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IN NUCLEAR SCIENCE ABSTRACTS

**COOLANT SURFACE
TURBULENCE STUDY
SEFOR REACTOR VESSEL**

E. E. POLOMIK
R. F. WILLIAMS

U.S. ATOMIC ENERGY COMMISSION
CONTRACT AT(04-3)-540

ADVANCED PRODUCTS OPERATION
GENERAL ELECTRIC
SAN JOSE, CALIFORNIA

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R. F. Williams

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SECTION II

SUMMARY OF RESULTS

Half-scale test equipment was constructed to simulate the upper plenum of the SEFOR sodium-cooled fast reactor for the purpose of evaluating surface conditions and gas entrainment to the coolant. Water was used as the flow medium. Tests were conducted over the flow range of 7 to 210 percent of reactor flow. Both uniform and cosine velocity profiles in the flow to the upper plenum were studied with a free surface condition. The cosine velocity distributions were also studied with three types of radiation shields immersed at various depths in the upper plenum water.

The radiation shields were found to provide sufficient calming of the surface to conclude qualitatively that gas entrainment below 150 percent flow should not be a serious problem. Conditions appear satisfactory with shield heights of 9 and 7-1/2 inches and 1 inch water over the shield surface; however, 3 inches of water or more over the shield surface results in more satisfactory conditions.

Free surface conditions were considerably turbulent and conducive to gas entrainment, although very little entrainment into the loop was observed until flows in the range of 150 to 200 percent were reached. Some entrainment was noted for flow as low as 100 percent, but apparently rose in the downcomer area, where the velocity was low, and was observed rising up through the downcomer orifice holes.

Flows and velocities used in the test design are higher than expected, so surface conditions are considered conservative or more severe than corresponding conditions in the reactor.

Sixteen-millimeter color movies at 64 frames/sec were taken of each test geometry at about four flows and various heights. These film rolls and an edited roll showing important conditions of the entire series are on file at the General Electric NED Library at 175 Curtner Ave., San Jose, California.

SECTION III

TEST EQUIPMENT

3.1 GENERAL DESCRIPTION

A schematic illustration of the vessel upper plenum mockup used in the tests is shown in Figure 3-1. This mockup was installed in an existing 36-inch diameter tank. The tank, mounted in a 2000-gpm flow loop with necessary control valves and metering equipment, was supplied by the General Electric Company. The mockup of the upper plenum of the reactor vessel was supplied under the SEFOR contract.

The internals designed for half-scale simulation of the upper plenum of the reactor are described below. Detail drawings are referenced or shown on General Electric Company Parts Lists P/L 148F629-Surface Wave Mockup, P/L 148F630-Traverse Assembly (for depth gages and Pitot tube mechanism), Drawing No. 706E969-Plexiglas Shield Mockup (central plug), and Drawing No. 886D204-Plexiglas Suspension Ring Mockup.

Water entered the bottom of the tank and passed through the inlet orifice plate into three zonal parallel paths formed by the outer circular riser pipe and two internal hexagonal channels. These three paths ended at the riser orifice(s). The riser orifices had 109 holes, each of which represented a reactor channel. The orifice holes were drilled on the same pattern as the channels of the reactor, except for some minor deviations at the periphery of the orifice plates.

Flow upward from the orifice plate thus simulated exit flow from the reactor core shield region above the core into the upper plenum of the reactor. Water in the test plenum then flowed downward by gravity through the annular outer downcomer orifice plate, and then to the pump to complete the circuit. The outer annular orifice plate was drilled with 180 holes, each of which represented the 180 downcomer channels in the reactor.

An orifice plate and manometers were used for flow measurement. A photo view of the inner and outer orifice plates, and the other equipment in the test plenum is shown on Figure 7-6.

An air separation tank with a glass level gage, not shown in the figure, was located between the outlet of the test tank and the pump. Any air entrained during the course of tests accumulated here and could be observed.

The Plexiglas radiation shield plug was mounted on rods which were supported by channels across the top of the tank. The Plexiglas suspension ring was fastened to the inside of the liner with metal clips. Essential features of the shield plug and ring which would affect the surface characteristics were simulated. A photo view of the latter may be noted in Figures 7-12 through 7-20. These figures also show simulation of reactor shield covers over the auxiliary flow inlet and outlet parts, and over the main flow exit port. The vertical white tape in these figures is essentially at the main flow inlet side of the plenum and serves as a reference for orientation.

A traverse bar, two depth gages, and two Pitot tubes, mounted so velocities in two adjacent holes can be measured, completed the test arrangement.

Figure 3-1. Schematic of Surface Wave Mockup Test

3.2 ORIFICES AND SHIELD-RING GEOMETRIES TESTED

The design program started with tests involving two riser orifice plates with essentially uniform radial velocity -- one high and one low velocity, such that reactor conditions would be bracketed. Two additional orifice plates, with high and low cosine radial velocity distributions, were added so a truer simulation of actual flow conditions was obtained. Addition of two cosine velocity distribution orifices necessitated addition of the inlet orifice plate and the two inner hexagonal riser pipes so a radial cosine velocity distribution could be simulated in three zones.

Two designs and three arrangements of the Plexiglas shield plug and suspension ring were tested. These were designated cases A, B, and C, and the essential differences are shown on Figure 3-2. Case A had a 7/16-inch circumferential gap with plug and ring at different elevations. Cases B and C were at heights of 9 and 7 1/2 inches above the plate, with a 1/4-inch circumferential gap in both. The latter gap was made, after testing of the 7/16-inch gap, to produce more damping of the fluid.

Orifices, shield, and ring were tested in the following arrangements, which are also listed in the chronological order of the tests.

TABLE 3-1
TEST COMPONENT ASSEMBLIES

<u>RISER ORIFICE</u>	<u>VELOCITY/ DISTRIBUTION</u>	<u>INLET ORIFICE</u>	<u>OUTER RISER PIPE</u>	<u>TWO INNER HEXAGONAL PIPES</u>	<u>SHIELD AND RING</u>
I	High/ Uniform	No	Yes	No	None
II	Low/ Uniform	No	Yes	No	None
III	High/ Cosine	Yes	Yes	Yes	None
IV	Low/ Cosine	Yes	Yes	Yes	None
IV	Low/ Cosine	Yes	Yes	Yes	Case A
IV	Low/ Cosine	Yes	Yes	Yes	Case B
IV	Low/ Cosine	Yes	Yes	Yes	Case C
III	High/ Cosine	Yes	Yes	Yes	Case C
III	High/ Cosine	Yes	Yes	Yes	Case B

Detailed design data on the expected performance of the four different orifices is contained in the following section in Table 4-1.

Figure 3-2. Schematic of Upper Plenum Showing Types of Radiation Shield Assemblies Tested

SECTION IV

DESIGN OF TEST EQUIPMENT

4.1 SIMILITUDE CONSIDERATIONS

The Froude Number, V^2/gL , and the Weber Number $V^2/(\sigma/\rho L)$ where σ is the surface tension, are the two parameters expected to control the surface conditions. If similitude is obtained by holding the ratio of Froude/Weber numbers constant for the model-reactor (at 700°F sodium) then a model-reactor length scale of $L_m/L_r = 0.60$ results. However, the celerity of wave propagation will be chiefly a function of the Froude number at the relatively high velocities for the case at hand. Thus an exact scale of 1/2 for model/reactor diameter ratio was chosen which could be expeditiously accomplished in existing available equipment. Liquid height in the plenum was an unrestricted variable.

The results obtained with 1/2 scale simulation are expected to be conservative because the design was based on a nominal total reactor flow of 5000 gpm, whereas recent design values are 4310 gpm. Thus, 100 percent of the 1/2 scale test flows correspond to 116 percent of the more recent design values. Relative values are shown in the tabulation below.

Length Scale (L_m/L_r)	$V_m^{(1)}$	Q_m - 1 Actual Test (Basis $Q_r = 5000$ gpm)	Q_m (Basis $Q_r = 4310$ gpm)	Q_{test}/Q_{design}
0.5	0.707 V_r	660 gpm (75%)	760	1.16
		883 gpm (100%)		
		1100 gpm (125%)		
		1320 gpm (150%)		

(1) subscript m = model and r = reactor;
V = velocity and Q = volumetric flow rate.

4.2 UNIFORM ORIFICE PLATES-I, II

Reactor average velocities, at channel exit to the upper plenum region, were estimated at 2.5 ft/sec. It was decided to design one orifice with vena contracta velocities of about twice this value (5 ft/sec) which should be comparable to the reactor case with 1,4 radial peaking and an additional allowance of 1.4 for local channel variation. Another orifice was to be designed for a lower velocity, near the average of 2.5 ft/sec, as permitted by the largest hole that could be drilled in the orifice plates.

The orifice plate radius was divided to form three zones which corresponded well with the mechanical arrangement of channels in the reactor. Radii and number of orifice holes (corresponding to reactor channels) are shown on Figure 4-1.

ZONE	<u>1</u>	<u>2</u>	<u>3</u>	<u>TOTALS</u>
MEAN RADIUS TO ZONE (1/2 SCALE MODEL), in.	3.65	6.5	8.7	
NO. CHANNELS (ORIFICES) IN ZONE	19	42	48	109
FRACTION OF POWER/ZONE	0.233	0.414	0.353	1.0
MODEL FLOW/ZONE, gpm	204	366	313	883
AVERAGE VELOCITY IN ZONE ft/sec(a)	3.83	3.07	2.30	
REACTOR FLOW (NOMINAL) gpm				5000

(a) ORIFICE AREA = 0.908 in.² PER CHANNEL.

Figure 4-1. Radial Reactor Power Distribution

A trial procedure outlined below was followed to determine the hole sizes. It was decided to make all holes the same since the radial variation was not great due to a Reynolds number of about 120,000 in the riser to the orifice plate.

1. Estimate hole diameter
2. Calculate β , the ratio of hole diameter/1.66 in. and assumed effective inlet diameter below the orifice hole.
3. Estimate zone 1 average approach velocity = $1.05 (\bar{V})_{\text{riser}} = V_{a1}$;
 Estimate zone 2 average approach velocity = $1.00 (\bar{V})_{\text{riser}} = V_{a2}$
 Estimate zone 3 average approach velocity = $0.97 (\bar{V})_{\text{riser}} = V_{a3}$.
4. Calculate $V_D = V_a / \beta^2$ = Average Orifice Hole Velocity.
5. Find C_c , the vena contracta value.
6. Calculate $V_c = V_D / C_c$, the vena contracta velocity desired.
7. Calculate the total flow, using the holes and velocities applicable to each zone to ensure a reasonable check with the required value of 883 gpm. These usually checked with 2 percent.

The results of the final design used for the uniform velocity orifices are in Table 4-1. A few additional holes in orifice II were required at the outer radius as it was physically impossible to drill 48 of the 1.281-inch holes required.

4.3 COSINE ORIFICE PLATES - III, IV, APPROACH CHANNELS, AND INLET ORIFICE PLATE

The preliminary design values of reactor radial relative power used are shown in Figure 4-1. These vary from 1.5 at the centerline to 0.7 at the outer core radius, and were assumed as a true cosine distribution. Actual reactor flow should follow this curve to keep coolant exit temperatures across the core radius approximately constant. Volumetric integration of this curve, and application of the 5000-gpm nominal reactor flow and 1/2-scale model size, resulted in the flow rates for each zone shown in Table 4-1.

Two orifices were designed (III and IV): one for the highest velocity expected at exit to the plenum, and one for about half this velocity. The basis for this procedure was:

Average velocity at reactor channel exit - 4 ft/sec, and average velocity at fuel handles above the channel exit - 2.2 ft/sec.

A conservative approach estimates that central core exit velocities may approach twice the average of 4 ft/sec, or 8 ft/sec, due to radial flow variation (1.39) and local channel peaking. A more realistic value was that exit velocities would be on the order of twice the average value at the fuel handles, or about 4 ft/sec. These values, for a 1/2-scale model, resulted in two target design velocity values of $8/\sqrt{2} = 5.65$ ft/sec and $4/\sqrt{2} = 2.8$ ft/sec. The low velocity of 2.8 ft/sec could not be realized due to the physical limitation on the maximum size orifice hole that could be drilled.

Final calculations resulted in radial velocity variations of 5.65/3.25 (III) and 3.55/2.07 (IV) ft/sec for the vena contractas of the two orifices, as shown in Table 4-1. The increased velocity for orifice IV should cause the test effects to seem more severe than anticipated.

TABLE 4-1

SUMMARY OF ORIFICE AND PIPE DESIGN DATA FOR SURFACE WAVE TEST

(Basis: $Q = 883$ gpm which simulates Froude No., for 5000 gpm in reactor, in a half-scale model).

Test Case	UPPER ORIFICE						LOWER ORIFICE AND INLET CHANNELS					
	Part No.	Item*	Zone					Part No.	Item	Zone		
			1	2	3a	3b	3c			1	2	3
I - Flat Radial Profile - High Velocity	P/L 146F629-P3 (237E855P1)	N	19	42	48			None Assembled				
		D _{in}	1.016	1.016	1.016							
		V _D	3.34	3.18	3.10							
		V _C	5.13	4.88	4.77							
		V _r	7.25	6.91	6.75							
		Q	160	336	375							
II - Flat Radial Profile - Low Velocity	P/L 146F629-P15 (237E854P1)	N	19	42	36	12	12	None Assembled				
		D _{in}	1.281	1.281	1.281	1.125	0.625					
		V _D	2.11	2.01	1.98							
		V _C	3.02	2.87	2.83							
		V _r	4.27	4.05	4.00							
		Q	162	343	380							
III - Cosine Profile - High Velocity (1.5 at ϕ to 0.7 at outer radius)	P/L 146F629-P16 (237E868P1)	N	19	42	48			P/L 146F629	9 } Inner and outer channels 112C2089			
		D _{in}	1.094	1.094	1.109				10 } G1 and G2 assembled			
		V _D	3.67	2.95	2.16							
		V _C	5.65	4.45	3.25							
		V _r	8.00	6.30	4.60							
		Q	204	366	313							
IV - Cosine Profile - Low Velocity	P/L 146F629-P17 (237E869 P1)	N	19	42	48	24		Same as III above.				
		D _{in}	1.313	1.328	1.343	0.563						
		V _D	2.51	2.01	1.48							
		V _C	3.55	2.82	2.07							
		V _r	5.02	3.99	2.93							
		Q	204	366	313							

Outer orifice plate (downcomer area) P/L 146F629-PN4 (237E856) has one hundred eighty 1-inch holes.

* N = Number of holes in each zone.

D_{in} = Diameter of holes in inches.

V_D = ft/sec estimated in D_{in}.

V_C = ft/sec estimated in vena contracta.

V_r = $\sqrt{2} V_C$ = ft/sec velocity in reactor for same Froude No. at 5000-gpm flow.

Q = Flow in gpm.

The procedure for calculation of the upper and lower orifice plates then proceeded as follows:

1. Three pressure-drop equations were written for the three parallel paths, and the known required flows through each. Unknowns were the three upper and three lower orifice holes.
2. Upper orifice hole sizes were calculated by:
 - a. Assuming a contraction coefficient.
 - b. Calculating V_D , orifice hole velocity, and D the upper orifice hole size from the desired exit velocity and total zone flow rate required.
 - c. Calculating $\beta = D/1.65$ inch and comparing the value of C_c until it checked the assumed value.
3. Values of D for the upper plate were then substituted into the three pressure-drop equations, from item 1 above; a reasonable value assumed for d_1 , the first zone of the lower plate; and d_2 and d_3 solved. This procedure was repeated until a reasonable orifice size and variation were obtained. It was found that the same lower orifice plate could be used with both the high-velocity (III) and low-velocity (IV) upper orifice plates.

Final results of the calculations for orifice holes and flows are shown in Table 4-1. The design exit velocity profiles expected from the two cases are plotted on Figure 4-2.

Figure 4-2. Design Radial Velocity Distribution for Surface Wave Test

SECTION V

TEST PROCEDURE

5.1 GENERAL OPERATION

Equipment was assembled chronologically into the flow circuit as shown in Table 3-1. Adjustments were necessary on the supports of the large existing tank to get it into a level position.

When the equipment was assembled, the loop was filled with water to the desired level above the orifice. Flows were set by a manometer chart. A 4.078-inch orifice was used throughout the tests, and flows are estimated to be within 1.5 percent with oscillations on the order of $\pm 3/4$ percent.

The flow was run a few minutes at about 100 to 150 percent to eliminate air.

Water temperatures were kept in the range of about 65 to 95°F.

Measurements of orifice exit velocities and surface depth radii for some of the more important conditions of flow and water height over the orifice.

Surface conditions were studied visually, and a polaroid photo was taken of each condition of flow and water height.

Sixteen-millimeter color movies, at 64 frames/sec, were also taken for the range of conditions for all orifices--with and without the radiation shield and ring.

SECTION VI

DATA REDUCTION

The most important results were obtained visually and recorded in the photos and movies taken, particularly on orifices III and IV. The latter represent the reactor conditions more accurately, and are believed to do so in a conservative manner. Thus, sufficient data was reduced on velocities and surface conditions to obtain general characteristics and the bulk of results shown by photo.

6.1 TOTAL FLOW AND PITOT TUBE VELOCITIES

System flow was obtained from a manometer chart as previously described.

The Pitot tubes used were the conventional Prandtl type, and velocities were calculated directly from the total head.

$$V = \sqrt{2g \Delta H}$$

U-tube manometers were used with oils of 1.75 (blue) and 1.20 (yellow) specific gravity to obtain required accuracy.

6.2 EQUIPMENT CONSTANTS

Heights of water over the orifice plate at flow conditions, and the corresponding radii, were determined from the scale readings attached to the horizontal traverse bar and the vertical scales attached to the depth probes. The dimensions of the equipment were such that the following equations applied for the two depth probes:

$$H = D - 5.5, \text{ for both depth probes}$$

Where: H = Inches from orifice plate to mean surface, and
 D = Depth gage reading.

Radii to each of the depth probes was obtained from,

$$R_1 = 17.0 - S$$

$$R_2 = 13.13 - S,$$

Where: R_1 = Inches from centerline of orifice plate to depth probe 1,
 R_2 = Inches from centerline of orifice plate to depth probe 2, and
 S = Inches horizontal scale reading.

Depth probe 1 was located at the left, when looking at Figure 3-1, which corresponds to the reactor main flow outlet side. Probe 2 was mounted in the same traverse block, 3-7/8 inches to the right or toward the main flow inlet side. The square depth probes (which support the Pitot tubes), the traverse block, and bar may be seen in Figure 7-6.

The centerlines of the Pitot tubes in the block were made to match the orifice plate hole pitch so velocities in two holes could be measured simultaneously. Thus, the radius, to the velocity measured in any particular hole, corresponds to the hole radius on the drawing for that orifice.

SECTION VII

RESULTS AND DISCUSSION

7.1 VELOCITY VERSUS DEPTH AND HEIGHT ABOVE ORIFICE

Pitot tube tips were located 1/4 inch above the orifice holes, which was found to be the optimum location to measure maximum vena contracta exit velocities. Vertical velocity components were measured at various heights above the orifice to determine the decrease with height. These data for orifice plates II and III are presented in Table 7-1 and plotted on Figures 7-1 and 7-2, respectively. For all cases shown, the normalized velocity ratio is in the range of 0.5 to 0.6 at 3 inches above the orifice hole. Velocity decrease with height is more pronounced with the uniform orifice (II) than with the cosine distribution of orifice III. This is consistent with the higher efflux velocities of orifice III and the higher fraction of the total volume rate in zones 1 and 2. The latter may be compared in Table 4-1.

7.2 RADIAL VELOCITY PROFILES

Results of the actual radial efflux velocities for orifices III and IV are shown in Table 7-2 and plotted on Figure 7-3. The zones can easily be distinguished in Figure 7-3. The over-all simulation of a cosine velocity exit distribution is very good, especially for the most important orifice plate, IV.

The test velocities obtained in Figure 7-3 are in good agreement with the design values which are shown on Figure 4-4. On orifice II, at the outer zone 3, a test velocity of 2.7 ft/sec was obtained compared to a design value of about 3.2. Orifice IV was also slightly lower than design at the outer radius for zone 3. The central zone was almost exactly at the design value desired.

7.3 EFFECT DEPTH AND FLOW ON SURFACE HEIGHT

The maximum center-trough heights (ΔH on Figure 7-4), for the uniform velocity orifices I and II, were measured for several cases. However, the results are not presented due to the variations in the relatively small heights which showed scatter up to 50 to 100 percent.

The free surface of the cosine velocity distribution orifices III and IV was considerably higher than the uniform at the center for corresponding conditions. A representative amount of the former is presented from which estimates can be made for various conditions.

A typical radial profile for the two cosine orifices is shown in Figure 7-5.

The relationship between center-trough surface height, still height, and flow for the two cosine orifice plates is shown in Figure 7-4. ΔH , a measure of the potential for surface roughness and gas entrainment, decreases very rapidly with the flow rate and quite rapidly as the water height in the plenum is increased.

TABLE 7-1

VELOCITY VARIATION WITH DISTANCE ABOVE ORIFICE HOLES

ORIFICE III (COSINE-HIGH VELOCITY)
HOLE NO. 1 AT CENTER OF ORIFICE
PLATE 100 PERCENT FLOW (883 gpm)

STILL WATER HEIGHT ABOVE ORIFICE PLATE

9 inches (61 to 77°F water)					6 inches (76 to 83°F water)				
RUN	HEIGHT PITOT ABOVE PLATE (inches)	INCHES MANOMETER BLUE OIL 1.75 sp. gr.	VELOCITY (ft/sec)	$\frac{V}{V_o}$	RUN	HEIGHT PITOT ABOVE PLATE (inches)	INCHES MANOMETER BLUE OIL 1.75 sp. gr.	VELOCITY (ft/sec)	$\frac{V}{V_o}$
80	0.0	8.12	5.69	1.00	80A	0.00	8.09	5.67	1.00
	0.25	8.17	5.70	1.003		0.25	7.95	5.61	0.990
	0.50	8.05	5.67	0.998		0.50	7.80	5.56	0.978
	0.75	7.84	5.58	0.982		0.75	7.67	5.52	0.973
	1.00	7.35	5.40	0.951		1.00	7.30	5.38	0.948
	2	5.15	4.53	0.798		2	4.7	4.32	0.762
	3	2.82	3.37	0.593		3	2.37	3.07	0.542
	4	1.65	2.55	0.449		4	1.05	2.05	0.361
	5	1.19	2.21	0.389					
	6	0.87	1.87	0.329					

ORIFICE II (UNIFORM-LOW VELOCITY)
HOLE NO. 1 AT CENTER ORIFICE PLATE
ABOUT 100 PERCENT FLOW (883 gpm)

6 inches (62 to 76°F)				9 inches (96 to 107°F)				18 inches (90°F)			
RUN	HEIGHT (inches)	VELOCITY	$\frac{V}{V_o}$	RUN	HEIGHT (inches)	VELOCITY	$\frac{V}{V_o}$	RUN	HEIGHT (inches)	VELOCITY	$\frac{V}{V_o}$
46A	0	2.38	1.00	46B	0.00	2.47	1.00	42A	0.0	2.72	1.00
	0.25	2.32	0.975		0.25	2.46	0.995		0.25	2.68	0.985
	0.50	2.22	0.933		0.50	2.33	0.943		0.50	2.52	0.925
	1.00	1.94	0.813		0.75	2.18	0.882		0.75	2.37	0.870
	2	1.52	0.639		1.00	1.98	0.802		1.00	2.20	0.808
	3	1.29	0.543		1.25	1.50	0.607				
	4	0.95	0.40		1.50	1.34	0.542				
					2	1.16	0.470				
					4	0.99	0.400				
					6	1.69	0.685

Figure 7-1. Orifice II (Uniform - Low Velocity) Velocity versus Height above Orifice Plate Center

Figure 7-2. Orifice III (Cosine - High Velocity) Velocity versus Height above Orifice Plate Center

Figure 7-3. Radial Velocity Distribution - Orifice Plates III and IV

Figure 7-4. Effects of Flow and Height on Surface Height

Figure 7-5. Typical Surface Profiles

TABLE 7-2
COSINE SIMULATED VELOCITY PROFILES

100 Percent Flow (883 gpm)
9 Inches Still Water Height Over Orifice Plate.

Hole No.	Radius		Hole Exit Velocity ⁽¹⁾	
	(Inches)	(Foot)	Orifice IV (Run 110)	Orifice III (Run 81 A)
R ₁	0	0.0	3.69	5.70
R ₂	1.585	0.132	3.58	5.67
R ₃	3.170	0.264	3.36	5.63
R ₄	4.755	0.396	2.52	4.18
R ₅	6.340	0.528	2.68	3.99
R ₆	7.925	0.660	1.69	2.72
R ₁	0	0	3.69	5.70
R ₅₆	1.585	-0.132	-	-
R ₅₇	3.170	-0.264	3.43	5.56
R ₅₈	4.755	-0.396	2.72	4.17
R ₅₉	6.340	-0.528	2.60	3.99
R ₆₀	7.925	-0.660	2.19	2.96

(1) Pitot tip 1/4 inch above orifice plate holes.

7.4 PHOTOS OF FREE SURFACE FOR ORIFICE PLATES I (HIGH) AND II (LOW)-UNIFORM VELOCITY DISTRIBUTION

The polaroid photos taken of all orifice and flow conditions provide a convenient and effective means of showing the results of surface conditions. In many cases, exact detail cannot be determined due to the lack of depth, and the vertically downward angle necessary. However, comparison of different conditions provides a good method for determining relative surface conditions.

Figure 7-6, for orifice plate I shows various conditions, some with the traverse bar, depth gages, and Pitot tubes assembled. In Figure 7-6 (f), the vertical white tape on the inside of the tank liner corresponds to the reactor inlet side. The two lower protrusions on the inside of the liner simulate reactor auxiliary flow inlet and outlet pipe shields. The larger protrusion at the left simulates the shield cover on the reactor main flow outlet.

Characteristic increase of surface roughness and number of waves may be noted, either due to increase of flow or decrease of water height over the orifice plate.

Figures 7-7 through 7-9 show various conditions for orifice plate II at lower exit velocities -- 100 percent flow = 2.9 ft/sec.

A much smoother surface, due to the much lower velocity, may be noted by comparison of equivalent conditions on Figures 7-7 and 7-8 to those of Figure 7-6.

Some evidence of vortexing is noted, particularly in the top part of the photos on Figure 7-9. This was believed to be caused by interference of reflected waves from the two auxiliary port shield covers.

In Figure 7-8 d, e, and f (150 to 200 percent flows), frothing may be noted at the upper vortex location. This was due to air entrainment. At these higher flows net air entrainment was observed at the separator tank; however, there was a considerable amount of air moving upward from the orifice plate holes, indicating de-entrainment of air as the total flow moved down through the downcomer orifices. No net entrainment of air was noted until flows of 150 percent or above were reached.

7.5 PHOTOS OF ORIFICE PLATE III (HIGH VELOCITY-COSINE DISTRIBUTION)

The free surface for this plate at various conditions is shown in Figures 7-10 and 7-11. The pronounced central dome over the orifice, due to the cosine velocity distribution, is well shown in Figure 7-11. Comparison of Figures 7-11 and 7-6, at 9 inches water height, show the increased surface waves and activity in the outer annular downcomer region of the photo. Figure 7-11 (f), at 200 percent, is a good example of air entrainment with frothiness in the downcomer annular area and the milky appearance of the water. Net air entrainment was again noted with flows in the range of 150 to 200 percent. For orifice plate III and Case A shield, 1/8 to 1/4 inch of air in a 30-inch tank was observed with 18 inches water height and 200 percent flow for 4 minutes. The same rate of entrainment was noted, except at 8 to 10 inches of height and 100 to 150 percent flow, which showed that more than an inch of water over the shield surface was required for satisfactory operation.

Orifice III with the high radiation shield Case B is shown in Figure 7-12 and 7-13, and orifice III with the lower radiation shield Case C is shown in Figures 7-14 and 7-15. A good view of the shield is shown on Figure 7-12 (a).

General improvement of the surface, due to damping in the shield-ring annulus and central annular holes, may be noted by comparison of Figures 7-12 and 7-14 to Figure 7-11. Considerable roughness and frothiness, particularly at the central annuli in the plug, at the flows in the 150 to 200 percent flow range are shown in Figure 7-15.

Figures 7-12, 7-13, and 7-14 indicate surface conditions are approximately the same for shield B or C, with B slightly better. A considerable improvement in roughness as water height is increased to 2 inches above the shield is shown in Figure 7-14.

7.6 PHOTOS OF ORIFICE PLATE IV (LOW VELOCITY-COSINE VELOCITY DISTRIBUTION)

The free surface conditions with this orifice plate are shown on Figures 7-16 and 7-17. A general improvement is noted in the conditions of the surface, with comparison to Figure 7-11 for orifice III, which was at about 50 percent higher central exit velocity, but not as much as would be expected. The dome height, refer to Figure 7-5, was considerably lower with less activity in the downcomer region, which is difficult to visualize from the still photos. The milkiness and frothiness accompanying air entrainment at 200 percent flow are shown again in Figures 7-16 (f) and 7-17 (e).

The photos in Figures 7-18 through 7-22 show orifice plate IV with the three cases of shield plug and ring tested.

Conditions were generally satisfactory for both shield cases B and C, with B exhibiting less burbles at the central annuli than C. A reasonably good surface at 200 percent flow with 2 inches of water over the shield is shown in Figure 7-20. Relatively good surfaces at or below 150 percent flow with very little or no net air entrainment observed are shown in Figures 7-21 and 7-22. The effect of water height over the surface is discernible in Figure 7-22, and less waviness and burbling at the central region were obtained at 2 inches of water over the shield.

It was concluded that at least 2 inches of water over the shield surface would produce conditions least susceptible to air entrainment.

7.7 HIGH-SPEED MOTION PICTURES

High-speed 16-millimeter color movies at 50 to 64 frames/sec, were taken of each test assembly. One-hundred-foot reels were used with 0.3 in./frame. At 50 to 64 frames/sec, this resulted in about 1-1/2 ft/sec, or provided a shooting time of about .70 sec/reel. Titles were photographed before each condition (about 4 seconds), except as noted below, and surface conditions (2-1/2 to 3 seconds) to show about 10 to 14 different conditions of flow and water level height on each reel.

The various reels taken of the cosine velocity orifice plates, III and IV, were edited to produce one composite reel, No. 14, showing the most important conditions of the free surfaces and also those with the radiation shield plug and ring assemblies.

The reels and their contents are tabulated below. These reels have been stored in the NED Library of the General Electric Company at San Jose, California.

TABLE 7-3
SUMMARY OF HIGH-SPEED MOVIES (50 to 64 frames/sec)

REEL NO.	ORIFICE PLATE	CONDITIONS			COMMENT
		WATER HEIGHT (inches)	FLows (percent)	SHIELD/RING CASE	
1 (no titles)	I	1-18	7-150	-	-
2 (no titles)	II	1-18	7-150	-	-
3 (with titles)	II	1-18	7-150	-	-
4 (with titles)	II	9-18	100-200	-	-
5 (with titles)	III	1-18	25-210	-	Poor
6A (with titles)	III	1-18	25-210	-	Retake to
6B (with titles)	III	1-18	25-210	-	improve
7A (with titles)	III	4-15	25-210	Case A (10-5/8/9 inches)	-
7B (with titles)	III	4-15	25-210	Case A (10-5/8/9 inches)	-
8A (with titles)	IV	6-18	25-210	Case A (10-5/8/9 inches)	-
8B (with titles)	IV	6-18	25-210	Case A (10-5/8/9 inches)	-
9A (with titles)	IV	1-18	7-210	-	-
9B (with titles)	IV	1-18	7-210	-	-
10 (with titles)	IV	9-11	50-210	Case B (9 inches)	-
11 (with titles)	IV	7-1/2 - 9-1/2	50-210	Case C (7-1/2 inches)	-
12 (with titles)	III	7-1/2 - 9-1/2	50-210	Case C (7-1/2 inches)	-
13 (with titles)	III	9-11	50-210	Case B	-
14 (with titles)	III and IV	-	-	-	Composite of reels 6A, 13, 9A, and 10 to show effect of shield.

(a) Orifice and Downcomer Plates

(c) 9-inch Still Height Water Over Plate-50 percent flow

(e) 9-inch - 75 percent

(d) 9-inch 125 percent (1105 gpm)

(f) 9-inch - 150 percent

(g) 4-inch - 75 percent

Figure 7-6. Free Surface - Orifice Plate I - 5.0 ft/sec Uniform Exit Velocity

(a) 1-inch-15 percent flow still
height water over plate

(b) 2-inch-15 percent

(c) 3-inch-50 percent

(d) 6-inch-50 percent

(e) 6-inch-100 percent (883 gpm)

(f) 9-inch-50 percent

Figure 7-7. Free Surface-Orifice Plate II-2.9 ft/sec Uniform Exit Velocity

(a) 9-inch - still height water over plate - 75 percent flow

(b) 9-inch - 100 percent (883 gpm)

(c) 9-inch - 125 percent

(d) 9-inch - 150 percent

(e) 9-inch - 180 percent

(f) 9-inch - 210 percent

Figure 7-8. Free Surface-Orifice Plate II-2.9 ft/sec Uniform Exit Velocity

(a) 12-inch still height water over plate- 50 percent flow

(b) 15-inch-100 percent
(883 gpm)

(c) 18-inch-100 percent

(d) 13-inch-150 percent

(e) 18-inch-200 percent

Figure 7-9. Free Surface-Orifice Plate II-2.9 ft/sec Uniform Exit Velocity

(a) 1-inch-still height water over plate-
7 percent flow

(b) 3-inch-7 percent

(c) 3-inch-50 percent

(d) 6-inch-100 percent
(883 gpm)

(e) 12-inch-100 percent

(f) 18-inch-100 percent

(g) 18-inch-150 percent

Figure 7-10. Free Surface-Orifice III- 5.7/3.3 ft/sec Cosine Velocity Distribution

(a) 9-inch-still height water over plate-
25 percent flow

(b) 9-inch-50 percent

(c) 9-inch-100 percent (885 gpm)

(d) 9-inch-125 percent

(e) 9-inch-150 percent

(f) 9-inch-200 percent

Figure 7-11. Free Surface-Orifice Plate III-5.7/3.3 ft/sec Cosine Velocity Distribution

(a) 9-(0-) inch-25 percent flow
 ↑ still water height above shield
 ↓ still water height above orifice plate

(b) 9-(0-) inch-100 percent flow
 (883 gpm)

(c) 9-(0-) inch-200 percent

(d) 9-(0-) inch-50 percent

(e) 9-(0-) inch-150 percent

Figure 7-12. Orifice III (High Velocity Cosine Distribution)-Radiation Shield Case B
 (9 inches above Orifice Plate -1/4 in. annulus)

(a) 9-(0-) inch-25 percent flow
 ↑ still water height above shield
 ↑ still water height above orifice plate

(b) 11-(2-)inch-100 percent (883 gpm)

(c) 11-(2-)inch-150 percent

(d) 10-(1-)inch-100 percent

(e) 18-(9-)-100 percent

(f) 11-(2-)inch-200 percent

Figure 7-13. Orifice Plate II (High Velocity Cosine Distribution)-
 Radiation Shield Case B (9 inches above Orifice Plate-1/4 in. annulus)

(a) 9-(0-) inch-25 percent flow
 ↑ still water height above shield
 ↓ still water height above orifice plate

(b) 8 1/2-(1-) inch-50 percent

(c) 9 1/2-(2-)inch-50 percent

(d) 7 1/2-(0-)inch-100 percent (883 gpm)

(e) 8 1/2-(1-) inch-100 percent

(f) 9 1/2-(2-)inch-100 percent

Figure 7-14. Orifice III (High Velocity Cosine) -Radiation Shield Case C (7-1/2 inches above Plate, 1/4-inch annulus)

(a) 9-(0-) inch-25 percent flow
 ▲ still water height above shield
 └ still water height above orifice plate

(c) 9 1/2-(2-) inch-150 percent

(c) 9 1/2-(2)inch-150 percent

(d) 7 1/2-(0-)inch-200 percent

(e) 8 1/2-(1-)inch-200 percent

(f) 9 1/2-(2-)-200 percent

Figure 7-15. Orifice III (High Velocity Cosine)-Radiation Shield Case C
 (7-1/2 inch above Orifice Plate, 1/4-in. annulus)

(a) 3-inch-still height water over plate-
50 percent

(b) 6-inch-100 percent (883 gpm)

(c) 18-inch-100 percent

(d) 6-inch-50 percent

(e) 12-inch-100 percent

(f) 18-inch-200 percent

Figure 7-16. Free Surface-Orifice IV-3.6/2.1 ft/sec Cosine Velocity Distribution

(a) 9-inch-still height water over plate-
75 percent

(b) 9-inch-125 percent

(c) 9-inch-100 percent (883 gpm)

(d) 9-inch-150 percent

(e) 9-inch - 200 percent

Figure 7-17. Free Surface-Orifice IV-3.6/2.1 ft/sec Cosine Velocity Distribution

(a) 9-(0-) inch-25 percent flow
 ↑ still water height above shield
 — still water height above orifice plate

(b) 9-(0-) inch-150 percent

(c) 9-(0-) inch-200 percent

(d) 12-(3-) inch-100 percent

(e) 18-(9) inch-150 percent

Figure 7-18. Orifice IV (3.6/2.1 ft/sec Cosine Distribution) - Radiation Shield
 Case A 9/10 5/8-in. Height, 7/16-inch annulus)

(a) 9-(0-) inch-25 percent flow
 ↑ still water height above shield
 ↓ still water height above orifice plate

(b) 10-(1-) inch- 50 percent

(c) 91(0-) inch-100 percent

(d) 10-(1-) inch-100 percent

(e) 11-(2-) inch-100 percent

Figure 7-19. Orifice IV (3.6/2.1 ft/sec Cosine Distribution)-
 Radiation Shield Case B/(9 inch Height, 1/4-in. annulus)

(a) 9-(0-) inch-25 percent flow
 ↑ still water height above shield
 — still water height above orifice plate

(b) 10-(1-) inch-150 percent

(c) 11-(2-) inch-150 percent

(d) 9-(0-) inch -200 percent

(e) 10-(1-) inch-200 percent

(f) 11-(2-) inch-200 percent

Figure 7-20. Orifice IV (3.3/2.1 ft/sec Cosine Distribution)-
 Radiation Shield Case B (9-inch in height, 1/4-in. annulus)

(a) 9-(0-) inch-25 percent flow
 still water height above shield
 still water height above orifice plate

(e) 8 1/2-(1-)inch-100 percent

(b) 8 1/2-(1-)inch-50 percent

(f) 9 1/2-(2-)inch-100 percent

(c) 9 1/2 (2-)inch-50 percent

(g) 8-(1/2-)inch-100 percent
 1/2-inch shield tilt

(d) 7 1/2-(0-)inch-100 percent

(h) 8 3/4-(1 1/4-)inch-100 percent
 1 1/2-inch shield tilt

Figure 7-21. Orifice IV (3.6/2.1 Cosine Distribution) - Radiation Shield
 Case C 7-1/2-inch Height, 1/4-in. annulus)

(a) 7 1/2-inch-150 percent flow still height over shield plate--7 1/2-inch still height over orifice.

(b) 8 1/2-(1-) inch-150 percent

(c) 9 1/2 (2-) inch-150 percent

(d) 7 1/2-(0-) inch-200 percent

(e) 8 1/2-(1-) inch-200 percent

(f) 9 1/2-(2-)inch-200 percent

Figure 7-22. Orifice IV (3.6/2.1 Cosine Distribution)-Radiation Shield Case C (7-1/2-inch Height, 1/4-inch annulus)

SECTION VIII

DETAILED SUMMARY OF RESULTS

Flow from the reactor channels into the upper plenum was simulated in a 1/2-scale model with orifice holes to simulate each channel. Four basic types of orifice plates were tested.

- I - Uniform Flow Distribution - High Velocity (5.1 to 4.8 ft/sec)
- II - Uniform Flow Distribution - Low Velocity (3.0 to 2.8 ft/sec)
- III - Cosine Flow Distribution - High Velocity (5.7 to 3.3 ft/sec)
- IV - Cosine Flow Distribution - Low Velocity (3.6 to 2.1 ft/sec)

Orifice plates III and IV were tested with three types of shield plug configurations to calm the surface:

- Case A - 9 inches from orifices to top of outer ring;
10-5/8 inches from orifices to top of center plug;
Overlap between laminations of ring and plug.
- Case B - 9 inches from orifices to top of outer ring and plug;
1/4-inch circumferential annulus between ring and plug.
- Case C - Same as case B, except 7-1/2 inches from orifices to top
of ring and plug.

Exit flow from the orifices was run at 7, 25, 50, 75, 100, 125, 150, and 200 percent of reactor rated flow (883 gpm test equivalent to 5000 gpm reactor).

Liquid heights over the orifices (without plug) were at 1, 3, 6, 9, 12, and 18 inches; and 0, 1, 2, and 3 inches over the top plug surface.

Significant results of the tests are summarized below:

1. Orifices I and II (Uniform Flow, No Shield Plug or Ring)

A rough surface was formed with turbulent outer edge waves and intermittent vortexes, particularly at the auxiliary flow and outlet shield protrusions.

This condition is more severe for orifice I at low water heights of 1 to 6 inches. An acceptably smooth surface was obtained at heights above about 12 inches.

There was evidence of air carryunder to the downcomer holes, but no appreciable carryunder through the downcomer system until flows of 150 to 200 percent were reached.

2. Orifices III and IV (Cosine Flow, No Shield Plug or Ring)

These conditions showed a much more turbulent surface than the uniform velocity orifices I and II, with a pronounced water dome over the exit area.

Vortexing and waves at the outer edges were more pronounced and, in general, considered unsatisfactory.

No appreciable carryunder of air through the system was noted until flows were reached in the range of 150 to 200 percent.

3. Orifices III and IV (Cosine Flow, Shield Plug - Case A - 9 inches, 10-5/8 inches)

The shield plug assembly resulted in a much quieter surface and again no air entrainment was noted until flows in the range of 150 to 200 percent were reached. A considerable amount of vortexing occurred at the instrumented tube holes in the center plug; however, no entrainment of gas was noted.

The low velocity orifice IV resulted in a slightly better condition, but not as pronounced as was expected.

Water levels of 3 inches or more above the shield plug resulted in acceptable smooth surface conditions.

4. Orifices III and IV (Cosine Flow, Shield Plugs - Case B - 9 inches, and C - 7-1/2 inches)

III (High Velocity - This orifice showed a considerable amount of vortexing and waves around the instrumented tube holes at the 7-1/2-inch height (Case B).

The 9-inch height resulted in a much smoother and less turbulent surface for corresponding conditions.

Water levels of 3 inches or more above the shield were required for satisfactory surface conditions.

IV (Low Velocity) - Satisfactory calming of the surface was obtained for both plug Cases B and C with 2 inches or more of water over the surface. The effect of shield height was not as pronounced as for orifice III, with the 9-inch height, Case B, slightly better.

5. A tilt of about 1/2 inch: 28 inches on the center shield plug resulted in no noticeable effect on the surface conditions. Drainage of water from the plug was satisfactory with interspersed areas of water trapped with air in the laminations on the underside of the plug.

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