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Application of an Integral Scaling Methodology to an Off-take Phenomenon at the Pressurizer Surge Line and its Validation Using RELAP5/MOD3.2

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Abstract

RELAP5/MOD3.2 code calculations of an off-take phenomenon at the pressurizer surge line are conducted for the validation of the integral scaling methodology. Two scaled-down models are designed based on the present method and Ishii's scaling method given length and area scales of 1/5 and 1/100, respectively. RELAP5/MOD3.2 calculations show that the scaled-down model based on the present scaling method well maintains the similarity of the discharge quality by off-take into a surge line. It was also found that the scale effects are not observed for the surge line diameter due to the lack of the information from the experimental correlations implemented in the RELAP5/MOD3.2.

1. Introduction

An integral response scaling methodology[1] was developed and has been applied to the design of the integral and the separate effect test facilities for shutdown operation.

Figure 1 shows the overall procedures for the development and application of the present scaling methodology to the integral test facility.

These procedures include three parts. The first one is to develop scaling methodology for integral test facility(Fig. 2). For this purpose an integral response scaling method is developed and scaling parameters are identified using an integral response function[2] and scaling distortion is optimized through Phenomena Identification and Ranking Table(PIRT).

The second part of these procedures is an assessment of the code scalability to apply a well-scaled best-estimate code to the scaling validation(Fig. 3). The physical model can be improved if the data base of Separate Effect Tests(SETs) is available.

The last part of these procedures is a scaling methodology validation(Fig. 4). This scaling validation is proceeded with two steps, that is, component or phenomena-based and integral-based scaling validation for the first and second stages, respectively. Sample problems for scaling assessment of local phenomena are calculated by the best-estimate code, RELAP5/MOD3.2 for the first stage validation. Finally we check the code and the present scaling methodology using integral test results.

When stratified conditions occur in a horizontal pipe, the discharge of a gas-liquid mixture from a large horizontal pipe into a small flow path is called an off-take[3]. This situation is of interest in a loss of RHR event during mid-loop operation where the RCS water level is below the top of the hot leg flow area and the pressurizer manway located at the pressurizer top is open[4]. Steam generated in a reactor core discharges from a large diameter horizontal part of the hot leg into a small diameter of the surge line. Water is pulled through the steam flow and this results in the water hold-up in the pressurizer which has a direct effect on the pressure and water inventory of the RCS[5].

From the PIRT process the off-take phenomenon at the pressurizer surge line is considered as one of the high-ranked phenomena. Therefore this sample case is studied for the validation of the present scaling methodology following the present scaling procedures.

2. Scaling Procedures for Off-take Phenomenon

2.1 PIRT process

Recently plant operation at shutdown conditions has produced the great concern on the nuclear reactor safety. After shutdown RCS water inventory is reduced so that the water level is lower than the top of hot leg flow area and reactor cooling is achieved by the Residual Heat Removal(RHR) system. If the function of RHR system is lost during this reduced inventory condition the core can be uncovered due to the boiling in the core and steam and/or liquid discharge into the containment. Because of the importance of this shutdown operation PIRT activity has been completed to identify the processes and thermal-hydraulic phenomena that control the reduced inventory operation.

Each phenomenon that is of great significance is assigned a relative importance ranking, either high, medium, or low from the engineering judgment. The ground for this decision is as follows:

① Degree of unknown
② Relative importance
③ Code model deficiency
④ Validation deficiency

Table 1 provides a PIRT for the key phenomena investigated in this study. For each component, the important phenomena are classified and ranked. The degrees of importances are the high-ranked phenomena(shown as "H" in the table), the medium-ranked phenomena("M"), and the low-ranked phenomena("L"). Four items are classified with these 3 degrees of importance. The ranking number is at the right side of PIRT and if the phenomenon is most high-ranked, it is ranked as 1.

The high-ranked phenomenon, "the stratification in horizontal & inclined pipes" is selected as the sample case for the validation of the present scaling methodology following the present scaling procedures.

Table 1 PIRT results for shutdown operation

Separate/ System effects	Phenomena	U	I	C	V	Rank
Integral Loop (IL)	Asymmetric loop behavior	UM	IM	CM	VM	2
	Flow through openings (manways, vents)	UM	IM	CH	VH	2
	Inventory distribution in loops	UH	IH	CH	VH	1
	Structural heat and heat losses	UL	IM	CL	VL	2
	Boron mixing and transport (boron dilution)	UH	IH	CH	VH	1
	Loop seal clearing and filling	UM	IH-M	CM	VH	1
	Natural circulation in 1-phase flow, primary side	UL	IM	CL	VL	3
	Natural circulation in 2-phase flow, primary side	UM	IH	CM	VM	1
SG / IL	Reflux condensation with& without noncondensibles	UM	IH-M	CM	VH	1
	Heat transfer in SG primary side	UL	IM	CL	VL	3
Hot Leg & Cold Leg / IL	CCFL in horizontal and inclined pipe	UM	IM	CM	VM	2
	Stratification in horizontal & inclined pipes	UM	IM	CM	VM	1
	Condensation with&without noncondensibles	UM	IM	CM	VM	2
	Break flow	UM	IH	CM	VM	1
	ECC-mixing and condensation	UH	IH	CH	VH	1
Core & RPV / IL	Mixture level and entrainment in the core	UL	IH	CL	VL	3
	Mixture level formation in upper plenum and hot legs	UL	IM	CL	VL	3
	Heat transfer in covered core	UL	IH	CL	VL	3
	Heat transfer in partially uncovered core	UM	IH	CM	VM	2
PRZ / IL	Hold-up in PRZ	UM	IH-M	CM	VH	1
Pump	1-and 2-phase pump behavior	UM	IM	CM	VM	2

Item	Degree		
	High	Medium	Low
Degree of **U**nknown	UH	UM	UL
Relative **I**mportance	IH	IM	IL
Code Model Deficiency	CH	CM	CL
Validation Deficiency	VH	VM	VL

2.2 Code scalability

In the stage of code scalability the capabilities of the code are assessed by comparing calculations against experimental data to determine code accuracy, scale-up capability, and to determine the effects of scale.

Several series of tests have been carried out to study two-phase flow in an off-take branch connected to a larger diameter horizontal pipe containing stratified flow. Some major experimental studies are summarized in table 2. The experiments in table 2 were conducted by setting up a steady-state in which known flow-rates of gas and liquid were introduced into the main pipe.

Table 2 Summary of test conditions in major experimental studies

Experiment	Working fluid	Main Pipe diameter (mm)	Off-take pipe diameter (mm)	Pressure range (MPa)	Orientation of off-take pipe H=horizontal U=upward D=downward
KfK[7]	air-water	206	6, 12, 20	0.2-0.5	H
	air-water	206	12, 20	0.2-0.5	U
	air-water	206	6, 8, 12	0.2-0.5	D
CEA[3]	steam-water	135	20	2.0	H, U, D
UCB[6]	air-water	102	3, 6, 10	<1.1	U
	steam-water	102	3	<1.1	H
	steam-water	102	3, 6	<1.1	U, D
INEL[9]	steam-water	284	34	3.4-6.2	H, D

The results of upward oriented off-take experiments[6,7] showed that the critical depth for the onset of liquid entrainment could be defined by an equation of the form:

$$h_b = \frac{K_{off} W_g^{0.4}}{(g \rho_g \Delta\rho)^{0.2}}, \tag{1}$$

where W_g is the steam flow rate and a value of K_{off} is correlated as 1.67 for the upward oriented off-take.

The discharge quality concerned with the amount of the liquid entrainment is given by the following simple correlation[3]:

$$x = R^{3.25(1-R)^2}, \tag{2}$$

where $R = h_{off}/h_b$ and h_{off} is the distance from the stratified liquid level to an off-take branch.

If we define the nondimensional depth h^+_{off} as

$$h^+_{off} = \frac{h_{off}}{D}, \tag{3}$$

the discharge quality ratio of the scaled-down model can be obtained using the relationship between Eqs. (1) and (2) as follows:

$$x_R = \frac{D_R h^+_{off,R}}{(W_g^{0.4})_R}. \tag{4}$$

In the present scaling model[1] the steam flow rate is scaled as the area ratio(a_R) and the horizontal pipe diameter as $a_R^{2/5}$. Therefore, the discharge quality ratio in Eq. (4) becomes 1, and is preserved in the present scaling model if we preserve the nondimensional water level ($H^+ = 1 - h^+_{off}$).

However, the steam flow rate is scaled as $a_R l_R^{1/2}$ and the horizontal pipe diameter as $a_R^{1/2}$ in Ishii's scaling model[1,8]. Using these scaling ratios, Eq. (4) becomes

$$x_R = \frac{a_R^{0.1}}{l_R^{0.2}} \quad \text{for Ishii's scaling.} \tag{5}$$

We can see from Eq. (5) that the discharge quality of Ishii's scaling model cannot be preserved.

Now let us check the scalability of the off-take model in RELAP5/MOD3.2.

We can see that scaling of the surge line diameter(d) has no effect on the discharge quality in off-take if the steam flow rate is scaled as power scaling(or flow rate scaling) from Eq. (4). For the applicable ranges of the off-take through the pressurizer surge line of Korea Standard Nuclear Power Plant(KSNPP), we must consider that the experiments in Table 2 are for the prediction of break mass flow rate in small break LOCA characterized by a large main channel flow diameter to break flow diameter ratio; $D/d \gg 1$. For this reason the applicability of the previous test results to KSNPP(D=42", d=10") should be verified.

3. Validation Using RELAP5/MOD3.2

To validate and compare the present scaling model for upward off-take with Ishii's scaling, the simple test problem shown in Fig. 5 is used. The test case of the prototype consists of a horizontal pipe with the inner diameter of 106.7 cm into which steam and water are fed by time-dependent junctions. A 25.7 cm diameter off-take branch discharging into a time-dependent volume at a fixed pressure of 0.1 MPa is connected to the center of the main pipe.

Table 3 Design parameters for the scaling models

Scaling model	h^*	**D(cm)**	**d(cm)**	W_s**(kg/sec)**
prototype	0.34	106.7	25.7	5.224
present model		16.9	4.1	5.224e-2
Ishii's model		10.7	2.6	2.337e-2

The steady-state calculation results of the prototype, present and Ishii's scaling models are shown in Fig. 6. The solid curve in Fig. 6 is based on the empirical correlation in Eq. (2). 3 RELAP5 calculation points are all on this solid curve because RELAP5/MOD3.2 including the horizontal stratification entrainment model is able to give an accurate description of discharge behavior in an upward off-take. Figure 6 also shows that calculation result of the present model is in good agreement with that of the prototype to validate the present scaling in an off-take phenomenon. In the Ishii's scaling scale down of the diameter(D) is more dominant than that of the steam flow, so the discharge quality is underpredicted by the ratio,

$$x_R = \frac{(1/100)^{0.1}}{(1/5)^{0.2}} \simeq 0.87, \tag{6}$$

with length and area scales of 1/5 and 1/100, respectively.

Transient calculations are performed to simulate the water level decrease due to the water entrainment from the main pipe. Figure 7 shows that the nondimensional levels(H^+) are decreasing from the initial value(0.75). The discharge quality of Ishii's model is lower than that of the prototype or present model, so much more water is discharged and water level decreases more rapidly.

We can conclude that the scaling requirement for a horizontal pipe diameter satisfies not only the counter-current flow limitation requirement[1] but also the upward off-take scaling.

4. Conclusions

Following the present scaling procedures the scaling study of the off-take phenomenon was conducted.

For the validation of the present scaling two scaled-down models are designed based on the present method and Ishii's scaling method given length and area scales of 1/5 and 1/100, respectively.

- Steady off-take simulation with given steam flow shows that the present scaling model is in good agreement with the prototype model but the discharge quality by Ishii's model is lower than that by the prototype.

- Present scaling model well simulates the water level decrease by an upward off-take but Ishii's model leads to more rapid decrease than the prototype.

We found that scaling of the surge line diameter(d) has no effect on the discharge quality in off-take if the steam flow rate is scaled as power scaling(or flow rate scaling).

To verify the applicability of the off-take model to KSNPP, experimental work should be done with the similar boundary conditions and geometry of KSNPP.

References

[1] Hee Cheon NO and Hyoung Tae Kim, "Comparison of an Integral Response Scaling Method with Ishii's Scaling Method and its Validation Using RELAP5/MOD3.2," Proc. of KNS Spring Meeting, Pohang, Korea (May 1999).

[2] S.I. Lee and Hee Cheon NO, "An integral Response Scaling Method for a Scaled-Down Test Facility Simulating SB-LOCA in a Passive PWR," NURETH-6, **2**, 1387, Grenoble, France (Oct. 1993).

[3] K.H. Ardron and W.M. Bryce, "Assessment of Horizontal Stratification Entrainment Model in RELAP5/MOD2 by Comparison with Separate Effects Experiments," *Nucl. Eng. Des.*, **122**, 263 (1990).

[4] Korea Power Eng. Company.(KOPEC), INC, "Analysis of Loss of RHR Events During Mid-Loop Operation of UCN 3&4 Nuclear Power Plants," KOPEC/NED/TR-1 (Feb. 1997).

[5] G.R. Kimber, "RELAP5/MOD3 Analysis of BETHSY Test 6.9a Loss of Residual Heat Removal System Pressurizer Manway Open," AEA RS 5644 (March 1994).

[6] V.E. Schrock, S.T. Revankar, R. Mannheimer, and C-H. Wang, "Small Break Critical Discharge -The Roles of Vapor and Liquid Entrainment in a Stratified Two-Phase Region Upstream of the Break," NUREG/CR-4761, LBL-22024 (Dec. 1986).

[7] C. Smoglie, "Two Phase Flow Through Small Branches in a Horizontal Pipe with Stratified Flow," KfK Report 3861 (December 1984).

[8] M. Ishii, S.T. Revanka et al., "Scientific Design of Purdue University Multi-Dimensional Integral Test Assembly(PUMA) for GE SBWR," NUREG/CR-6309 (March 1996).

[9] "Critical Flow Through Small Pipe Breaks," EPRI NP-4532, (May 1986).

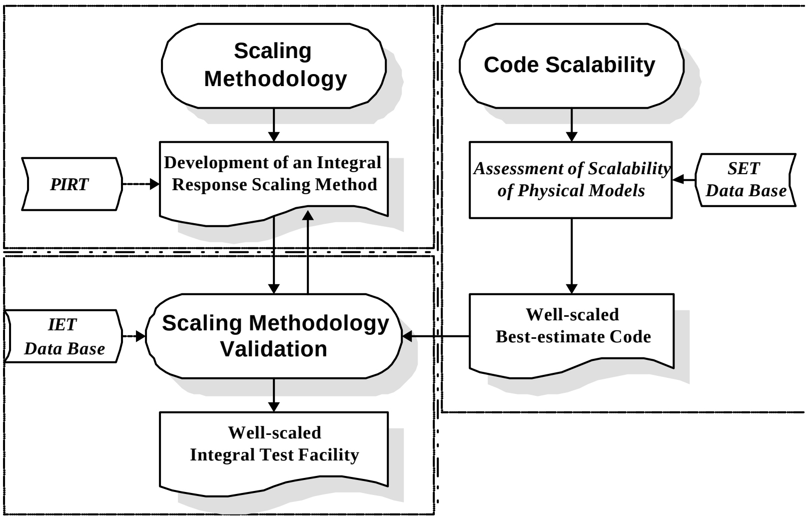

Fig. 1 The overall scaling procedures

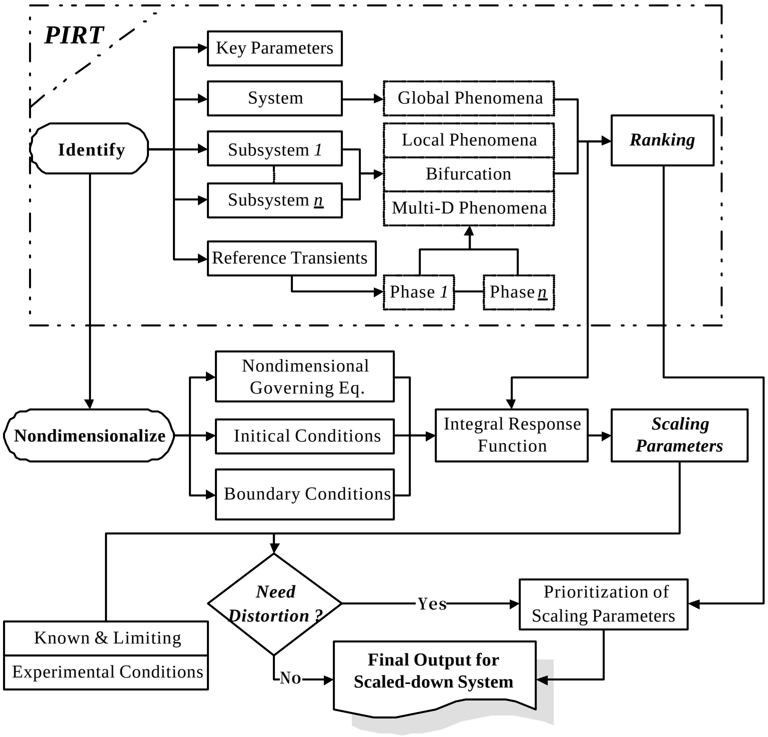

Fig. 2 Integral response scaling methodology

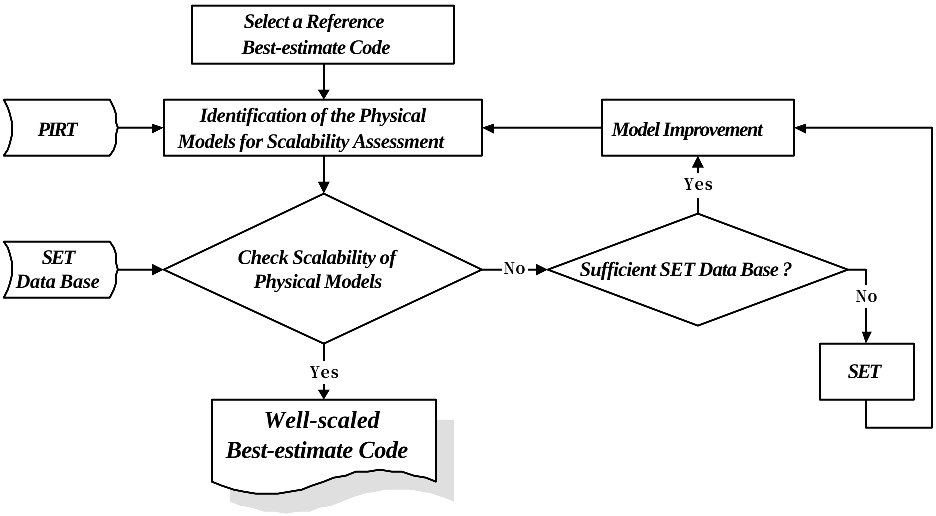

Fig. 3 Code scalability

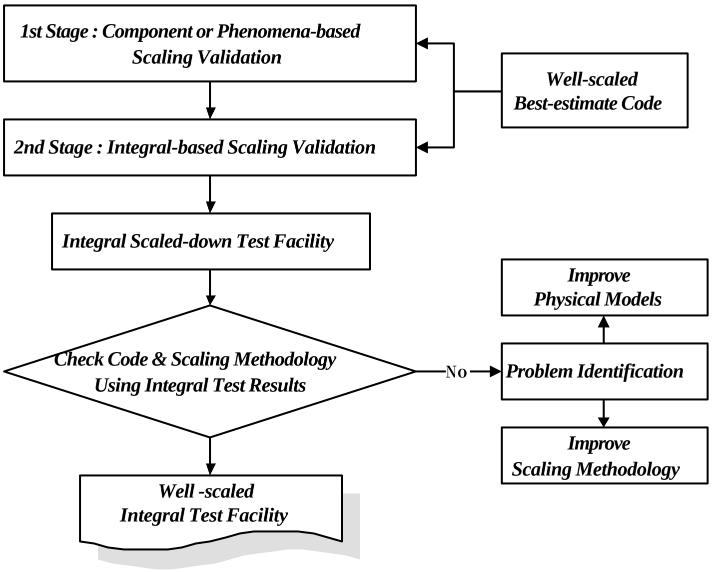

Fig. 4 Scaling validation

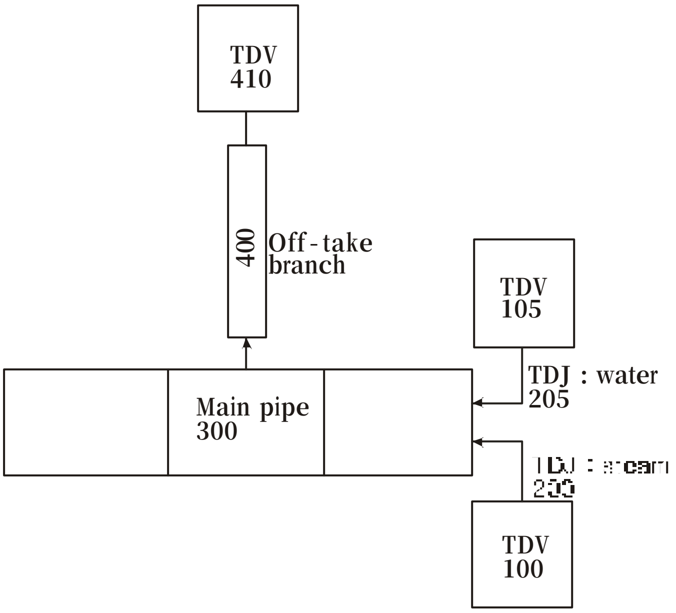

Fig. 5 RELAP5 nodalization of off-take model

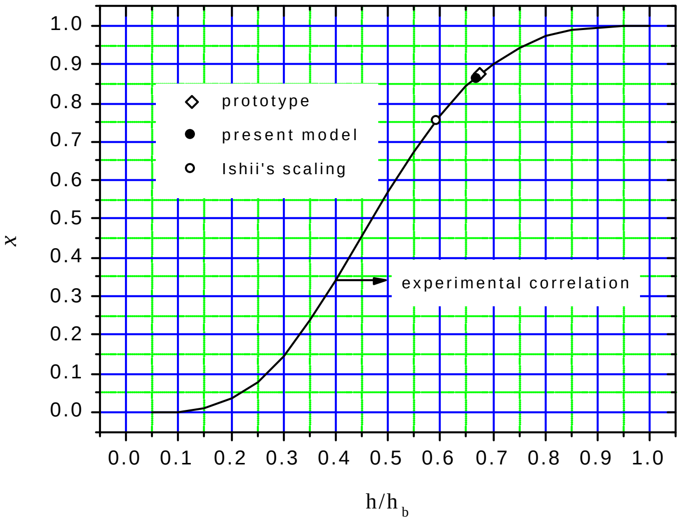

Fig. 6 Comparison of discharge qualities in the constant water level

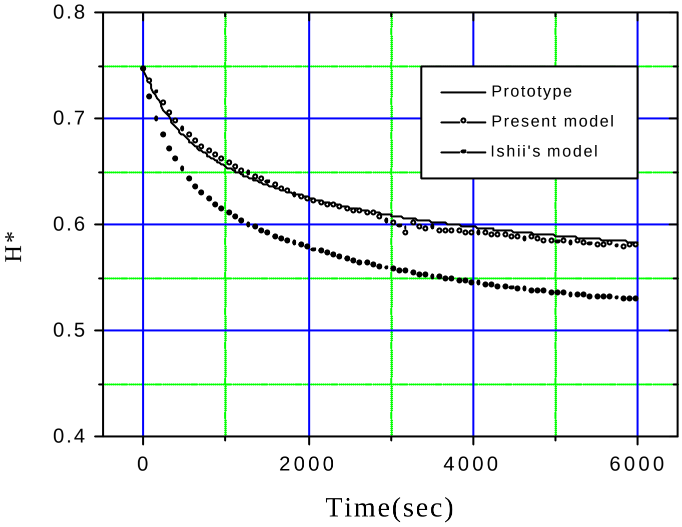

Fig. 7 Comparison of the water level decrease in the scaled models