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COMPRESSIBLE ANALYSIS OF INLET PLENUM PRESSURE RISE DUE TO SODIUM BOILING IN FUEL SUBASSEMBLIES DURING PUMP COASTDOWN OF AN LMFBR

by

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ABSTRACT

The effect of sodium compressibility and steel elasticity on the rise in inlet plenum pressure occurring during boiling in a loss-of-flow accident in an LMFBR has been investigated using the PTA-2 code. These effects do not seem large enough to require consideration in accident analysis. The pressure rise is less for pool than for loop designs.

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A2015	Reactor Safety Modeling and Assessment

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EXECUTIVE SUMMARY

The rise of inlet plenum pressure in an LMFBR because of sodium boiling and consequent downward sodium slug ejection can have an important inhibiting effect on the velocity of such ejection, which might in turn have an important effect on an accident sequence. In the SAS code compressibility of the sodium in the inlet plenum is used to smooth pressure fluctuations in calculating the coupling of the in-core sodium flow to the sodium flow in the primary loop. It seemed to be of interest to investigate whether sodium compressibility and structural elasticity effects are of real physical importance in accident calculations.

These effects have been investigated using the one-dimensional Pressure Transient Analysis Code PTA-2, using a single channel to model the core. The reactor model used was based on the CRBR, with the geometrical elevations and dimensions taken from the CRBR design. The free sodium surfaces in the reactor and pump vessels have been explicitly modeled. In addition to the loop-type CRBR design, a pool-type reactor has been simulated by using a pipe length between the pump outlet and the inlet plenum of 50 ft rather than 500 ft. The initial coolant flow and the bubble pressure-time history data input to the analysis were based on a SAS-3A calculation of a loss of flow accident for the CRBR reported earlier.

It was found that the inlet plenum pressure buildup in the loop case was considerably larger than that in the pool case, implying an important difference in the retarding effect of the pressure buildup. This difference was caused by the difference in inertia effect of the two different liquid lengths in the inlet pipe. In either case the effect of sodium compressibility and steel elasticity on the inlet plenum pressure itself was small. For the loop case, however, the pressure difference between core and inlet plenum was considerably greater when these effects were taken into account, resulting in an increase by about a factor of two in lower sodium slug ejection rate (from 1.5 ft/sec to 3.1 ft/sec). However, this ejection velocity was still small compared to that in the pool case (approximately 14.3 ft/s and insensitive to compressibility and elasticity effects). It does not appear that these effects are large enough to require consideration in accident analysis, although it would be desirable to carry out PTA-2 calculations in which the core is modeled by two or more channels with different pressure-time curves to see if the effects are larger with such a treatment.

Compressible Analysis of Inlet Plenum Pressure Rise Due to Sodium Boiling in Fuel Subassemblies During Pump Coastdown of an LMFBR

Kalimullah and H. H. Hummel

I. Introduction

The rise of inlet plenum pressure due to sodium boiling in the fuel subassemblies during the pump coastdown accident analysis of an LMFBR can have an important effect on the course of the accident because of the possible inhibiting effect on downward sodium slug ejection and the consequent reduction in sodium voiding ramp rate. Since the bubble pressure rises quite fast (in SAS calculations the bubble pressures in different channels rise from 2-4 atm to 10-30 atm in 200-400 msec), the effects of liquid sodium compressibility and structural material elasticity (piping, hex-can, etc.) have been investigated in the present analysis. In the SAS code compressibility of the sodium in the inlet plenum is used to smooth pressure fluctuations in calculating the coupling of the in-core sodium flow to the sodium flow in the primary loop. It seemed to be of interest to investigate whether sodium compressibility and structural elasticity effects are of real physical importance in accident calculations. Calculations have been carried out using the one-dimensional Pressure Transient Analysis code PTA-2 (based on the method of characteristics)[1,2] for a loop design and a pool design. For comparison purposes, both designs are CRBR-sized and differ only in the length of the pipe between the pump vessel outlet and lower plenum inlet (the pipe between junctions 9 and 4 in Fig. 1), 500 ft for the loop design (a typical value as shown in Table I) and 50 ft for the pool design.

II. Primary System Model

Figure 1 is a line diagram of the one-dimensional model used in the analysis and Table II gives the physical dimensions and initial coolant pressures and velocities of the components in the primary system. The geometrical elevations and dimensions have been taken from the CRBR design and the free surfaces of sodium in the reactor vessel and the pump vessel have been explicitly modeled. The initial coolant flow and the bubble pressure-time history data input to this analysis are based on a SAS-3A calculation of a loss of flow accident for the CRBR reported earlier[3] (the particular case assuming static sodium film on cladding, no axial feedback and with clad motion). In the SAS-3A calculation 10 channels were used to model the core subassemblies, but these channels have been averaged to one core channel in the pressure transient analysis because of the limited number of pressure sources allowed in the PTA-series of codes (one pressure source allowed in PTA-1 and two in PTA-2). The steady-state coolant velocities in the averaged core channel, the bypass channel (the pipe between junctions 3 and 1 in Fig. 1) and the pipe between the pump outlet and the inlet nozzle are 18.5, 5.0 and 23.0 ft/sec. The surface roughnesses of the core and bypass channels used in the pressure transient analysis have been adjusted to obtain the steady-state frictional pressure drop equal to that in the SAS-3A calculation, i.e. 81.5 psi. The roughness of the pipe between the pump outlet and inlet nozzle has been adjusted to obtain a steady-state frictional pressure drop of 25 psi (see Table I) for the loop design and 15 psi for the pool design (in an actual pool design a large part of this 15 psi pressure drop takes place in flow restrictors used in the pipe and the inlet plenum). The roughness of the pipe between outlet nuzzle and pump vessel inlet has also been adjusted to obtain the steady-state flow from the 8 ft (based on CRBR design) of driving head between the two free surfaces.

The zero time of the pressure transient analysis refers to 18.34 sec after beginning of flow coastdown (i.e., 18.34 sec of the SAS-3A calculation) when the sodium velocity in the pipe between the pump and the inlet plenum has decreased to 4.85 ft/sec, i.e. 21.1% of the steady-state value, and the pump head has decayed to 4.8% of its steady-state value. All the SAS-3A channels start boiling before this time or within 20 msec after this time, and furthermore, most of the bubble pressure rise (shown in Table III) happens after this time. The initial pressures and velocities shown in Table II (which form the initial conditions for the pressure transient analysis) have been taken from the SAS-3A calculation. The step rise in initial pressure at junction 10 (see Fig. 1) given in Table II is due to the pump head, 5.5 psi (4.8% of the steady-state head of 113.8 psi) for the loop design and 5.0 psi (4.8% of the steady-state head of 103.8 psi) for the pool design. The bubble pressure-time history shown in Table III is the channel-averaged pressure of the lowest bubbles which retard the lower liquid slug in the channels. This pressure source is assumed to act at the top of the upper blanket in the core channel (see Fig. 1) in the pressure transient analysis. The pressure of the lowest bubble has been used to be more accurate in the lower liquid slug velocity calculation (than in the upper liquid slug velocity calculation) because the course of the accident (core voiding, dry-out, clad melting, etc.) is more sensitive to the lower liquid slug motion.

The pipe wall thickness for the subassembly length containing fuel pins (the pipes between junctions 8 and 7 in Fig. 1) given in Table II has been obtained from the subassembly can wall thickness (0.12 inch) by correcting for the presence of fuel pins (the pins are assumed to be rigid inclusions) by a multiplicative factor[2], flow area inside the can/gross area inside the can ([illegible].7 in^2/16.3 in^2). Since the subchannel hydraulic diameter rather than the equivalent diameter of the gross area inside the can is input as the pipe diameter, the above corrected wall thickness is further multiplied by the factor, subchannel hydraulic diameter/equivalent diameter of the gross area inside the can, so that the elastic wave speed is properly calculated. All the structural material is taken to be stainless steel 314, and the whole system is assumed to remain at a uniform temperature of 700°F during the transient.

III. Results and Discussion

For each primary system design, three PTA-2 calculations have been made: (1) assuming the liquid sodium to be compressible and all the structural material to be elastic, (2) assuming sodium to be compressible and all the structural material to be rigid, and (3) assuming sodium to be incompressible (bulk modulus made 12.5 times too high) and all the structural material to be rigid. Tables IV to VI give the results for the loop design and Tables VII to IX give the results for the pool design. The differences in the lower liquid slug velocity and in the sodium velocity in the pipe between the pump outlet and the lower plenum due to design (loop-type vs. pool-type) are due to the difference in inertial head in the inlet pipe and are larger than the effects of sodium compressibility and structural material elasticity. The latter are not negligible in the case of the loop design, but are probably not large enough to make an important difference in the course of an accident. For the loop case during the 300 msec of the pressure transient, the lower slug velocity changes from 3.4 ft/sec to -3.1 ft/sec (the minus sign indicates reversal of flow direction from the normal) in the compressible and elastic case vs. from 3.4 ft/sec to -1.5 ft/sec in the incompressible and rigid case. This difference is larger for a loop design with a 900 ft long pipe between the pump outlet and the lower plenum. At the end of the transient the sodium velocity has a variation of a factor of 2 over the length of the pipe between pump outlet and lower plenum in the compressible and elastic case vs. no variation in the incompressible and rigid case. In the case of the pool design the sodium compressibility and material elasticity effects are insignificant (the lower slug velocity changes from 3.4 ft/sec to about -14.3 ft/sec, and the sodium velocity in the 50 ft-pipe changes to about -11.5 ft/sec). The maximum pressures in the lower plenum during the transient are about 183 psi and 137 psi for the loop and pool designs and undergo relatively small changes when sodium compressibility and structural material elasticity are taken into account. However, in the case of the loop design the pressure difference between the inlet plenum and the core, which is small, is considerably larger if compressibility and elasticity are taken into account. The sodium velocity in the bypass channel (non-boiling) rises from 1.9 ft/sec to 6.5 ft/sec for the loop design and to 5.4 ft/sec for the pool design, and is not sensitive to compressibility and elasticity assumption for either design. For both designs, irrespective of the assumptions about compressibility and elasticity, the upper liquid slug velocity in the core channel rises from 3.4 ft/sec to 34.5 ft/sec and the pressure at pump outlet remains practically constant.

Although the sodium compressibility and structural material elasticity effects found in the present calculations are not large enough to require taking into account, it seems desirable to carry out PTA-2 calculations in which the core is modeled by two or more channels with different bubble pressure-time curves. These effects on the lower slug velocity may be larger with such a model than with the 1-core channel model. The same number of core channels may be used in a SAS calculation and the results of both codes may be compared. Sometimes in SAS calculations a fictitiously high value of the lower plenum volume (several times the actual volume) is used to account for its elastic strain in the computation of sodium pressure in the lower plenum. This assumption also may be verified.

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TABLE I. Typical Features of the Primary Heat Transport System of Various Loop-Type LMFBR Designs

Electric power	350-1200 MWe
Pump position	Commonly hot leg
Pipe diameter	24-40 inch
Sodium velocity	$\leq$ 30 ft/sec
Number of loops	3 or 4
IHX pressure drop	15-25 psi
Check valve pressure drop	5-10 psi
Length of pipe between pump outlet and inlet nozzle	400-650 ft
Pressure drop in the pipe between pump outlet and inlet nozzle (including minor losses)	20-30 psi
Subassembly pressure drop	~100 psi
Pressure Drop (vessel inlet nozzle to subassembly inlet) + (subassembly outlet to vessel outlet nozzle)	10-15 psi
Pump head	150-180 psi
Flow during pump coastdown without pony motor	18-22% of normal flow at 20 sec. 10-14% of normal flow at 30 sec.

TABLE II. Physical Dimensions and Initial Conditions of the 1-D Model of the Primary System of a CRBR-sized LMFBR Used in the Pressure Transient Analysis

Serial No.	Pipe ident., first jn./ second jn.	Length ft	Inclination to horizon[a], deg	Hyd. dia./ wall thick., in	Surface roughness, in	Flow area, in^2	Initial[b] pressure first jn./ second jn., psi	Initial[b] velocity ft/sec
1	8/2	5.3	-90.0	0.157/0.0017	0.0044	1331.4	40.10/31.94	3.40
2	3/8	7.7	-90.0	2.9/0.12	0.0	1331.4	42.98/40.10	3.40
3	3/1	29.0	-90.0	0.157/0.0017	0.0597	806.0	42.98/21.30	1.88
4	4/3	9.0	-90.0	243.0/4.5	0.0	46377.0	46.35/42.98	0.13
5	2/7	4.0	-90.0	0.157/0.0017	0.0044	1331.4	31.94/25.79	3.40
6	7/1	12.0	-90.0	2.9/0.12	0.0	1331.4	25.79/21.30	3.40
7	1/5	10.6	90.0	243.0/4.5	0.0	46377.0	21.30/25.27	0.13
8	1/6	10.1	-90.0	243.0/4.5	0.0	46377.0	21.30/17.52	0.0
9	5/11	100.0	-1.55	35.0/0.5	4.095	2886.3	25.27/21.26	2.10
10	11/10	5.0	90.0	100.0/1.75	0.0	23562.0	21.26/23.13	0.26
11	11/12	10.0	-90.0	100.0/1.75	0.0	23562.0	21.26/17.52	0.0
12	10/9	5.0	90.0	100.0/1.75	0.0	23562.0	d	0.26
13	9/4	c	c	23.0/0.5	c	1246.4	d/46.35	4.85

[a] The inclination to horizontal is positive when the direction from the first junction of the pipe towards the second junction points down.

[b] The zero time of the transient refers to 18.34 sec after the beginning of flow coastdown when the sodium velocity in pipe 13 (from junction 9 to 4) has decreased to 21.1% of the steady state value of 23.0 ft/sec.

[c] The length is 500.0 ft for the loop design and 50.0 ft for the pool design. The inclination to horizontal is 2.304° for the loop design and 23.7° for the pool design. The surface roughness is 0.1258 in for the loop design and 5.967 in for the pool design.

[d] The initial pressure at junction 10 (the pump impeller exit) is 28.63 psi for the loop design and 28.13 psi for the pool design. The initial pressure at junction 9 (the pump vessel exit) is 30.50 psi for the loop design and 30.00 psi for the pool design.

TABLE III. Sodium Vapor Bubble Pressure-Time History Used at the Top of the Upper Axial Blanket of Core Subassemblies in the Pressure Transient Analysis

Time, ms	Pressure, psi
-5	35.2
112.4	45.8
122.5	47.9
192.7	59.3
212.5	76.4
230.1	109.5
262.7	146.4
278.3	160.1
294.3	179.0

TABLE IV. Results of Pressure Transient Analysis for the Loop Design, Elastic and Compressible Case[a]

Time, ms	P_2 psi	P_3 psi	P_a psi	P_9 (pipe) psi	U_2 (lower) ft/sec	U_2 (upper) ft/sec	U_3 (by pass) ft/sec	U_4 ft/sec	U_a ft/sec	U_9 ft/sec
0	31.94	42.98	38.42	30.50	3.40	3.40	1.88	4.85	4.85	4.85
16	37.10	42.75	38.43	30.32	3.38	4.01	1.83	4.83	4.83	4.82
32	38.54	43.51	38.42	30.40	3.27	4.75	1.83	4.79	4.80	4.80
48	39.99	45.40	38.40	30.52	3.15	5.54	1.87	4.73	4.78	4.78
64	41.43	47.20	38.03	30.44	3.08	6.35	1.96	4.68	4.75	4.75
80	4[illegible].87	48.28	38.77	30.31	3.02	7.20	2.06	4.63	4.71	4.72
96	44.32	49.18	40.68	30.26	2.92	8.07	2.15	4.59	4.66	4.69
112	45.76	50.50	42.42	30.35	2.79	8.93	2.23	4.54	4.60	4.68
128	48.79	52.53	43.46	30.40	2.60	9.84	2.33	4.48	4.55	4.63
144	51.39	55.56	44.39	30.43	2.40	10.83	2.46	4.41	4.51	4.54
160	53.99	58.55	46.13	30.37	2.27	11.85	2.63	4.33	4.47	4.46
176	56.59	60.89	47.51	30.37	2.16	12.87	2.78	4.26	4.40	4.39
192	59.18	63.03	48.74	30.39	2.00	13.89	2.92	4.21	4.30	4.34
208	72.50	67.64	49.83	30.43	1.34	15.29	3.08	4.11	4.19	4.27
224	97.98	82.72	50.98	30.46	-0.23	17.72	3.48	3.82	4.10	4.18
240	120.68	113.64	52.23	30.50	-2.16	21.42	4.33	3.21	4.03	4.05
256	138.78	144.44	54.98	30.46	-2.56	25.31	5.35	2.61	3.91	3.93
272	154.54	160.91	67.94	30.44	-2.27	29.01	6.01	2.27	3.61	3.82
288	171.52	168.35	97.15	30.45	-2.46	32.28	6.32	2.09	3.00	3.73
296	179.00	173.20	113.45	30.59	-2.9[illegible]	33.79	6.44	1.98	2.66	3.67
300	179.00	176.44	120.83	30.53	-3.12	34.49	6.51	1.91	2.50	3.63

[a]Symbol 'P' stands for pressure and 'U' for velocity. The subscripts are the junction numbers. The subscript 'a' refers to the midpoint of the 500 ft long pipe between junctions 9 and 4.

TABLE V. Results of Pressure Transient Analysis for the Loop Design, Rigid and Compressible Case

Time, ms	P_2 psi	P_3 psi	P_a psi	P_9 (pipe) psi	U_2 (lower) ft/sec	U_2 (upper) ft/sec	U_3 (by pass) ft/sec	U_4 ft/sec	U_a ft/sec	U_9 ft/sec
0	31.94	42.98	38.42	30.50	3.40	3.40	1.88	4.85	4.85	4.85
16	37.10	42.67	38.42	30.37	3.39	4.00	1.84	4.83	4.83	4.83
32	38.54	44.40	38.34	30.28	3.30	4.73	1.84	4.79	4.80	4.80
48	39.99	45.90	37.98	30.44	3.27	5.51	1.90	4.74	4.78	4.77
64	41.43	46.64	39.61	30.37	3.18	6.35	1.97	4.71	4.73	4.75
80	42.87	48.21	41.25	30.43	3.07	7.21	2.05	4.66	4.69	4.73
96	44.32	49.68	42.01	30.39	2.99	8.08	2.15	4.62	4.65	4.66
112	45.76	50.80	44.01	30.45	2.89	8.94	2.24	4.58	4.61	4.61
128	48.79	53.08	43.79	30.38	2.73	9.85	2.34	4.53	4.55	4.56
144	51.39	56.42	43.36	30.43	2.61	10.83	2.49	4.48	4.50	4.50
160	53.99	57.95	44.81	30.43	2.48	11.84	2.64	4.39	4.44	4.44
176	56.59	60.28	46.21	30.42	2.26	12.87	2.76	4.31	4.36	4.39
192	59.18	63.74	47.94	30.49	2.12	13.88	2.91	4.23	4.28	4.32
208	72.50	70.04	50.67	30.41	1.57	15.28	3.10	4.10	4.20	4.22
224	97.98	90.72	52.75	30.52	0.55	17.70	3.61	3.81	4.11	4.13
240	120.68	123.10	57.51	30.45	-0.36	21.42	4.56	3.41	3.96	4.02
256	138.78	139.06	76.52	30.56	-0.55	25.31	5.37	3.16	3.66	3.90
272	154.54	152.35	106.20	30.65	-1.31	29.01	5.80	2.92	3.22	3.70
288	171.52	171.14	120.15	31.03	-1.85	32.27	6.26	2.62	2.95	3.20
296	179.00	179.92	124.55	31.14	-2.09	33.81	6.48	2.47	2.84	3.82
300	179.00	183.83	126.83	31.11	-2.13	34.45	6.58	2.40	2.76	3.61

TABLE VI. Results of Pressure Transient Analysis for the Loop Design, Rigid and Incompressible Case

Time, ms	P_2 psi	P_3 psi	P_a psi	P_9 (pipe) psi	U_2 (lower) ft/sec	U_2 (upper) ft/sec	U_3 (by pass) ft/sec	U_4 ft/sec	U_a ft/sec	U_9 ft/sec
0	31.94	42.98	38.42	30.50	3.40	3.40	1.88	4.85	4.85	4.85
16	37.10	43.70	37.98	30.36	3.40	4.05	1.84	4.83	4.83	4.83
32	38.54	44.68	39.71	30.36	3.37	4.76	1.86	4.80	4.80	4.80
48	39.99	45.69	39.46	30.37	3.31	5.54	1.91	4.76	4.76	4.76
64	41.43	46.96	40.87	30.38	3.23	6.35	1.98	4.73	4.73	4.73
80	42.87	48.24	40.74	30.38	3.14	7.20	2.06	4.69	4.69	4.69
96	44.32	49.64	41.86	30.39	3.05	8.06	2.15	4.65	4.65	4.65
112	45.76	50.96	42.07	30.40	2.95	8.92	2.24	4.60	4.60	4.60
128	48.79	53.63	43.66	30.41	2.83	9.83	2.36	4.55	4.55	4.55
144	51.39	55.96	44.79	30.42	2.69	10.82	2.49	4.49	4.49	4.49
160	53.99	58.36	46.03	30.43	2.54	11.83	2.64	4.42	4.42	4.42
176	56.59	60.83	47.41	30.44	2.39	12.86	2.78	4.35	4.35	4.35
192	59.18	63.30	48.38	30.45	2.24	13.88	2.91	4.27	4.27	4.27
208	72.50	74.81	54.23	30.48	1.97	15.26	3.19	4.17	4.17	4.18
224	97.98	97.05	64.87	30.54	1.49	17.67	3.78	4.03	4.04	4.04
240	120.68	118.99	77.55	30.61	0.79	21.38	4.61	3.82	3.83	3.83
256	138.78	137.28	85.22	30.65	0.14	25.27	5.28	3.57	3.57	3.57
272	154.54	153.69	95.13	30.72	-0.47	29.97	5.81	3.26	3.26	3.26
288	171.52	170.17	100.98	30.76	-1.06	32.23	6.24	2.91	2.91	2.91
296	179.00	178.49	108.69	30.79	-1.36	33.78	6.45	2.71	2.71	2.71
300	179.00	178.43	103.61	30.78	-1.50	34.46	6.53	2.62	2.62	2.61

TABLE VII. Results of Pressure Transient Analysis for the Pool Design, Elastic and Compressible Case

Time, ms	P_2 psi	P_3 psi	P_4 psi	P_9 (pipe) psi	U_2 (lower) ft/sec	U_2 (upper) ft/sec	U_3 (by pass) ft/sec	U_4 ft/sec	U_9 ft/sec
0	31.94	42.98	46.35	30.00	3.40	3.40	1.88	4.85	4.85
16	37.10	41.55	44.93	29.89	3.34	4.01	1.81	4.62	4.60
32	38.54	40.70	44.01	30.03	3.01	4.75	1.74	4.41	4.41
48	39.99	42.98	46.28	30.20	2.63	5.54	1.73	4.18	4.21
64	41.43	45.73	49.06	30.17	2.42	6.35	1.81	3.89	3.91
80	42.87	46.00	49.32	30.03	2.24	7.20	1.91	3.57	3.56
96	44.32	45.23	48.51	29.96	1.86	8.07	1.95	3.26	3.25
112	45.76	46.38	49.66	30.18	1.37	8.93	1.98	2.93	2.94
128	48.79	49.39	52.68	30.33	0.89	9.85	2.08	2.55	2.57
144	51.39	52.32	55.61	30.38	0.46	10.84	2.24	2.10	2.11
160	53.99	53.70	56.99	30.36	-0.01	11.85	2.38	1.60	1.59
176	56.59	54.82	58.09	30.42	-0.64	12.88	2.49	1.06	1.06
192	59.18	57.21	60.48	30.49	-1.35	13.89	2.60	0.47	0.48
208	72.50	62.11	65.28	30.54	-2.50	15.29	2.77	-0.23	-0.18
224	97.98	75.86	78.93	30.76	-4.52	17.72	3.17	-1.17	-1.06
240	120.68	102.20	105.27	31.40	-6.92	21.42	3.95	-2.65	-2.50
256	138.78	123.48	126.41	31.86	-8.24	25.32	4.80	-4.72	-4.66
272	154.54	127.70	130.25	31.94	-9.76	29.01	5.23	-7.13	-7.14
288	171.52	126.55	128.64	31.83	-12.33	32.28	5.32	-9.55	-9.55
296	179.00	129.05	130.95	31.82	-13.89	33.80	5.36	-10.77	-10.74
300	179.00	131.26	133.07	31.79	-14.60	34.49	5.40	-11.39	-11.35

TABLE VIII. Results of Pressure Transient Analysis for the Pool Design, Rigid and Compressible Case

Time, ms	P^2 psi	P^3 psi	P^4 psi	P^9 (pipe) psi	U^2 (lower) ft/sec	U^2 (upper) ft/sec	$U3$ (by pass) ft/sec	$U4$ ft/sec	$U9$ ft/sec
0	31.94	42.98	46.35	30.00	3.40	3.40	1.88	4.85	4.85
16	37.10	40.40	43.70	30.05	3.30	4.00	1.80	4.62	4.63
32	38.54	42.50	45.83	29.98	2.96	4.73	1.73	4.42	4.43
48	39.99	44.56	47.88	30.23	2.83	5.51	1.80	4.15	4.14
64	41.43	42.98	46.27	30.11	2.51	6.35	1.82	3.87	3.88
80	42.87	46.03	49.34	30.21	2.14	7.21	1.86	3.59	3.59
96	44.32	46.60	49.92	30.19	1.90	8.08	1.96	3.25	3.24
112	45.76	46.34	49.63	30.32	1.45	8.94	2.00	2.91	2.92
128	48.79	50.11	53.41	30.25	0.99	9.85	2.10	2.53	2.54
144	51.39	51.60	54.88	30.46	0.59	10.83	2.25	2.07	2.07
160	53.99	52.67	55.94	30.37	-0.02	11.84	2.35	1.59	1.60
176	56.59	56.43	59.71	30.52	-0.61	12.87	2.49	1.04	1.05
192	59.18	57.33	60.58	30.46	-1.20	13.88	2.63	0.43	0.43
208	72.50	63.65	66.83	30.63	-2.36	15.28	2.78	-0.26	-0.23
224	97.98	83.17	86.28	31.03	-3.89	17.70	3.29	-1.31	-1.25
240	120.68	106.08	109.11	31.59	-5.70	21.42	4.12	-2.93	-2.89
256	138.78	113.33	116.10	31.60	-7.59	25.32	4.70	-4.95	-4.94
272	154.54	123.10	125.63	31.81	-10.14	29.01	5.02	-7.15	-7.13
288	171.52	132.99	135.15	31.88	-12.39	32.28	5.35	-9.61	-9.60
296	179.00	135.38	137.29	32.00	-13.65	33.81	5.47	-10.90	-10.90
300	179.00	136.37	138.21	31.90	-14.22	34.49	5.51	-11.55	-11.54

TABLE IX. Results of Pressure Transient Analysis for the Pool Design, Rigid and Incompressible Case

Time, ms	P_2 psi	P_3 psi	P_4 psi	P_9 (pipe) psi	U_2 (lower) ft/sec	U_2 (upper) ft/sec	U_3 (by pass) ft/sec	U_4 ft/sec	U_9 ft/sec
0	31.94	42.98	46.35	30.00	3.40	3.40	1.88	4.85	4.85
16	37.10	40.68	43.97	30.01	3.26	4.05	1.79	4.64	4.64
32	38.54	43.06	46.37	30.08	2.06	4.76	1.76	4.40	4.40
48	39.99	43.38	46.68	30.10	2.80	5.54	1.78	4.15	4.15
64	41.43	44.26	47.55	30.13	2.52	6.35	1.82	3.87	3.87
80	42.87	45.50	48.81	30.18	2.21	7.20	1.88	3.57	3.57
96	44.32	46.18	49.49	30.20	1.86	8.06	1.94	3.25	3.25
112	45.76	47.43	50.74	30.25	1.49	8.92	2.01	2.90	2.90
128	48.79	49.44	52.73	30.31	1.07	9.83	2.11	2.51	2.51
144	51.39	51.43	54.72	30.36	0.58	10.82	2.23	2.06	2.06
160	53.99	53.53	56.81	30.42	0.04	11.83	2.36	1.57	1.57
176	56.59	55.56	58.83	30.47	-0.55	12.86	2.49	1.02	1.02
192	59.18	57.56	60.82	30.52	-1.19	13.87	2.61	0.42	0.42
208	72.[illegible]	66.87	70.08	30.71	-2.04	15.26	2.86	-0.33	-0.33
224	97.98	84.93	88.04	31.08	-3.37	17.67	3.37	-1.42	-1.42
240	120.68	101.92	104.89	31.42	-5.32	21.38	4.09	-3.03	-3.03
256	138.78	114.42	117.21	31.66	-7.50	25.27	4.65	-5.00	-5.00
272	154.54	123.63	126.14	31.81	-9.85	28.97	5.05	-7.25	-7.25
288	171.52	132.14	134.27	31.93	-12.29	32.23	5.32	-9.69	-9.69
296	179.00	135.06	136.95	31.96	-13.57	33.78	5.45	-10.97	-10.97
300	179.00	133.47	135.24	31.93	-14.19	34.46	5.48	-11.61	-11.61

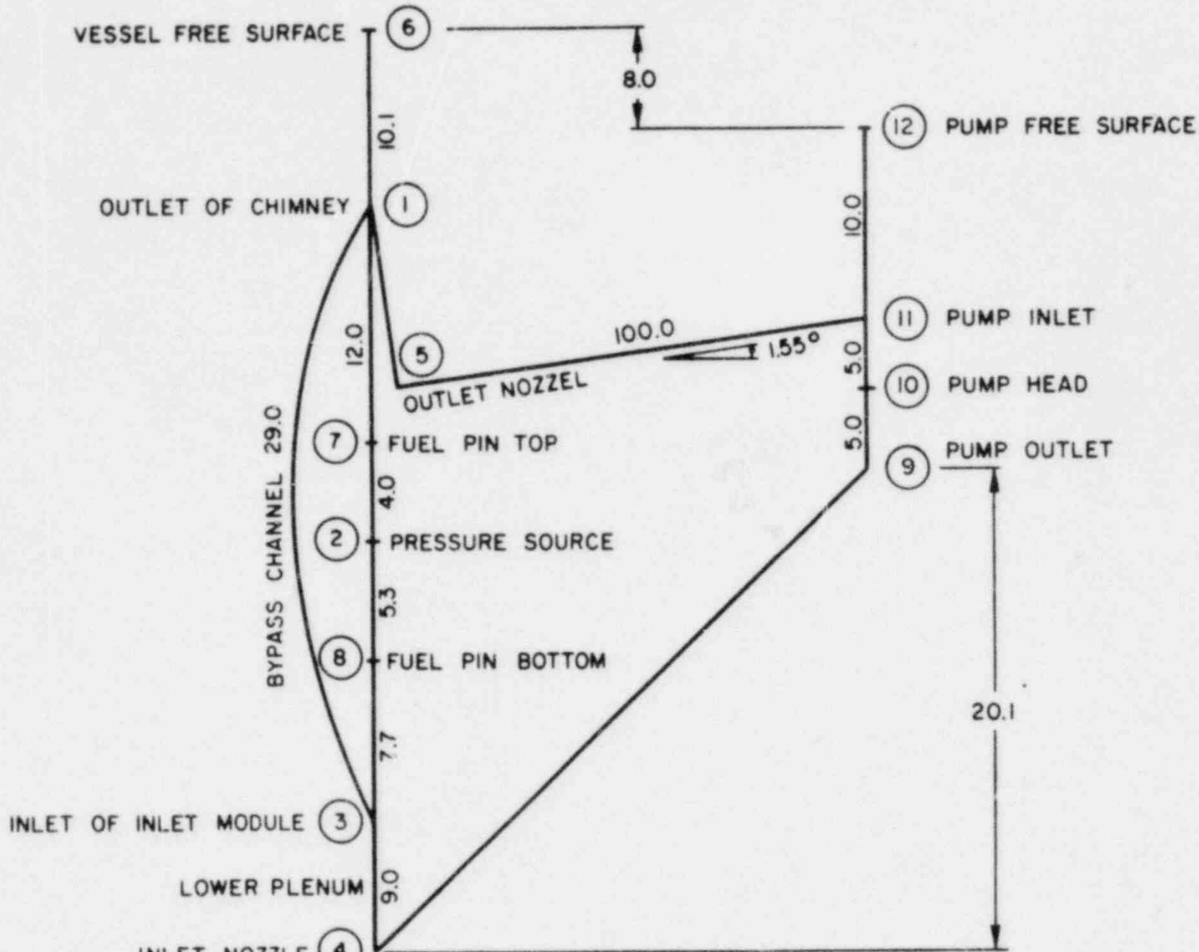

Fig. 1

One dimensional model of the primary system of a CRBR-sized LMFBR used in the analysis of a pressure transient due to boiling in fuel subassemblies. The circled numbers are used to locate junctions. The numbers along the pipes are their lengths in feet. For (a) the loop and (b) the pool systems, the length and inclination to horizontal of the pipe between junctions 4 and 9 are (a) 500.0 ft and 2.304°, and (b) 50.0 ft and 23.7°.

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