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T. C. NICHOLS, JR.
VICE PRESIDENT AND GROUP EXECUTIVE
NUCLEAR OPERATIONS

July 29, 1981

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U.S. NUCLEAR REGULATORY COMMISSION

Mr. Harold R. Denton, Director
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Subject: Virgil C. Summer Nuclear Station
Docket No. 50/395
Model Study of Reactor Building Sump

Dear Mr Denton:

In response to FSAR question 211.132 South Carolina Electric and Gas Company agreed to conduct a model study of the flow characteristics of the reactor building sump following a postulated LOCA for the Virgil C. Summer Nuclear Station. Ten (10) copies of that study, conducted by Alden Research Laboratory are provided.

The report contained several minor errors which were hand corrected. These appear on pages 3 and 17. The report will be reissued in approximately two to three weeks to revise those pages and to provide better quality pictures. It is being submitted now with the markerd pages to allow you to expedite your review. The revised report will be sent to you when issued.

Also included in this letter as Attachment 1 is justification for performing the model tests at ambient temperature conditions.

As described in the report no significant vortex phenomena ocurred in the model test program; therefore the existing sump design is acceptable and no modifications are required. In the next FSAR amendment (#27) the response to question 211.132 will be revised to incorporate the results of the report. A marked up copy of that revised response is also included in this letter.

If you have any questions, please let us know.

Yours very truly,

T. C. Nichols, Jr.

T. C. Nichols, Jr.

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RBC:TCN:lkb
Attachments
cc: H. R. Denton (10)
V. C. Summer w/o attach.
G. H. Fischer w/o attach.
H. N. Cyrus w/o attach.
T. C. Nichols, Jr. w/o attach.
J. C. Ruoff
D. A. Nauman w.o attach.
W. A. Williams, Jr. w/o attach.
R. B. Clary w/o attach.
O. S. Bradham w/o attach.
A. R. Koon w/o attach
M. N. Browne w/o attach.
B. A. Bursey
J. L. Skolds w/o attach.
J. B. Knotts, Jr.
C. A. Price w/o attach.
G. M. Moffatt w/o attach.
H. E. Yocom w/o attach.
J. B. Cookinham w/o attach.
PRS w/o attach.
File w/o attach.

ALDEN RESEARCH LABORATORY
WORCESTER POLYTECHNIC INSTITUTE

May 6, 1981

Mr. Gary Moffatt
South Carolina Electric & Gas Company
Post Office Box 764
Columbia, SC 29202

VCS/SUMP-ARL-260E

Dear Mr. Moffatt:

With respect to the question of conducting high temperature tests as part of the ongoing reduced scale model study at the ARL for the Virgil C. Summer Station, we would like to provide a general review of model similitude considerations, a summary of tests on the scale model to date, and a review of why high temperature tests will be conducted as part of the full scale parametric sump study through Sandia for NRC-DOE. This will be followed by our recommendation regarding the possible need to conduct high temperature tests using the V.C. Summer model.

Review of Model Scaling Considerations

General

Models involving a free surface are constructed and operated using Froude similarity since the flow process is controlled by gravity and inertia forces. The Froude number, representing the ratio of inertia to gravitational force,

$$F = u/\sqrt{gs} \quad , \qquad (1)$$

where

u = average velocity in the pipe
g = gravitational acceleration
s = submergence

is, therefore, made equal in model and prototype

$$F_r = F_m/F_p = 1 \qquad (2)$$

where m, p, and r denote model, prototype, and ratio between model and prototype, respectively.

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In modeling an intake sump, it is important to select a reasonably large geometric scale to achieve large Reynolds numbers and to reproduce the curved flow pattern in the vicinity of the intake (4). An asymptotic behavior of energy loss coefficients with Reynolds number is usually observed in similar flows (2). Hence, with $F_r = 1$, the basic Froudian scaling criterion, the Euler numbers, E, will be equal in model and prototype. This implies that the flow patterns and loss coefficients are equal in model and prototype.

Similarity of Vortex Motion

Fluid motions involving vortex formation in sumps have been studied by several investigators (1, 4, 5, 6).

In addition to the primary forces of gravity and inertia, viscous and surface tension forces could influence the formation and strength of vortices (1, 5). The relative magnitude of these forces to the fluid inertia force is reflected in the Reynolds and Weber numbers, respectively, which are defined as:

$$R = u\,d/\nu \tag{3}$$

$$W = \frac{u}{(\sigma/\rho r)^{1/2}} \tag{4}$$

where

- d = intake diameter
- r = characteristic radius of vortex
- σ = surface tension force per unit length
- ν = kinematic viscosity, a function of water temperature
- ρ = mass density per unit volume

It is important for a reduced scale model study to ascertain any deviations in similitude (scale effects) attributable to viscous and surface tension forces in the interpretation of model results. For large R and W, the effects of viscous and surface tension are minimal, i.e., inertial forces predominate. Surface tension effects are negligible when r is large, which will be true for weak vortices where the free surface is essentially flat. Conversely, only strong air core vortices are subject to surface tension scale effects. Moreover, an investigation using liquids of the same viscosity but different surface tension coefficients ($\sigma = 4.9 \times 10^{-3}$ lb/ft to 1.6×10^{-3} lb/ft) showed practically no effect of surface tension forces on vortices (1). The vortex severity, S, is therefore mainly a function of the Froude number, but could also be influenced by the Reynolds number.

$$S = S\,(F, R) \tag{5}$$

Anwar (4) has shown by principles of dimensional analysis that the dynamic similarity of fluid motion at an intake is governed by the following dimensionless parameters

$$\frac{4Q}{u_\theta d^2}, \quad \frac{u}{\sqrt{2gs}}, \quad \frac{Q}{\nu s}, \quad \text{and} \quad \frac{d}{2s}$$

where

Q = discharge through the outlet
u_θ = tangential velocity at a radius equal to that of outlet pipe

The influence of viscous effects was defined by the parameter $Q/(\nu\ s)$, known as a radial Reynolds number, R_R. For similarity between the dimensions of a vortex of strengths up to and including a narrow air-core type, it was shown by experiments that the influence of R_R becomes negligible if $Q/(\nu\ s)$ was greater than 3×10^4 (4). For the prototype of this study, the value of R_R for the operating temperature range of 70° and above, and using the submergence to the floor grating, was greater than 1.1×10^5. In the scale model, the value of R_R for the RHR sumps was 2.6×10^4 for Froude velocity and 4.4×10^4 for prototype velocity, both for water temperatures of 50°F. Thus, viscous forces would have a negligible role in this model study. Dynamic similarity is obtained by equalizing the parameters $4Q/u_\theta d^2$, $u/\sqrt{2gs}$, and $d/2s$ in model and prototype. A geometrically similar Froudian model satisfies this condition.

To compensate for any possible excessive viscous energy dissipation (Reynolds number scale effect) and consequently less intense model vortex, various investigators have proposed increasing the model flow and, therefore, the intake and approach velocity, since the submergence is maintained constant. Operating the model at the prototype inlet velocity (pipe velocity) is believed by some researchers to achieve the desired results (1). This is often referred to as the Equal Velocity Rule. The test procedure for the present study incorporated testing the model at prototype pipe velocities to achieve conservative predictions.

ARL Vortex Activity Projection Technique

ARL has conducted independent research to assure that no scale effect on vortex activity due to Reynolds number exists in models with weak vortices. A technique was developed (9) to extrapolate model vortex activity to prototype Reynolds numbers by using elevated model water temperatures and varying model flow velocity (Froude ratio), and this has been applied to several studies (7, 8, 10, 11, 12). Figure 1 illustrates the method. The ordinate, F_r, is the

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ratio of model to prototype Froude number, while the abscissa is the inlet pipe Reynolds number, R. The objective is to determine flow conditions at $F_r = 1$ at prototype R from tests at lower than prototype R. Assume the model to operate at flow less than Froude scaling ($F_r < 1$) at point a_1. By increasing the discharge in the model while keeping the same submergence and water temperature, F_r and R are increased in increments, corresponding to a point, a_N, where a vortex of type N is observed. The model Reynolds number can also be changed by varying the kinematic viscosity with temperature changes, and similar tests performed to locate b_N, another point on the locus of type N vortices. Extrapolation of the line of constant vortex strength of type N can be made to a prototype Reynolds number at the proper Froude number ($F_r = 1$), point P_N. The locus could represent any expedient measure of vortex severity, including inlet loss coefficient and inlet swirl angle. Any scale effects due to viscous forces would be evaluated and taken into account by such a projection procedure.

Figures 2, 3, and 4, and Table 1, show the effect of increasing Reynolds number and increasing Froude ratio for the final designs of four containment sump model studies conducted at ARL having scale ratios of 1 to 2.5 to 1 to 4. The vortex types designated on these figures are shown in Figure 5. In all cases, the data show no measurable changes in vortex strength, even for types 3 and 4, with Reynolds number at constant Froude ratio. This is reasonable since the Reynolds numbers are all above the limiting value (1, 4), a previously described similitude requirement. Minor increases in vortex strength occur when the Froude ratio is increased. Other measurements, such as swirl in the inlet pipe, have also shown no measurable dependence on Reynolds number. This indicates that reduced scale model tests are a direct indication of prototype performance for weak vortices, particularly if vortex suppressors are part of the design, even at Froude scaled flow (i.e., $F_r = 1$). Tests at higher than Froude scaled flow are seen to give conservative results, i.e., somewhat stronger vortices than expected in the prototype.

V.C. Summer - Test Results

Approximately 50 conditions of varying approach flow distribution, and various combinations of blocking the bar racks and screens have been tested in the reduced scale model. Measurements include classification of vortex type, swirl in the inlet pipe, and inlet loss coefficient. These tests show that no vortices stronger than type 1 (incoherent surface swirl) occurred for any combination of test variables, including operating the model at prototype inlet velocities as well as at Froude scaled velocity. The only swirl observed is generated by obstructions in the approach flow, and these swirls are weak (type 1) and transient. Pipe Reynolds numbers are greater than 1.2×10^5 for the minimum flowrate modeled, the RB spray inlet. This Reynolds number is comparable to the minimum for the previous studies which indicated no increase in vortex activity for increasing Reynolds numbers at constant Froude ratio.

The horizontal floor grating and the relatively deep submergence of the inlet pipes apparently act to suppress the formation of any coherent vortices above the reactor floor.

Full Scale Parametric Sump Study

The generic study of full scale containment sumps being conducted at the ARL via Sandia Laboratories for the NRC-DOE addresses an unresolved safety issue (Task A-43) associated with ECCS systems. As part of this general study, testing will be conducted using water heated to about 160°F to approach prototype operating conditions. Two sump configurations will be selected for these tests, both configurations having been previously testing with normal water temperature, and showing evidence of intermittent air core vortices and air ingestion into the inlet pipes.

The basic reason for the high temperature tests are to determine the effects of decreased water viscosity and surface tension on two phase flow phenomena involving air and water. The effects of increased vapor pressure per se are expected to be negligible since the amount of air and water vapor released from the liquid phase is minimal compared to the ingestion of air by vortices. Also, the effects of increased Reynolds number on single phase flow parameters such as inlet loss coefficient and swirl angle (except due to change in vortex strength) are expected to be minimal since Reynolds numbers with normal water temperatures are already above any transitional values for changes in flow patterns. Basically, the high temperature tests are to determine if a coherent but weak vortices (type 3 or 4) becomes an air core vortex, and if a weak air core vortex becomes stronger-and ingests more air (i.e., will the void fraction increase). Coherent vortices could become stronger with higher water temperature since vortex cores are regions of high shear (velocity gradients) and a decrease in viscosity could increase tangential velocities. Based on work by others, the effects are expected to be small since the Reynolds number for all test conditions are well above suggested minimum values relative to scale effects (1, 4). All testing will be conducted without any vortex suppressor such that the vortex can become stronger should that be the tendency.

Evaluation and Conclusions

Based on general similitude considerations, the results from the V.C. Summer sump reduced scale model testing program, and the intent of the high temperature tests in the full scale sump facility, the following conclusions may be made regarding high temperature tests for the V.C. Summer model.

The V.C. Summer model was designed for minimal scale effects at Froude scale flow, but was also tested for conservatism at prototype velocities. No coherent vortices were observed for any combination of test parameters. Past work at ARL with high temperature testing of scale models has shown that swirls and weak vortices are not subject to scale effects when Reynolds numbers are above recommended minimum values. The horizontal floor bar rack of the V.C. Summer sump acts as a vortex suppressor, which together with the

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lack of coherent vortices and scale effects, makes the question of how higher Reynolds may effect vortices a moot point. There is no technical reason that the observed weak swirls (type 1 vortices) will become objectionable vortices for the V.C. Summer sump design, and tests at elevated water temperatures are, therefore, not warranted in this case.

Please contact us should you have any questions or if you would like any additional material.

Sincerely,

George E. Hecker
Professor and Director

GEH/nmb
Enclosures

REFERENCES

1. Daggett, L.L., and Keulegan, G.H., "Similitude Conditions in Free Surface Vortex Formations," Journal of Hydraulics Division, ASCE, Vol. 100, pp. 1565-1581, November 1974.

2. Daily, J.W., and Harleman, D.R.F., Fluid Dynamics, Addison-Wesley Publishing Company, 1965.

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4. Anwar, H.O., Weller, J.A., and Amphlett, M.B., "Similarity of Free-Vortex at Horizontal Intake," Journal of Hydraulic Research, IAHR 16, No. 2, 1978.

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7. Durgin, W.W., Neale, L.C., and Churchill, R.L., "Hydrodynamics of Vortex Suppression in the Reactor Building Sump Decay Heat Removal System," ARL Report No. 46-77/M202FF, February 1977.

8. Padmanabhan, M., "Hydraulic Model Studies of the Reactor Containment Building Sump, North Anna Nuclear Power Station, Unit 1," ARL Report No. 123-77/M250CF, July 1977.

9. Durgin, W.W., and Hecker, G.E., "The Modeling of Vortices at Intake Structures," Joint Symposium of Design and Operation of Fluid Machinery, Colorado State University, June 1978.

10. Padmanabhan, M., "Hydraulic Model Investigation of Vortexing and Swirl Within a Reactor Containment Recirculation Sump," D.C. Cook Nuclear Power Station, ARL Report No. 108-78/M178FF.

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12. Padmanabhan, M., "Investigation of Vortexing and Swirl Within a Containment Recirculation Sump Using a Hydraulic Model," Seabrook Nuclear Power Station, ARL Report No. 25-81/M296HF, 1981.

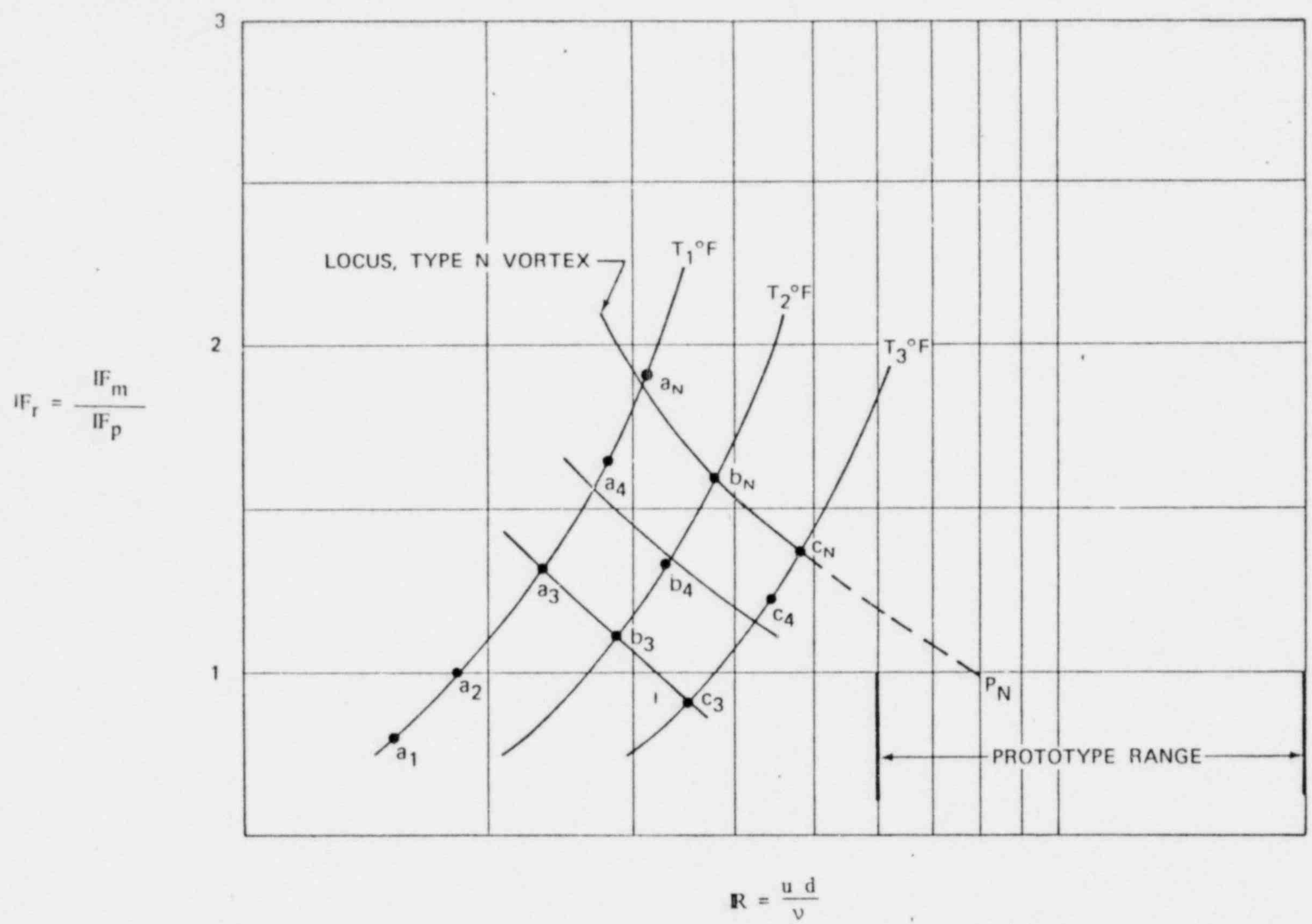

FIGURE 1 DEPENDENCE OF VORTEX SEVERITY ON FROUDE AND REYNOLDS NUMBERS

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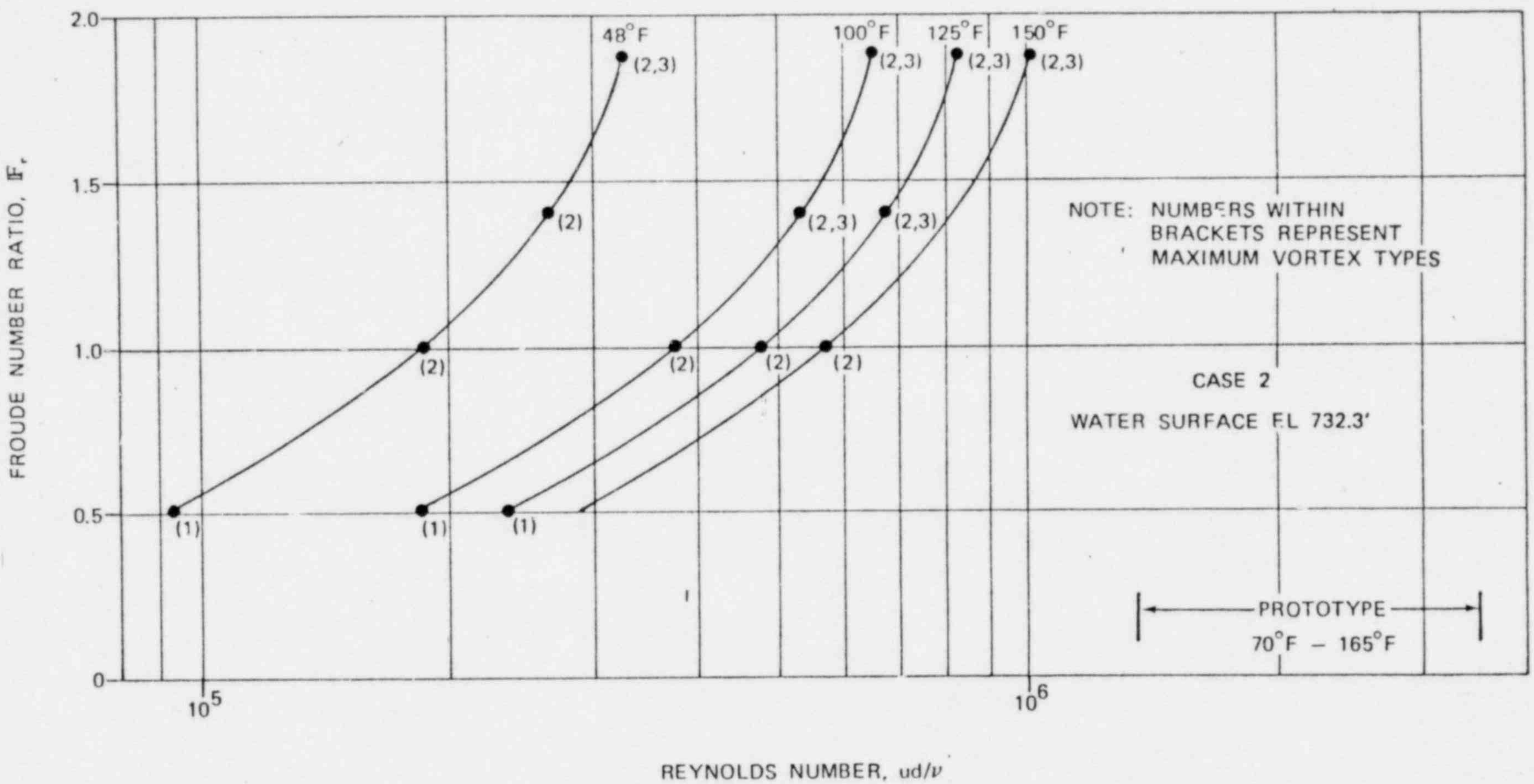

FIGURE 2 FROUDE NUMBER RATIO VERSUS REYNOLDS NUMBER SHOWING MAXIMUM OBSERVED VORTEX TYPES IN THE SUMP

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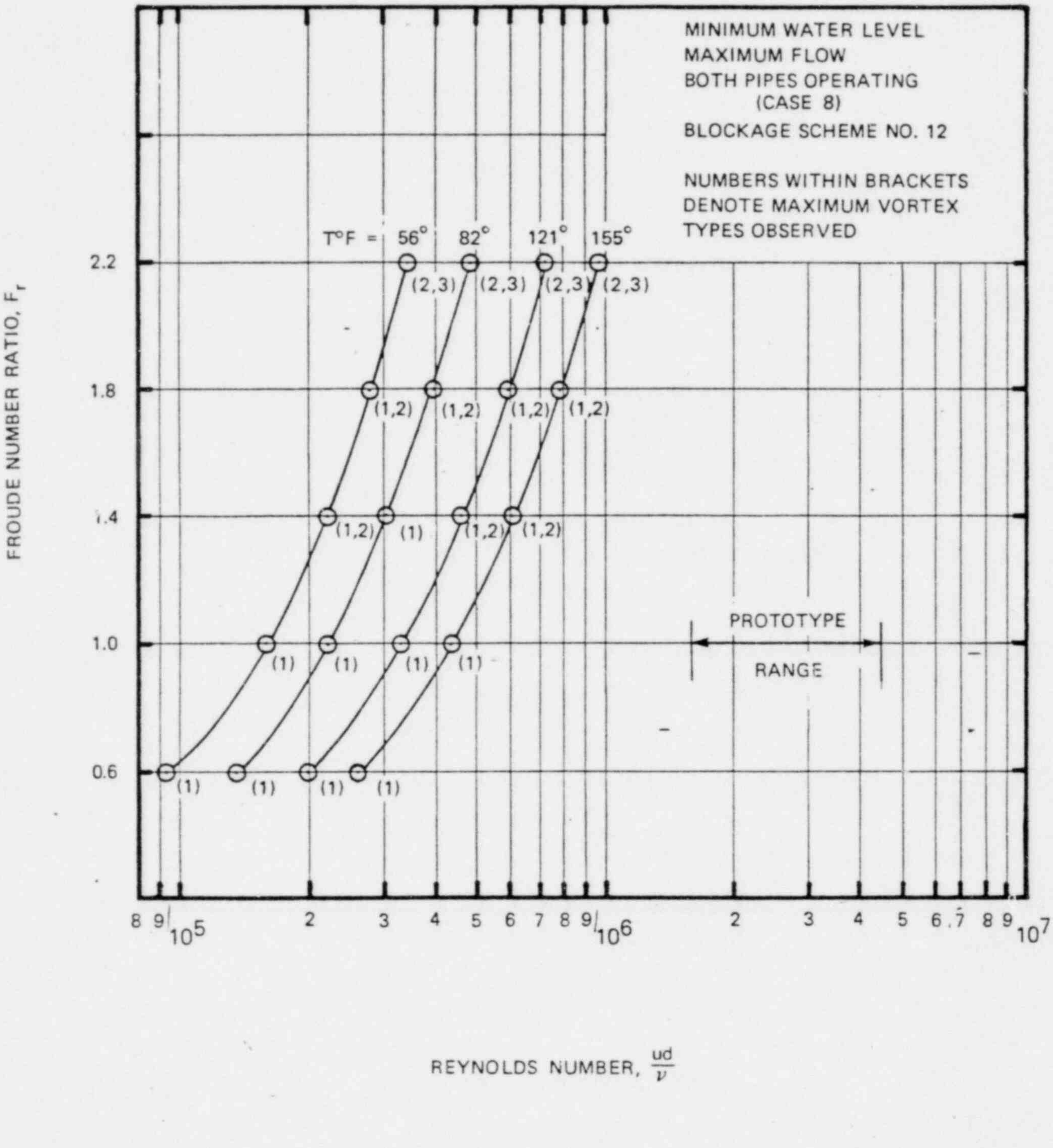

FIGURE 3 FROUDE NUMBER RATIO VERSUS REYNOLDS NUMBER SHOWING MAXIMUM OBSERVED VORTEX TYPES IN THE SUMP

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CASE 1 PIPE 2 AT 9,500 GPM
W.S. EL 602 FT 10 INCHES
WITH GRATING BLOCKAGE SCHEME 5

NOTE: NUMBERS WITHIN BRACKETS DENOTE VORTEX TYPES

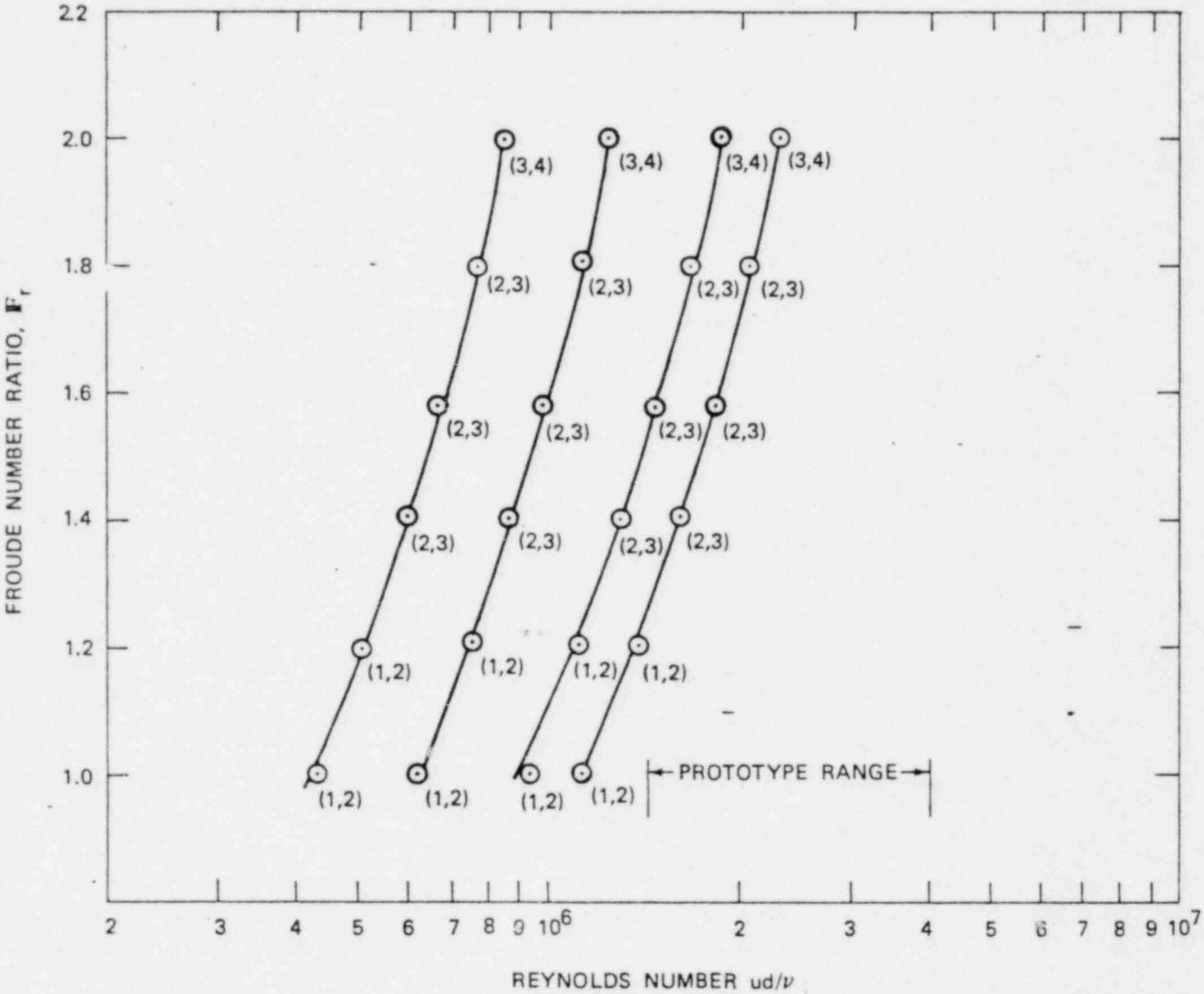

FIGURE 4 VORTEX TYPES OBSERVED DURING HIGH TEMPERATURE-HIGH VELOCITY TESTS (MODIFIED SUMP)

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VORTEX TYPE	
1	INCOHERENT SURFACE SWIRL
2	SURFACE DIMPLE; COHERENT SWIRL AT SURFACE
3	DYE CORE TO INTAKE; COHERENT SWIRL THROUGHOUT WATER COLUMN
4	VORTEX PULLING FLOATING TRASH, BUT NOT AIR
5	VORTEX PULLING AIR BUBBLES TO INTAKE
6	FULL AIR CORE TO INTAKE

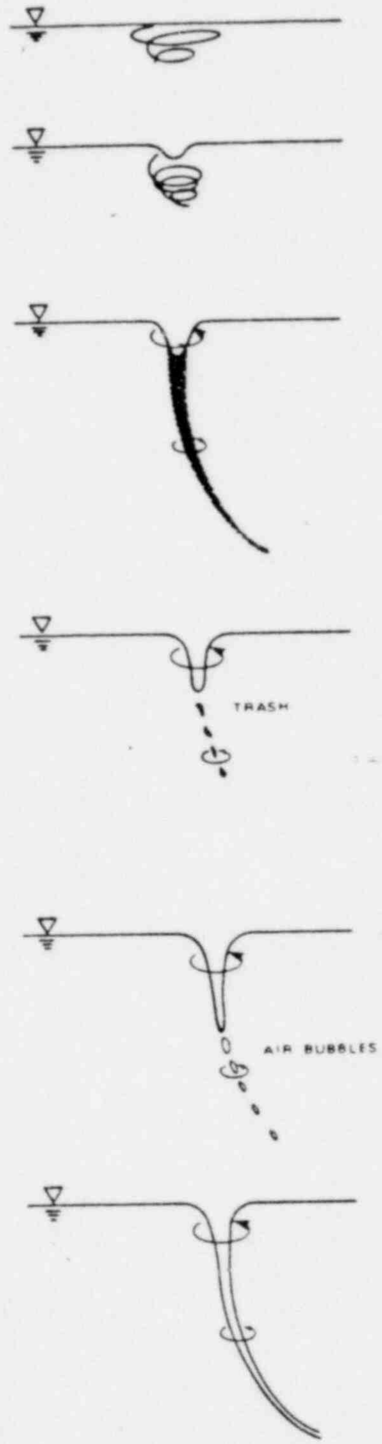

FIGURE 5 VORTEX STRENGTH SCALE FOR INTAKE STUDY

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TABLE 1

EXPERIMENTAL OBSERVATIONS OF VORTEX ACTIVITY IN THE SUMP
PHASE 3 TEST SERIES; SCHEME 4 WITH SCREEN BLOCKAGE

TEST NUMBER	DATE	F_r	WATER TEMPERATURE °F	MODEL $\mathbb{R} \times 10^{-5}$ INLET 2	VORTIMETER READING REV/100 SEC.	REMARKS
6-1	6/22/77	1.0	64	1.50	34, 35, 35	Surface swirls and dimples observed (Types 1-2)
6-2	6/22/77	1.4	65	2.10	49, 49	Surface swirls and dimples observed (Types 1-2)
6-3	6/22/77	1.8	65	2.70	51, 51, 49	Surface swirls and dimples observed (Types 1-2)
6-4	6/23/77	1.8	104	4.37	46, 46	Surface swirls and dimples observed (Types 1-2)
6-5	6/23/77	1.4	107	3.40	45, 45, 46	Surface swirls and dimples observed (Types 1-2)
6-6	6/23/77	1.0	103	2.43	15, 15, 15	Surface swirls and dimples observed (Types 1-2)
6-7	6/24/77	1.0	140	3.38	25, 25, 24	Surface swirls and dimples observed (Types 1-2)
6-8	6/24/77	1.4	143	4.73	47, 48, 45	Surface swirls and dimples observed (Types 1-2)
6-9	6/24/77	1.8	139	5.74	49, 50, 48	Surface swirls and dimples observed (Types 1-2)

Other potential blockage sources include:

1. Fifteen fibrous reinforced silicon rubber enclosures (approximately 4 square feet each) which provide forced air cooling of equipment inside the pressurizer cubicle,

2. Rubber expansion joints in the ring header duct, and

3. Rubber boots for reactor nozzel and support feet ventilation (6 total at approximately 14 square feet each).

The blockage potential of the equipment covers is subject to the same location considerations as the Temp Mat inside the pressurizer cubicle. In addition, the covers are located high in the cubicle and would have to clear instruments, piping, and grating to reach the cubicle opening at the bottom. The ductwork expansion joints are so removed from the sumps and potential missiles that their 23
blockage potential is very small. The reactor nozzel and support ventilation boots are bolted to the wall and clamped to the pipe. However, if a boot became free due to its physical location, it would most likely remain in the incore instrument tunnel.

The potential for debris getting into the suction piping and causing blockage or damage to the pumps or other components, is greately reduced by the trash racks and screens. For the components in the ECCS flow path the Reactor Building Spray nozzles are the determining factor for sizing the smallest strainer screens. Strainer screens with 1/4 inch square openings will allow only those particles smaller than 1/4 inch square to pass completely through the system.

In order to perform a complete analysis, SCE&G contracted Alden Research Laboratories to perform a model study of the Virgil C. 27
Summer Nuclear Station ECCS sumps and suction piping. The study

investigated several design phenomena including swirling and vortexing under full flow and 50% block strainer conditions, losses leading to insufficient NPSH, and air entrainment. Scaling factors were also evaluated to ensure similarity between the model and prototype operating under LOCA conditions. ~~If problems with the current design are uncovered during the study, design modifications will be investigated until an adequate solution is found. These design modifications will then be made to the full scale sump designs.~~ 27

The results of this study demonstrate that no significant vortex phenomena occurred. Therefore, it was determined that the existing sump design is acceptable and that no modifications are required.

RHR and RB Spray pump flow beyond rated runout is another condition which requires evaluation. Due to the different known and unknown conditions of operation, this evaluation is more important for the RHR system. Therefore, full scale tests of the RHR pumps were performed at the Virgil C. Summer Nuclear Station for the different modes of injection and recirculation. As a result of these tests, flow restricting orifices have been installed at the outlet of each heat exchanger. A retest of the RHR system will be performed to insure the adequacy of these orifices. 23

A full scale test of the RB Spray discharge ring headers and spray nozzles is not feasible. However, this system is only subjected to two worst case operating conditions, injection and recirculation, as its design basis. Full scale tests have been performed using the suction and recirculation test returns to the RWST. Test data on the suction piping has been compared to the results of the design calculations as a measure of their accuracy. A detailed analysis was then performed of the Reactor Building Spray System's calculations to ensure that flow rates beyond runout are not possible with subsequent pump damage. 27

~~Also, please refer to SCE&G letter to NRC dated December 29, 1980 for additional information regarding the model tests performed by Alden Laboratories.~~