  BREAK(FT)                 DIRECTION

  8.973                      2.780                  0 DEGREES

PIPE BENDING              PIPE ROTATION             MAX. ALLOWABLE
STRAIN                    STABILITY                 BENDING MOMENT
LIMIT( IN/IN )            LIMIT(DEGR.) .            (FT-LBS)

 8.653E-02                 7.3509                      980800.

IMPACT VELOCITY=  39.87 FT/SEC            IMPACT TIME= 0.0230 SECONDS

ANGLE OF ROTATION OF BEAM LENGTH L2 EXCEEDS
    ANGLE OF ROTATION AT INSTABILITY.  HINGE 2 =  0.1094E 02 DEGREES

NUMBER OF BARS            DEFL. OF STRUC.           DEFL. OF RESTR.                  RELATIVE DEFL.             TOTAL DEFL.
COMPOSING THE             IN DIRECTION OF           IN DIRECTION OF                  OF PIPE END                OF THE PIPE END
RESTRAINT                 THRUST (IN.)              THRUST (IN.)                     IN THE DIRECTION OF THE THRUST (IN.)

       8                   0.8506                    1.0223                          6.3030                     16.8276

FORCE ON RESTR.           FORCE ON STRUC.           TIME  AT PEAK                    DEFL. TIME                 TOTAL
IN DIRECTION OF           IN DIRECTION OF           DYNAMIC LOAD                     FOR PIPE END               TIME OF
THRUST (LBS.)             THRUST (LBS.)             (SECONDS)                        (SECONDS AFTER IMPACT)     MOVEMENT

  850604.                  850604.                   0.0326                          0.0242                     0.0472

TOTAL ENERGY              ENERGY ABSORBED           ENERGY ABSORBED                  ENERGY ABSORBED            TOTAL ABSORBED
ABSORBED BY               BY THE                    BY THE                           BY THE                     ENERGY
THE RESTRAINT             STRUCTURE                 BOTTOM HINGE                     RESTRAINT HINGE            (FT-LBS)
(FT-LBS)                  (FT-LBS)                  (FT-LBS)                         (FT-LBS)

   97410.                  37652.                     6057.                          227559.                    370078.

ENERGY ABSORBED            RESTRAINT                 RESTRAINT                       PIPE DEFL.                 PIPE DEFL.
BY THE                    LOAD (PEAK)               LOAD (STATIC)                    AT RESTRAINT               AT THE BREAK
TOP HINGE                   COMPONENTS (LBS)          COMPONENTS (LBS)               COMPONENTS (IN.)           COMPONENTS (IN.)
(FT-LBS)                  PD1              PD2      PS1              PS2           XR1            XR2         XP1            XP2

      0.                 850604.           0.      162292.           0.            8.4459          0.         16.5275         0.


*** EXCEPT FOR THE RESTRAINT LOAD COMPONENTS PD1 AND PD2, ALL VARIABLES
    BELOW ARE IN A DIRECTION PARALLEL TO THE BLOWDOWN FORCE  ***

   TIME     PIPE DISPL.   PIPE VELOCITY   PIPE ACCELERN    NET  DISPL.   TOTAL DISPL     RESTR  LOAD      RESTR. LOAD     BLOWDOWN
            AT RESTRAINT  AT RESTRAINT    AT RESTRAINT       OF END        OF END        COMP. PD1        COMP. PD2        FORCE
   (SEC)     (INCHES)      (FT/SEC)        (FT/SEC2)       (INCHES)       (INCHES)       (POUNDS)         (POUNDS)        (POUNDS)

 0.00601    8.873E-01     1.278E 01       1.629E 03        0.             6.624E-01          0.              0          [illegible]

 0.00920    1.195E 00     1.792E 01       1.600E 03        0.             1.305E 00          0.              0          [illegible]

 [illegible] 1.79?E 00   2.1??E 01       1.587E 03        0              1.857E 00          0.              0          [illegible]
```

Table 3 (Continued)

PIPE DISPLACEMENTS

0.01378	2 389E 00	2.518E 01	1.675E 03	0.	2.609E 00	0.	0.	284617
0.01564	2.987E 00	2.811E 01	1.673E 03	0.	3.262E 00	0.	0.	284617
0.01732	3.584E 00	3.076E 01	1.669E 03	0.	3.914E 00	0.	0.	284617
0.01887	4.181E 00	3.318E 01	1.665E 03	0.	4.567E 00	0.	0.	284617
0.02032	4.778E 00	3.546E 01	1.661E 03	0.	5.219E 00	0.	0.	284617
0.02168	5.376E 00	3.757E 01	1.659E 03	0.	5.871E 00	0.	0.	284617
0.02297	5.973E 00	3.957E 01	1.656E 03	0.	6.524E 00	0.	0.	284617
0.02397	6.442E 00	3.813E 01	-2.731E 03	2.623E-02	7.064E 00	383107.	0.	284617
0.02497	6 878E 00	3.453E 01	-4.082E 03	1.234E-01	7.637E 00	619109.	0.	284617
0.02597	7.268E 00	3.016E 01	-4.535E 03	2.907E-01	8.229E 00	736607.	0.	284617
0.02697	7.602E 00	2.553E 01	-4.683E 03	5.257E-01	8.820E 00	813631.	0.	284617
0.02797	7.880E 00	2.083E 01	-4.702E 03	8.186E-01	9.426E 00	864718.	0.	284617
0.02897	8.102E 00	1.618E 01	-4.668E 03	1.166E 00	1.002E 01	900511.	0.	284617
0.02997	8.268E 00	1.153E 01	-4.581E 03	1.539E 00	1.059E 01	926118.	0.	284617
0.03097	8.378E 00	7.002E 00	-4.485E 03	1.930E 00	1.114E 01	940846.	0.	284617
0.03197	8.437E 00	2.677E 00	-4.375E 03	2.455E 00	1.167E 01	948998.	0.	284617
0.03250	8.446E 00	0.	0.	2.762E 00	1.199E 01	950604.	0.	284617

After 0.0151 seconds, $G = 9020\ \mathrm{lbm/sec\text{-}ft^2}$,

$t > 0.0151$ seconds,

$$\dot{m} = G\pi DX$$

$$= \pi \left(\frac{9020\ \mathrm{lbm}}{\mathrm{sec\text{-}ft^2}}\right) (1.513\ \mathrm{ft}) \left(\frac{\mathrm{ft}}{12\ \mathrm{in}}\right) X$$

$$= 3580X\ \mathrm{lbm/sec}$$

Where X is in inches. See Figure 11.

3.4 TOTAL BREAK FLOW

The results of Sections 3.2 and 3.3 are shown in Figure 12. At any time, the minimum flow rate of either Section 3.2 or 3.3 is used.

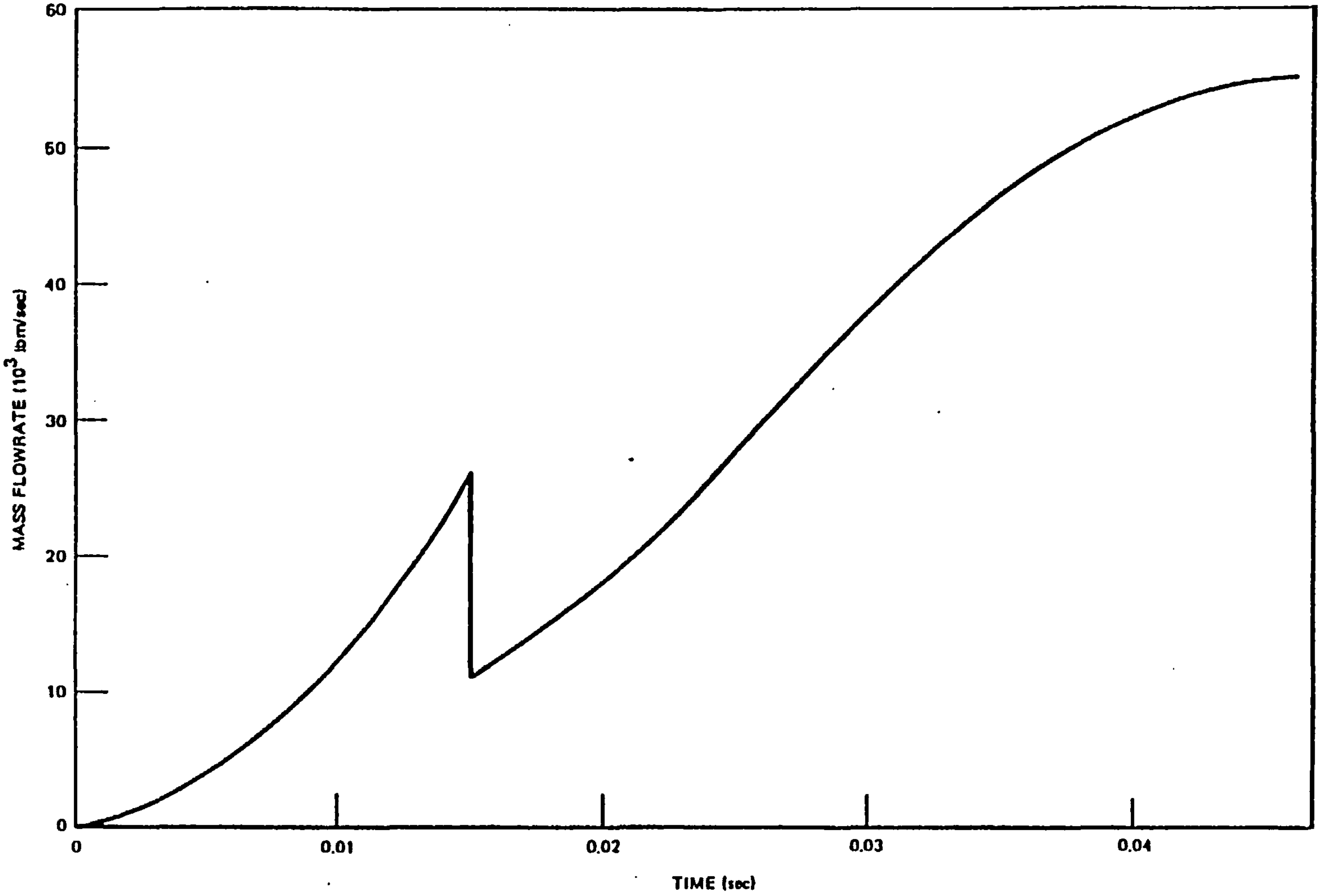


Figure 11. Finite Break Opening Time Flowrate, Recirculation Line Break

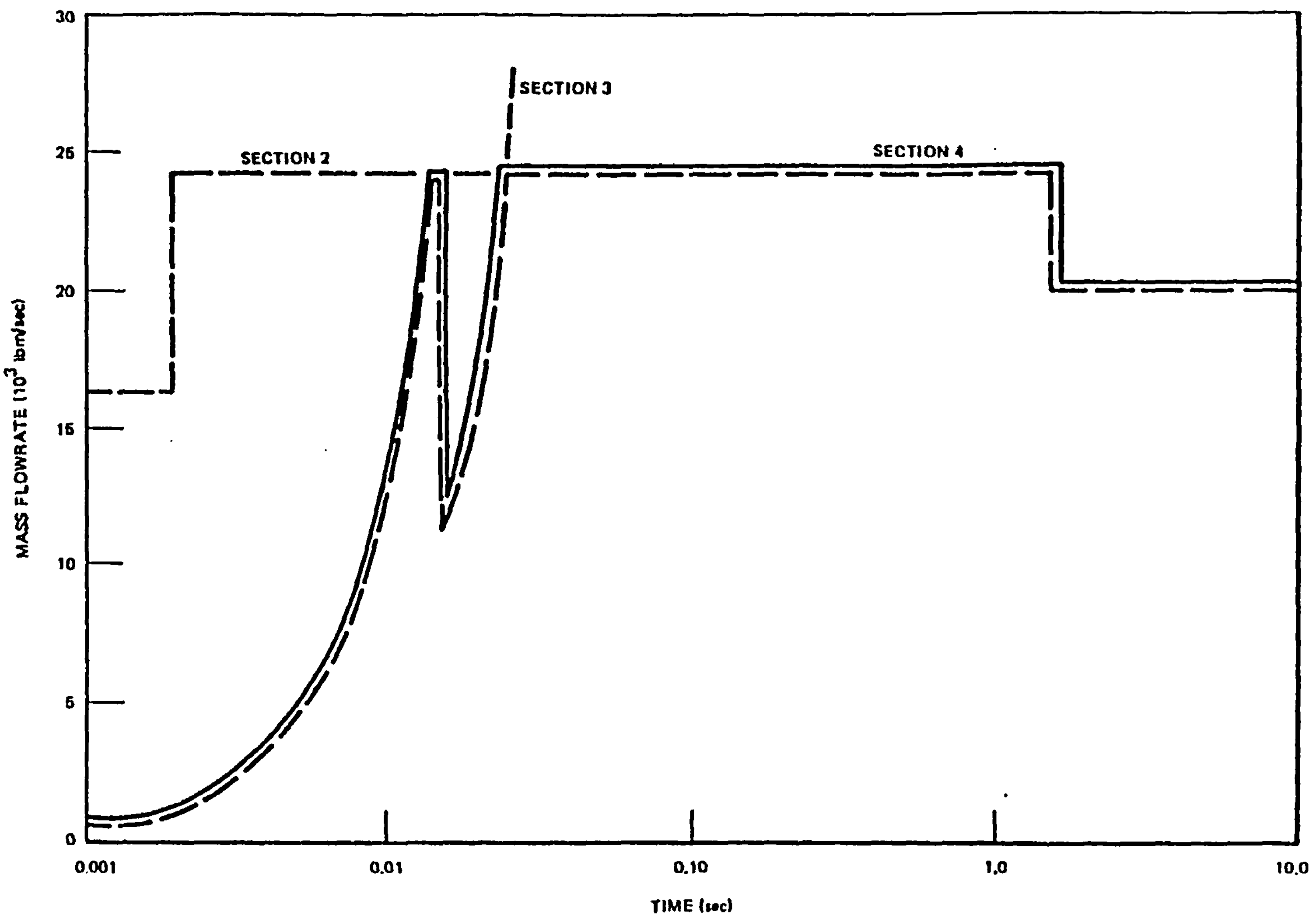


Figure 12. Combined Flowrate - Recirculation Line Break

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