GEFR-SP 247

DATE 6-28-81

CONF-811108--4

TITLE: Water Simulation of Sodium Reactors

AUTHORS: S. S. Grewal, E. L. Gluekler

MASTER

Prepared for publication in
Proceedings of AIChE 74th Annual Meeting
November 8-12, 1981, New Orleans, Louisiana

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ADVANCED REACTOR SYSTEMS DEPARTMENT • GENERAL ELECTRIC COMPANY
SUNNYVALE, CALIFORNIA 94086

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ABSTRACT

The thermal hydraulic simulation of a large sodium reactor by a scaled water model is examined. The Richardson Number, friction coefficient and the Peclet Number can be closely matched with the water system at full power and the similarity is retained for buoyancy driven flows. The simulation of thermal-hydraulic conditions in a reactor vessel provided by a scaled water experiment is better than that by a scaled sodium test. The results from a correctly scaled water test can be tentatively extrapolated to a full size sodium system.

1. INTRODUCTION

Shutdown heat removal in Large Breeder Reactors is an important safety consideration; the safety objective is to demonstrate adequate core coolability under off-normal conditions. Various systems have been proposed to perform this function. These systems can be divided into two groups; those that are a part of the reactor vessel and those that are a part of the primary, and secondary and tertiary coolant loops. A schematic of an auxiliary cooling system and flow paths for a loop-type large sodium breeder reactor is shown in Figure 1. The auxiliary cooling system may consist of Direct Reactor Heat Exchangers (DRHX). The heat removed is transported by a NaK natural convection loops to a natural convection air draft heat exchanger. The system would be mainly applied in unlikely situations in which the normal heat transport system is not available. In this paper the similitude analysis for experiments with water to study the in-vessel shutdown heat removal is presented.

The verification of the safety adequacy of the in-vessel shutdown heat removal system (IVSHRS) can be accomplished by scaled experiments and by analytical (numerical) studies that include the evaluations of flow mixing and stratification phenomena, flow redistribution in the reactor core under shutdown heat removal conditions and the effect of heat removal systems operation on core coolability. Both studies are based on models derived from the partial differential equations for momentum, mass and energy with the requisite boundary conditions, and, if transients are to be studied, initial conditions as well.

The numerical finite difference or finite element solution is subject to approximations that result from (i) finite size of spatial and temporal nodes, (ii) empiricism in the several coefficients that are used in lieu of exact modelling, and (iii) inability to model all the boundary conditions

correctly. Furthermore, for the low velocities of buoyancy dominated flow, several additional factors need to be considered: (i) change of friction coefficient with velocity profile, (ii) flow instability, (iii) invalidity of a lumped numerical solution for flow recirculation within channels, (iv) approximations with regard to turbulence models and parameters - which have not been well characterized. Several simplified approaches are being followed to obtain numerical solutions for the IVSHRS behavior. One approach is to use 1-D codes instead of 3-D codes; another would be to perform small tests that isolate the individual phenomenon and to use the results empirically in the one-dimensional and three-dimensional codes.

An adequately scaled test would provide the overall test of the adequacy of the one-dimensional and three-dimensional computer codes. In addition, it is shown in this paper that with the correct scaling methods, the results of an experiment done on a small-scale model using water could be extrapolated directly to the sodium cooled large breeder reactor. The experimental solution to the governing differential equation of the system can be obtained with sufficient accuracy.

The scaling parameters are obtained by transforming the partial differential equations of the system into a dimensionless form. The dimensionless coefficients can be simulated in a scaled experiment to solve the equations. The experimental solution, much like the numerical one, is also subject to several approximations: (i) all the dimensionless parameters for the large sodium system cannot be matched exactly for a scaled test, i.e., priorities need to be established among these parameters, (ii) all geometric details, especially in the core, cannot be modelled in a scaled experiment.

Approximations are examined further in this paper to determine the accuracy of the experimental solution. One aspect that will be reported separately is the heat transfer between the fluid and the

structures which may significantly affect structural temperatures and flow fields during certain reactor transients.

The similitude analysis along these lines has been performed earlier by Heisler and Singer ⁽¹⁾ and by Vidil, Martin and Grand ⁽²⁾. This paper uses many of the concepts developed in the two references.

2. WATER SIMILITUDE

To design a scaled water test for shutdown heat removal investigations that is an acceptable representation of the large sodium reactor, priorities can be established as to which parameters should be matched exactly and which ones could be approximated. The most important criterion is the exact matching of the coefficients of the momentum equation for the sodium reactor to the water model. The energy equation is next.

2.1 Momentum Equation

The momentum equation is derived from the Navier-Stokes equations and uses the Boussinesq approximation. In terms of dimensionless variables, the equation is

$$\frac{\partial u^*}{\partial t^*} = \frac{\partial p^*}{\partial z^*} - \left\{ \frac{g \beta \Delta T L}{u_o^2} \right\} \theta^* - \left\{ \frac{\Delta P_h}{\rho u_o^2} \right\} + \frac{1}{Re} \nabla^2 \sigma \quad (1)$$

$$= \frac{\partial p^*}{\partial z^*} - Ri \theta^* - Eu + \frac{1}{Re} \nabla^2 \sigma \quad (2)$$

Hydrodynamic scaling requires that (i) the geometry of the scaled model is similar, (ii) the boundary conditions are similar, (iii) the Richardson number, Euler number and the Reynolds number are the same. If we assume that the shear losses are small, the Reynolds number equality can be neglected. For the core modelled as a lumped system within the reactor vessel and flows in the plena, this is an acceptable assumption. The geometric and boundary condition similarities can be accomplished by appropriate test design.

2.2a Richardson Number Similarity

The Richardson number is a measure of the significance of the fluid buoyancy relative to its inertia.

$$Ri \equiv \frac{g\beta\Delta TL}{u_o^2}$$

To match this number for the sodium and water systems, we have to choose a reference velocity. This velocity is the average flow velocity at full reactor power. For operation of the auxiliary shutdown heat removal system, the power and flow are reduced from normal operating conditions to decay heat levels. Thus, the match of Richardson number has to be made over the entire range of operation. In this section the full power conditions are used for a reference; the next section shows that this ensures correct matching under natural circulation conditions as well.

The Richardson number can be expressed in terms of material properties and variables that describe the experimental design: the length scale L , the power Q and the mass flow rate M . The ratio for the velocity and temperature in the scaled water experiment to that in the

sodium reactor can be expressed in terms of the experimental variables as

$$[u_o]_R = \frac{M_R}{\rho_R L_R^2} \quad (3)$$

and

$$\Delta T_R = \frac{Q_R}{M_R C_R} \quad (4)$$

where R denotes the ratio between the scaled water model and the large breeder reactor .

The Richardson number ratio is then

$$Ri_R = \left(\frac{g \beta \rho^2}{C} \right)_R \left(\frac{Q L^5}{M^3} \right)_R \quad (5)$$

For exact matching of the Richardson number

$$Ri_R = 1 \quad (6)$$

This equation provides the relation between the power, mass flow rate and scale that has to be maintained in the scaled model. The first group of parameters is a ratio of the properties of water and sodium. For an average sodium temperature of 427°C and a water temperature of 27°C,

$$\left(\frac{g \beta \rho^2}{C} \right)_R = K = 0.443 \quad (7)$$

This shows that from a Richardson number perspective, water at 27°C and sodium at 427°C are not dissimilar; for a scaled sodium system, this ratio would have been one. For a scaled water test, the test facility parameters are

$$Ri_R = 0.443 \left(\frac{Q L^5}{M^3} \right)_R \quad (8)$$

In Figure 2 this equation is expressed graphically for the parameters of a scaled water system using a large sodium reactor of 2500 MW power and $14.8 \text{ m}^3/\text{s}$ flow rate as a reference. The curves represent power levels of 1, 0.5, 0.1, 0.05 and 0.01 MW. Figure 2 shows that for the same power level, the required flow rate increases with scale. Using Equation 4 and a temperature difference of 280°F for the large breeder reactor core, the temperature difference for the scaled water experiment has been evaluated and is shown in Figure 3 for the same power levels as in Figure 2. Figure 3 indicates that for a larger model the same power level results in a smaller temperature rise.

A consideration in the experimental design is the volumetric heat generation rate. In a water model, the heat is generated electrically and only a fraction of the reactor power density can be attained. The ratio of the heat generation rates, shown in Figure 4, indicates limitations of useful power levels for the various scales. The maximum power density that can be tolerated in the water test is determined from the requirement that there be no boiling.

Another important aspect is that of flow velocities obtained in the scaled model for Richardson number similitude. Figure 5 shows the velocities at full flow in the scaled model. The velocities during natural circulation will be less than five percent of these velocities. A main test requirement is that the velocities in the water experiment should be measurable; within acceptable accuracy limits. Therefore, it is advisable to maximize the flow rate.

Based on the parameter correlations given in Figures 2 through 5, a choice for the scale, mass flow rate and power can be made. With any operational point chosen from these figures, the Richardson number is matched exactly from full power to natural circulation conditions (as developed in the next section).

2.2b Equivalence Under Natural Convection

The Richardson number using a reference velocity u_0 , can be expressed

in terms of a reference average mass flow rate ratio M_R between the scaled water and full scale sodium system where

$$M_R = (u_o \rho L^2)_R \quad (9)$$

or, using a subscript N for natural circulation conditions, the flow rate ratio M_{NR} , is

$$M_{NR} = (u_o \rho L^2)_{NR} \quad (10)$$

where $[u_o]_{NR}$ is the reference velocity under natural circulation conditions. One choice for this natural convection reference velocity (Ref. 2) is

$$[u_o]_{NR} = (g\beta\Delta TL)^{1/2} \quad (11)$$

Using Equations 3 and 4, this can be transformed to a reference mass flow rate ratio (with respect to the sodium system) M_{NR} as

$$(M_{NR})^3 = K Q_{NR} L_{NR}^5 \quad (12)$$

where K is the combination of properties defined in Equation 7. If the same experiment is used for both full flow and natural convection,

$$L_{NR} = L_R \quad (13)$$

In addition, if the decay power for the water test is the same fraction of the sodium reactor decay power as is the full power, then,

$$Q_R = Q_{NR} \quad (14)$$

Thus,

$$(M_N)_R^3 = K Q_R L_R^5 \quad (15)$$

From Equation 8

$$M_R^3 = K Q_R L_R^5 \quad (16)$$

Thus,

$$(M_N)_R = M_R \quad (17)$$

This shows that choosing a reference velocity by equation 11 is equivalent to matching the Richardson number under full power/full flow conditions; the ratio of the natural convection velocity to the velocity at full power/full flow will be the same for both the scaled water system and the large sodium reactor. Thus, the Richardson numbers can be matched at full power conditions and the similarity retained at the reduced flows including completely buoyancy driven flow.

2.2c Temperature Effect on Buoyancy Forces in Water

The coefficient of volumetric expansion for water changes more with temperature than that for sodium. The coefficient of volumetric expansion for sodium is $2.65 \times 10^{-4} \text{ } ^\circ\text{C}^{-1}$ at 250°C and $2.92 \times 10^{-4} \text{ } ^\circ\text{C}^{-1}$ at 600°C . More variation is observed for water, for which the expansion coefficient changes from $2.07 \times 10^{-4} \text{ } ^\circ\text{C}^{-1}$ to $7.5 \times 10^{-4} \text{ } ^\circ\text{C}^{-1}$ for temperatures between 20°C and 100°C . As the coefficient of volumetric expansion is an important term in the Richardson number, this change in the coefficient needs to be accounted for in the Richardson Number matching for the water scale test (see Figure 6). Figure 6 shows that the ΔT should be chosen for the average temperature of the water that is used in the actual test.

2.3 Euler Number

The second dimensionless parameter in the momentum equation is the Euler Number, Eu , which describes contributions to friction from the viscous flow in channels and from losses due to orificing, obstructions, expansions and contractions.

$$Eu = \sum \frac{fL}{d_h} + \sum_i C_i \quad (18)$$

In the scaled system this number should be matched for the entire hydraulic circuit. Furthermore, this has to be accomplished within the constraint of an exact match of the Richardson number. In practice, these are not conflicting requirements, because the friction coefficient depends primarily on geometry.

The friction coefficient characterizes the pressure losses in the various portions of the circuit. These pressure losses are known for the large breeder reactor. For friction coefficient similitude

$$Eu_R = 1 \quad (19)$$

and similarly

$$\left(\frac{\Delta P \cdot g}{2\rho u^2} \right)_R = 1 \quad (20)$$

where ΔP is the pressure drop across the component for which this similitude applies. Using Equation 3, the ratio pressure drop in the scaled water model to that in the large reactor system is given by

$$\Delta P_R = \left(\frac{M^2}{\rho L^4} \right)_R \quad (21)$$

With an exact Richardson number similarity, using Equation 8,

$$\Delta P_R = \frac{K}{\rho} \left(\frac{Q}{L} \right)^{2/3} \quad (22)$$

For water and sodium properties at 60°C and 427°C, respectively, this equation is shown graphically in Figure 7. From Figure 7, for example, the approximately 80 psi core pressure drop under full flow conditions would correspond to 0.80 psi (multiplier of 0.01) for a 0.5 MW, 1/8th scale water model.

The pressure drop as a result of the above similitude requirements is small for a scale model. In addition, the viscous friction portion (fl/d_h) is reduced substantially; for the water test, l is scaled down, but it is not possible to scale d_h as well (Equation 19). The hydraulic diameter for the reactor components is small and in general, the scaled model hydraulic diameter will be approximately the same. Consequently, the factor fl/d_h is small and in compensation, the form loss portion must be increased. Additional orificing will be needed in the scaled model to increase the pressure loss to compensate for the reduced viscous friction coefficient. Thus, in the large reactor, the major portion of the pressure drop in the fuel channels is due to the friction term, and in the scaled model, the form loss term will dominate. This may be acceptable because the detailed evaluation of flow conditions in the core is not the purpose of the experiment; only the core interaction with the reactor system must be adequately represented.

The Euler number has to be matched over the entire range of operation of the test section from full flow to natural convection conditions. It is recognized that this cannot be accomplished. However, the following discussion will indicate that the effects of the mismatch between the reactor and model test parameters can be ameliorated. In the large breeder reactor, the flow in the fuel assemblies under full flow condition is turbulent ($Re = 6 \times 10^4$). At flow rates of

approximately 3% full flow, the flow becomes laminar. For the turbulent flow regime, the friction factor is approximately constant; it changes in the transition regime to laminar flow and with laminar flow. The form loss coefficient is approximately constant through the entire range of flow rates. As the viscous friction portion is a major component of the Euler number, the Euler number is fixed until a low flow rate is reached. For the scaled model, the Reynolds number is an order of magnitude lower (say 6000). Thus, the transition to laminar flow could take place at 33% of full flow. Below this the viscous friction term is a function of the Reynolds number. The viscous friction term for the scaled model is much smaller than that in the sodium reactor and the contribution of the form loss coefficient to the Euler number is more than 80%; this contribution remains constant. Thus, when the flow is in the turbulent regime, the scaled water model may provide an accurate simulation of the core behavior as a part of the heat transport system.

It can be concluded that for the momentum equation, a scaled water model could provide an acceptable solution for both steady state and transient conditions. No advantage is gained in this respect by using sodium as the model working fluid. The representation is based on the Richardson number and is correct for full flow and full power to the fractional flow and fractional power conditions.

3. ENERGY EQUATION SIMILARITY

The non-dimensional equation for the transport of energy by convection and conduction is

$$\frac{\partial \theta^*}{\partial t^*} = \nabla \theta^* + \frac{1}{Pe} \Delta^2 \theta^* \quad (23)$$

where Pe is the Peclet number. The Peclet number represents the ratio of the convective to conductive transports of energy.

Matching the Peclet number, in addition to the momentum equation similarity, and providing similar boundary conditions would ensure that the scaled experiment would provide an exact solution to the reactor operation as defined by these differential equations. The matching of the Richardson number established a relation between the parameters of the scaled water experiment and a scale could be selected on the basis of providing sufficient geometric detail, acceptable power density in core, measureable temperature changes and flow rates. Thus, it may be desirable, for a reasonable scale, to match the Peclet number as well.

$$Pe_R = \frac{U_R L_R}{\alpha_R} \quad (24)$$

For an exact match

$$Pe_R = 1. \quad (25)$$

Using Equations 3 and 8, and properties of sodium and water at 427°C and 27°C respectively, equation 25 can be written as

$$Pe_R = 352.7 (L_R^2 Q_R)^{1/3} \quad (26)$$

for water at an average temperature of 27°C and sodium at an average temperature of 427°C. For a scaled sodium model of the larger breeder reactor, the Peclet Number ratio would be

$$Pe_R = (L_R^2 Q_R)^{1/3} \quad (27)$$

Figure 8 shows Equation 26 graphically for scaled power levels of 1, 0.1 and 0.01 MW compared to the large system power of 2500 MW. Figure 8 shows that there is less mismatch for the water models at these power levels than there is for a similar size model with sodium.

This can be inferred from Equation 24 as well. As indicated by Equation 24, for any scaled model, both the velocity and length scale are reduced; to compensate for this and to make the Peclet numbers equal, the thermal diffusivity has to be reduced. This can only be accomplished by using a fluid other than sodium in the scaled model. The lower thermal diffusivity of water is then a correction in the right direction. Thus, in a scaled model with water, the heat transport by thermal diffusion is close to what is necessary for Peclet number similarity, while for a scaled sodium model it is quite different. Thus, compared to an exact match at $Pe_R = 1$, Figure 8 shows the scaled water model to be much closer to the reactor system than an sodium model of the same scale.

3.1 Peclet Number Considerations in Upper Plenum

Heat transport effects take place in every component of the test section. Of particular interest is the stratification of the fluid in the upper plenum and related structural effects. Heisler and Singer⁽¹⁾ analyzed the stratified upper plenum using an analysis similar to the one that follows.

During shutdown conditions, a strong thermal stratification is predicted for the upper plenum. This has also been observed in a 1/5th scale plenum tests.⁽³⁾ The fluid rises from the core to the top of the plenum, while the auxiliary shutdown heat removal system or the primary loop extracts fluid at a lower level. Under these conditions, a small fluid velocity would be expected in downward direction. Heisler and Singer⁽¹⁾ estimated this velocity to be about 6.1×10^{-4} m/sec and 2.1×10^{-3} m/sec for the pool and loop type reactors, respectively. The energy equation for steady state conditions in a stratified pool can be derived from equation 23 as

$$\frac{d\theta^*}{dz^*} - \frac{1}{Pe} \frac{d^2\theta^*}{dz^{*2}} = 0 \quad (28)$$

From this equation after integrating for θ^* , the ratio of conductive to convective heat transfer at a point half-way up in the plenum is calculated as

$$Q_r = e^{-0.5 Pe} / (e^{-Pe} - 1) \quad (29)$$

Heisler and Singer⁽¹⁾ evaluated the Peclet number for a large sodium cooled reactor system assuming the characteristic length to be the distance travelled by the fluid in 1 sec and the characteristic velocity at 1% of full flow. For this they obtained Peclet numbers of 0.07 and 0.02 for the loop and pool systems, respectively.

Figure 9 shows the plot of Q_r , the ratio of the conduction to convection Q_r , versus the Peclet number. For Peclet numbers of 0.02 and 0.07, the Q_r is 14.3 and 50.

If water were used in a full scale mockup of the reactor, the Peclet number for the loop type reactor would be 29 (Ref. 1). Thus, the behavior of water would watch that of sodium very well. However, the simulation may be better than with scaled sodium models.

For an 1/8th size Richardson number matched water model, the velocity of the fluid is 0.914×10^{-4} m/sec with a consequent Peclet number of 0.057 (see Table 1). This gives a Q_r of 17.5 very close to the full size sodium system, i.e., the temperature profile in the water simulated upper plenum will resemble that in the large reactor system closely. For a 1/8 scale sodium system, the Peclet number is 0.0011, and the conductive heat transfer would be much larger than that in the LBR.

TABLE 1

Peclet Number and Thermal Stratification Comparisons
of Scaled Models to the Large Sodium Reactor

	Sodium Full Size	Water 1/8 Scale	Sodium 1/8 Scale
$u[m/s]$	2.1×10^{-3}	0.91×10^{-4}	2.5×10^{-4}
Pe	0.07	0.057	0.0011
Q_r	14.3	17.54	909

4. Simultaneous Matching of Richardson and Peclet Numbers.

Richardson numbers and Peclet number similarity can be achieved simultaneously. By setting both Pe_R and Ri_R equal to 1 (equation 8 and 26), the test section parameters are obtained as

$$Q_R = (352.7^3 L_R^2)^{-1} \quad (30)$$

and
$$M_R^3 = 0.443 \frac{L_R}{352.7} \quad (31)$$

Thus, for every scale there exists a combination of heat rate and mass flow rate that will satisfy both requirements at the same time. Table 2 shows the parameter combinations for similarity with a large breeder reactor. The average ΔT is calculated assuming that the ΔT for the large breeder reactor is 138°C.

Table 2: Heat Rate, Water Flow Rate and ΔT for exact similarity of Richardson and Peclet numbers.

Scale	Power (MW)	Flow Rate ($\text{m}^3 \text{s}^{-1}$)	ΔT (°C)
5	0.0014	0.0056	0.0613
10	0.0057	0.0028	0.49
15	0.0128	0.0019	1.66
20	0.0228	0.0014	3.93
25	0.0356	0.0011	7.67
30	0.0513	0.0009	13.25

Table 2 indicates that it is possible to match both the number for very small scale models with a measurable ΔT . For the small scales, the Reynolds number variation would be large because the flow rate and velocities are reduced substantially (see Figures 2 and 5). It is concluded that very small scale experiments would not be suitable for providing velocity data, but would allow good temperature measurements. Thus, for a scale model, it may be desirable not to match the Peclet numbers exactly if both temperature and velocity data need to be generated.

5. Dimensionless Time For Momentum And Energy Equations

The momentum and energy equations were non-dimensionalized separately; each had its own dimensionless time. The dimensionless times for the momentum and energy equation are

$$t_m^* = \frac{u_o t}{L} \quad (32)$$

$$t_e^* = \frac{\alpha t}{L^2} \quad (33)$$

In the solution of the differential equations for the large sodium reactor, the two dimensionless times will be unequal. For the scaled model, the ratio of the two times should be the same as that for the large reactor. Thus,

$$(t_m/t_e)_R = 1 \quad (34)$$

This is equivalent to

$$\left(\frac{u_o L}{\alpha} \right)_R = 1 \quad (35)$$

The above number is identified as the Peclet number. Thus, deviations from the Peclet number similitude result in a change in the phase relationship between the momentum and energy equations.

6. Concluding Remarks

In order to derive an understanding of the in-vessel shutdown heat removal operation, scaled water models are desirable. The matching of the key dimensionless groups, between a scaled water experiment and the large breeder reactor is acceptable. Thus, it may be possible to extrapolate water experiment results to the sodium reactor if the similitude analysis outlined in this paper is followed.

Nomenclature

c	specific heat
Eu	Euler number
f	friction factor
k	$(g\beta\rho^2/c)_R$ ratio of properties
g	acceleration due to gravity
L	length
M	mass flow rate
p	pressure
Pe	Peclet Number
Q	Power
Re	Reynold No.
t	time
u	velocity
z	height
ΔP	pressure drop
ΔT	average temperature difference
β	coefficient of volumetric expansion
θ	temperature
ρ	density
σ	stress tensor

Subscripts

o - reference

R - ratio between the scaled model and a full size reactor

r - ratio of conductive to convective transports

h - hydraulic

Superscript

* denotes dimensionless variable

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81-405-01

Figure 1. SCHEMATIC OF THE IN-VESSEL SHUTDOWN HEAT REMOVAL SYSTEM OF A LARGE SODIUM BREEDER REACTOR

81-405-02

Figure 2. WATER FLOW RATE VERSUS SCALE FOR POWER LEVELS FROM 1.0 TO 0.01MW WITH RICHARDSON NUMBER MATCHING WITH A LARGE BREEDER REACTOR

81-405-03

Figure 3. THE WATER ΔT VERSUS SCALE FOR POWER LEVELS FROM 1.0 TO 0.01MW WITH RICHARDSON NUMBER MATCHING WITH A LARGE BREEDER REACTOR

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Figure 4. POWER DENSITY RATIO, BETWEEN A WATER EXPERIMENT AND A LARGE BREEDER REACTOR, VERSUS SCALE FOR RICHARDSON NUMBER SIMILARITY

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Figure 5. FLOW VELOCITY VERSUS SCALE FOR A SCALED WATER MODEL AT POWER LEVELS OF 1, 0.5 AND 0.1 MW WITH RICHARDSON NUMBER SIMILARITY WITH A LARGE BREEDER REACTOR

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Figure 6. EFFECT OF AVERAGE WATER TEMPERATURE ON THE ΔT FOR RICHARDSON NUMBER SIMILARITY OF A SCALED WATER EXPERIMENT WITH A LARGE BREEDER REACTOR

81-405-07

Figure 7. ΔP_R VERSUS SCALE FOR FRICTION COEFFICIENT SIMILARITY

81-405-08

Figure 8. PECLET NUMBER RATIO BETWEEN A SCALED WATER EXPERIMENT AND A SODIUM REACTOR WITH RICHARDSON NUMBER SIMILARITY AND AN AVERAGE WATER TEMPERATURE OF 140°F AND SODIUM AT 800°F

Figure 9. Q_r VERSUS PECLET NUMBER FOR STRATIFIED UPPER PLENUM