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LAPUR 6.0 Benchmark Against Data from the GENESIS Facility

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ABSTRACT

This report contains an evaluation of the LAPUR6 code against stability data measured in the GENESIS facility in Delft University of Technology, Netherlands. LAPUR6, a computer program in FORTRAN, is a mathematical description of the core of a boiling water reactor (BWR). Its two linked modules, LAPURX and LAPURW, respectively solve the steady-state governing equations for the coolant and fuel and the dynamic equations for the coolant, fuel, and neutron field in the frequency domain. The result of these calculations is a closed-loop transfer function that relates power oscillations to external perturbations in core reactivity. The stability parameters of merit, decay ratio (DR) and frequency of oscillation are estimated from the calculated transfer function. The LAPUR code has been validated in the past against a reasonable array of BWR test data.

The GENESIS facility is located in the Reactor Institute of Delft University of Technology, Netherlands. It is a boiling, natural circulation facility where flows, void fraction, and density wave instabilities can be studied over a wide range of conditions. The facility was initially constructed to simulate the conditions of the ESBWR design and was scaled so that, using Freon 134a at low power, the results could be extrapolated to water at full ESBWR power and pressure. Previous publications describe the GENESIS scaling laws in detail. The GENESIS facility may be run on purely thermal-hydraulic mode, by keeping the thermal power constant, or with a simulated reactor neutronic feedback. For the later purpose, the core pressure drop is measured and the core-average void fraction is estimated based on a one-channel model. The reactivity feedback and the fuel response are modeled on a control computer, and the thermal power is modulated according to the predicted reactor response. All data used for this benchmark includes the simulated reactivity feedback.

Twenty-seven GENESIS measurements at different operating conditions were simulated by LAPUR6. All geometry and measurements were scaled to water properties for use in LAPUR6. Ninety-two axial nodes were used to model GENEIS (17 for the core and 75 for the chimney). The results of these benchmark calculations show that LAPUR6 predicts an oscillation frequency of ~0.7 Hz, which agrees with the measured frequency, and indicates that the chimney has little or no effect on the dynamic oscillations. The DRs calculated by LAPUR6 are in agreement with those measured in GENESIS.

CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

1.0 INTRODUCTION

This report contains an evaluation of the LAPUR 6.0 code [Refs. 1 and 2] against stability data measured in the GENESIS facility [Refs. 3, 4, and 5] in Delft University of Technology, Netherlands.

LAPUR, a computer program in FORTRAN, is a mathematical description of the core of a boiling water reactor (BWR). Its two linked modules, LAPURX and LAPURW, respectively solve the steady-state governing equations for the coolant and fuel and the dynamic equations for the coolant, fuel, and neutron field in the frequency domain. The result of these calculations is a closed-loop transfer function that relates power oscillations to external perturbations in core reactivity. The stability parameters of merit, decay ratio (DR) and frequency of oscillation are estimated from the calculated transfer function.

The LAPUR code has been validated in the past against a reasonable array of BWR test data as documented in Refs. 6 through 12. These old validation data include:

1. Peach Bottom tests (see Ref. 6)
2. Vermont Yankee stability tests (see Ref. 6)
3. Dresden local stability test (see Ref. 7)
4. Browns Ferry single-loop stability test (see Refs. 8 and 9)
5. Susquehanna-2 stability tests (see Refs.10 and 11)
6. Grand Gulf-1 stability tests (see Refs. 10 and 11)
7. Cofrentes stability tests (see Ref. 12)

2.0 LAPUR6 DESCRIPTION

This section presents the computer program LAPUR, a version coded in the FORTRAN language of the mathematical description of a BWR. This program consists of two autonomous modules, LAPURX and LAPURW, which are linked by means of an intermediate storing device.

The first module, LAPURX, solves the coolant and the fuel steady-state governing equations as described in Sect. 3.2.1 of Ref. 1. Maps of core steady-state parameters are generated by LAPURX and stored into two data files for subsequent use by the dynamics module LAPURW.

The second module, LAPURW, solves the dynamic equations for the coolant, fuel, and neutron field in the frequency domain according to the formulations developed in Sect. 3 of Ref. 1.

General input requirements to run a problem are as outlined:

For steady-state calculation (LAPURX), system operating status:

1. State parameters: reactor pressure, thermal power generated, core flow rate, and coolant temperature at the inlet plenum.
2. Power map: Vertical power shape of representative channels and either steam exit quality or amount of power generated in each channel.
3. Fraction of power deposited into the coolant by neutron moderation and γ ray absorption.

For steady-state calculation (LAPURX), system design parameters:

1. Mechanical: channel box and fuel pin dimensions.
2. Physical: hydraulic diameters, friction multipliers, orifice flow coefficients, fuel and clad densities, and gap thermal conductance.

For steady-state calculation (LAPURX), user options:

1. Error criteria for the iterative calculations.
2. Adjustable parameters for two-phase correlations.
3. Number of nodes desired in the boiling part of a channel.
4. Output options.

For dynamic calculation (LAPURW), systems parameters:

1. Recirculation loop pressure to flow rate gain and time constant.

For dynamic calculation (LAPURW), neutronic parameters:

1. Effective neutron lifetime table.
2. Steady-state core reactivity table.
3. Delayed neutron fractions and their time constants.
4. Doppler reactivity coefficient.
5. Table of density reactivity coefficients.

For dynamic calculation (LAPURW), output options:

1. Frequencies of interest for the dynamic analysis.
2. Edit and plotting options.
3. Stability calculation options.

Note that each sub core must be assigned a set of neutronic parameters.

Steady-state calculation LAPURX generates a map of the thermo hydraulic parameters in the core, that is, of the following:

1. Channel flow rate, pressure drops, and exit quality (or power) for each channel.
2. Nodal coolant density, void fraction, enthalpy, quality, velocities, and friction components at each node along each channel.
3. Set of coefficients for the dynamics calculation.

The dynamic calculation determines:

1. For the fuel, the response of the heat flux to the coolant and of the average temperature to driving perturbations of power generation, coolant temperature, and coolant flow rate at each node in every channel.
2. For the coolant flow in a channel box:
    - The response of the coolant parameters at every node to driving perturbations of power generation at each sub core level, coolant flow rate, and coolant inlet temperature.
    - The open-loop transfer function (TF) for the channel hydrodynamics, its natural frequency, and decay ratio.
    - The reactivity feedback induced in each node by the driving perturbations. (This is accomplished by properly weighting the coolant density and fuel temperature perturbations with reactivity coefficients.)
3. For each nuclear sub core:
    - Feedback reactivity TFs for driving perturbations in power at each sub core, inlet temperature, and core flow rate.
    - Open-loop TF matrix; total core natural frequency and decay ratio.
    - Closed-loop TF matrix of reactivity to power.
4. Nyquist and magnitude phase plots for all open-loop TFs; Bode plots for closed-loop TFs.

3.0 GENESIS FACILITY DESCRIPTION

The GENESIS facility [Refs. 3, 4, and 5] is located in the Reactor Institute of Delft University of Technology, Netherlands. It is a boiling, natural circulation facility where flows, void fraction, and density wave instabilities can be studied over a wide range of conditions. The facility was initially constructed to simulate the conditions of the ESBWR design and was scaled so that using Freon 134a at low power the results could be extrapolated to water at full ESBWR power and pressure. The operating pressure of GENESIS is 11.4 bar [Ref. 3], compared to ~70 bar for a typical BWR. The power required is approximately 50 times smaller due to the boiling characteristics of Freon 134a [Ref. 3]. Refs. 3, 4, and 5 describe the GENESIS scaling laws in detail.

Figure 1 shows a schematic of the facility. A heated area with 25 heated rods is followed by a long adiabatic chimney. A heat exchanger at the top of the facility condenses the steam and returns feedwater flow through the downcomer. Two valves can be adjusted manually to simulate the inlet and steam separator pressure drops. To evaluate the K value of the valves, single phase flow is established with the pump and the pressure drop and flow are measured. For all other measurements, the flow is established by natural circulation as voids are formed in the heated section. Relevant instrumentation includes: (1) inlet temperature, (2) exit void fraction, (3) thermal power, and (4) pressure drops across the valves. Other instruments are included, as shown in Table 1.

The GENESIS facility may be run on purely thermal-hydraulic mode, by keeping the thermal power constant, or with a simulated reactor neutronic feedback. For the later purpose, the core pressure drop is measured and the core-average void fraction is estimated based on a one-channel model (see Refs. 3, 4, and 5 for details). The reactivity feedback and the fuel response are modeled on a control computer. The thermal power is modulated according to the reactor response predicted by the simulated point kinetics reactivity feedback. The GENESIS heated rods have a very fast time constant (< 0.5 sec), and the time constant of the reactor fuel must be simulated in the control computer. Typically, the fuel time constant is simulated in the GENESIS control computer as ~5 seconds (see Refs. 3, 4, and 5 for details).

A series of experiments have been conducted in the GENESIS facility to determine: (1) the natural circulation flow, and (2) the stability of the facility for a combination of operating conditions. Both the stability of the purely thermal-hydraulic system and the reactivity-feedback system were studied. The primary finding is that when the reactivity feedback is enabled, the frequency of the resulting oscillation changes significantly as the mode of oscillation changes from a loop- (manometer-) type to a density wave in the core. The complete results of these experiments are shown in Refs. 3, 4, and 5.

Table 1 Available signals measured at the GENESIS facility

1	pressure inlet element	21	temperature vessel 1 (bottom)	41	void fraction outlet element (BGO)
2	pressure vapour outlet	22	temperature core 16	42	capacitance (void inlet riser)
3	pressure feedwater inlet	23	temperature vapour (tc)	43	capacitance (void outlet riser)
4	temperature core 13	24	temperature feedwater inlet (tc)	44	capacitance (void downcomer)
5	temperature core 1	25	temperature core 17	45	capacitance (level vessel)
6	temperature core 2	26	dT riser	46	voltage power supply 1
7	temperature core 3	27	temperature inlet (pt100)	47	voltage power supply 2
8	temperature core 4	28	temperature vapour (pt100)	48	voltage power supply 3
9	temperature core 5	29	temperature feedwater inlet (pt100)	49	voltage power supply 4
10	temperature core 6	30	dP inlet valve (PMD235)	50	voltage power supply 5
11	temperature core 7	31	dP riser valve (FMD533)	51	voltage power supply 6
12	temperature core 8	32	dP separator vessel (level) (PMD633)	52	voltage power supply 7 (1 rod only)
13	temperature core 9	33	dP inlet (Keller)	53	current power supply 1
14	temperature core 10	34	dP core (Keller)	54	current power supply 2
15	temperature core 11	35	dP core (not used yet)	55	current power supply 3
16	temperature core 12	36	VRF alpha_av	56	current power supply 4
17	temperature riser 1 (bottom)	37	ControlPower	57	current power supply 5
18	temperature riser 2	38	flow inlet element	58	current power supply 6
19	temperature core 14	39	flow vapour outlet	59	current power supply 7
20	temperature riser 15	40	flow feedwater inlet	60	level buffer vessel (NR Koeling)

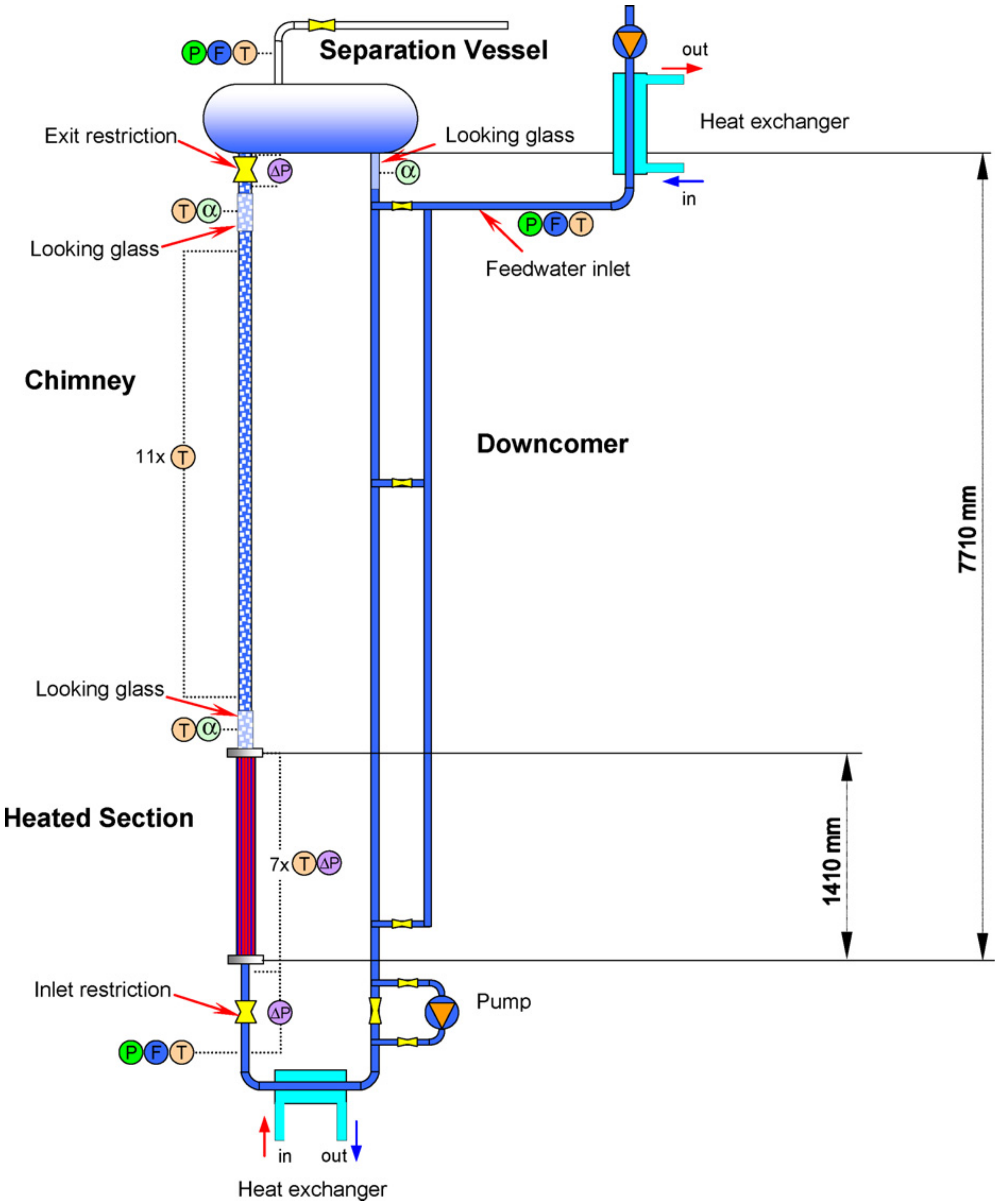

Figure 1 Schematic of the GENESIS facility (*M. Rohde et al. / Nuclear Engineering and Design 240 (2010) 375–384*)

4.0 LAPUR6 MODEL

The LAPUR code only describes in detail the core region. The recirculation loop, including the downcomer and recirculation pumps are only modeled by an integral momentum approach, which provides dynamic core flow feedback given changes in core pressure drop. However, it does not model variations in temperature and density of the downcomer necessary to model the U-tube or loop oscillations that were observed in GENESIS when the neutronic feedback is turned off. When the neutronic feedback is turned on in the GENEIS facility, the dominating dynamics occur on the core, and LAPUR6 is design to model that dynamic behavior.

The LAPUR6 model for GENESIS includes a single radial channel with 92 axial nodes (17 for the core and 75 for the chimney). The variable flow area feature of LAPUR6 was used to specify the areas of the core and chimney respectively. The axial nodalization is shown graphically in Figure 2.

Six spacers were explicitly modeled as local losses. The inlet and outlet valves in the GENESIS facility were modeled in LAPUR6 as the channel-inlet and channel-outlet local losses. Note that the LAPUR6 channel for these simulations covers both the core and chimney regions. The core region is 3 m and the chimney is 12.81 m. These dimensions are scaled values for water. The real dimensions of the GENESIS facility are 47% smaller.

All dimensions, pressures, powers and flows were scaled to the water equivalent. Table 2 shows the scaling rules that were developed in Refs. 3 through 5.

Table 3 describes the operating conditions for all points analyzed. The inlet and outlet valves were set at a constant value and not changed for the duration of the tests.

The GENESIS facility is designed to operate in purely thermo-hydraulic mode (i.e., constant power) or with simulated reactivity feedback. The reactivity feedback is simulated by estimating the core-average void fraction from the measured core pressure drop using a TH model. The point kinetics approximation is used to simulate the power feedback in a reactor core.

The GENESIS heaters are thin rods with a very fast thermal time constant. In reactors, the fuel has a slow time response, of the order of 5 seconds. The GENESIS facility simulates the fuel thermal conductivity in the computer side by filtering the power feedback before it is applied to the rods. For this purpose, a 5 second first order filter is used. For these LAPUR6 benchmark cases, UO_2 fuel rods were used. The radius of the fuel rod was adjusted by trial and error for each case until the calculated fuel time constant was 5 seconds. In particular, the fuel rod radius was adjusted by trial and errors until transfer function CBQ calculated by LAPUR (see Refs. 1 or 2) has a phase of -45 degrees at 0.2 Hz, which is equivalent to a first order 5 second delay. Figure 3 and Figure 4 show the LAPUR fuel transfer function CBQ for one example where the phase is -45 degrees at 0.2 Hz after adjusting the fuel radius.

Table 2 Scaling Rules

Variable	Scaling Factor
Length	0.4700
Power	0.0230
Mass flux	1.0070
Time	0.6800
Pressure	0.1600
Flow area	0.2209
Mass flow	0.2224

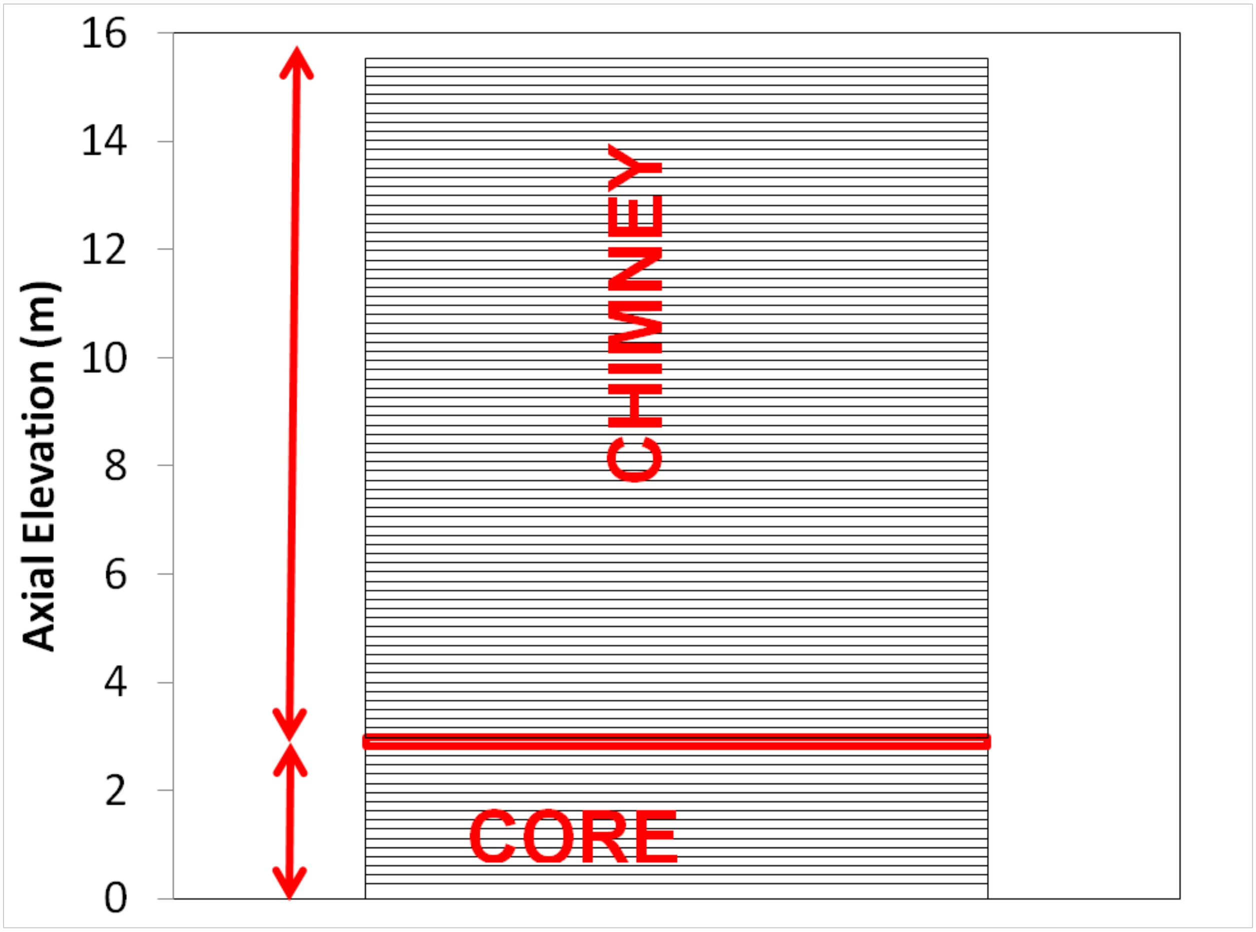

Figure 2 LAPUR6 axial nodalization

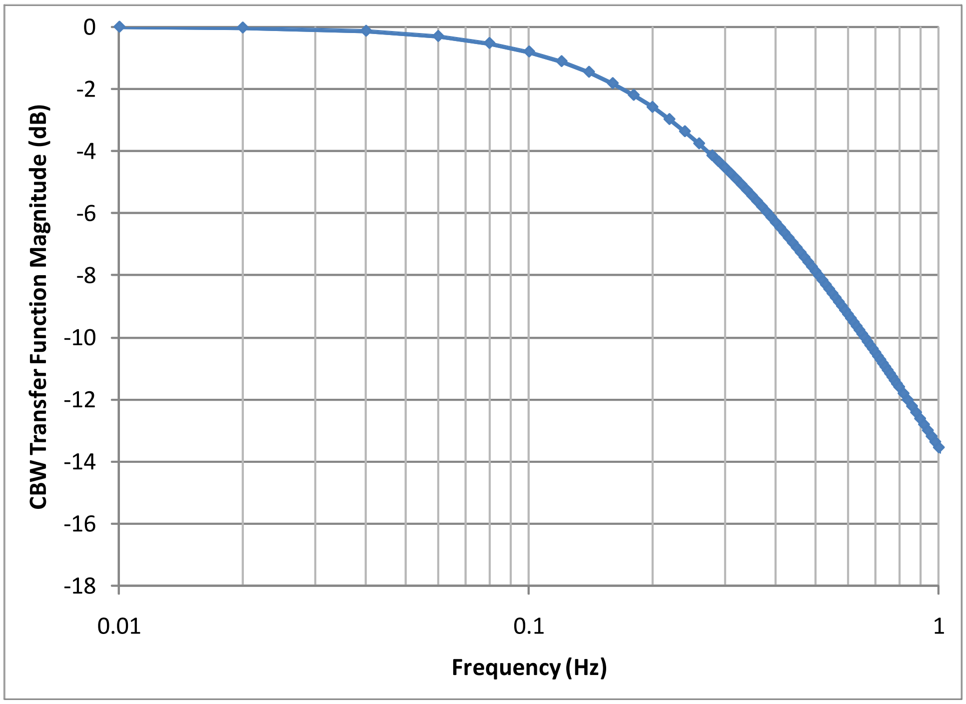

Figure 3 Magnitude of Fuel Transfer Function (CBQ) for point 0602081340

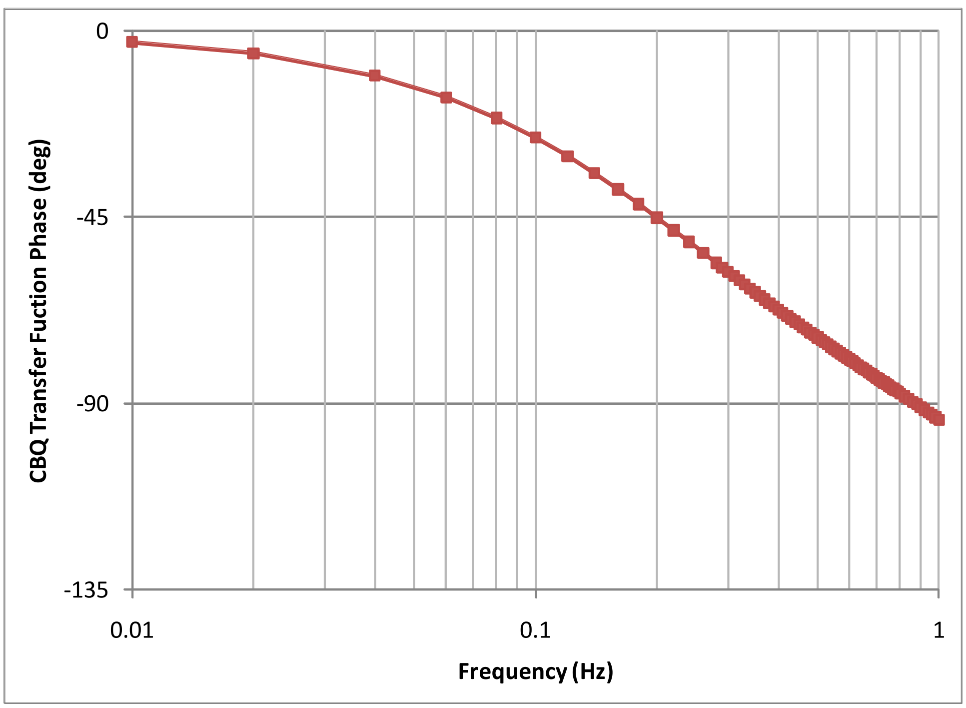

Figure 4 Phase of Fuel Transfer Function (CBQ) for point 0602081340

5.0 LAPUR RESULTS

A number of operating conditions in the GENESIS facility had been analyzed with LAPUR6. Table 3 shows the relevant input parameters for each operating point. All variables have been scaled to water-equivalent conditions.

5.1. STEADY STATE VOID FRACTION BENCHMARK

Figure 5 shows the calculated void fractions for three conditions at different power levels. We can observe that the void fraction calculated by LAPUR increases in the core, but it remains constant in the adiabatic chimney.

Figure 6 and Figure 7 show a comparison between the core exit quality and void predicted by LAPUR6 and the one measured in the GENESIS facility for the steady state measurements of Table 3. Excellent agreement is observed. This is an excellent validation of the LAPUR6 void correlations against a large number of experimental conditions covering exit qualities from 3% to 25%.

5.2. STEADY STATE PRESSURE DROP BENCHMARK

Figure 8 shows the pressure drop calculated by LAPUR6 for all tests. This pressure drop encompasses both the core and chimney regions. Since the GENESIS facility is operated at natural circulation, the calculated pressure drop should be the same for all conditions because this pressure drop must equal the weight of the downcomer.

We observe that LAPUR6 computes essentially the same pressure drop for all tests within a precision of ±1.5%. The only exception is a test point (0602201437) where the exit void fraction is very low (~30%) and the dP error is of the order of 8%. All other conditions have void fractions more representative of reactor operating conditions.

We conclude that LAPUR6 benchmarks the GENSIS pressure drops accurately.

5.3. DECAY RATIO BENCHMARK

LAPUR6 calculates transfer functions (TF) in the frequency domain for all the components of the dynamic response of the reactor. In particular, LAPUR6 computes the open-loop TF, which contains all the reactor dynamics minus the reactivity feedback. This open-loop TF represents the TH conditions in GENESIS when the reactivity feedback is turned off. The LAPUR6 closed-loop TF joins together the open-loop TH TF with the point kinetics reactivity feedback to estimate the reactivity-to-power TF, which represents the GENESIS dynamics when the reactivity feedback is turned on.

Figure 9 shows the open-loop TH TF calculated by LAPUR for case 0602141115. We can see a small resonance (representative of an oscillation frequency) at ~0.2 Hz, which represents the loop time constant including the chimney. A smaller resonance can be observed at ~0.6 Hz, which corresponds to the channel residence time. When the reactivity feedback is turned on, we obtain the closed loop TF of Figure 10. We see that when the reactivity feedback is active, the 0.2 Hz resonance disappears and only one main frequency at ~0.8 Hz is visible.

The above results are consistent with the observed behavior in the GENSIS facility when the feedback is enabled [Ref. 3 through 5]. Experimentally, The GENESIS facility exhibits a low frequency oscillation (0.1 to 0.2 Hz, depending on conditions) when the power is kept constant (purely TH conditions). This frequency is associated experimentally with the loop time constant, including the chimney. When the reactivity feedback is enabled and the power is allowed to oscillate as function of the measured void fraction, the low frequency component disappears and only a high frequency component (0.6 to 1 Hz, depending on operating conditions) is observed. This high frequency is associated experimentally with the residence time in the channel.

To further investigate this phenomenon, LAPUR6 simulations were conducted where the TH stability of the loop was reduced artificially by increasing the outlet friction coefficient (K_{out}). Figure 11 shows the open-loop TH TF as function of K_{out}. We observe that as K_{out} is increased, the ~0.2 Hz peak increases significantly, with K_{out} values ~500% of nominal, the TF is essentially unstable for these conditions (test 0602141115). The channel peak at ~0.6 Hz also increases in amplitude when K_{out} is increased, but the ~0.2 Hz is always dominant when the reactivity feedback is not enabled.

When the reactivity feedback is enabled, LAPUR6 obtains the results shown in Figure 12. We observe that when the TH conditions are de-stabilized by increasing K_{out}, the ~0.8 Hz peak is more dominant. For conditions that are almost unstable without feedback, a second peak starts forming at ~1 Hz, but the ~0.8 Hz peak is dominant.

To further study the effect of the reactivity feedback, Figure 13 shows a series of LAPUR6 simulations where the reactivity feedback coefficient was decreased from 0.085 $/%void to 0.017 $/%void. We observe that as the reactivity feedback magnitude is reduced, the ~0.8 Hz peak becomes less and less dominant.

All the above LAPUR6 results are consistent with the published GENESIS experimental findings [Ref. 3 through 5], which show an oscillation frequency of 0.1 to 0.2 Hz without feedback and oscillations of 0.6 to 1 Hz with feedback. These findings support the conclusion that the chimney dynamics play a minor role in density wave instabilities in a nuclear reactor.

A different set of experimental values was analyzed to evaluate the decay ratio and oscillation frequency. These experimental points are those documented in Ref. 4. The operating conditions and measure decay ratios are shown in Table 4 along with the decay ratios and oscillating frequencies calculated by LAPUR6.

Figure 14 shows a comparison between the measured and calculated decay ratios. Overall we observe good agreement, but a larger bias is observed at larger subcooling values (lower temperatures). Figure 15 shows a comparison between the LAPUR6 and measured frequencies. For these GENESIS runs, LAPUR6 predicts two frequencies of oscillations (see for example the green line in Figure 12) and the automated algorithm to find the peak oscillation frequency "jumps" from one to the other. For this reason, the frequency benchmark for the GENESIS runs shows a large scatter about the measured frequency for real reactors, only one frequency is present and the LAPUR6 frequency finding algorithm has shown singifcant consistency on frequency estimation.

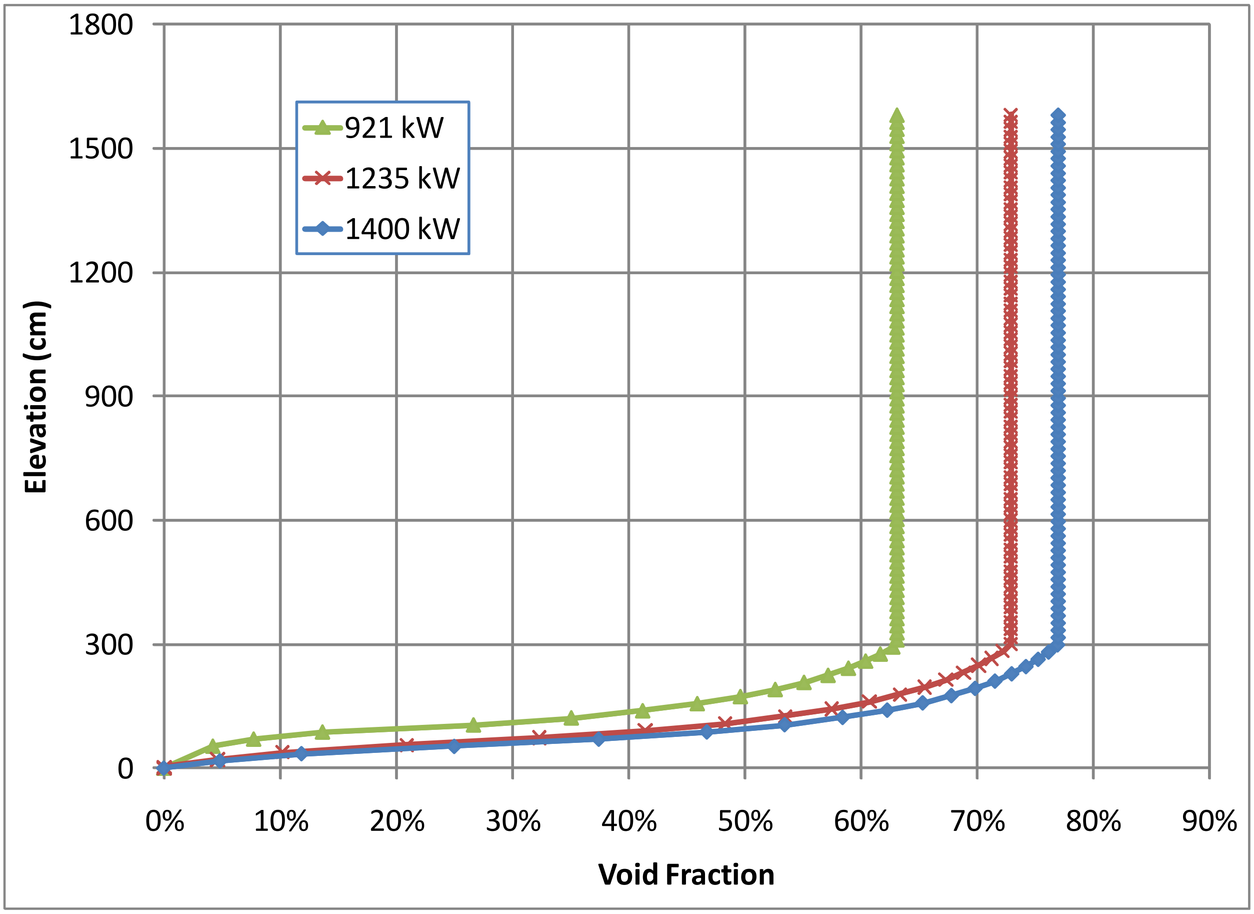

Figure 5 Calculated void fractions at different power levels

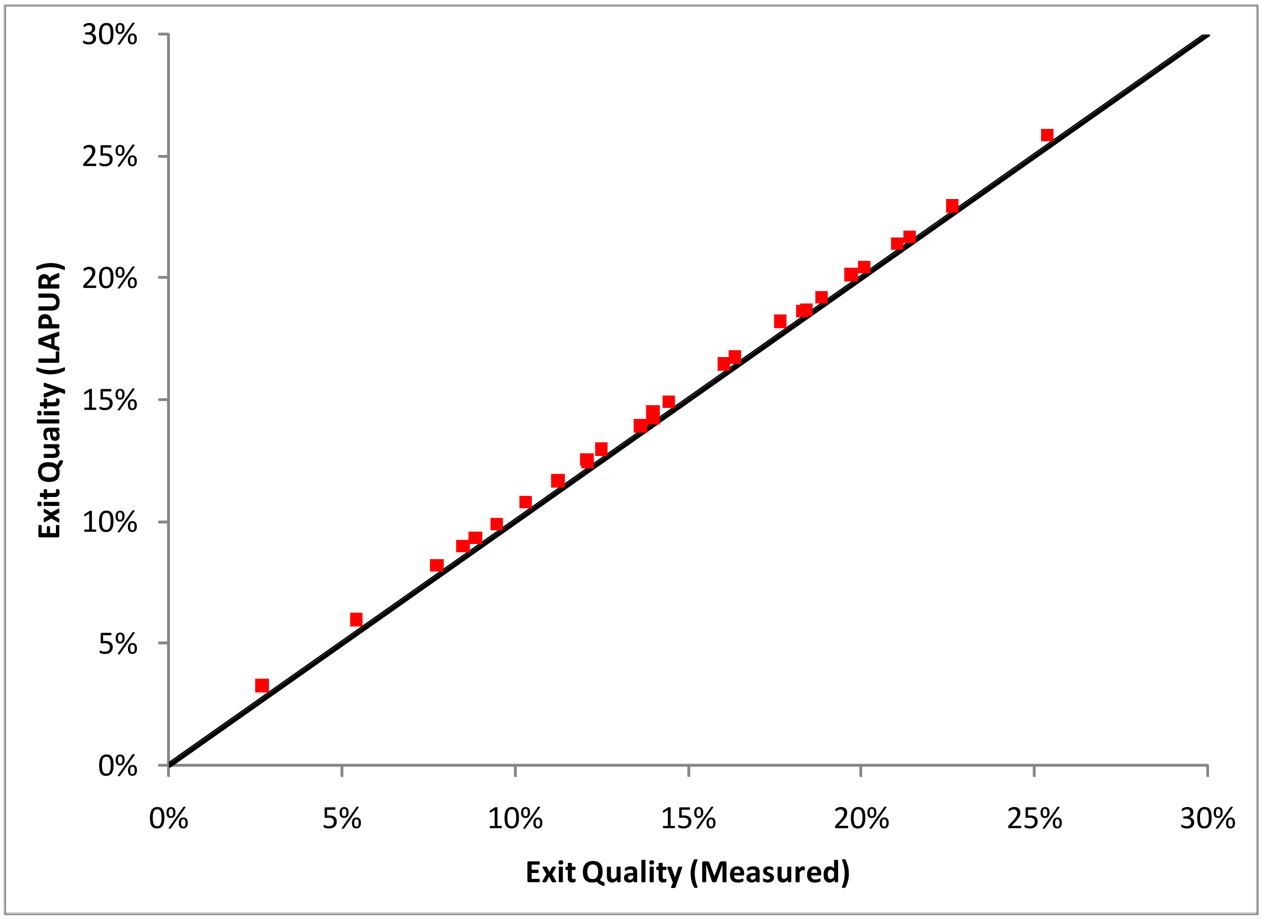

Figure 6 Comparison between predicted and measured core exit quality

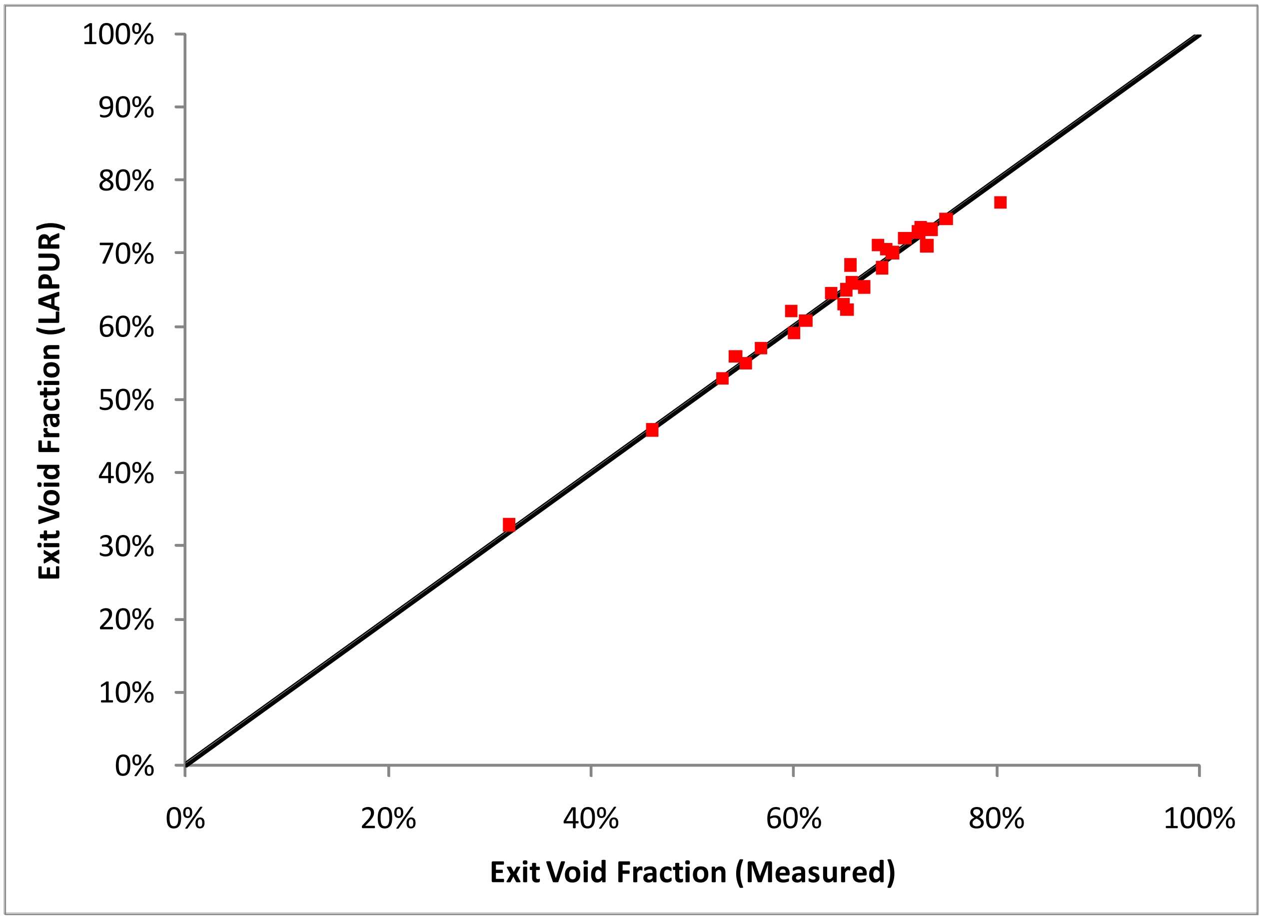

Figure 7 Comparison between predicted and measured core exit void

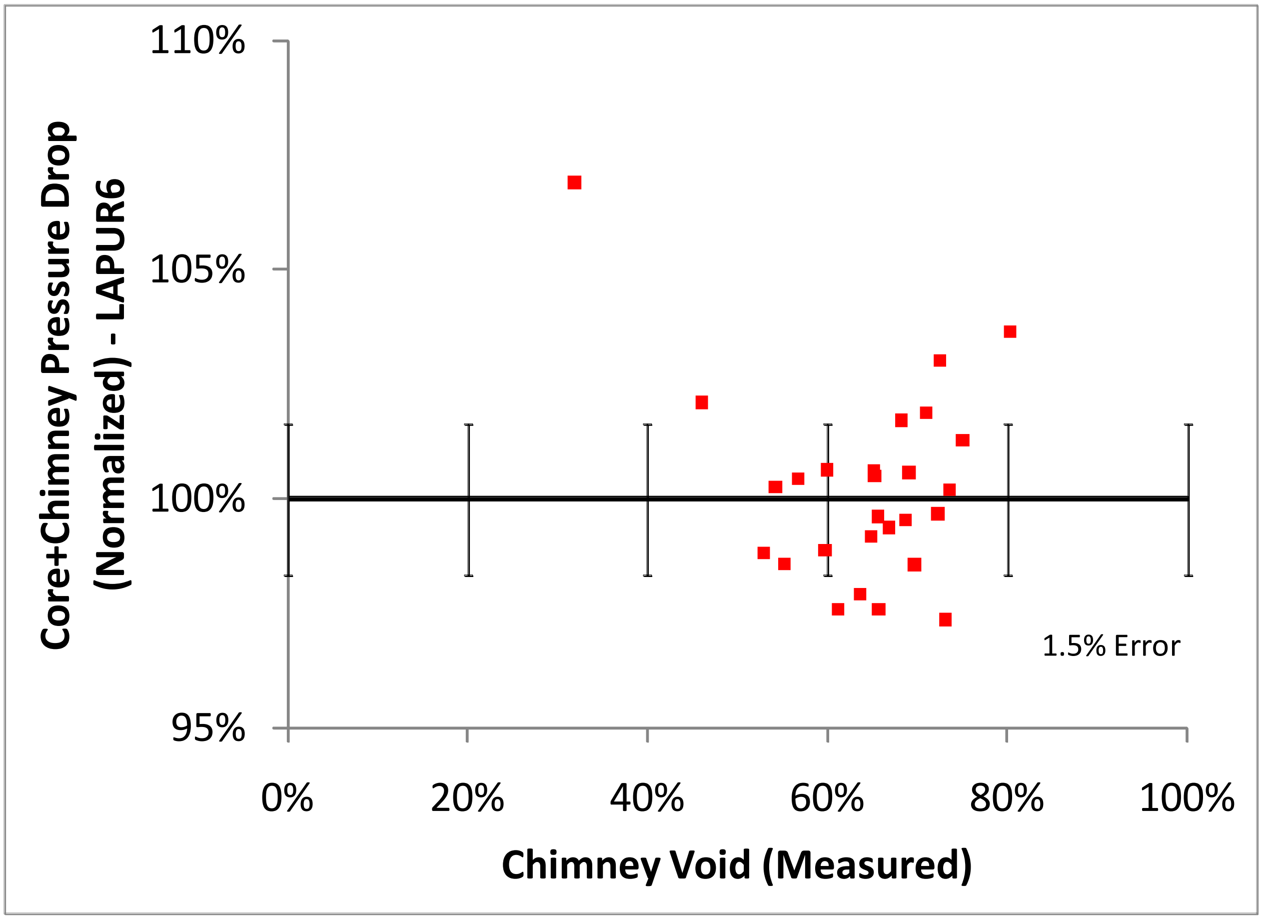

Figure 8 Calculated pressure drop as function of chimney void fraction

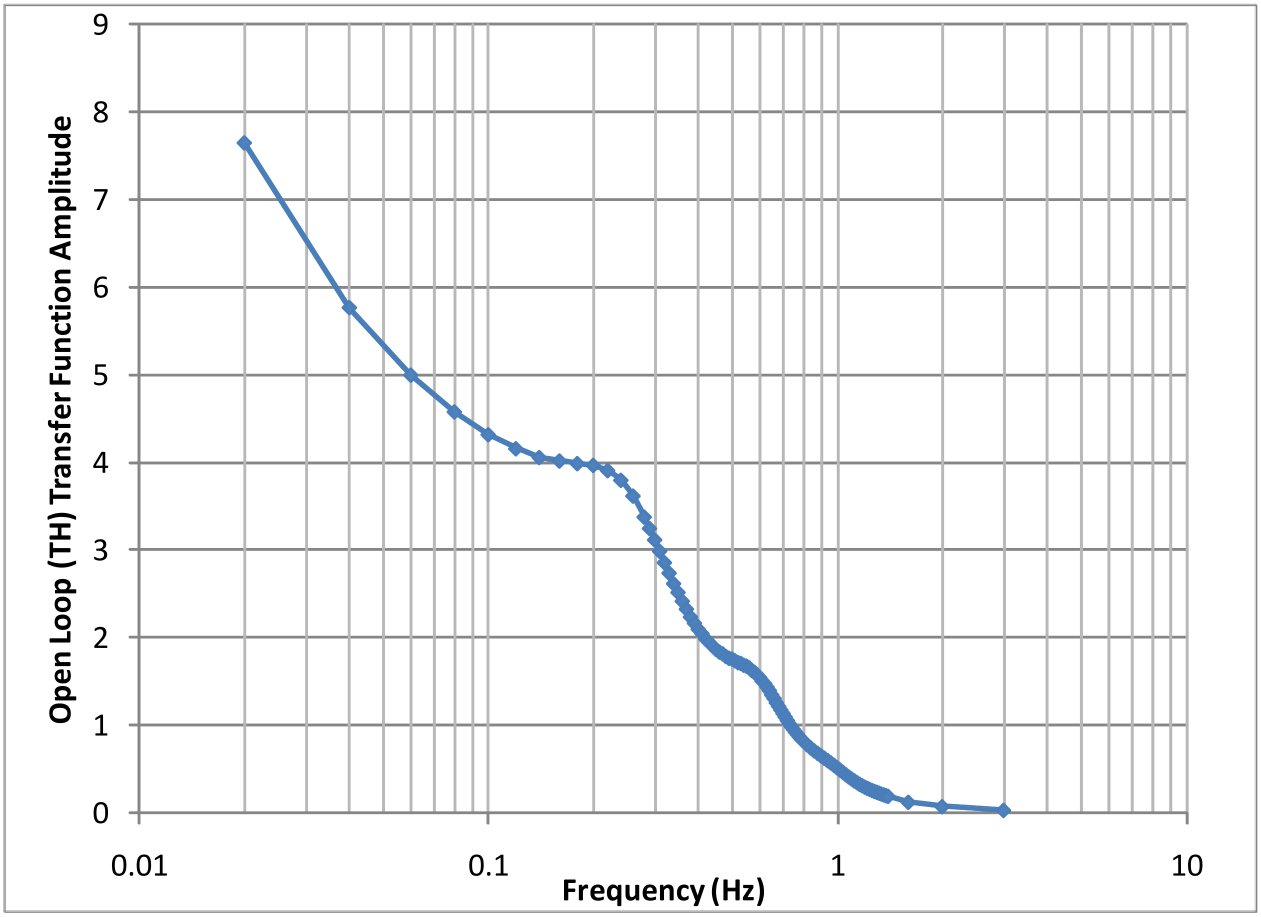

Figure 9 Thermal-Hydraulic (no feedback) transfer function for case 0602141115

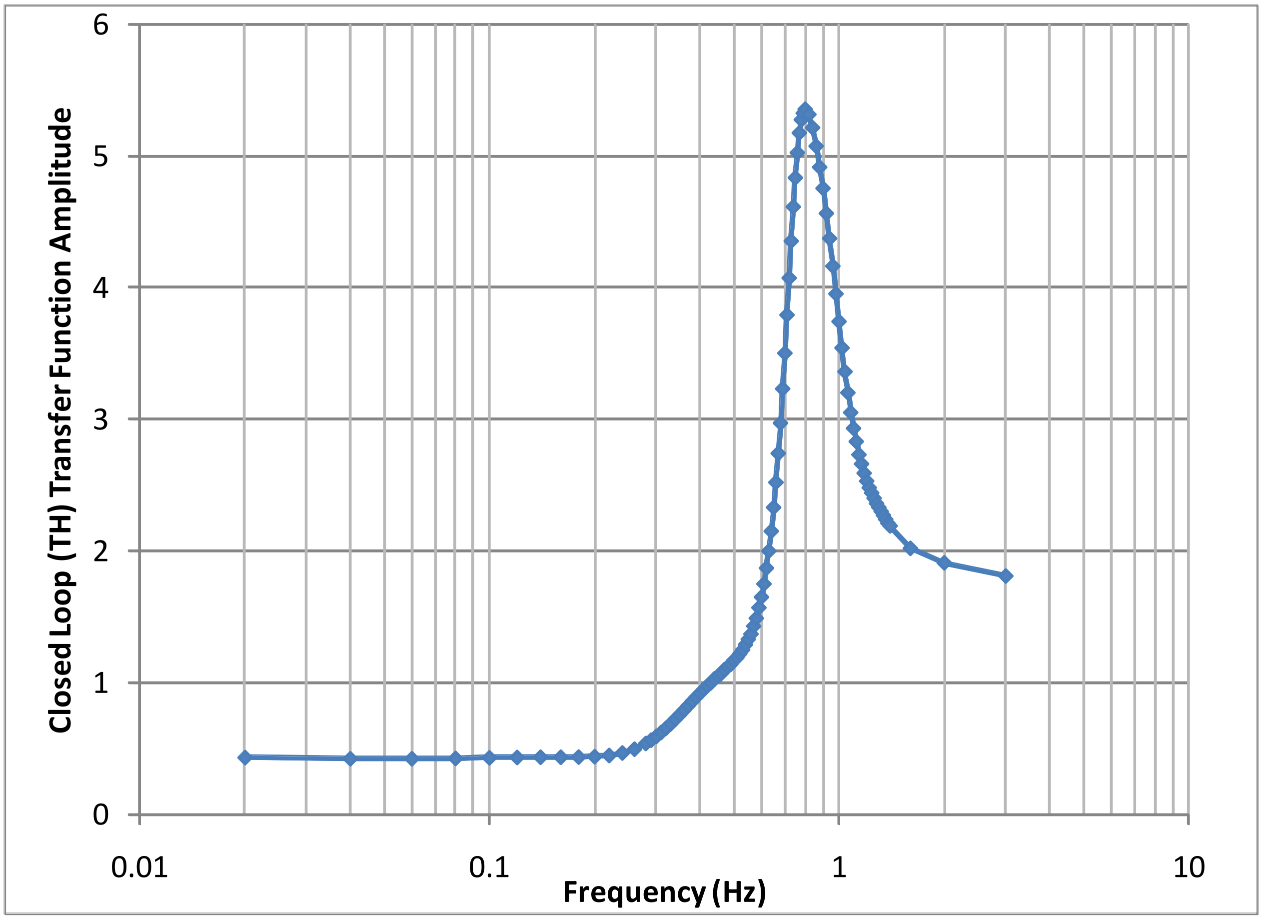

Figure 10 Closed loop (with feedback) transfer function for case 0602141115

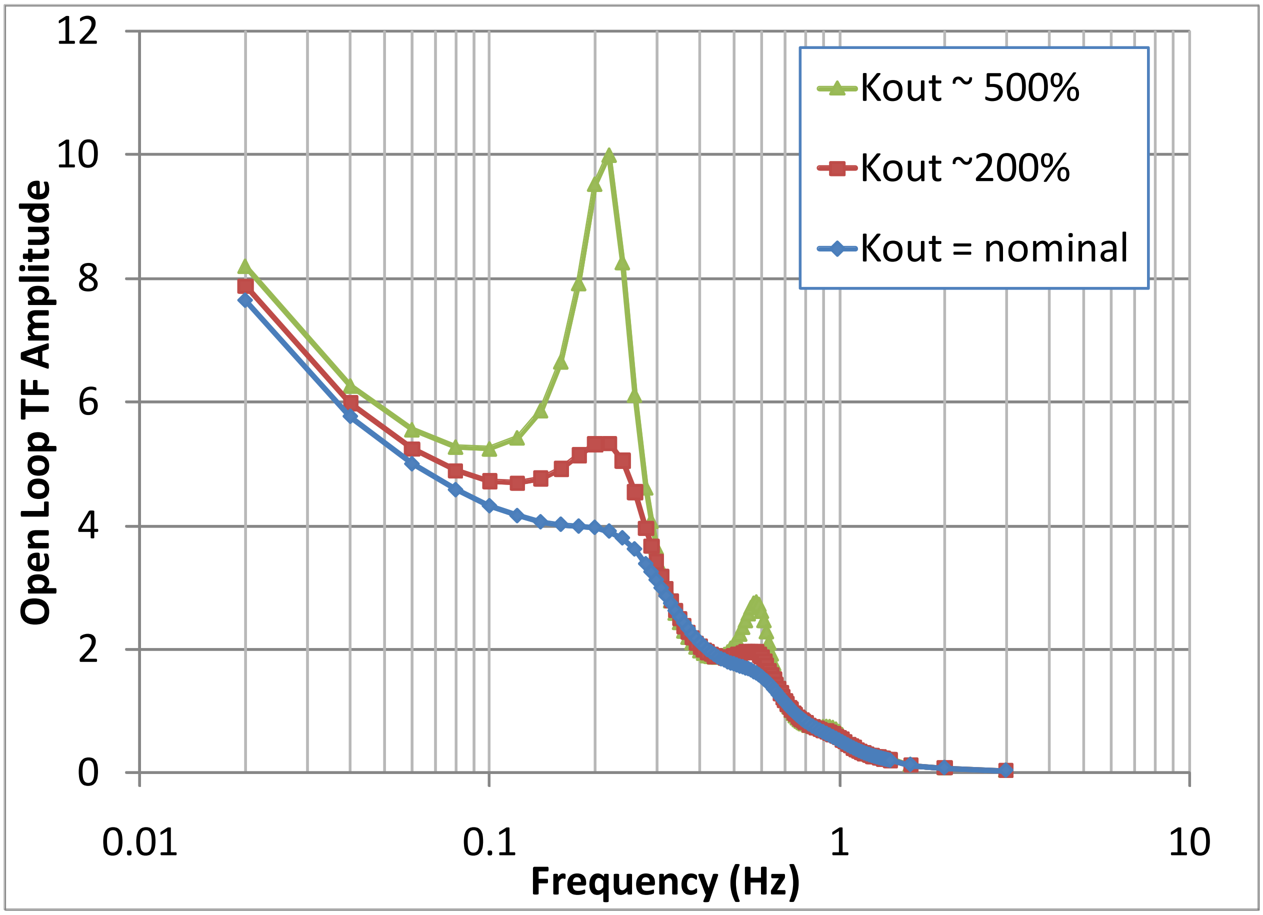

Figure 11 TH transfer function as function of outlet friction

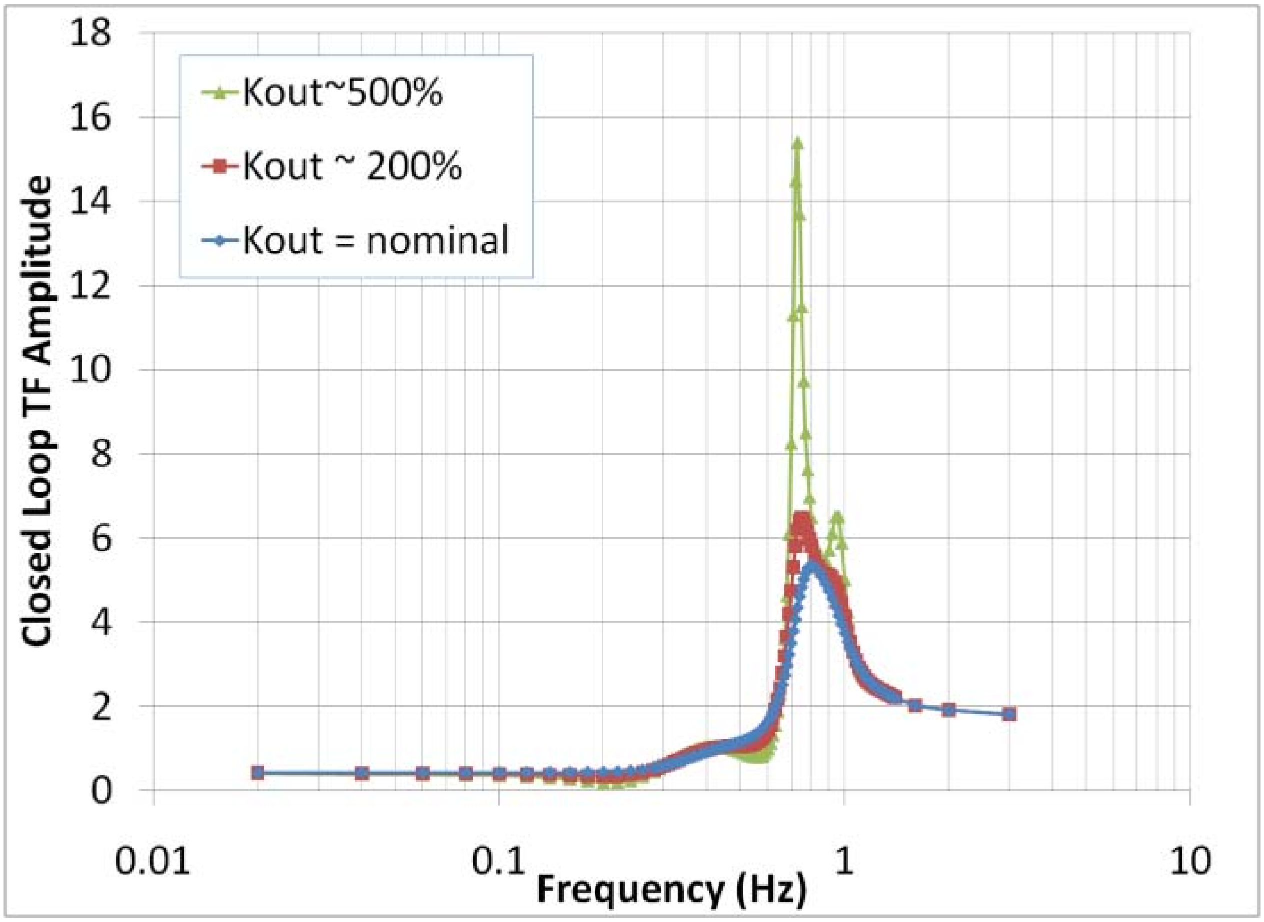

Figure 12 Closed loop transfer function as function of outlet friction

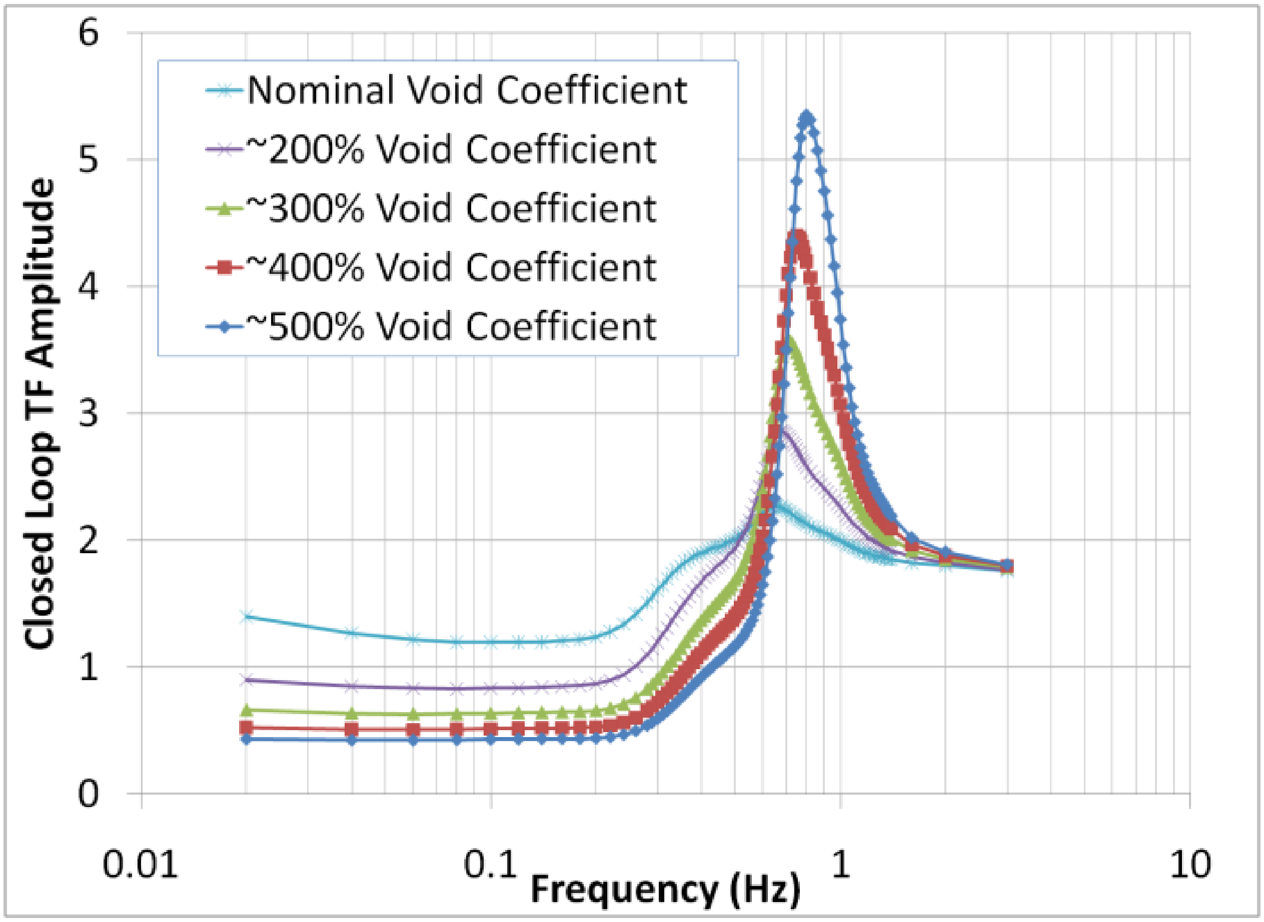

Figure 13 Closed loop transfer function as function of reactivity feedback coefficient

Table 3 Analyzed GENESIS steady state operating conditions

Point	P (kW)	T_{inlet} (C)	Mass flow (kg/s)	Core Outlet Void	Core Outlet Quality
0602060959	1053	257.8	3.17	65%	12.1%
0602071330	1040	262.9	3.09	67%	14.0%
0602071434	1324	261.4	2.96	73%	21.0%
0602071501	1378	261.5	2.93	75%	22.6%
0602071535	1201	262.8	3.01	69%	18.3%
0602081159	894	262.6	3.17	60%	10.3%
0602081340	921	266.1	3.10	65%	12.5%
0602081421	988	253.7	3.25	54%	8.8%
0602081548	1321	252.0	3.15	69%	16.0%
0602081615	1388	251.6	3.10	70%	17.6%
0602091140	1192	254.3	3.18	65%	14.0%
0602101357	1251	266.4	2.93	72%	21.4%
0602101413	1177	267.0	2.94	71%	19.7%
0602131122	1235	264.6	2.96	72%	20.1%
0602141115	1400	265.3	2.83	80%	25.3%
0602141621	827	252.5	3.19	46%	5.4%
0602171331	770	262.6	3.17	53%	7.7%
0602171451	785	270.4	3.07	61%	11.2%
0602171526	708	270.5	3.10	57%	9.4%
0602201437	636	253.1	2.95	32%	2.7%
0602201513	580	275.6	3.07	55%	8.5%
0602211422	1072	265.9	3.02	66%	16.3%
0602221156	1010	265.6	3.07	66%	14.4%
0602221344	958	266.2	3.08	64%	13.6%
0602221502	879	267.2	3.09	60%	12.1%
0602221620	1138	267.4	2.96	68%	18.8%
0603011234	1048	268.0	2.81	73%	18.4%

Table 4 Analyzed GENESIS dynamic operating conditions. All data scaled to water

Point	Nzu	Nsub	Flow (kg/s)	Power (kW)	Tin (C)	DR (data)	Freq (data)	DR (LAPUR)	Freq (LAPUR)
C01	6.15	1.48	2.70	1342.57	264.97	0.47	0.66	0.51	0.71
C02	5.87	1.32	2.70	1282.49	267.22	0.39	0.84	0.45	0.71
C03	5.66	1.59	2.70	1235.63	263.29	0.47	0.84	0.57	0.84
C04	4.33	1.33	2.70	945.99	267.12	0.15	0.69	0.33	0.61
C05	4.74	1.39	2.70	1034.45	266.22	0.21	0.79	0.60	0.70
C06	5.41	1.85	2.70	1181.89	259.56	0.57	0.71	0.52	0.63
C07	4.89	0.76	2.70	1067.10	275.47	0.23	0.75	0.19	0.46
C08	2.95	1.40	2.70	643.75	266.05	0.05	0.85	0.19	0.46
C09	2.91	0.75	2.70	634.69	275.62	0.11	0.80	0.27	0.75
C10	3.43	0.79	2.70	748.30	274.99	0.17	0.73	0.25	0.48
C11	3.72	1.65	2.70	812.76	262.43	0.17	0.81	0.26	0.51
C12	4.39	0.72	2.70	959.51	276.05	0.16	0.75	0.36	0.90
C13	7.80	1.51	2.70	1702.96	264.55	0.69	0.65	0.60	0.78
C14	7.53	1.47	2.70	1644.26	265.10	0.55	0.86	0.59	0.77
C15	6.75	0.71	2.70	1473.70	276.19	0.32	0.67	0.45	1.06
C16	7.47	1.50	2.70	1631.60	264.67	0.62	0.63	0.59	0.77
C17	7.20	1.25	2.70	1572.09	268.29	0.48	0.78	0.51	0.77
C18	7.08	1.54	2.70	1546.48	264.02	0.49	0.75	0.59	0.75
C19	6.37	1.51	2.70	1390.80	264.46	0.42	0.71	0.55	0.72
C20	6.71	0.77	2.70	1464.79	275.37	0.21	0.64	0.47	1.05
C21	6.86	0.90	2.70	1497.81	273.46	0.37	0.65	0.50	1.04
C22	5.99	1.32	2.70	1307.24	267.22	0.45	0.64	0.50	1.04
C23	7.49	1.21	2.70	1634.61	268.85	0.49	0.81	0.50	0.78
C24	5.74	0.73	2.70	1253.54	275.86	0.20	0.70	0.42	1.00
C25	4.11	1.73	2.70	896.60	261.34	0.17	0.70	0.32	0.53
C26	5.64	2.16	2.70	1231.90	255.03	0.75	0.83	0.54	0.60
C27	7.01	2.43	2.70	1531.63	251.07	0.93	1.05	0.73	0.66
C28	6.44	2.37	2.70	1406.11	251.89	0.90	0.81	0.67	0.63
C29	4.82	2.32	2.70	1051.68	252.57	0.61	1.01	0.36	0.53

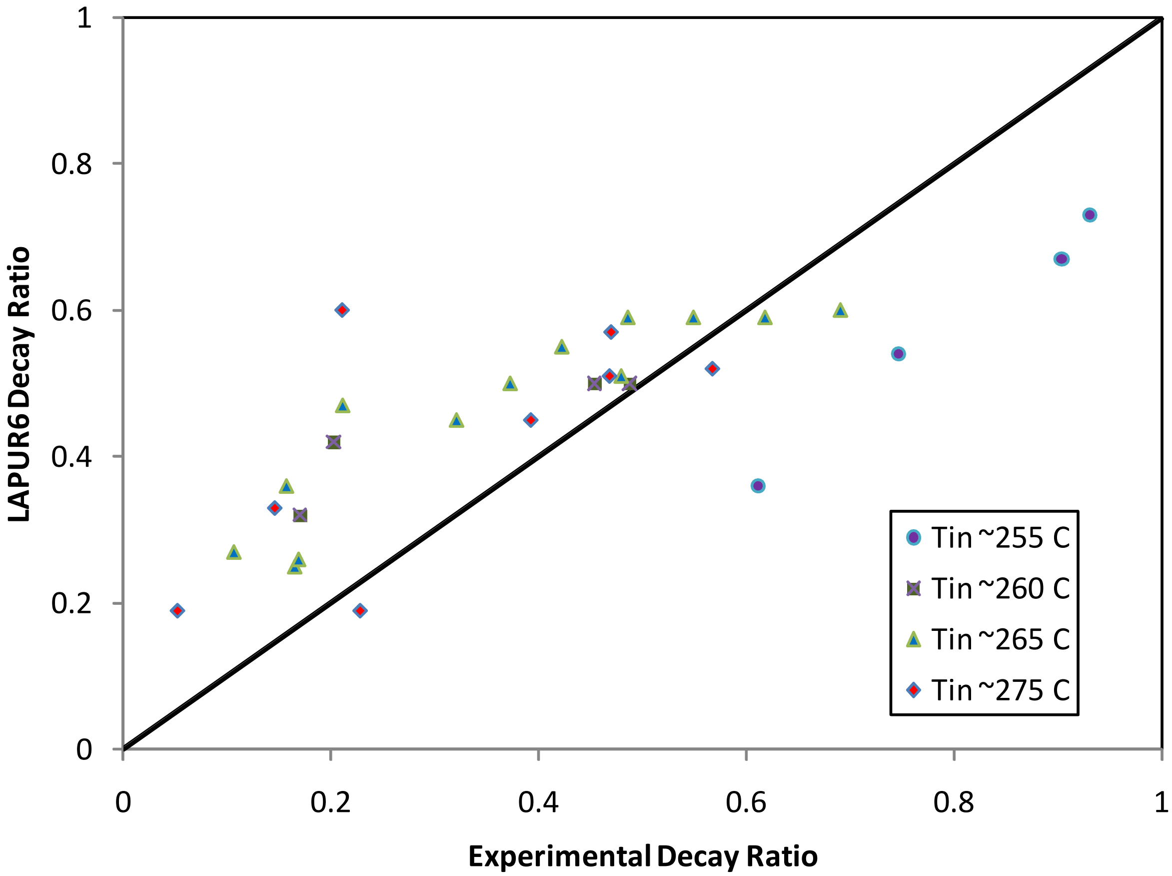

Figure 14 Comparison between measured and calculated decay ratios

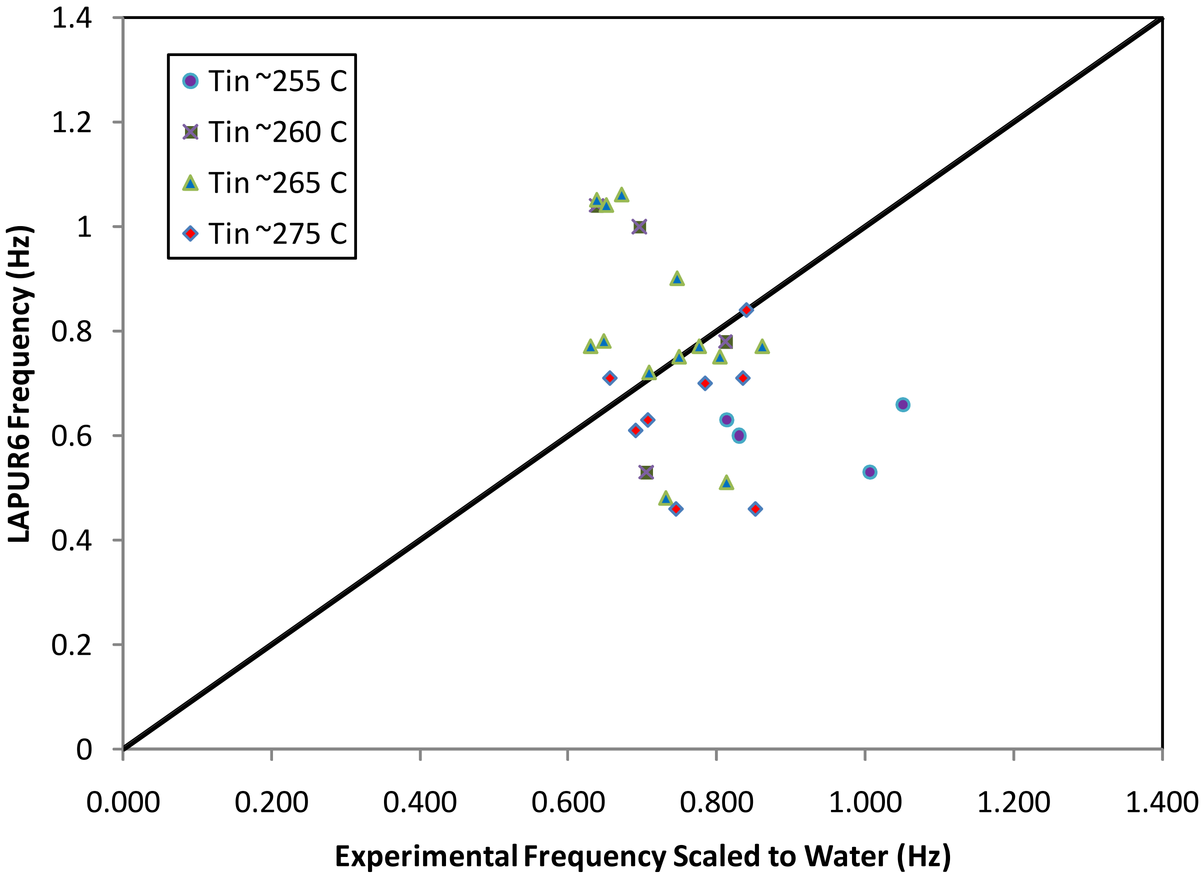

Figure 15 Comparison between measured and calculated frequencies of oscillation

6.0 CONCLUSIONS

The LAPUR6 code [Ref. 1 and 2] has been benchmarked against experimental data from the GENESIS natural circulation facility [Ref. 3 through 5]. The GENESIS experimental data was collected using Freon R134a as a coolant, and scaled to water-equivalent conditions using the methodology described in Refs. 3 through 5. The following are the major conclusions from this benchmarking exercise:

1. The steady state void fractions and qualities calculated by LAPUR6 compare favorably with those measured at the GENESIS facility. This benchmark validates the LAPUR6 void models.
2. The pressure drops calculated by LAPUR6 compare favorably with those measured at the GENESIS facility. This benchmark validates the capability of LAPUR6 to calculate natural circulation conditions.
3. LAPUR6 predicts that the oscillation frequencies in GENESIS should be of the order of 0.1 to 0.2 Hz when the reactivity feedback is not enabled. The actual frequency depends on the operating conditions. This is the range of oscillation frequencies observed in the GENESIS facility.
4. LAPUR6 predicts that, when the reactivity feedback is enabled, the oscillation frequency increases to the 0.6 to 1.0 Hz range and that the 0.1 to 0.2 Hz thermal-hydraulic oscillation is not present. The change in frequency was observed experimentally in the GENESIS facility.
5. The decay ratios calculated by LAPUR6 compare favorably against the measured data in the GENESIS facility

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11. ABSTRACT *(200 words or less)*
This report contains an evaluation of the LAPUR6 code against stability data measured in the GENESIS facility in Delft University of Technology, Netherlands. Twenty seven GENESIS measurements at different operating conditions were simulated by LAPUR6. All geometry and measurements were scaled to water properties for use in LAPUR6. Ninety two axial nodes were used to model GENEIS (17 for the core and 75 for the chimney). The results of these benchmark calculations show that LAPUR6 predicts an oscillation frequency of ~0.7 Hz, which agrees with the measured frequency, and indicates that the chimney has little or no effect on the dynamic oscillations. The DRs calculated by LAPUR6 are in agreement with those measured in GENESIS.

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