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ANALYSIS ON NON UNIFORM FLOW IN STEAM GENERATOR DURING STEADY STATE NATURAL CIRCULATION COOLING

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Analysis on Non Uniform Flow in Steam Generator during Steady State Natural Circulation Cooling

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Steady-state natural circulation (NC) in the PWR was investigated focusing on non uniform flow among steam generator (SG) U-tubes observed in the ROSA/LSTF experiments. In the analysis using the RELAP5/MOD3 code, the SG behavior was analyzed using the partial SG model with one, five, or nine parallel flow paths in the primary side and boundary conditions based on the experiments. The results showed that simulations using the model with five or nine tubes were capable to capture important non uniform phenomena such as reverse flow, fill and dump and stagnant vertical stratification, and the stable SG outlet flow as observed in the experiments. Heat transfer rates to the secondary side were, however, underpredicted by up to 15%. Furthermore, difficulties were found in establishing the steady state condition especially for the low pressure analysis: only when the inlet flow rate was carefully imposed, stable NC behavior was obtained.

Keywords: The ROSA/LSTF Facility, RELAP5/MOD3, Natural Circulation, SG U-tubes, Non Uniform Flow, Flow Stability

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定常自然循環冷却時の蒸気発生器における非一様流動の解析

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ROSA/LSTF 実験で観測された蒸気発生器(SG)U 字管群での非一様流動に着目し PWR における定常自然循環を検討した。RELAP5/MOD3 コードを用いた解析では、SG 挙動を、一次系を１本、又は、５本、又は、９本の平行流路で表し、実験に基づく境界条件を使用する SG モデルを用いて解析した。その結果、５ないし９本の平行流路を用いる場合、逆流、流入と排水、二相成層のような重要な非一様流動現象や、実験と同様な安定な出口流動を再現できる事がわかった。しかし二次系への伝熱量は最大１５％過小評価された。さらに、特に低圧条件において注意深く入口流量を設定する場合のみ安定な自然循環挙動が得られるなど、定常状態を確立するための問題が見出された。

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Contents

目次

List of Tables

List of Figures

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1. Introduction

As part of the joint research program in the field of nuclear safety between JAERI and BATAN, investigation on natural circulation cooling has been conducted in JAERI between January 2004 to July 2004. The investigation was in order to better understand the phenomena in natural circulation cooling as this plays important role in long term heat transfer from primary side of nuclear plant post LOCA accident. The focus of this research is the steam generator behavior in which non uniform flow occurs among U-tubes during LOCA transient and long term natural circulation cooling. Tests conducted in LSTF found that there are several different modes of non uniform behavior in steam generator. Those are single phase normal and reverse flows, two phase normal and reverse flow, cyclic fill and dump, stagnant vertical stratification, and reflux condensation (ref. 1 and ref. 2). Reference 2 revealed that calculation for SBLOCA transient without taking into account non uniform behavior would over predict the heat transfer from primary side. Beside that, low pressure long term cooling calculation also provided very oscillatory result. Some works have been done in order to deal with non uniform behavior using different approaches. For high pressure case, Reference 3 used steam generator model consists of 3 different tubes. Although this approach could show the existence of some non uniform modes, it could not however, predict fill and dump phenomena occurred in the test. For low pressure case, analysis on stagnant flow using two parallel tubes with high flow resistance in one of the tubes as explained in Reference 2 could reproduce the behavior better, though not sufficiently.

More specifically, this work was to look for RELAP5 model that could be used to observe phenomena such as reverse flows, fill and dump, and stagnant vertical stratification. The reference highlighted that stagnant vertical stratification, and fill and dump are the distinguishing characteristics between low and high pressure natural circulation. In dealing with that two general conditions were investigated, at high pressure and low pressure. The investigation was simplified by looking at the phenomena in steam generator during steady state condition and only partial steam generator model was used. Boundary conditions matched with experimental data were applied to the model. In order to get the insight view on the flow non-uniformity, steam generator models having more than one tube were developed. Calculations were carried out for several conditions as conducted in test.

This report presents the modeling used in this work and discussion on the calculation result for different models and boundary conditions. The report is divided into several sections. The following section will briefly explain the facility under consideration. The focus is on the main design of steam generator. The second section deals with description of data for which this analysis is based on. The description covers the scope of the data and how the tests were performed. After that the section is followed by explanation of the computer code used in the analysis and also the modeling of steam generator including the boundary condition. The final section will discuss the result of calculation.

2. Facility description.

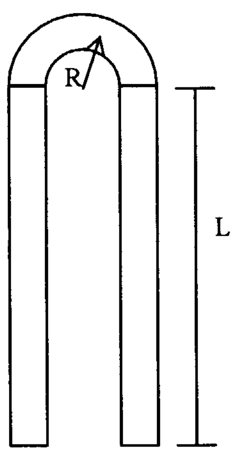
LSTF is a facility in JAERI that able to simulate PWR thermal hydraulic response for broad range of transient scenario, such as small break LOCA, steam generator tube rupture, natural circulation cooling, abnormal transient, etc. The facility mainly consists of an electrically heated core, two primary loops and a pressurizer. The design power of the core is 10 MWatt with design pressure and temperature at 16 MPa and 598 K. Basically, this facility is a scale down of Westinghouse-type PWR reactor with scaling ratio of 1/48 for the volume and 1/1 for the height. Each of the two primary loops consists of centrifugal pump and steam generator. The steam generator has component characteristic similar to those in the reference PWR. The similarities include the number of U-tubes, the height of steam generator, the position of feed water ring, etc. Some of the main characteristic of the steam generator is as shown in table 2.1. Other data can be seen in Appendix 1 or Reference 4 :

Table 2.1. Major Design Characteristic of LSTF steam generator

Max heat removal rate (MW)	35.7
Number of U-tubes	141
Feed water flow rate (kg/s)	2.76
Steam flow rate (kg/s)	2.76
Average length of U-tube (m)	19.7
Pitch of U-tube (mm)	32.5
Pressure in SG Steam dome (MPa)	7.34

As shown in the table, there are 141 U-tubes in the LSTF's steam generator. These tubes have 9 different length and for each length there are different number of tubes. Details of these tubes geometry are shown in the following table 2.2.

Table 2.2. Details of U-tubes length



Type	R (mm)	L (mm)	No. of tubes
1	50.8	9439.9	21
2	83.3	9590.7	19
3	115.8	9741.2	19
4	148.3	9891.7	19
5	180.8	10042.2	17
6	213.3	10192.7	15
7	245.8	10343.2	13
8	278.3	10493.7	11
9	310.8	10644.2	7
	ID = 19.6 mm		
	OD = 25.4 mm		
	Pitch=32.5mm Square		

3. Experimental Data Description.

Data used in this work are steady state data observed during low and high pressure natural circulation tests that have been conducted in LSTF as explained in References 1 and 2. In general the experiments were done by draining primary loop mass inventory step wisely from the bottom of the core and then recorded the data after steady state condition were reached for each of the step. Each drain removed approximately 5 % of the original mass inventory. In high pressure case, the experiment were conducted by keeping the secondary side pressure at about 6.7 MPa and steam generator water level at about 9.5 meter. Meanwhile the primary side pressure was at nominal PWR working pressure which then decreased gradually as the mass inventory discharged. Similar practices were applied for the low pressure case. In this experiment however, the working pressure was about 0.13 MPa for secondary side and about 0.3 MPa for primary side. The core power were 1.4 MWatt and 0.94 MWatt for high pressure and low pressure tests respectively. A more detailed experimental data can be seen in the Appendix 2. From the two loops data available for this purpose, arbitrarily loop B data was chosen.

Qualitatively, results of the experiments show that for high pressure natural circulation test, reverse flow was observed in long tube during 100% of mass inventory, and flow and fill and dump flow were observed in several U-tubes during 73% of mass inventory (Reference 1). For low pressure natural circulation test, stagnant vertical stratification flow was observed when mass inventory between 70 to 91 % (Reference 2).

For the need of this work and based on qualitative result, two experimental data were chosen for each test. For high pressure calculation, data of 100% and 73 % mass inventory were used. For low pressure calculation, data of 100% and 75 % mass inventory were used. Samples of the data are presented in the table 3.1.

Table 3.1. Sample data of the low pressure natural circulation test.

Parameter	**Value**	**Standard Deviation**
Mass inventory (%)	**100.0**	
Total core heat (MW)	0.933	
P upper plenum (MPa)	0.319	0.00288
Core outlet vapor flow rate (kg/s)	0.050043	0.0059021
Loop B Primary side:		
Primary loop flow rate (kg/s)	4.675	0.02042
T hotleg (K)	408.924	0.16662
T coldleg (K)	386.839	0.14904
Loop B Secondary side:		
Feed water flow rate (kg/s)	0.069	0.01292
T feedwater (K)	361.416	0.45148
Steam line flow rate (kg/s)	0.181	0.00222
T steam line (K)	380.288	0.06186
P sec-side of SG (MPa)	0.13	0.00027
Liquid level (m)	12.214	0.04167

4. RELAP5 Description

RELAP5 is a transient analysis code developed originally at the Idaho National Engineering Laboratory (INEL) for the US Nuclear Regulatory Commission. RELAP5 is highly generic code that can be used for the simulation of a wide variety of hydraulic and thermal transients in both nuclear and non-nuclear system involving steam, water, non-condensable and solute fluid mixture. The code contains system component model applicable to LWRs such as point neutronics model, pump, valve, separator, controls, etc. Improvements have been conducted to this code since its first development. Details of these improvements can be obtained in Reference 5. The RELAP5 version used in this analysis is RELAP5/Mod3.

5. Modeling Description

The steam generator model for this work is developed using several generic model available in RELAP5 such as single volume, pipe, branch, junction, time dependent junction, separator and valve. For boundary conditions, time dependent volumes are used. The model can be divided into two parts, primary side and secondary side. The primary side consists of two single-volumes that represent steam generator's inlet and outlet plenums and some parallel pipes that represent U-tubes. Hot liquid and vapor were supplied to inlet plenum using time dependent junction and will exit through outlet plenum to boundary condition.

The secondary side consists of more complicated structure. Annulus, pipe, separator, single volume and branch are used to simulate the construction of secondary side. Pipe model is used as the place where water boils and vapors build up. Feed water is supplied using time dependent junction to boiling pipe through annulus and will be converted into vapor. The time dependent junction is controlled by water collapsed level in the boiling pipe. From the boiling pipe, vapor will go through separator in which it will be filtered up from its water content. The water will be fed back to the boiling pipe while steam will exit through steam line pipe.

The primary side and secondary side are connected by heat structures attached to both the U-tube and boiling pipe models, and that structures will calculate heat transfer from primary side to secondary side. In order to get detail view of the phenomena in steam generator, the U-tubes and boiling pipe of the model are divided into several small calculation volumes. The boiling pipe model is divided into 18 volumes while the U-tube models are divided into volume cells between of 32 to 36 depending on their length. Nodding of the model is shown in the following Figure 5.1.

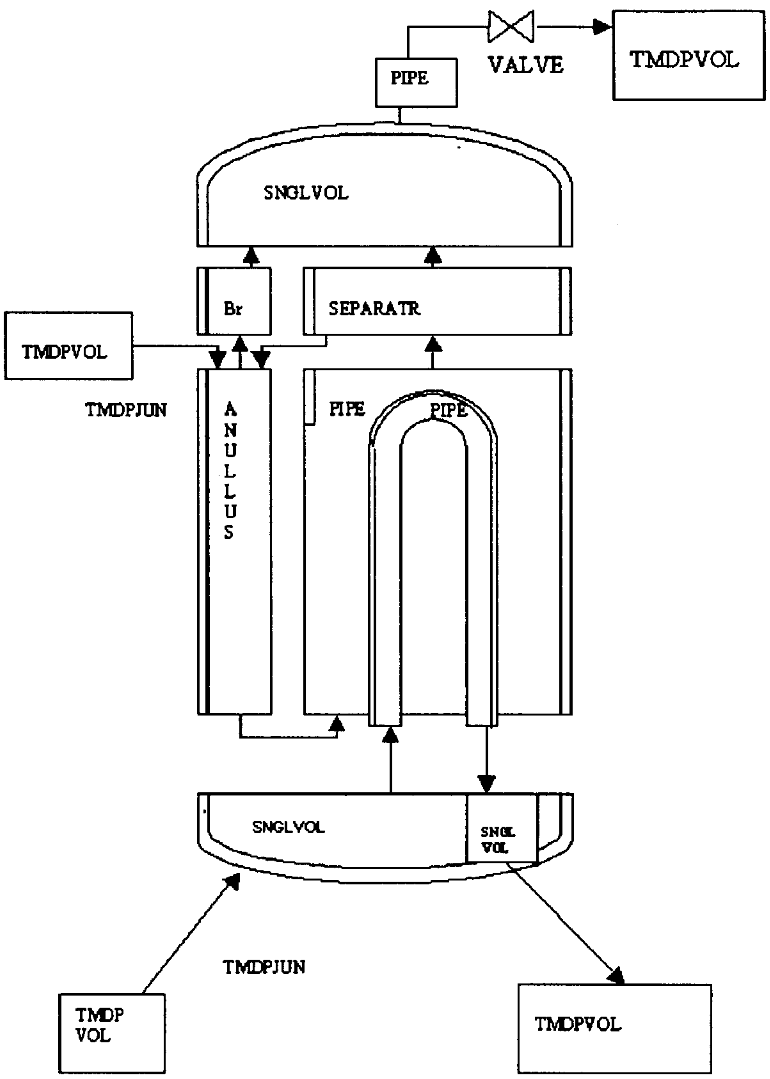


Figure 5.1. Noding diagram of Steam Generator

As the upper side of U-tube has half circular shape and RELAP5 has no such generic model, this upper part was approached using two similar pipe connected as shown in Figure 5.2. In making this approach, the total length and height of the tubes are preserved to remain the same.

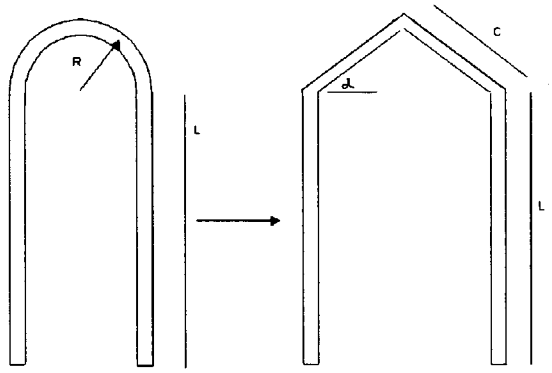


Figure 5.2. Approximation of U-tube geometry

In order to accommodate the need of this research which is to observe the main non uniform flow modes in steam generator, three models were developed. Those are steam generator model using single tube, 9-tubes and 5-tubes. The steam generator with single tube model is basically adopted from the LSTF's system-wide input deck model that has been used for other calculation before. In this model, all U-tube is represented by single tube that will be the place of heat transfer from primary side to secondary side. The 5-tube and 9-tube model is extension of the single tube model. The 9-tube model were selected as physically the steam generator has 9 different tube length (see facility description section). The 5-tubes model is simplification of the 9 tube model, in which grouping was made for two adjacent tubes. Three tubes model was not developed as Reference 3 showed that this model did not show up fill and dump phenomena during high pressure calculation. Detail of U-tube geometric value can be seen in table A.1.4 to A.1.6. in Appendix 1. Based on the modeling above, RELAP5 input deck were then created. The input deck list for each model were presented in Appendix 5.

6. Boundary Condition

As stated before, in this work investigation on natural circulation cooling was focused on the behavior inside steam generator. For this reason the model prepared was partial only, and boundary conditions were applied as needed. In primary side, the temperature and mass flow of both liquid and vapor were imposed at the inlet boundary. The working pressure of the primary side was set using outlet boundary. This boundary for some calculation was adjusted to make the differential pressure between inlet and outlet plenum matches with experimental data. For the secondary side, the boundary conditions imposed were temperature of feed water, steam generator water level, and saturated temperature/pressure of steam in the steam line. The feed water flow will be depending on the water level in the boiling pipe. If the level exceed the prescribed limit, feed water will stop and if the water level drop below the prescribed limit, feed water will flow. Complete boundary condition for each calculation can be seen in the Appendix 3.

7. Results and discussions

Using boundary condition explained before, several code run were executed. Different number of tubes models were used. Single tube model was executed, as the base for comparison but will not be explained further because this model can not deal with non uniform flow. The 9-tubes and 5-tubes models were executed to get the insight on what happens in U-tubes.

7.1. High Pressure Case

7.1.1. Nine-tubes Model

In steady state calculation for 100% of mass inventory case, the result shows that at least there are three flow circumstances depending on how the boundary conditions are approached. They are circumstances where flows in U-tubes are: forward in all tubes (Appendix 4.5.1), reverse in short tubes while forward in other tubes (Appendix 4.5.2) and reverse in long tubes while forward in other tubes (Appendix 4.5.3).

For all cases, the steady differential pressure is positive, meaning that pressure in outlet plenum is higher than in inlet plenum. The positive differential pressure can be understood by comprehending that as the flow runs slowly and the secondary side water temperature distribution are almost uniform (less than 1 K different between upper and lower levels), the heat is mostly transferred in the upside of tube. In other word the cooling of primary fluid temperature mostly occurs in the upside of U-tube. That condition would make average temperature in upside is higher than in downside so overall water density in the up side tubes are lower than overall density in downside. And because the density in downside is higher than in upside tube, this means the pressure in outlet plenum is higher than in inlet plenum.

The first flow circumstance, which shows disagreement with qualitative result stating non-uniform flow among U-tubes, was obtained by putting all boundary condition similar to the test data while initial condition for each component was filled in with uniform arbitrary value. This situation shows that not only the current boundary condition is behind the cause of the reversing flow. A trial run by reducing the flow rate to a certain lower value and then returning back the flow to the original value ends up with the second stable circumstance, in which flows in short tubes were reversed. This shows that in order to get reverse flow, the primary flow must be sufficiently slow. When flow becomes slow, the inlet flow rate could not maintain flow in all tube in forward direction. If overall water head of the downside tube is sufficiently high to overcome the total head in upside tube and the pressure drop in the short tube, the flow in the short tube would go reversed. In this case the short tube is more preferred as short tube has smallest total head. When the flow has reversed, the differential pressure become lower, but still remain positive. As the flow rate back to original value, the differential pressure remains positive. That means the reverse flow can be maintained to remain reverse. These two different circumstances support claim in Reference 1 stating that flow in natural circulation is considered as in unstable region in which occurrence of non uniform flow is possible and flow can remain reverse once it is reversed for flow rate in unstable region.

The second flow circumstance shows that the preferred reverse flow during unstable flow was in short tube. This result differs from the qualitative test result which indicated that the preferred tube to have reverse flow was the long tube. This different occurred because realistic transient during the test was not reproduced in this steady state calculation. However, from the previous explanation, it can be understood that if during the slowing down of the flow, the differential pressure was negative, it is possible to have the long tube flow reverses. The differential pressure could go to negative value if the average temperature of the upside is lower than the down side. That can happen if inlet temperature drops for some time. As previously recognize, the flow rate as much as 5.808 kg/s is low enough in which a partial water need about 110 s to move from the inlet to the top of U-tube. If lower temperature inlet entered for this period of time, it is possible to get the differential pressure a negative value. An execution using this approach ends up with result in the third stable circumstance where flows in two long tube are reversed.

These three flow circumstances show that transient before final steady state play important role on selection of the flow modes among U-tubes. Combination of flow and temperature transient will determine whether a reverse flow on short or long tube will be obtained or not. This result comply with statement in Reference 1 that the behavior of tubes is somehow depending on the history of the transient through which the final condition is reached.

When reverse flow occurs, colder water from outlet plenum will enter to inlet plenum. This condition will reduce the temperature in inlet plenum to some degrees. The calculation using 9-tube model which has three tubes with reversing flow exhibits that the temperature decreases for about 3.3 K. The three long-tubes having reverse flow in this model are equivalent with 22 % of tubes in real steam generator. Although some of tubes have reverse flow, however, comparison shows that the amount of heat transfer from primary side is almost no difference between the calculation with all tubes having uniform forward flow and the calculation with some tubes having reverse flow. The discrepancy was less than 0.3 %. With less forward flow tubes, the capability of steam generator does not affected. This indicates that the steam generator have capability to transfer more heat than the current transfer rate during 100 % of mass inventory natural circulation cooling. However such heat transfer comparison must be understood as for partial model situation in which inlet flow is kept constant. In system wide model, the temperature drop in inlet plenum will affect the balance of water density between the upside and downside which then affect the driving force for the natural circulation in steam generator. The reverse flow occurred in some steam generator's U-tubes may would affect the flow rate in the system afterward.

For calculation using 73 % of mass inventory data, the fill and dump phenomena can be observed in model with 9 tubes. Fill and dump is intermittent flow occurred in tubes having enough supply of vapor so that condensation is occurred in the upper side of tubes. When the accumulated water produced from condensation reaches the top of U-tube, it will then be discharged quickly to down side tube (Reference 1). This periodic fill and dump can be seen in Figures A.4.6.3 to A.4.6.7 of Appendix 4, in which the mass flow rate on the top of tube becomes periodically fast in short period. The 73% calculation result shows that the fill and dump occurred in 68 % of total tubes while in the other tubes continuous oscillatory flows exist (Figures A.4.6.4 to A.4.6.9 in Appendix 4). It also shows that the fill and dump period among the tube comes out of phase and the differential pressure is about close to zero. The existence of fill and dump make the outlet flow rate becomes slightly oscillatory. This situation excellently match with the qualitative result explained in Reference 1.

In term of heat transfer from the primary to secondary side, calculation indicates that the existence of fill and dump in half of tubes affected the heat transfer rate. Although the result shows a little oscillatory, comparison on average value reveals that calculation using 9-tubes model transfers 6 % less heat than the single tube model does for 73% of mass inventory. It can be expected that if more tube having fill and dump modes (eg. for lower mass inventory), the discrepancy will be greater. This discrepancy shows the important of non uniform consideration in dealing with steam generator during LOCA calculation. Failing to use model that be able to capture fill and dump phenomena would end up with faster reduction of primary side pressure.

7.2. Low Pressure Case

Like in the high pressure natural circulation cooling calculation, different steam generator model were also used for low pressure calculation. For single tube model, calculation provides similar outcome with result in Reference 2. The general characteristic for this calculation is the existence of cyclic oscillatory flow including reverse flow in steam generator primary side (Figure A.4.3.3. in Appendix 4). The result shows oscillatory flow occurred for both 100 % and 75 % of mass inventory calculation. The reference noted that the oscillatory is due to the low vapor supply rate while the condensation rate in tube is much higher so that the pressure in tube can not be steadily maintained.

When calculation was done the using 9-tubes model, for 100% of mass inventory, stable flow circumstance was achieved in which some tubes have reverse flow (Appendix 4.7.). With the existence of the reverse flow, vapor supply was somehow balanced with the condensation rate in U-tube so oscillatory was not occurred. However, in conducting the calculation some difficulties was encountered in order to reach stable result. Unstable oscillatory flow would occur if arbitrary initial conditions were used for the intended boundary condition and once the instability occurs, the condition inside steam generator would never gets stable. Example of the unstable oscillatory flow can be seen in Figure A.4.7.4. This situation is typically occurred in low pressure natural circulation calculation only and somehow could make calculation fail to converge on a stable value. Realizing the problem, an approach before implementing the steady state boundary condition was performed. The approach used was by applying the primary side with sufficiently high pressure and high flow rate. Using this method, stable circumstance at high flow rate could be achieved. The flow was in forward direction for all tubes. When such circumstance reached steady, calculation was continued by making a transient simulation to the boundary condition matched with experimental data. The boundary pressure was reduced quickly enough into experimental data value while at the same time the flow was reduced into very low rate. After that, slowly the flow rate was increased to the intended boundary value. Using this approach, it was expected that flow in U-tubes will reconfigure themselves and go to directions based on the condition at that time. However, trial using this approach shows that not any transient combination leads to non-oscillatory result. For example if the time needed to reach intended flow rate was 160 s then the flow instability would occur, while if the time was 180 s the calculation result will be stable. Trials on many more data show that only at certain flow increase rate that can successfully reach stable condition. The following table 7.1. presents calculation result using different flow increase rate which is represented by time needed to reach intended value. The table shows that there was no clear pattern on the increase rate that would bring to stable circumstance. Moreover, although the stable results exhibit the existence of reverse flow, the tubes having reverse flow tend to be different on one another.

Table 7.1. Effect of flow increase rate on flow stability of the result

dt(s)	Flow stability	Note	Q (MW)	Standard deviation (%)
160	oscillatory	-	0.496	82.66
170	oscillatory	-	0.523	78.97
179	stable	9,7,6,5 reverse	0.492	0.89
180	stable	9,8,5 reverse	0.494	1.72
184	oscillatory	-	0.529	72.78
186	oscillatory	-	0.532	73.68
190	stable	9,8,7,6 reverse	0.494	1.84
194	stable	1,2 reverse	0.499	0.96
195	oscillatory	-	0.516	77.13
200	oscillatory	-	0.526	73.00
202	oscillatory	-	0.511	74.76
210	stable	9,7,5 reverse	0.495	0.95
214	oscillatory	-	0.499	73.55
225	oscillatory	-	0.505	75.84
230	stable	8,7,6 reverse	0.495	1.49
238	oscillatory	-	0.502	79.08
242	oscillatory	-	0.516	72.87
252	stable	8,3,4 reverse	0.493	0.73
256	oscillatory	-	0.510	79.02

Similar problem encountered in 100% of mass inventory case was also happened for 75% of mass inventory calculation. The unstable oscillatory flow result would occur when arbitrary initial condition applied. In the 75 % of mass inventory calculation, the stable result of the 9-tubes model provides qualitative outcomes as the one observed in the test (Appendix 4.8). Stagnant flow in most of tubes and continuos two phase flow in some other tubes were presented. The result shows that the tube #1 and #2 have continuos flow while in tube #3 until tube #9 the flow were stagnant. Reference 2 explains that the stagnant flow exists because of the temperature distribution at secondary side which has contour in which the bottom and topmost parts have lower temperature than in the middle (Figure A.4.8.4, Appendix 4). This temperature profile exists due to the saturated pressure in secondary side at low pressure is comparable with the static head pressure of the water level. When feed water enter to the bottom of boiling pipe, its temperature will increase to saturated value as it flows up. The saturated temperature is affected by the local pressure which decreases as its position increases. So after the temperature goes up and reaches saturated value at about in the middle position, it will then decrease to lower value because the pressure is lower. The secondary side temperature profile like this would make the condensation and evaporation occurred in primary side along the U-tube. Inside the U-tube, the vapor will be produced in the middle of tube after condensation in the lower side. As the vapor move up after the evaporation, the condensation will occur again in the upper part of U-tube. This phenomenon happens for both the upside and downside of the U-tube. When condensation and evaporation reach balanced after the transient that leads to vapor existence in the tube, this profile will bring stagnant flow in the tube. The primary flow then will be directed to other tubes which do not have vapor slug. Using partial model Reference 2 showed this evaporation and condensation balance.

The existence of stagnant flow in steam generator U-tubes captured by the 9-tubes model means the reduction of flow and heat transfer area. This conditions more or less will affect the heat transfer to secondary side. The effect of this situation can be clearly seen if we compare heat transfer rate between single tube and 9-tubes models in Figures A.4.4.1 and A.4.8.1, Appendix 4. Although the single tube model result was quite oscillatory, the average value somehow still can be compared. The calculation show that using the 9-tubes model and with the existence of stagnant vertical stratification in most of tubes and continuos flow in two short tubes, the heat transfer will be 15 % less than using single tube model. The two tubes with continuos flow in the model equivalent with 40 tubes in real steam generator. This supports claim in Reference 2 that the non uniform behavior become the reason behind over prediction of heat transfer during LOCA transient. A closer look on the heat transfer in each tube shows that 63 % of heat transfer occurred in the two tubes with continuos flows and 37% remainder occurred in tube with stagnant flows (Figure A.4.8.1, Appendix 4). The tube with stagnant flow still play significant contribution to the heat transfer because vapor are distributed to all stagnant tube and due to its density it will naturally go up and then will condense in tube. By the reason of vapor bring much higher enthalpy than water, small fraction of vapor releases significant heat during condensation.

Realizing that the condition of final non-uniformity among U-tubes is affected on how the boundary condition is imposed as in the 100% of mass inventory case, it can be considered that calculation for the 75 % of mass inventory boundary condition data can lead to different tubes having continuos flow. A trial simulation using different way to reach the boundary condition ended with tube#1, tube#5 and tube#8 having continuos flow while other tubes having stagnant vertical stratification mode. The three tubes with continuos flow in this result is equivalent with 49 tubes in real steam generator. The average heat transfer was about 12 % lower than using single tube model. This shows that less number of U-tubes having continuos flow will transfer less heat to secondary side.

Although using 9-tubes model there is significant reduction on heat transfer rate compared with the single tube model as described before, the grouping into 9 bunch still have possibility to over predict the heat transfer rate. This because single tube in the model is equivalent on average with 15 tubes in real steam generator. Realizing that the tube with continuos flow play significant influence on heat transfer, this suggests that in order to get more accurate result for transient involving flow stagnation, greater number of group is needed. However such an effort is a trade in between precision and calculation cost.

From the oscillatory point of view, the 9-tube model provide much better result. Figure A.4.8.2. shows the primary side flow rate and Figure A.4.8.7 shows flow in each tubes. Although the oscillation still occurs along the tubes with continuous flow but in this calculation, the unrealistic reverse flow does not appear. This result excellently matches with the test result. Little oscillation also occurs in the liquid collapsed level in the tube with stagnant flow (Figures A.4.8.5 to A.4.8.14). This oscillation indicates that the stagnant tube somehow plays role on compensating oscillation appears in tube with continuos flow.

7.3. Five-tubes Model

When calculation was performed using 5-tube model, the qualitative result was similar with the 9-tubes model. Reverse flow in 100% mass inventory calculation and fill and dump flow in 73% of mass inventory calculation could be observed in high pressure calculation. For the low pressure case, the stagnant vertical stratification was also excellently simulated. Result of this calculation can be seen in Appendix 4.9 to 4.12. This conclude that steam generator model using 5 and 9 different tube are capable to be used to capture main phenomena occurred during high pressure and low pressure natural circulation test.

8. Conclusion

Steady-state natural circulation (NC) in the PWR geometry was analyzed using the RELAP5/MOD3 code focusing on non-uniform flow among steam generator (SG) U-tubes that was observed in the ROSA/LSTF experiments. Two steady-state experiments were selected for the analysis to represent high and low pressure conditions during accidents in PWR: ST-NC-02 conducted at ~7 MPa and ST-NC-17 at ~0.2 MPa. For both experiments, the primary mass inventory was the main test parameter, while the other parameters were kept constant at a specified value.

The SG behavior were analyzed using the partial SG model with one, five, or nine flow paths in the primary side and boundary conditions based on the experiments. The imposed boundary conditions were flow rate, quality, pressure of the inlet side of the primary and feedwater temperature, liquid level, and pressure in the secondary. In general, the simulations using the model with five or nine tubes were capable to capture important non uniform phenomena such as reverse flow, fill and dump, and stagnant vertical stratification. As a result of appropriate simulation of the non-uniform flow, the calculated SG outlet flow in the primary loop was stable as observed in the experiments.

Effects of the nonuniform flow on the heat transfer from the primary to secondary were dependent on calculated cases. For the case of high pressure and 100% mass inventory, three flow distributions among tubes were calculated from the same imposed boundary conditions. The calculated flow distributions were i) uniform, ii) mostly normal and partially reversed through the longest tube, and iii) reversed through the shortest tube. It seems the history of transient plays an important role on the selection of the flow distribution among tubes. Interestingly, the calculated heat transfer rates were almost the same among the three flow distributions.

On the other hand, the calculated heat transfer rates were 6% lower when the fill and dump mode was simulated using the 9 tubes model for the case of high pressure and 75 % mass inventory. Similarly, the heat transfer rate was 15% lower when the coexistence of the flow stratification and two-phase flow was simulated for the case of low pressure and 75% mass inventory. These results clearly indicate the importance of the simulation of the nonuniform flow in predicting both the flow stability and heat transfer between the primary and secondary.

Furthermore, difficulties were found in establishing the steady state condition especially for the low pressure analysis. Only when the inlet flow rate was carefully imposed, stable NC behavior was obtained.

References

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(2) YONOMOTO, T., ANODA,Y., "Thermal-hydraulic Research on Next Generation PWRS Using ROSA/LSTF ", IAEA-TECDOC., 1149 (2000) 233-246
(3) SCHULTZ, R. R., CHAPMAN, J.C.,KUKITA. Y., et al., "Single and two-phase natural circulation in Westinghouse pressurized water reactor simulators: phenomena, analysis and scaling", Proc. Of the Winter Annual Meeting of ASME, Boston, MA, FED-Vol. 61, HTD-Vol. 92 (1987) 59-70
(4) The ROSA-V group, "ROSA-V Large Scale Test Facility (LSTF) System description for The Third and Fourth Simulated Fuel Assemblies ", JAERI-Tech 2003-037, March 2003.
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Appendix 1.

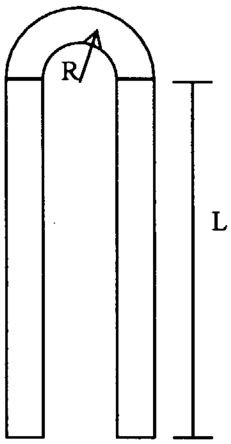
Table A.1.1. Steam generator geometry *

Height	**m**
Inner height of SG Vessel	19.840
Inner height of plenum	1.813
Inner height of SG secondary side	17.693
Height of u-tube (max)	10.620
Height of u-tube (min)	9.156
Height of down comer	14.101
Fluid volume per one SG	**m^3**
SGB inlet plenum	0.4371
SGB outlet plenum	0.2089
Compartment	0.1990
Vertical part of sleeve	0.0099
Inside u-tube	0.8384
Inside tube sheet	0.0282
Total primary coolant in SG-B	1.512
Lower down comer piping	0.349
Total Secondary Coolant in SG-B	7.030
Flow Area per one SG	**m^2**
Inside u-tube	0.0425
Boiler Section	0.2293
U-tube support plate	0.0712
Flow distributer	0.0771
Separator vane	0.129
Down comer annulus	0.0743
Lower downcomer	0.0296
Main steam line	0.0862
Main feedwater line	0.001924

Table A.1.2. Major design characteristic *

Max heat removal rate (MW)	35.7
Number of u-tubes	141
Feed water flow rate (kg/s)	2.76
Steam flow rate (kg/s)	2.76
Pressure in SG Steam dome (MPa)	7.34
Temperature at SG inlet (K)	598.7
Temperature at SG outlet (K)	562.4
Average length of u-tube (m)	19.7

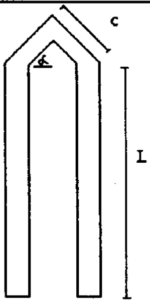
Table A.1.3. U-tube geometry details *



Type	**R** (mm)	**L** (mm)	**No. of tubes**
1	50.8	9439.9	21
2	83.3	9590.7	19
3	115.8	9741.2	19
4	148.3	9891.7	19
5	180.8	10042.2	17
6	213.3	10192.7	15
7	245.8	10343.2	13
8	278.3	10493.7	11
9	310.8	10644.2	7
	ID = 19.6 mm		
	OD = 25.4 mm		
	Pitch =32.5 mm . Square		

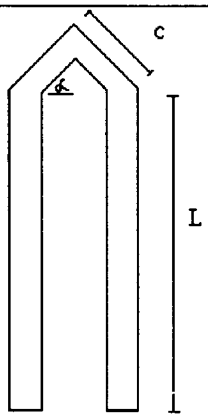
***) source: LSTF system description, table 5.3-3**

Table A.1.4. Approximation of U-tube geometry for single-tube model



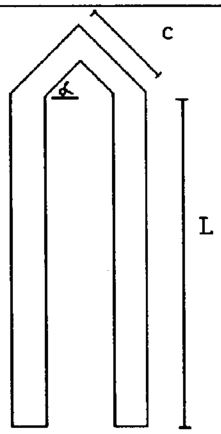
Type	C (mm)	L (mm)	No. of tubes
1	2945.8	7677.2	141
	α =73.4		

Table A.1.5. Approximation of U-tube geometry for 9-tube model



Type	C (mm)	L (mm)	No. of tubes
1	79.80	9439.9	21
2	130.85	9590.7	19
3	181.90	9741.2	19
4	232.95	9891.7	19
5	284.00	10042.2	17
6	335.05	10192.7	15
7	386.10	10343.2	13
8	437.15	10493.7	11
9	488.20	10644.2	7
	α = 39.54		

Table A.1.6. Approximation of U-tube geometry for 5-tube model



Type	Grouping	C (mm)	L (mm)	No. of tubes
1	1 &2	104.0	9511.5	40
2	3&4	207.4	9816.5	38
3	5	284.0	10042.2	17
4	6&7	358.8	10262.6	28
5	8&9	457.0	10552.2	18
	α = 39.54			

Appendix 2.

Table A.2.1. Data for steady state high pressure natural circulation tests

NUM	Initial Timing	End Timing	%Mass(w/oPzr)	LDC	SLDC	WGCORE	SWGCORE	JGSHL	SJGSHL	RJGSHL
1	5650	5750	101.21	9.6018	0.0090483	0	0	0	0	0
2	11950	12050	100	9.4253	0.0071032	0	0	0	0	0
3	14950	15050	96.255	9.2483	0.0057679	0.058281	0.0094857	0.0033865	0.0005512	0.058194
4	16450	16550	89.575	8.4129	0.013208	0.091231	0.0063729	0.0053399	0.0003739	0.073075
5	18950	19050	82.794	7.9275	0.0083387	0.44315	0.0058427	0.027687	0.0003658	0.16639
6	21150	21250	78.239	7.8246	0.012132	0.78194	0.0080414	0.050637	0.0005193	0.22503
7	22650	22750	73.178	7.7126	0.015328	0.87835	0.015831	0.057308	0.001034	0.23939
8	24150	24250	68.117	7.2303	0.020241	0.92385	0.013356	0.060371	0.0008736	0.2457
9	25450	25550	62.955	6.725	0.018753	0.94118	0.0051713	0.06154	0.0003375	0.24807
10	26950	27050	57.895	6.4721	0.037828	0.94788	0.0042354	0.062048	0.0002763	0.2491
11	28150	28250	52.834	6.3918	0.011807	0.94751	0.0045679	0.062136	0.0003003	0.24927
12	29750	29850	47.773	6.3902	0.015456	0.94449	0.0021394	0.061959	0.0001419	0.24892
13	30950	31050	42.611	6.3769	0.016139	0.94433	0.0023628	0.061951	0.0001562	0.2489
14	32150	32250	37.551	6.3814	0.011363	0.9442	0.0041714	0.062043	0.0002744	0.24908
15	33350	33450	32.389	6.3698	0.0090519	0.94632	0.0034871	0.062273	0.0002298	0.24955

NUM	SRJGSHL	JGSTU	SJGSTU	RJGSTU	SRJGSTU
1	0	0	0	0	0
2	0	0	0	0	0
3	0.023478	0.00871	0.0014171	0.093306	0.037645
4	0.019336	0.01373	0.0009612	0.11717	0.031003
5	0.019125	0.07118	0.0009403	0.26679	0.030664
6	0.022788	0.13018	0.001335	0.3608	0.036538
7	0.032156	0.14733	0.0026581	0.38383	0.051557
8	0.029557	0.1552	0.0022459	0.39395	0.047391
9	0.018371	0.15821	0.0008677	0.39775	0.029456
10	0.016623	0.15951	0.0007103	0.39939	0.026652
11	0.017329	0.15974	0.000772	0.39967	0.027785
12	0.011914	0.15928	0.0003649	0.3991	0.019102
13	0.012499	0.15926	0.0004016	0.39908	0.020041
14	0.016564	0.1595	0.0007054	0.39937	0.026559
15	0.015158	0.16009	0.0005907	0.40011	0.024303

NUM	Initial Timing	End Timing	%Mass(w/oPzr)	PUP	SPUP	PSGA	SPSGA	PSGB	SPSGB	TSUP	STSUP
1	5650	5750	101.21	15.567	0.00207	6.641	0.00186	6.671	0.00199	618.26	0.01107
2	11950	12050	100	12.313	0.00186	6.67	0.00263	6.7	0.00269	599.77	0.01199
3	14950	15050	96.255	9.057	0.00268	6.668	0.00074	6.699	0.00122	576.91	0.02132
4	16450	16550	89.575	8.907	0.00917	6.67	0.00112	6.7	0.00112	575.71	0.07369
5	18950	19050	82.794	7.672	0.00195	6.693	0.00137	6.723	0.00122	565.21	0.01769
6	21150	21250	78.239	7.072	0.003	6.71	0.0017	6.74	0.00158	559.63	0.02876
7	22650	22750	73.178	6.953	0.00195	6.661	0.00153	6.691	0.00107	558.48	0.01898
8	24150	24250	68.117	6.928	0.00253	6.662	0.00126	6.691	0.00049	558.24	0.02469
9	25450	25550	62.955	6.919	0.00197	6.675	0.00112	6.705	0.00113	558.15	0.01916
10	26950	27050	57.895	6.901	0.00209	6.692	0.0014	6.721	0.00117	557.97	0.02046
11	28150	28250	52.834	6.873	0.0017	6.696	0.00067	6.725	0.00085	557.7	0.01662
12	29750	29850	47.773	6.867	0.00261	6.7	0.00068	6.728	0.00058	557.65	0.02564
13	30950	31050	42.611	6.867	0.00213	6.704	0.00117	6.733	0.00096	557.64	0.02103
14	32150	32250	37.551	6.842	0.00247	6.683	0.00113	6.711	0.00175	557.39	0.02424
15	33350	33450	32.389	6.819	0.0017	6.665	0.00127	6.693	0.00132	557.17	0.01675

NUM	TSGA	STSGA	TSGB	STSGB	DENL1	SDENL1	DENG1	SDENG1	DENL2A	SDENL2A	DENG2A	SDENG2A	DENL2B
1	555.4	0.01876	555.7	0.02003	592.81	0.03842	102.66	0.02235	746.49	0.03385	34.455	0.01067	745.95
2	555.69	0.02648	555.99	0.02679	649.71	0.03127	72.492	0.01485	745.97	0.04785	34.622	0.01514	745.42
3	555.67	0.00766	555.98	0.01227	704.31	0.04541	49.163	0.01733	746	0.01349	34.612	0.00427	745.44
4	555.69	0.01133	555.99	0.01113	706.86	0.15572	48.192	0.05887	745.97	0.02032	34.621	0.00641	745.41
5	555.92	0.01387	556.22	0.01222	728.12	0.03422	40.515	0.01177	745.55	0.02491	34.753	0.00785	745.01
6	556.09	0.01707	556.39	0.01588	738.73	0.05365	36.952	0.01756	745.24	0.03093	34.851	0.00979	744.7
7	555.6	0.01541	555.9	0.01094	740.86	0.03509	36.256	0.01136	746.12	0.02785	34.572	0.00877	745.58
8	555.61	0.01284	555.9	0.00547	741.3	0.04537	36.113	0.01469	746.11	0.02303	34.574	0.00725	745.59
9	555.74	0.01123	556.04	0.01157	741.47	0.03545	36.058	0.01144	745.87	0.02041	34.653	0.00643	745.33
10	555.91	0.01422	556.2	0.01183	741.79	0.03762	35.955	0.01213	745.56	0.0256	34.748	0.00807	745.04
11	555.96	0.00692	556.24	0.00849	742.3	0.03053	35.792	0.00983	745.48	0.01219	34.773	0.00384	744.97
12	555.99	0.00685	556.27	0.0058	742.4	0.04694	35.761	0.01511	745.43	0.01235	34.792	0.0039	744.92
13	556.03	0.01188	556.32	0.00979	742.4	0.03842	35.759	0.01237	745.34	0.02128	34.818	0.00673	744.82
14	555.82	0.0115	556.1	0.01752	742.86	0.04445	35.611	0.01428	745.73	0.0205	34.696	0.00648	745.22
15	555.64	0.01293	555.92	0.01342	743.27	0.03071	35.481	0.00981	746.05	0.02303	34.595	0.00728	745.55

NUM	SDENL2B	DENG2B	SDENG2B	LSGA	SLSGA	LSGB	SLSGB	WAH	SWAH	WAL	SWAL	WBH	SWBH
1	0.03616	34.627	0.01143	9.535	0.01639	9.842	0.01352	5.839	0.07214	5.613	0.01963	5.551	0.09863
2	0.04873	34.794	0.01545	9.491	0.00432	9.557	0.00467	5.412	0.09234	5.707	0.01768	5.614	0.10748
3	0.0221	34.786	0.00699	9.552	0.00281	9.547	0.00316	5.547	0.09537	5.866	0.02029	5.937	0.12406
4	0.02033	34.796	0.00642	9.565	0.00348	9.531	0.00261	5.896	0.08817	6.021	0.02454	6.076	0.09027
5	0.02224	34.924	0.00704	9.576	0.00238	9.534	0.00252	8.296	0.09191	8.374	0.07281	8.018	0.08414
6	0.02868	35.024	0.0091	9.561	0.02849	9.811	0.03836	9.957	0.18205	10.118	0.16498	10.12	0.18059
7	0.01959	34.742	0.00615	9.404	0.02054	9.595	0.00276	8.153	0.31838	8.295	0.29697	9.212	0.34453
8	0.00925	34.74	0.00279	9.544	0.00389	9.489	0.0043	4.373	0.45306	4.553	0.42942	4.674	0.45955
9	0.02062	34.822	0.00653	9.567	0.00219	9.427	0.01106	2.499	0.00259	1.435	0.73315	2.511	0.07239
10	0.02123	34.916	0.00673	9.351	0.00228	9.514	0.00134	2.489	0.00103	-1.036	0.34173	2.489	0.00656
11	0.01533	34.937	0.00487	9.51	0.00232	9.513	0.00222	2.484	0.0056	-1.183	0.10537	2.483	0.00397
12	0.01054	34.955	0.00336	9.478	0.00181	9.5	0.00192	2.474	0.00116	-1.193	0.16443	2.471	0.00193
13	0.0176	34.985	0.00554	9.533	0.00238	9.533	0.00344	2.472	0.00227	-1.204	0.12525	2.47	0.00164
14	0.03178	34.856	0.01005	9.541	0.00184	9.552	0.00215	2.467	0.00713	-1.205	0.04841	2.473	0.00571
15	0.0241	34.754	0.0076	9.537	0.00238	9.551	0.00171	2.465	0.00155	-1.178	0.01989	2.474	0.0019

NUM	WBL	SWBL	MST	SMST	QCORE	SQCORE	LPR	SLPR	LCORE	SLCORE	LUP	SLUP	LUPCore
1	5.68	0.02662	-2880.1	4.8996	1.438	0.00198	1.119	0.00071	3.975	0.00533	2.091	0.00371	6.066
2	5.808	0.0223	-2859.8	4.8201	1.439	0.00274	1.372	0.00067	3.977	0.00409	2.095	0.00356	6.072
3	6.142	0.02396	-2841.2	4.6733	1.44	0.00335	0.94	0.00055	3.978	0.00353	2.085	0.00388	6.063
4	6.255	0.02313	-2839.7	1.9344	1.439	0.00239	1.311	0.02724	3.972	0.00587	2.037	0.00409	6.009
5	8.231	0.0499	-2835.3	6.4615	1.44	0.0022	1.71	0.00091	3.844	0.00563	1.369	0.00509	5.213
6	10.244	0.17218	-2827.3	6.4787	1.44	0.00269	1.555	0.00063	3.647	0.0086	1.253	0.00643	4.9
7	9.299	0.33964	-2824.9	5.8452	1.438	0.00582	1.503	0.00086	3.488	0.00788	1.207	0.00824	4.695
8	4.769	0.47495	-2821.8	5.8868	1.439	0.00532	1.469	0.00077	3.225	0.01094	1.148	0.00987	4.373
9	1.586	0.51521	-2820.3	4.8873	1.441	0.00367	1.446	0.00067	3.038	0.00879	1.102	0.00815	4.14
10	-0.453	0.72883	-2821.2	4.7872	1.441	0.00646	1.42	0.00081	2.927	0.01386	1.088	0.00996	4.015
11	-0.962	0.15917	-2821.1	4.2123	1.441	0.00686	1.398	0.00051	2.904	0.01277	1.088	0.01012	3.992
12	-0.877	0.37313	-2820.5	4.4911	1.44	0.003	1.371	0.00078	2.9	0.00843	1.09	0.01134	3.99
13	-0.975	0.15761	-2821.2	4.7828	1.439	0.0032	1.353	0.00074	2.895	0.00812	1.088	0.01112	3.983
14	-0.98	0.16316	-2821.2	5.7418	1.439	0.00629	1.334	0.00069	2.897	0.01085	1.09	0.01151	3.987
15	-1.003	0.03459	-2821.2	4.8587	1.442	0.0052	1.315	0.00067	2.893	0.00973	1.078	0.0113	3.971

NUM	SLUPCore	DPPV	SDPPV	LLSAD	SLLSAD	LLSAU	SLLSAU	LLSBD	SLLSBD	LLSBU	SLLSBU	DPPUA	SDPPUA
1	0.006494	0.668	0.01196	4.206	0.00298	3.451	0.00373	4.174	0.00373	3.427	0.00269	-3.147	0.03712
2	0.005422	0.719	0.01363	4.296	0.00286	3.463	0.00521	4.264	0.0036	3.433	0.00292	-3.15	0.03076
3	0.005246	0.797	0.01958	4.365	0.00224	3.473	0.00275	4.335	0.00516	3.441	0.00599	-3.179	0.03955
4	0.007154	0.888	0.02201	4.368	0.00356	3.478	0.00681	4.335	0.00263	3.44	0.0021	-3.257	0.02617
5	0.00759	2.09	0.03377	4.371	0.00454	3.488	0.00469	4.344	0.0071	3.451	0.00547	-4.92	0.07164
6	0.010738	3.607	0.07283	4.363	0.00838	3.497	0.00688	4.334	0.01168	3.464	0.00653	-6.601	0.16013
7	0.011401	4.449	0.10291	4.382	0.01138	3.488	0.00786	4.342	0.01319	3.458	0.00782	-5.284	0.23907
8	0.014734	3.346	0.18587	4.412	0.01534	3.475	0.01226	4.376	0.01239	3.44	0.00751	-3.165	0.17195
9	0.011987	1.653	0.14812	4.42	0.01993	3.467	0.01515	4.388	0.01771	3.43	0.01351	-2.368	0.10755
10	0.017068	0.86	0.31111	4.423	0.02669	3.467	0.02045	4.382	0.02456	3.436	0.01768	-2.058	0.05598
11	0.016294	0.569	0.12423	4.432	0.0267	3.465	0.02499	4.385	0.02256	3.438	0.02074	-2.007	0.07226
12	0.01413	0.608	0.11277	4.421	0.02715	3.476	0.0245	4.383	0.02519	3.437	0.02046	-1.974	0.11828
13	0.013769	0.567	0.14892	4.36	0.03261	3.463	0.02696	4.394	0.02845	3.436	0.02131	-2.015	0.03469
14	0.015818	0.519	0.12257	3.646	0.01384	3.465	0.01235	4.389	0.02792	3.44	0.02378	-2.023	0.01573
15	0.014912	0.473	0.04813	3.621	0.00629	3.472	0.00264	3.579	0.00719	3.438	0.00978	-2.032	0.00903

NUM	DPPUB	SDPPUB	LCLA	SLCLA	LCLB	SLCLB	LHLA	SLHLA	LHLB	SLHLB	THLA	STHLA	THLB
1	-3.593	0.03722	0.201	0.00116	0.207	0	0.204	0.0026	0.205	0.00246	578.23	0.40004	576.71
2	-3.553	0.03593	0.201	0.00099	0.207	0	0.204	0.00262	0.204	0.00264	577.92	0.38411	576.52
3	-3.533	0.04007	0.201	0.00071	0.207	0	0.205	0.00263	0.205	0.00241	577.27	0.35635	575.91
4	-3.608	0.03821	0.201	0.00064	0.207	0	0.198	0.00112	0.197	0.00122	576.7	0.24803	575.38
5	-5.002	0.0818	0.162	0.00104	0.187	0.00089	0.159	0.00322	0.158	0.00227	566.68	0.37272	565.23
6	-6.9	0.15085	0.138	0.00259	0.157	0.00279	0.141	0.00605	0.136	0.00532	561.13	0.4875	559.82
7	-6.486	0.31367	0.103	0.00584	0.121	0.00349	0.138	0.00529	0.128	0.00388	560.07	0.21414	558.81
8	-3.471	0.21766	0.074	0.00425	0.086	0.00338	0.135	0.00391	0.129	0.00327	559.78	0.41863	558.4
9	-2.585	0.09723	0.05	0.00483	0.054	0.00432	0.132	0.00345	0.126	0.00263	559.64	0.40662	558.13
10	-2.301	0.08119	0.026	0.00566	0.035	0.00626	0.127	0.00271	0.125	0.00283	559.44	0.27962	557.16
11	-2.192	0.08968	0.021	0.00402	0.02	0.00407	0.127	0.00253	0.125	0.00303	559.16	0.33141	557.16
12	-2.189	0.13039	0.016	0.00466	0.023	0.00576	0.127	0.00284	0.124	0.00301	559.28	0.38819	557.09
13	-2.186	0.06555	0.018	0.00295	0.016	0.00405	0.126	0.00299	0.124	0.00251	559.15	0.35383	557.27
14	-2.207	0.06683	0.018	0.00177	0.018	0.00475	0.126	0.00335	0.124	0.00286	558.79	0.39819	556.91
15	-2.228	0.01314	0.018	0.00088	0.019	0.0013	0.108	0.00359	0.107	0.00289	558.53	0.36546	556.44

NUM	STHLB	TCLA	STCLA	TCLB	STCLB	DPR	SDPR	MPR	SMPR
1	0.13673	555.56	0.22568	555.49	0.17184	596.35	0.36125	186.86	0.17352
2	0.1549	555.9	0.30108	555.8	0.32286	652.67	0.60828	250.65	0.29481
3	0.42951	555.97	0.3612	555.92	0.34233	702.11	0.29301	184.79	0.09994
4	0.2383	555.87	0.09231	555.72	0.41467	709.12	0.60215	259.95	5.7479
5	0.15023	558.39	0.92408	556.77	0.46397	728.38	0.56809	348.68	0.31234
6	0.24519	558.48	0.46352	558.66	0.41393	738.7	0.5072	321.61	0.25417
7	0.25937	557.84	0.48518	558.04	0.37696	740.65	0.32637	311.71	0.23467
8	0.53893	557.92	0.17544	557.89	0.45021	741.55	0.41855	304.99	0.26082
9	0.19536	557.82	0.5059	557.66	0.47069	741.78	0.38043	300.2	0.1635
10	0.31942	557.96	0.34619	557.56	0.52061	742.03	0.52315	294.97	0.20141
11	0.38288	557.68	0.33768	557.48	0.46281	742.84	0.54945	290.7	0.24787
12	0.37667	557.65	0.48489	557.52	0.39331	742.91	0.58361	285.2	0.27784
13	0.38381	557.61	0.40148	557.76	0.19159	743.4	0.47346	281.5	0.201
14	0.40079	557.46	0.21491	557.25	0.35955	743.8	0.57589	277.73	0.2979
15	0.36238	557.26	0.34038	557.13	0.31305	744.27	0.30129	273.95	0.18015

NUM	Initial Timing	End Timing	%Mass(w/oPzr)	Cpower	Scpower	PUP	SPUP	PSGA	SPSGA	PSGB	SPSGB
0	5650	5750	101.21	1.438	0.00198	15.567	0.00207	6.641	0.00186	6.671	0.00199
2	11950	12050	100	1.439	0.00274	12.313	0.00186	6.67	0.00263	6.7	0.00269
3	14950	15050	96.255	1.44	0.00335	9.057	0.00268	6.668	0.00074	6.699	0.00122
4	16450	16550	89.575	1.439	0.00239	8.907	0.00917	6.67	0.00112	6.7	0.00112
5	18950	19050	82.794	1.44	0.0022	7.672	0.00195	6.693	0.00137	6.723	0.00122
6	21150	21250	78.239	1.44	0.00269	7.072	0.003	6.71	0.0017	6.74	0.00158
7	22650	22750	73.178	1.438	0.00582	6.953	0.00195	6.661	0.00153	6.691	0.00107
8	24150	24250	68.117	1.439	0.00532	6.928	0.00253	6.662	0.00126	6.691	0.00049
9	25450	25550	62.955	1.441	0.00367	6.919	0.00197	6.675	0.00112	6.705	0.00113
10	26950	27050	57.895	1.441	0.00646	6.901	0.00209	6.692	0.0014	6.721	0.00117
11	28150	28250	52.834	1.441	0.00686	6.873	0.0017	6.696	0.00067	6.725	0.00085
12	29750	29850	47.773	1.44	0.003	6.867	0.00261	6.7	0.00068	6.728	0.00058
13	30950	31050	42.611	1.439	0.0032	6.867	0.00213	6.704	0.00117	6.733	0.00096
14	32150	32250	37.551	1.439	0.00629	6.842	0.00247	6.683	0.00113	6.711	0.00175
15	33350	33450	32.389	1.442	0.0052	6.819	0.0017	6.665	0.00127	6.693	0.00132

NUM	DP(PUP-P2A)	DP(PUP-P2B)	LSGA	SLSGA	LSGB	SLSGB	TFWA	STFWA	TFWB	STFWB	WFWA	SWFWA
0	8.926	8.896	9.535	0.01639	9.842	0.01352	473.87	0.26839	473.32	0.73035	0.49	0.00247
2	5.643	5.613	9.491	0.00432	9.557	0.00467	485.71	0.55586	486.27	0.25072	0.408	0.00274
3	2.389	2.358	9.552	0.00281	9.547	0.00316	496.19	0.4871	496.17	0.51803	0.43	0.00235
4	2.237	2.207	9.565	0.00348	9.531	0.00261	499.34	0.24654	499.25	0.15358	0.429	0.00253
5	0.979	0.949	9.576	0.00238	9.534	0.00252	508.55	0.20562	508.44	0.27691	0.454	0.00234
6	0.362	0.332	9.561	0.02849	9.811	0.03836	509.27	0.88532	508.49	1.1909	0.339	0.02991
7	0.292	0.262	9.404	0.02054	9.595	0.00276	492.49	0.63817	492.71	0.76052	0.523	0.02982
8	0.266	0.237	9.544	0.00389	9.489	0.0043	490.12	0.2588	489.85	0.23179	0.45	0.00279
9	0.244	0.214	9.567	0.00219	9.427	0.01106	499.95	0.51908	499.74	0.34188	0.437	0.01788
10	0.209	0.18	9.351	0.00228	9.514	0.00134	506.07	0.16762	505.92	0.19266	0.454	0.00274
11	0.177	0.148	9.51	0.00232	9.513	0.00222	509.03	0.42948	508.53	0.33878	0.444	0.00237
12	0.167	0.139	9.478	0.00181	9.5	0.00192	513.85	0.45243	513.65	0.48623	0.453	0.01674
13	0.163	0.134	9.533	0.00238	9.533	0.00344	517.17	0.85491	517.04	0.89661	0.463	0.00222
14	0.159	0.131	9.541	0.00184	9.552	0.00215	502.63	0.93054	502.35	0.78662	0.458	0.00216
15	0.154	0.126	9.537	0.00238	9.551	0.00171	494.94	0.52073	494.78	0.67251	0.437	0.00212

NUM	WFWB	SWFWB	WMSLA	SWMSLA	WMSLB	SWMSLB	CWSGA	SCWSGA	CWSGB	SCWSGB	LTUAL1	SLTUAL1
0	0.316	0.08588	0.307	0.06218	0.483	0.00803	0.37457	0.00051541	0.37416	0.00091196	12.679	0.00767
2	0.406	0.0038	0.359	0.04751	0.492	0.00446	0.38554	0.00089508	0.38614	0.00080609	12.681	0.00896
3	0.41	0.00326	0.354	0.05139	0.494	0.00357	0.39586	0.0010613	0.39593	0.0010767	12.65	0.01005
4	0.425	0.00273	0.351	0.05547	0.492	0.00349	0.39901	0.00070542	0.39901	0.00068365	12.644	0.00635
5	0.431	0.00264	0.394	0.04161	0.498	0.00439	0.40896	0.00066228	0.40892	0.00064514	12.609	0.01211
6	0.253	0.00292	0.398	0.04615	0.498	0.00577	0.40972	0.0010219	0.40895	0.0013019	12.541	0.02182
7	0.426	0.00385	0.335	0.05708	0.502	0.00573	0.39167	0.001733	0.39196	0.00175	8.201	0.19764
8	0.403	0.00231	0.366	0.04643	0.496	0.00539	0.3898	0.0014642	0.38961	0.0014586	2.122	0.1264
9	0.482	0.00235	0.372	0.04352	0.499	0.00382	0.40005	0.0010134	0.39991	0.00095024	1.988	0.04076
10	0.428	0.00215	0.377	0.04446	0.505	0.00342	0.40652	0.0018136	0.40644	0.0018613	1.906	0.06618
11	0.423	0.00249	0.383	0.04725	0.507	0.00372	0.40976	0.0019923	0.40929	0.0021332	1.868	0.04649
12	0.429	0.00283	0.407	0.04265	0.513	0.00396	0.41498	0.0010061	0.41483	0.0010705	1.759	0.03343
13	0.452	0.00261	0.393	0.04526	0.514	0.00433	0.41844	0.0016478	0.41837	0.0016983	1.34	0.02064
14	0.44	0.00914	0.383	0.04356	0.513	0.00418	0.40241	0.0018964	0.4022	0.0018851	0.807	0.01996
15	0.442	0.00205	0.374	0.05035	0.515	0.00326	0.39514	0.0014363	0.39505	0.001513	0.311	0.00567

NUM	LTUAM1	SLTUAM1	LTUAS1	SLTUAS1	LTUAL2	SLTUAL2	LTUAM2	SLTUAM2	LTUAS2	SLTUAS2	LTUBL1	SLTUBL1	LTUBM1
0	12.108	0.00826	10.835	0.00714	12.787	0.00633	12.424	0.00639	11.473	0.00575	13.296	0.01045	12.439
2	11.993	0.00731	10.735	0.00828	12.653	0.00859	12.275	0.00622	11.392	0.00708	13.106	0.00913	12.275
3	11.948	0.00737	10.77	0.00649	12.569	0.00806	12.167	0.00794	11.371	0.00658	12.975	0.01152	12.205
4	11.956	0.00785	10.786	0.00817	12.524	0.01	12.166	0.00706	11.379	0.00926	12.966	0.01497	12.211
5	11.72	0.01179	10.582	0.01874	12.435	0.01293	11.958	0.01356	11.148	0.0257	12.975	0.01133	12.268
6	11.615	0.01993	9.317	0.14544	12.323	0.02157	11.847	0.01871	10.205	0.12771	13.03	0.01975	12.292
7	9.843	0.29021	8.167	0.54676	8.088	0.46029	11.344	0.13338	8.496	0.59741	8.417	0.20561	10.251
8	9.559	0.81848	6.801	0.53862	6.921	0.24116	10.016	0.55464	7.472	0.42004	1.966	0.10526	9.558
9	8.044	0.43314	5.947	0.25855	3.686	0.51032	8.462	0.53365	6.279	0.19555	1.862	0.02788	8.076
10	7.158	0.22466	3.149	0.22722	1.899	0.09883	7.47	0.14804	2.083	0.09622	1.852	0.02507	7.257
11	1.723	0.07921	1.514	0.05056	1.787	0.04533	1.922	0.05827	1.981	0.05282	1.836	0.02005	1.852
12	1.531	0.03618	1.395	0.03914	1.67	0.03795	1.777	0.04291	1.859	0.04234	1.737	0.02233	1.663
13	1.11	0.02184	0.97	0.01973	1.257	0.02013	1.35	0.02313	1.431	0.02027	1.311	0.01265	1.234
14	0.581	0.01821	0.44	0.01818	0.731	0.01811	0.821	0.01905	0.896	0.01922	0.799	0.012	0.719
15	0.085	0.00549	-0.055	0.00536	0.236	0.00755	0.326	0.00804	0.399	0.00587	0.464	0.00825	0.382

NUM	SLTUBM1	LTUBS1	SLTUBS1	LTUBL2	SLTUBL2	LTUBM2	SLTUBM2	LTUBS2	SLTUBS2	DPSGAL1	SDPSGAL1	DPSGAM1
0	0.00549	11.579	0.00914	12.908	0.00572	12.066	0.00657	11.172	0.00796	-9.821	43.966	-0.879
2	0.00708	11.391	0.00706	12.786	0.00727	11.975	0.01099	11.039	0.00853	-20.218	117.22	-1.369
3	0.01084	11.28	0.00855	12.697	0.0049	11.913	0.00706	10.943	0.01025	-6.866	38.715	-1.295
4	0.00998	11.285	0.00675	12.639	0.00795	11.912	0.0106	10.934	0.01023	-53.263	157.68	-1.36
5	0.01168	11.14	0.02126	12.622	0.01376	11.981	0.00927	10.82	0.02275	-27.987	116.65	-2.042
6	0.02175	10.064	0.13975	12.633	0.02348	12.015	0.01831	10.098	0.12651	-12.479	157.96	-2.491
7	0.24803	8.676	0.51025	8.135	0.45119	11.247	0.11462	8.183	0.62185	6.134	53.482	0.073
8	0.80235	6.921	0.5641	6.58	0.23777	9.525	0.54785	6.779	0.41714	9.777	119.26	1.769
9	0.42629	6.096	0.25597	3.389	0.49656	7.998	0.52405	5.629	0.20514	34.985	51.284	1.402
10	0.25167	3.384	0.23935	1.674	0.06991	7.08	0.12735	1.526	0.08488	74.74	35.973	1.123
11	0.08711	1.784	0.03566	1.587	0.01836	1.577	0.04621	1.458	0.03556	63.04	45.047	1.045
12	0.02629	1.675	0.02509	1.482	0.02318	1.444	0.02589	1.345	0.02339	55.931	115.83	1.006
13	0.01114	1.241	0.01033	1.064	0.01192	1.011	0.01018	0.91	0.01289	64.898	50.05	0.361
14	0.01055	0.732	0.0093	0.562	0.01213	0.501	0.01003	0.405	0.01381	60.695	52.902	-0.144
15	0.0062	0.397	0.00618	0.23	0.00595	0.17	0.00823	0.069	0.00813	81.741	36.032	-0.167

NUM	DPSGAM1M	SDPSGAM1	DPSGAS1	DPSGAS1M	SDPSGAS1	DPSGAL2	DPSGAL2M	SDPSGAL2	DPSGAM2	DPSGAM2M
0	0.712	0.02887	0.453	0.836	0.04217	-3.11	2.129	0.04067	2.127	-0.803
2	1.202	0.02808	0.702	0.587	0.03921	-2.368	1.387	0.03531	2.227	-0.903
3	1.128	0.03321	0.542	0.747	0.041	-1.957	0.976	0.0263	1.796	-0.472
4	1.193	0.03051	0.462	0.827	0.03474	-2	1.019	0.03597	1.796	-0.472
5	1.875	0.09632	-0.319	1.608	0.0992	-2.612	1.631	0.09719	0.841	0.483
6	2.324	0.24244	-0.791	2.08	0.24711	-3.064	2.083	0.25924	0.188	1.136
7	-0.24	0.36556	1.761	-0.472	0.36441	-0.506	-0.475	0.37543	2.587	-1.263
8	-1.936	0.43199	3.431	-2.142	0.4333	1.177	-2.158	0.43909	4.173	-2.849
9	-1.569	0.3691	3.033	-1.744	0.37513	0.787	-1.768	0.36997	3.719	-2.395
10	-1.29	0.45071	2.742	-1.453	0.45822	0.447	-1.428	0.45396	3.052	-1.728
11	-1.212	0.24139	2.543	-1.254	0.24718	0.219	-1.2	0.24505	2.663	-1.339
12	-1.173	0.14308	2.524	-1.235	0.14004	0.188	-1.169	0.13837	2.546	-1.222
13	-0.528	0.15806	1.888	-0.599	0.17127	-0.428	-0.553	0.15688	1.877	-0.553
14	-0.023	0.06557	1.359	-0.07	0.07877	-0.946	-0.035	0.06505	1.372	-0.048
15	0	0.02776	1.289	0	0.02673	-0.981	0	0.02672	1.324	0

NUM	SDPSGAM2	DPSGAS2	DPSGAS2M	SDPSGAS2	DPSGBL1	SDPSGBL1	DPSGBM1	SDPSGBM1	DPSGBS1	SDPSGBS1	DPSGBL2
0	0.02883	-0.618	1.587	0.04289	-3.713	0.06476	-3.432	0.05986	-5.639	0.06496	-0.495
2	0.03053	-0.278	1.247	0.03301	-2.655	0.06607	-3.262	0.04974	-5.319	0.06735	-0.674
3	0.0353	-0.362	1.331	0.03937	-2.108	0.06766	-3.226	0.07144	-4.513	0.07604	-0.714
4	0.0333	-0.375	1.344	0.03504	-2.056	0.06734	-3.206	0.06317	-4.421	0.07664	-0.614
5	0.09768	-1.224	2.193	0.10198	-2.426	0.10723	-3.66	0.1177	-4.569	0.12594	-1.102
6	0.23672	-1.69	2.659	0.24683	-3.182	0.23515	-4.439	0.24711	-5.186	0.24294	-1.941
7	0.35747	0.931	0.038	0.35184	-1.575	0.42379	-2.834	0.39801	-3.547	0.39437	-0.37
8	0.40502	2.709	-1.74	0.43875	1.116	0.47912	-0.064	0.46195	-0.845	0.47307	2.333
9	0.38197	2.352	-1.383	0.38051	0.921	0.25996	-0.282	0.27633	-1.045	0.26307	2.109
10	0.43876	2.25	-1.281	0.44359	0.444	0.45389	-0.715	0.47437	-1.561	0.43167	1.636
11	0.23634	2.043	-1.074	0.23852	0.292	0.27729	-0.823	0.27696	-1.791	0.28936	1.467
12	0.13869	2.048	-1.079	0.14797	0.229	0.21314	-0.851	0.2101	-1.867	0.21411	1.379
13	0.15712	1.469	-0.5	0.16137	0.272	0.17408	-0.784	0.17226	-1.798	0.15448	1.419
14	0.07006	0.981	-0.012	0.07086	0.126	0.17604	-0.882	0.15215	-1.946	0.14685	1.251
15	0.02787	0.969	0	0.0316	-0.985	0.06474	-1.987	0.05352	-3.053	0.05713	0.126

NUM	SDPSGBL2	DPSGBM2	SDPSGBM2	DPSGBS2	SDPSGBS2
0	0.0455	1.527	0.04961	0.907	0.05711
2	0.04285	1.139	0.06156	1.246	0.05985
3	0.05178	0.782	0.05209	1.738	0.08048
4	0.07275	0.83	0.06163	1.881	0.0679
5	0.11706	0.156	0.12217	1.383	0.12185
6	0.24098	-0.75	0.2244	0.528	0.23413
7	0.40714	0.83	0.39486	2.064	0.40444
8	0.46802	3.524	0.4857	4.74	0.47175
9	0.26369	3.288	0.26511	4.489	0.28888
10	0.43506	2.804	0.46489	3.892	0.46489
11	0.30572	2.468	0.28453	3.682	0.27034
12	0.22028	2.394	0.21028	3.612	0.23781
13	0.15497	2.427	0.15346	3.667	0.17194
14	0.15168	2.299	0.16172	3.464	0.17631
15	0.06215	1.171	0.08791	2.345	0.07102

Table A.2.2. Data for steady state low pressure natural circulation tests

NUM	Initial Timing	End Timing	%Mass(w/oPzr)	LDC	SLDC	WGCORE	SWGCORE	JGSHL	SJGSHL	RJGSHL
1	4000	4200	100	8.6243	0.01384	0.050043	0.0059021	0.01295	0.0015666	0.1138
3	7500	7700	90.96	8.5781	0.02108	0.10273	0.0092664	0.027792	0.0025051	0.16671
4	9000	9300	85.643	8.5749	0.018854	0.1338	0.011924	0.037082	0.0033101	0.19257
5	10600	10850	80.313	8.0596	0.051585	0.18412	0.011158	0.051755	0.0031453	0.2275
6	12200	12600	74.991	7.3848	0.024465	0.23675	0.01084	0.06767	0.0031115	0.26013
7	13800	14900	69.679	7.3707	0.020016	0.28163	0.0095047	0.082189	0.0027916	0.28669
8	16000	16650	64.344	7.3567	0.028697	0.34373	0.0080425	0.10209	0.0023824	0.31951
9	18000	18550	59.025	7.3322	0.035558	0.38245	0.0068178	0.11585	0.0020729	0.34036
10	19600	20000	53.625	7.2534	0.025573	0.40028	0.0068683	0.12292	0.0021204	0.3506
11	21000	21650	48.306	6.4064	0.52983	0.42247	0.0060138	0.13148	0.001781	0.3626
12	22800	23600	43.098	5.3302	0.39696	0.42467	0.00096162	0.13459	0.00050613	0.36687
13	25000	25300	37.665	4.9071	0.051202	0.42403	0.00064666	0.13768	0.00026679	0.37105
14	26600	26900	32.476	4.8244	0.036585	0.42346	0.0007031	0.13912	0.00025852	0.37298
15	28440	28550	27.151	4.3713	0.021007	0.42328	0.00078233	0.14019	0.00029106	0.37442

NUM	SRJGSHL	JGSTU	SJGSTU	RJGSTU	SRJGSTU
1	0.03958	0.033292	0.0040274	0.18246	0.063462
3	0.050051	0.071446	0.00644	0.26729	0.08025
4	0.057533	0.095329	0.0085095	0.30875	0.092247
5	0.056083	0.13305	0.0080859	0.36476	0.089922
6	0.055781	0.17397	0.0079991	0.41709	0.089438
7	0.052836	0.21129	0.0071766	0.45966	0.084715
8	0.04881	0.26245	0.0061248	0.5123	0.078261
9	0.045529	0.29782	0.0053291	0.54573	0.073001
10	0.046048	0.316	0.0054513	0.56214	0.073833
11	0.042202	0.338	0.0045785	0.58138	0.067665
12	0.022497	0.346	0.0013014	0.58821	0.036074
13	0.016334	0.35395	0.00068587	0.59493	0.026189
14	0.016078	0.35764	0.00066457	0.59803	0.025779
15	0.017061	0.36039	0.00074827	0.60033	0.027354

NUM	Initial Timing	End Timing	Tmass	Massw/oPzr	%massw/oPzr	TmassDP	PUP	SPUP	PSGA	SPSGA	PSGB
1	4000	4200	7325	6334.9	100	7505	0.319	0.00288	0.125	0.00065	0.13
3	7500	7700	6651.9	5762.3	90.96	6685	0.289	0.00025	0.139	0.00062	0.141
4	9000	9300	6315	5425.4	85.643	6482	0.274	0.00033	0.136	0.00034	0.135
5	10600	10850	5977.8	5087.8	80.313	6014	0.266	0.0005	0.134	0.00033	0.135
6	12200	12600	5640.7	4750.6	74.991	5620	0.256	0.00049	0.137	0.00062	0.131
7	13800	14900	5304.3	4414.1	69.679	5244	0.245	0.00057	0.141	0.00119	0.128
8	16000	16650	4966.6	4076.2	64.344	4869	0.235	0.0006	0.141	0.00058	0.129
9	18000	18550	4630.1	3739.2	59.025	4553	0.225	0.00057	0.14	0.00069	0.131
10	19600	20000	4288.1	3397.1	53.625	4278	0.219	0.00054	0.136	0.00061	0.134
11	21000	21650	3951.3	3060.1	48.306	3927	0.212	0.00184	0.136	0.00077	0.133
12	22800	23600	3621.4	2730.2	43.098	3628	0.204	0.00176	0.136	0.00083	0.134
13	25000	25300	3277.7	2386	37.665	3258	0.193	0.00053	0.136	0.00072	0.134
14	26600	26900	2948.8	2057.3	32.476	2920	0.188	0.00037	0.138	0.00077	0.134
15	28440	28550	2611.6	1720	27.151	2562	0.185	0.00027	0.136	0.00064	0.136
			2449.9								

NUM	SPSGB	DP(P1-P2A)	DP(P1-P2B)	TSUP	STSUP	TSGA	STSGA	TSGB	STSGB	DENL1	SDENL1	DENG1
1	0.00027	0.194	0.189	408.827	0.3121	379.204	0.1507	380.288	0.06186	933.381	0.35542	1.555
3	0.00061	0.15	0.148	405.45	0.02977	382.287	0.13122	382.617	0.12923	936.896	0.22141	1.383
4	0.00023	0.138	0.139	403.636	0.0452	381.655	0.07612	381.393	0.05149	938.642	0.21315	1.302
5	0.00055	0.132	0.131	402.597	0.06413	381.108	0.07493	381.454	0.11978	939.783	0.21161	1.252
6	0.00033	0.119	0.125	401.375	0.0639	381.785	0.13852	380.581	0.07243	941.168	0.2383	1.191
7	0.0006	0.104	0.117	399.851	0.08262	382.713	0.25069	379.937	0.13613	942.634	0.27751	1.129
8	0.00039	0.094	0.106	398.584	0.08768	382.621	0.12527	379.998	0.08828	943.718	0.30057	1.084
9	0.00051	0.085	0.094	397.178	0.08486	382.383	0.14803	380.597	0.11278	945.073	0.27303	1.03
10	0.00052	0.083	0.085	396.208	0.0816	381.647	0.13421	381.102	0.11643	946.084	0.28852	0.992
11	0.00063	0.076	0.079	395.255	0.27861	381.512	0.16746	380.947	0.14211	946.948	0.39718	0.959
12	0.00091	0.068	0.07	393.987	0.27545	381.575	0.1819	381.117	0.20167	948.25	0.3752	0.911
13	0.00064	0.057	0.059	392.313	0.08649	381.685	0.15671	381.064	0.14119	949.926	0.31367	0.852
14	0.00076	0.05	0.054	391.5	0.06374	382.024	0.16621	381.169	0.16766	950.639	0.31077	0.827
15	0.00045	0.049	0.049	390.961	0.04613	381.51	0.1396	381.626	0.09719	951.093	0.2861	0.813

NUM	SDENG1	DENL2A	SDENL2A	DENG2A	SDENG2A	DENL2B	SDENL2B	DENG2B	SDENG2B	LSGA	SLSGA	LSGB	SLSGB
1	0.01801	950.684	0.14723	0.826	0.00497	948.89	0.13946	0.889	0.00493	12.66	0.04985	12.214	0.04167
3	0.01043	947.775	0.1357	0.929	0.00495	946.327	0.12661	0.983	0.00479	12.628	0.03768	12.321	0.03925
4	0.00959	947.904	0.13775	0.924	0.00496	946.803	0.11332	0.965	0.00417	12.379	0.03939	12.349	0.04097
5	0.00936	947.921	0.14069	0.923	0.0051	946.51	0.12144	0.976	0.00456	12.438	0.03817	12.275	0.04005
6	0.01019	947.021	0.14106	0.956	0.0052	946.82	0.12655	0.964	0.00465	12.376	0.04768	12.392	0.03235
7	0.01146	946.038	0.17982	0.993	0.00681	946.934	0.14031	0.959	0.00512	12.438	0.05942	12.396	0.03718
8	0.01206	945.877	0.12061	1	0.00453	946.59	0.1351	0.973	0.00504	12.431	0.06695	12.464	0.04637
9	0.01059	945.783	0.15337	1.003	0.00584	945.959	0.11494	0.996	0.00428	12.325	0.06209	12.36	0.04714
10	0.01095	946.077	0.13008	0.992	0.00492	945.499	0.12677	1.014	0.00481	12.442	0.05138	12.384	0.0451
11	0.01474	946.015	0.13399	0.994	0.00504	945.454	0.11359	1.016	0.00425	12.401	0.05363	12.435	0.0406
12	0.01349	945.867	0.13603	1	0.00514	945.246	0.1461	1.024	0.00559	12.491	0.07128	12.323	0.05404
13	0.01084	945.718	0.14408	1.006	0.00552	945.184	0.13195	1.027	0.00509	12.403	0.06147	12.42	0.0473
14	0.01052	945.46	0.15177	1.016	0.00582	945.072	0.12913	1.031	0.00496	12.338	0.05759	12.348	0.05258
15	0.00964	945.747	0.11238	1.005	0.00432	944.78	0.11883	1.043	0.00467	12.427	0.04591	12.301	0.03883

NUM	WAH	SWAH	WAL	SWAL	WBH	SWBH	WBL	SWBL	MST	SMST	QCORE	SQCORE	LPR
1	4.567	0.10158	4.701	0.05159	4.755	0.18325	4.675	0.02042	15510.6	5.66238	0.933	0.00218	9.551
3	7.335	0.27717	7.48	0.19888	6.575	0.41122	7.767	0.16731	16194.1	5.18262	0.934	0.00284	8.678
4	8.319	0.46275	8.448	0.24857	4.685	0.72627	7.454	0.26898	16540.8	5.82996	0.934	0.00259	8.677
5	8.061	0.4094	8.179	0.29358	4.427	0.84863	6.883	0.40826	16880.7	6.63995	0.934	0.00195	8.681
6	7.187	0.53109	7.282	0.43058	5.114	0.74407	7.117	0.39011	17229.3	6.28943	0.935	0.00195	8.685
7	7.673	0.7223	7.794	0.63954	3.967	1.0605	6.055	0.50977	17572.5	5.97317	0.935	0.00193	8.688
8	6.67	0.79913	6.792	0.7238	3.798	1.2309	4.535	0.66444	17921.5	5.50038	0.935	0.0018	8.692
9	4.858	1.25862	4.958	1.15201	3.603	1.58358	4.091	0.83724	18260.4	5.67798	0.935	0.00176	8.698
10	3.328	1.374	3.452	1.16469	2.983	1.54529	3.614	0.97643	18606.3	5.28931	0.935	0.00177	8.7
11	2.159	3.35961	2.334	3.23457	1.03	3.86841	2.429	3.15724	18953	5.74156	0.934	0.00183	8.703
12	0.659	1.45667	0.571	1.24564	-0.546	1.84229	1.179	1.23347	19297.7	6.26216	0.935	0.00206	8.706
13	0.206	1.10611	0.294	0.7184	-1.519	1.00164	0.652	0.72302	19669.1	6.19935	0.935	0.00152	8.711
14	0.087	1.04079	0.021	0.55609	-1.838	0.72707	0.213	0.59951	20016.2	5.83177	0.935	0.00168	8.712
15	-0.013	0.91012	-0.494	0.0612	-2.226	0.39443	-0.394	0.09188	20372.9	5.86296	0.935	0.00185	8.716

NUM	SLPR	LCORE	SLCORE	LUP	SLUP	LUPCore	SLUPCore	DPPV	SDPPV	LSGAIP	SLSGAIP	LSGBIP	SLSGBIP
1	0.11656	3.944	0.00943	2.004	0.04252	5.948	0.043553	-0.331	0.03694	1.695	0.00407	1.701	0.00409
3	0.00262	3.96	0.00728	1.455	0.013	5.415	0.0149	-0.07	0.23881	1.655	0.06716	1.632	0.05996
4	0.00307	3.962	0.01224	1.371	0.03103	5.333	0.033357	-0.747	0.41671	1.597	0.08718	1.579	0.10738
5	0.00323	3.927	0.02151	1.21	0.04768	5.137	0.052307	-2.605	0.64788	1.567	0.09534	1.482	0.11218
6	0.00287	3.718	0.03834	1.06	0.06577	4.778	0.076129	-6.178	0.74477	1.407	0.13763	1.524	0.10773
7	0.00313	3.561	0.04363	0.983	0.07611	4.544	0.087729	-8.257	0.72423	1.327	0.11465	1.475	0.11558
8	0.00321	3.279	0.03897	0.899	0.0629	4.178	0.073994	-11.892	0.68802	1.249	0.11014	1.394	0.10652
9	0.0033	3.073	0.05306	0.825	0.06654	3.898	0.085105	-14.516	0.71491	1.215	0.11672	1.314	0.10675
10	0.00292	2.927	0.0498	0.772	0.06705	3.699	0.083521	-15.968	0.64547	1.193	0.11224	1.264	0.10245
11	0.00287	2.686	0.16938	0.726	0.07598	3.412	0.18564	-10.961	3.16526	1.133	0.11936	1.183	0.11081
12	0.00294	2.488	0.07843	0.688	0.06215	3.176	0.10007	-3.122	2.97115	0.968	0.1097	1.051	0.09702
13	0.00316	2.449	0.04758	0.671	0.06159	3.12	0.077828	0.447	0.61675	0.64	0.08271	0.951	0.07465
14	0.00269	2.434	0.04417	0.663	0.05906	3.097	0.07375	1.204	0.45007	0.009	0.01644	0.524	0.05244
15	0.00296	2.244	0.02685	0.241	0.03318	2.485	0.042683	0.251	0.31351	-0.001	0.00144	0.004	0.00631

NUM	LLSAD	SLLSAD	LLSAU	SLLSAU	LLSBD	SLLSBD	LLSBU	SLLSBU	DPSGAH	SDPSGAH	DPSGAL	SDPSGAL	DPSGBH
1	6.055	0.00223	3.526	0.00114	6.054	0.00714	3.525	0.00091	1.592	0.02305	1.606	0.01585	1.586
3	6.039	0.04054	3.531	0.01871	6.025	0.04798	3.53	0.01613	0.377	0.22435	0.395	0.22024	0.199
4	6.026	0.04837	3.536	0.02536	5.942	0.05159	3.53	0.02136	0.767	0.42995	0.783	0.42036	0.755
5	6.032	0.04919	3.532	0.03241	5.95	0.06005	3.525	0.02847	3.031	0.44944	3.041	0.44634	3.95
6	6.023	0.07658	3.529	0.04696	5.953	0.07284	3.53	0.03704	8.726	0.52789	6.262	0.00021	7.007
7	5.947	0.04238	3.532	0.02716	5.954	0.07408	3.526	0.03983	10.695	0.66527	6.262	0.00051	10.187
8	5.955	0.0432	3.529	0.01902	5.951	0.0506	3.521	0.02151	15.697	0.55176	6.262	0.00021	15.489
9	5.922	0.04259	3.524	0.0173	6.004	0.05449	3.52	0.02647	19.33	0.73618	6.262	0.00021	19.738
10	5.655	0.05663	3.52	0.01371	5.804	0.06141	3.518	0.01212	18.979	0.72629	6.262	0.00021	19.999
11	5.387	0.34309	3.4	0.1575	5.515	0.32837	3.398	0.13724	15.02	2.29463	6.262	0.00021	15.906
12	5.025	0.22806	3.231	0.25892	5.521	0.31953	3.327	0.19106	8.59	2.70036	5.991	0.48751	11.066
13	4.607	0.03544	3.516	0.02453	4.975	0.05492	3.488	0.02446	0.296	0.05409	0.306	0.05065	1.084
14	4.014	0.05163	3.519	0.01989	4.584	0.0413	3.489	0.02286	0.274	0.04226	0.284	0.03224	0.28
15	3.867	0.03109	3.52	0.00243	3.843	0.03106	3.496	0.00197	0.253	0.02634	0.273	0.00524	0.329

NUM	SDPSGBH	DPSGBL	SDPSGBL	DPPUA	SDPPUA	DPPUB	SDPPUB	LCLA	SLCLA	LCLB	SLCLB	LHLA	SLHLA
1	0.03646	1.598	0.00744	2.581	0.09628	2.566	0.06241	0.205	0.00232	0.205	0.00229	0.205	0.00252
3	0.2443	0.222	0.23518	3.732	0.15811	3.897	0.16398	0.206	0.00198	0.205	0.00242	0.158	0.0072
4	0.37544	0.77	0.36466	4.276	0.27017	3.737	0.21968	0.205	0.00227	0.205	0.00243	0.153	0.00804
5	0.35552	3.965	0.35518	4.126	0.26475	3.446	0.26436	0.206	0.00177	0.204	0.00239	0.143	0.02313
6	0.4747	6.733	0.22525	3.644	0.2881	3.571	0.25662	0.202	0.00584	0.204	0.0024	0.09	0.02016
7	0.62549	6.861	0.00158	3.902	0.40209	3.085	0.25839	0.192	0.00969	0.204	0.00265	0.046	0.01488
8	0.61184	6.862	0.00039	3.398	0.40149	2.523	0.2512	0.179	0.01057	0.188	0.00643	0.033	0.01149
9	0.63167	6.863	0.00012	2.719	0.44306	2.405	0.35173	0.151	0.00973	0.166	0.00961	0.027	0.01414
10	0.79191	6.863	0.00012	3.071	0.3334	2.941	0.41075	0.06	0.01052	0.078	0.01119	0.054	0.02602
11	2.46704	6.862	0.00039	1.655	2.01546	1.909	2.04307	0.015	0.02212	0.019	0.0227	0.06	0.021
12	1.92365	6.862	0.00093	0.658	1.1375	1.372	1.25124	0.004	0.00942	0.01	0.01739	0.063	0.01663
13	0.3719	1.113	0.37085	1.964	0.50156	2.431	0.49468	0.001	0.00149	0.006	0.00727	0.061	0.01841
14	0.04708	0.313	0.03801	2.2	0.25782	2.387	0.34914	0.001	0.00164	0.001	0.00244	0.059	0.01479
15	0.02634	0.346	0.00437	2.398	0.06322	2.714	0.07596	0	0.00069	0.001	0.00101	0	0.00069

NUM	LHLB	SLHLB	THLA	STHLA	THLB	STHLB	TCLA	STCLA	TCLB	STCLB	DPR	SDPR	MPR	SMPR
1	0.205	0.00249	410.039	0.62878	408.924	0.16662	386.619	0.26875	386.839	0.14904	938.933	0.31315	989.82	12.792
3	0.151	0.01082	407.716	0.09937	406.408	0.15369	393.652	0.16016	394.02	0.12272	936.113	0.19506	889.593	0.22098
4	0.123	0.01381	405.895	0.11868	404.617	0.15203	393.411	0.16317	393.295	0.12691	936.174	0.23861	889.702	0.41835
5	0.103	0.01785	404.821	0.12316	403.62	0.14024	393.154	0.15055	393.826	0.15784	936.111	0.27366	890.007	0.38792
6	0.105	0.01987	403.563	0.13026	402.332	0.16689	394.01	0.15162	393.057	0.19639	935.753	0.25815	890.045	0.3947
7	0.098	0.02006	402.011	0.1372	400.849	0.15093	393.98	0.18436	392.581	0.21666	935.483	0.22804	890.319	0.37989
8	0.084	0.02041	400.736	0.11833	399.607	0.14423	393.727	0.30102	393.018	0.26819	935.314	0.27176	890.539	0.42906
9	0.071	0.02226	399.357	0.12179	398.215	0.13069	394.78	0.15312	393.544	0.26323	935.088	0.24405	890.917	0.45303
10	0.066	0.02116	398.358	0.14851	397.288	0.13711	394.055	0.20269	393.994	0.1654	934.959	0.26187	891.037	0.38803
11	0.064	0.02151	397.376	0.29127	396.327	0.26919	394.521	0.85465	394.516	0.8151	934.738	0.2327	891.193	0.36138
12	0.065	0.01534	396.089	0.28794	395.085	0.30054	394.631	0.70879	394.556	0.76598	934.409	0.27712	891.217	0.43055
13	0.065	0.01696	394.415	0.16981	393.39	0.16206	393.606	0.14685	393.563	0.23879	934.349	0.21917	891.65	0.38056
14	0.065	0.01416	393.716	0.10727	392.595	0.15801	392.875	0.12394	392.952	0.14442	934.023	0.20814	891.547	0.32773
15	0.001	0.00111	393.208	0.13042	392.233	0.12409	392.223	0.16169	392.273	0.17378	933.783	0.18291	891.629	0.45299

NUM	Initial Timing	End Timing	Cpower	Scpower	Tmass	Mass(w/oPzr)	%Mass(w/oPzr)	DPTMass	PUP	SPUP	PSGA
1	4000	4200	0.933	0.00218	7325	6334.9	100	7505	0.319	0.00287	0.125
3	7500	7700	0.934	0.00284	6651.9	5762.3	90.96	6685	0.289	0.00025	0.139
4	9000	9300	0.934	0.00259	6315	5425.4	85.643	6482	0.274	0.0003	0.136
5	10600	10850	0.934	0.00195	5977.8	5087.8	80.313	6014	0.266	0.00048	0.134
6	12200	12600	0.935	0.00195	5640.7	4750.6	74.991	5620	0.256	0.00049	0.137
7	13800	14900	0.935	0.00193	5304.3	4414.1	69.679	5244	0.245	0.00056	0.141
8	16000	16650	0.935	0.0018	4966.6	4076.2	64.344	4869	0.235	0.0006	0.141
9	18000	18550	0.935	0.00176	4630.1	3739.2	59.025	4553	0.225	0.00056	0.14
10	19600	20000	0.935	0.00177	4288.1	3397.1	53.625	4278	0.219	0.00056	0.136
11	21000	21650	0.934	0.00183	3951.3	3060.1	48.306	3927	0.212	0.00183	0.136
12	22800	23600	0.935	0.00206	3621.4	2730.2	43.098	3628	0.204	0.00178	0.136
13	25000	25300	0.935	0.00152	3277.7	2386	37.665	3258	0.193	0.00052	0.136
14	26600	26900	0.935	0.00168	2948.8	2057.3	32.476	2920	0.188	0.00039	0.138
15	28440	28550	0.935	0.00185	2611.6	1720	27.151	2562	0.185	0.00025	0.135
					2449.9						

NUM	SPSGA	PSGB	SPSGB	LSGA	SLSGA	LSGB	SLSGB	TFWA	STFWA	TFWB	STFWB	WFWA	SWFWA
1	0.00067	0.13	0.00024	12.66	0.04985	12.214	0.04167	324.392	1.35213	361.416	0.45148	0.572	0.00358
3	0.0006	0.141	0.00059	12.628	0.03768	12.321	0.03925	368.136	0.92116	366.618	0.79404	-0.046	0.01912
4	0.00035	0.135	0.00022	12.379	0.03939	12.349	0.04097	371.389	0.7399	371.32	0.20563	0.144	0.28944
5	0.00035	0.135	0.00055	12.438	0.03817	12.275	0.04005	367.378	0.74194	367.551	0.34903	0.017	0.20745
6	0.00062	0.131	0.00034	12.376	0.04768	12.392	0.03235	364.573	0.582	365.218	0.21649	0.066	0.26577
7	0.00118	0.129	0.00059	12.438	0.05942	12.396	0.03718	362.531	0.95299	362.921	0.36845	0.212	0.32328
8	0.00059	0.129	0.00041	12.431	0.06695	12.464	0.04637	361.333	0.83093	361.178	0.41097	0.297	0.31945
9	0.0007	0.131	0.0005	12.325	0.06209	12.36	0.04714	359.56	0.82465	359.733	0.24676	0.149	0.31485
10	0.0006	0.134	0.00054	12.442	0.05138	12.384	0.0451	359.374	0.84505	359.165	0.37923	0.132	0.31315
11	0.00074	0.133	0.00062	12.401	0.05363	12.435	0.0406	359.157	0.78451	359.846	0.20979	0.093	0.29586
12	0.00085	0.134	0.0009	12.491	0.07128	12.323	0.05404	358.76	0.86468	359.404	0.32546	0.043	0.26628
13	0.00071	0.134	0.00064	12.403	0.06147	12.42	0.0473	359.659	0.55557	359.667	0.21494	0.372	0.29494
14	0.00078	0.134	0.00077	12.338	0.05759	12.348	0.05258	358.702	0.79578	359.045	0.24374	0.386	0.28574
15	0.0006	0.136	0.00041	12.427	0.04591	12.301	0.03883	359.165	0.28286	358.847	0.17002	0.558	0.00275

NUM	WFWB	SWFWB	WMSLA	SWMSLA	WMSLB	SWMSLB	CWSGA	SCWSGA	CWSGB	SCWSGB	BUPL1.LTU	SBUPL1.LTU
1	0.069	0.01292	0.148	0.00449	0.181	0.00222	0.18889	0.0007213	0.201401	0.0004584	10.873	0.00408
3	0.204	0.18355	0.135	0.00672	0.181	0.0031	0.203777	0.0007867	0.203164	0.000595	0.424	0.06645
4	0.138	0.04107	0.199	0.0016	0.194	0.00135	0.205063	0.0007038	0.205074	0.0005723	0.237	0.07992
5	0.202	0.15406	0.186	0.00189	0.201	0.00236	0.203685	0.0005115	0.203704	0.0004668	0.593	0.11584
6	0.201	0.00538	0.205	0.00253	0.178	0.00163	0.20265	0.0004769	0.203053	0.0004406	0.884	0.11878
7	0.231	0.00629	0.227	0.00609	0.161	0.00243	0.201865	0.0005469	0.202376	0.0004353	1.21	0.15238
8	0.173	0.03937	0.224	0.00216	0.163	0.00188	0.201395	0.0004916	0.201684	0.0004084	1.704	0.14329
9	0.169	0.04132	0.217	0.0038	0.177	0.00214	0.200815	0.000532	0.201112	0.0003874	2.067	0.12054
10	0.157	0.00525	0.199	0.00234	0.188	0.00273	0.200752	0.0004998	0.200746	0.0004387	2.026	0.13709
11	0.274	0.03397	0.198	0.00335	0.188	0.00229	0.200691	0.0004591	0.201013	0.0003915	1.65	0.30903
12	0.313	0.0636	0.199	0.00417	0.191	0.00347	0.200619	0.0005318	0.200912	0.0004734	1.029	0.21497
13	0.355	0.02608	0.201	0.0028	0.19	0.00173	0.200976	0.0003492	0.201058	0.0003227	-0.05	0.04696
14	0.453	0.05542	0.209	0.00392	0.189	0.00143	0.200483	0.0004005	0.200717	0.000357	-0.134	0.02012
15	0.363	0.00413	0.195	0.00164	0.2	0.00099	0.200758	0.0004281	0.200625	0.0004007	-0.133	0.00025

NUM	BUPM1.LTU	SBUPM1.LTU	BUPS1.LTU	SBUPS1.LTU	BUPL2.LTU	SBUPL2.LTU	BUPM2.LTU	SBUPM2.LTU	BUPS2.LTU	SBUPS2.LTU
1	9.988	0.01236	9.423	0.01068	10.964	0.00813	10.03	0.01181	8.935	0.0003
3	8.698	0.07495	7.222	0.08427	7.943	0.0715	9.614	0.07915	7.8	0.0934
4	8.298	0.11982	6.511	0.12222	7.142	0.12286	9.447	0.11541	7.474	0.13224
5	7.841	0.13128	5.916	0.14957	6.192	0.14301	9.259	0.13504	7.203	0.13756
6	7.176	0.14505	5.303	0.14885	5.362	0.13999	8.916	0.14554	6.762	0.16528
7	6.207	0.16953	4.524	0.17037	4.408	0.14972	8.175	0.15327	6.091	0.18175
8	4.923	0.13387	3.502	0.14803	3.043	0.12719	7.024	0.13111	4.96	0.16054
9	2.475	0.1739	2.46	0.27186	2.165	0.12677	4.726	0.12874	3.262	0.16984
10	1.797	0.12976	2.083	0.1395	2.016	0.13551	1.837	0.11157	2.11	0.13971
11	1.349	0.28051	1.636	0.27642	1.581	0.26746	1.411	0.27124	1.667	0.26638
12	0.806	0.21844	1.09	0.21537	1.011	0.21464	0.869	0.21671	1.144	0.20275
13	-0.274	0.04916	0.015	0.04665	-0.066	0.04543	-0.204	0.04614	0.096	0.04438
14	-0.365	0.02121	-0.072	0.02195	-0.151	0.02135	-0.29	0.02259	0.016	0.0209
15	-0.359	0.00764	-0.076	0.01018	-0.149	0.01306	-0.281	0.0088	0.025	0.00344

NUM	BDwnL1.LTU	SBDwnL1.LTU	BDwnM1.LTU	SBDwnM1.LTU	BDwnS1.LTU	SBDwnS1.LTU	BDwnL2.LTU	SBDwnL2.LTU	BDwnM2.LTU
1	10.654	0.00095	9.8	0.00106	9.274	0.01351	10.71	0.00685	9.776
3	0.408	0.07909	8.685	0.06286	7.23	0.0683	7.893	0.06632	9.572
4	0.159	0.08184	8.223	0.07368	6.452	0.08684	7.022	0.08427	9.325
5	0.175	0.10363	7.428	0.09289	5.518	0.11599	5.717	0.09226	8.788
6	0.134	0.15047	6.431	0.09991	4.571	0.11786	4.547	0.10171	8.104
7	0.127	0.16015	5.129	0.13803	3.462	0.1387	3.251	0.11807	7.02
8	0.049	0.13368	3.277	0.08516	1.876	0.11369	1.31	0.08709	5.291
9	-0.053	0.07796	0.366	0.14783	0.369	0.26555	-0.046	0.08234	2.519
10	-0.118	0.09191	-0.339	0.06947	-0.034	0.07661	-0.228	0.07247	-0.399
11	-0.05	0.14751	-0.344	0.0499	-0.038	0.07091	-0.225	0.10321	-0.388
12	-0.144	0.02714	-0.355	0.02813	-0.055	0.02621	-0.273	0.0268	-0.406
13	-0.142	0.018	-0.355	0.01612	-0.052	0.01662	-0.28	0.01576	-0.409
14	-0.138	0.01787	-0.356	0.01755	-0.051	0.0163	-0.279	0.01637	-0.41
15	-0.129	0.00348	-0.355	0.00037	-0.045	0.00823	-0.289	0.00818	-0.408

NUM	SBDwnM2.LTU	BDwnS2.LTU	SBDwnS2.LTU
1	0.01039	9.248	0.00963
3	0.07163	8.207	0.09362
4	0.07331	7.788	0.10043
5	0.09227	7.158	0.11358
6	0.10757	6.346	0.13862
7	0.1086	5.265	0.15849
8	0.07826	3.409	0.13784
9	0.07677	1.175	0.15615
10	0.03048	-0.053	0.08415
11	0.06224	-0.069	0.11104
12	0.02765	-0.084	0.04016
13	0.01527	-0.095	0.01621
14	0.01738	-0.092	0.01635
15	0.00045	-0.096	0.00027

NUM	Initial Timing	End Timing	%Mass(w/oPzr)	LDC	SLDC	WGCORE	SWGCORE	RJGSHL	SRJGSHL	RJGSTU	SRJGSTU
1	4000	4200	100	8.6243	0.01384	0.050043	0.0059021	0.0259	0.0031332	9.3883	1.1357
2	5100	5800	98.209	8.5919	0.023263	0.1102	0.08719	0.056819	0.045265	20.596	16.408
3	7500	7700	90.96	8.5781	0.02108	0.10273	0.0092664	0.055583	0.0050102	20.148	1.8161
4	9000	9300	85.643	8.5749	0.018854	0.1338	0.011924	0.074164	0.0066201	26.883	2.3997
5	10600	10850	80.313	8.0596	0.051585	0.18412	0.011158	0.10351	0.0062906	37.521	2.2802
6	12200	12600	74.991	7.3848	0.024465	0.23675	0.01084	0.13534	0.006223	49.059	2.2557
7	13800	14900	69.679	7.3707	0.020016	0.28163	0.0095047	0.16438	0.0055833	59.584	2.0238
8	16000	16650	64.344	7.3567	0.028697	0.34373	0.0080425	0.20417	0.0047649	74.01	1.7272
9	18000	18550	59.025	7.3322	0.035558	0.38245	0.0068178	0.23169	0.0041458	83.985	1.5028
10	19600	20000	53.625	7.2534	0.025573	0.40028	0.0068683	0.24584	0.0042409	89.111	1.5373
11	21000	21650	48.306	6.4064	0.52983	0.42247	0.0060138	0.26295	0.003562	95.317	1.2911
12	22800	23600	43.098	5.3302	0.39696	0.42467	0.00096162	0.26919	0.0010123	97.571	0.36698
13	25000	25300	37.665	4.9071	0.051202	0.42403	0.00064666	0.27536	0.00053359	99.813	0.19342
14	26600	26900	32.476	4.8244	0.036585	0.42346	0.0007031	0.27823	0.00051703	100.85	0.18741
15	28440	28550	27.151	4.3713	0.021007	0.42328	0.00078233	0.28038	0.00058212	101.63	0.21101

Nomenclature

NUM : steady state number
Initial Timing : initial timing for a steady state
End Timing : end timing
%Mass(w/oPzr) : mass inventory w/o pressurizer mass
LDC : Downcomer collapsed liquid level (L for liquid level, DC for downcomer)
SLDC : Standard deviation in averaging LDC (S for standard deviation)
WGCORE : Core outlet vapor flow rate (W for flow rate in kg/s, G for vapor)
JGSHL : vapor volumetric flow rate (superficial vapor velocity)in the hot leg (J superficial vel. for HL for hot leg)
RJGSHL : Root JG star in HL (root of modified Froude number or wallis parameter)
JGSTU : TU for U-tubes
PUP : Pressure in upper plenum (UP)
PSGA : SG-A secondary side
PSGB : SG-B
TSUP : saturation temp. in UP (TS for sat. temp)
TSGA : SG-A (steam line or saturated) temp.
DENL1 : saturated liquid density in primary loop (DEN for density, L for liquid, 1 for primary loop)
DENL2A : 2A for SG-A secondary side
LSGA : SG-A liquid level
WAH : A loop flow rate measured with high range flowmeter (W for flowrate, H for high range flowmeter)
WAL : L for low range flowmeter
MST : Mass inventory in storage tank(ST) (all the discharged mass from the primary accumulats in the ST tank)
QCORE : Core power
LPR : PR for pressurizer
LUPCore: UPCore for upper plenum + core
DPPV : Differential pressure (DP) between bottom and top of Pressure vessel (PV)
LLSAD : Liquid level in loop seal (LS) in loop A (A) downflow side(D)
LLSAU : Liquid level in loop seal (LS) in loop A (A) upflow side(D)
DPPUA : DP across the pump (PU) in loop A (A)
LCLA : Liquid level in cold leg (CL) A (A)
LHLA : HL for hot leg
THLA : Temperature (T) in hot leg (HL) A (A)

DPR : Differential pressure (D) in pressurizer (PR)
(this should have been DPPR according to the naming convention)
MPR : M for mass
DP(PUP-P2A) : DP between upper plenum and SG-A secondary side
TFWA : Temperature (T) in feed water (FW) line in SG-A (A)
WFWA : Flow rate (W) in feed water (FW) line in SG-A (A)
WMSLA : Flow rate (W) in main steam line (MSL) in SG-A(A)
LTUAL1 : Liquid level (L) in the up flow side of U-tube (TU) in SG-A(A):
(L1 for one of the longest measured tube)
LTUAM1 : M1 for one of the medium length measured tube
SLTUAS1: S1 for one of the shortest
SLTUAL2: L2 for the other longest U-tube
DPSGAL1: DP between the inlet and top for SG-A U-tube L1
DPSGAM1M : ? M modified? (maybe bottom elevation adjusted)

CWSGA,B : are the main steam line flow rate calculated based on the SG secondary side energy balance.
CWSG=0.5*core power/(hout-hin)
hout: main steam line enthalpy
hin: feed water enthalpy

Appendix 3

Boundary condition data

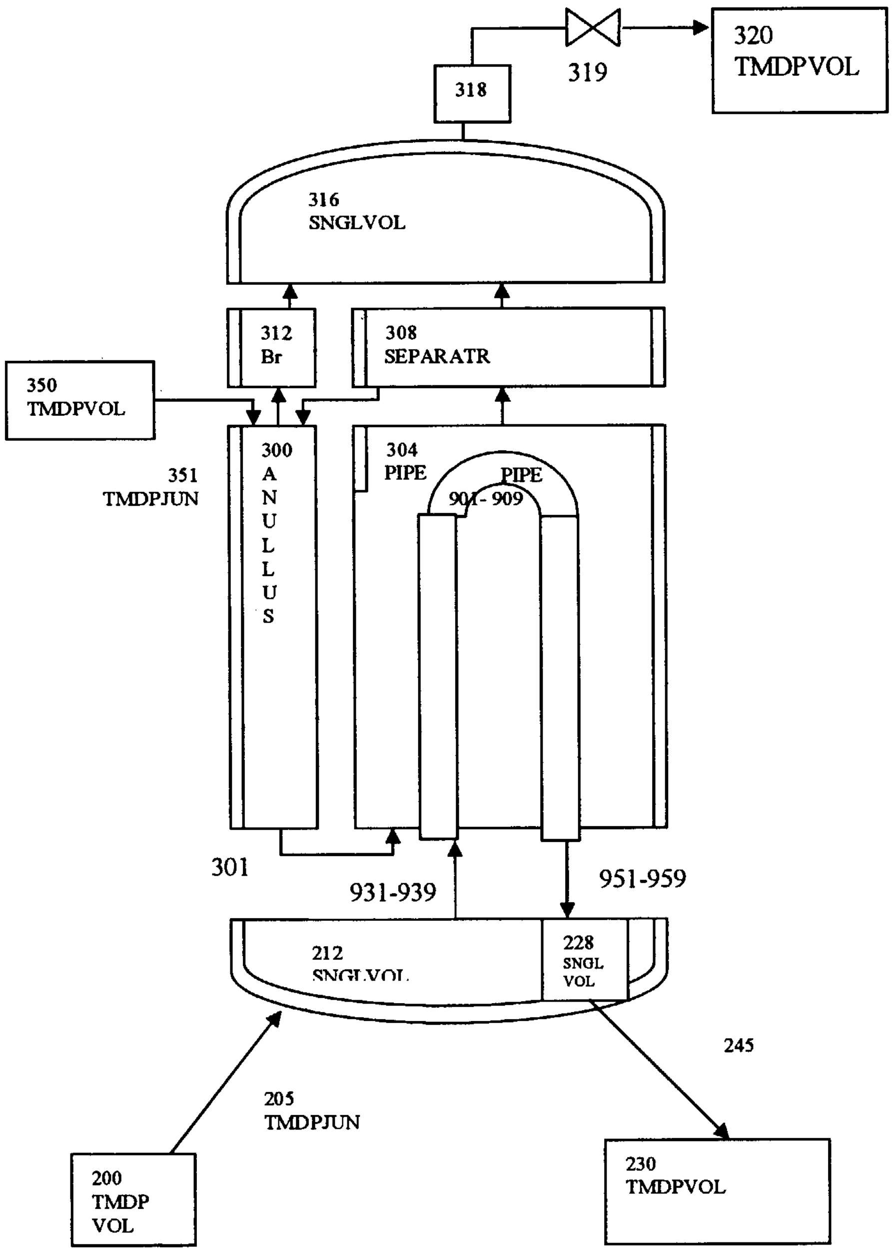


Figure A.3.1. Noding diagram of steam generator

Table A.3.1. Data of boundary condition

Model No.	**Parameters**	**HP**		**LP**	
		100% inventory	73% inventory	100% inventory	75% inventory
200	Temperature Pressure Quality	576.52 K 12.313 MPa -	558.81 K - 0.04723	408.924 K - 0.0053522	402.332 K - 0.01663
205	Liquid flow Vapor flow	5.808 kg/s -	8.859825 kg/s 0.439175 kg/s	4.6499785 kg/s 0.0250215 kg/s	6.998625 kg/s 0.118375 kg/s
230	Temperature Pressure Quality	555.8 K 12.313 MPa -	558.04 K 7.02628 MPa	386.839 K 0.319 MPa -	393.057 K 0.243586 MPa
350	Temperature Pressure Quality	486.27 K - 0	492.71 K - 0	361.416 K - 0	365.218 K - 0
320	Temperature Pressure Quality	555.99 K - 1.0	555.9 K 1.0	380.288 K - 1.0	- 0.131 MPa 1.0
Trip Logic	SG Water Level	9.557 m	9.595 m	12.214 m	12.392 m

Appendix 4

4.1. Result of 100% of mass inventory HP calculation using single tube model

Figure A.4.1.1 Heat transfer rate in U-tube

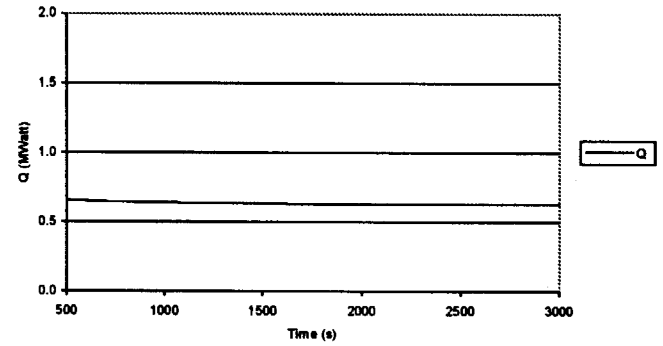


Figure A.4.1.2. Secondary side temperature distribution

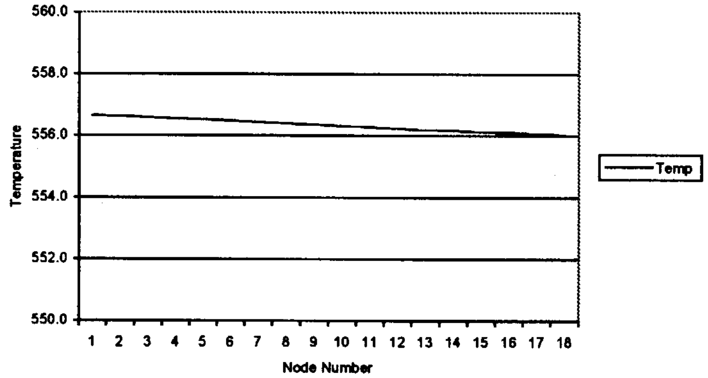


Figure A.4.1.3. Differential pressure

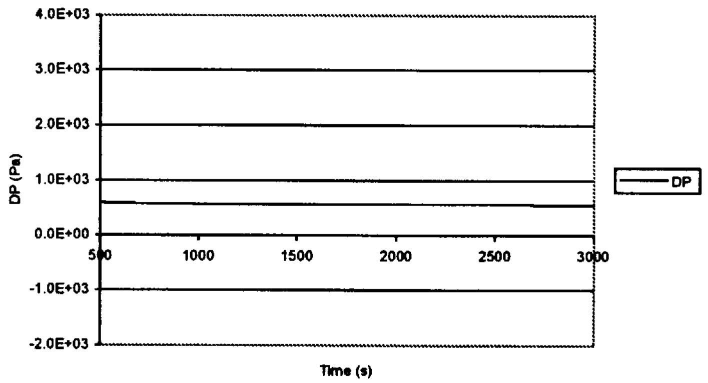
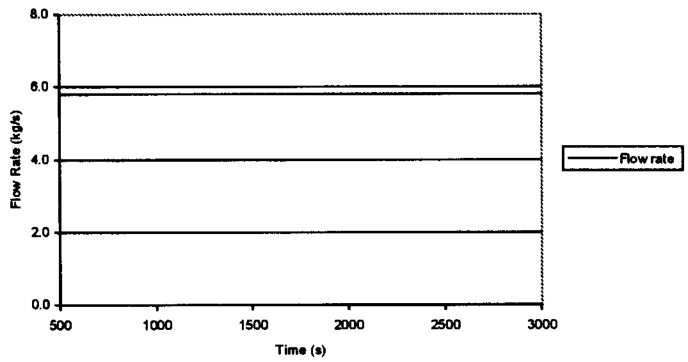


Figure A.4.1.4. U-tube flow



4.2. Result of 73% of mass inventory HP calculation using single tube model

Figure A.4.2.1. Heat transfer rate in U-tube

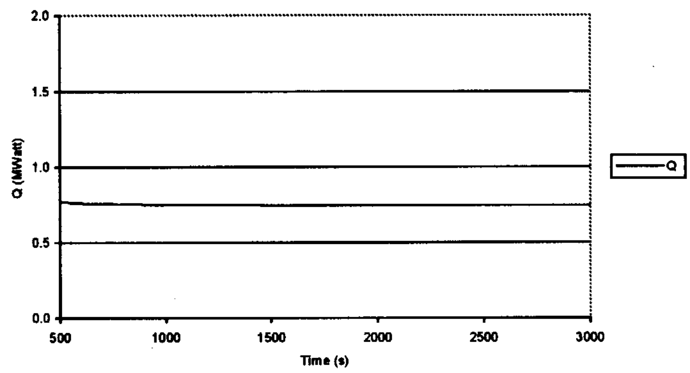


Figure A.4.2.2. Secondary side temperature distribution

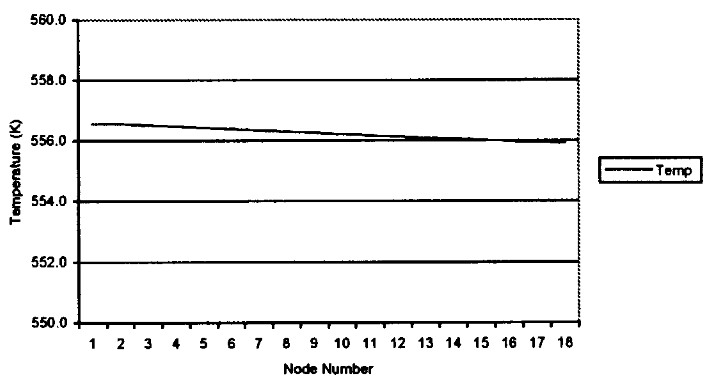


Figure A.4.2.3. U-tube flow

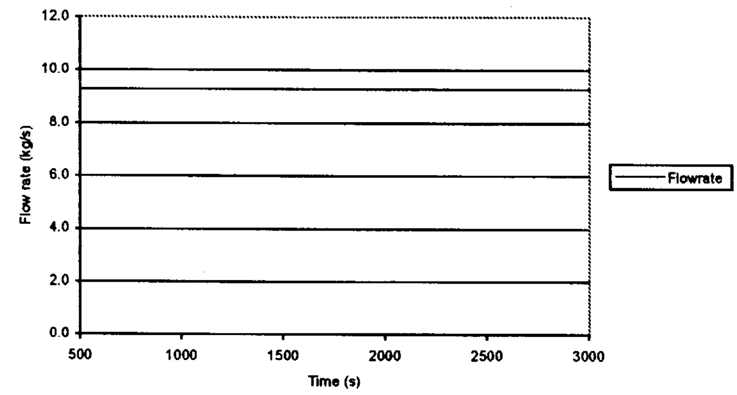
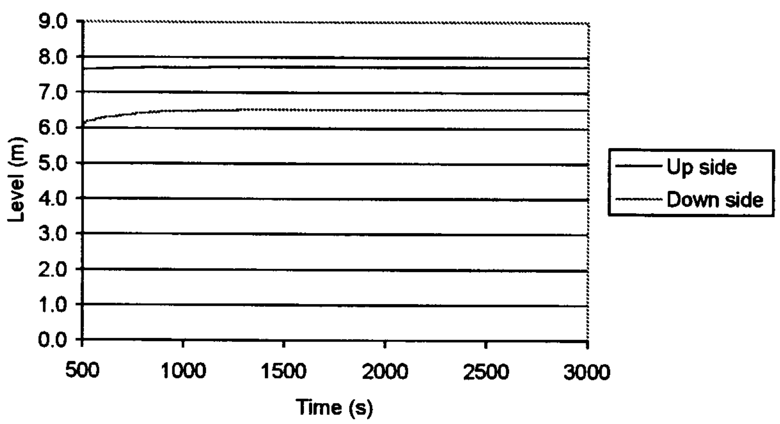


Figure A.4.2.4. U-tube collapsed liquid level



4.3. Result of 100% of mass inventory LP calculation using single tube model

Figure A.4.3.1. Heat transfer rate in U-tube

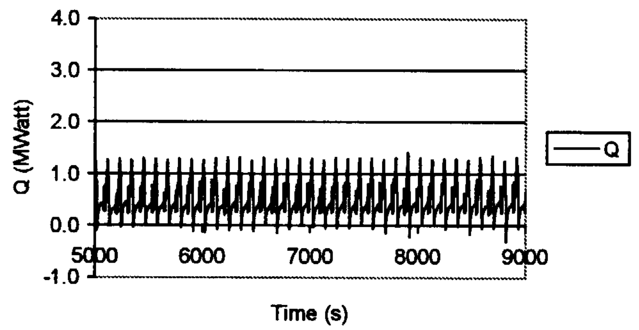


Figure A.4.3.2. Differential pressure

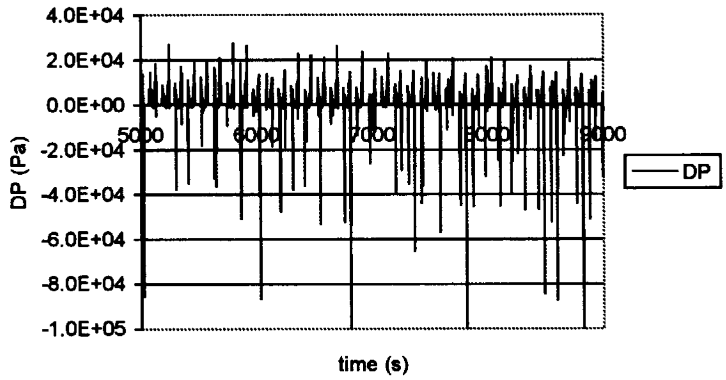


Figure A.4.3.3. U-tube flow rate

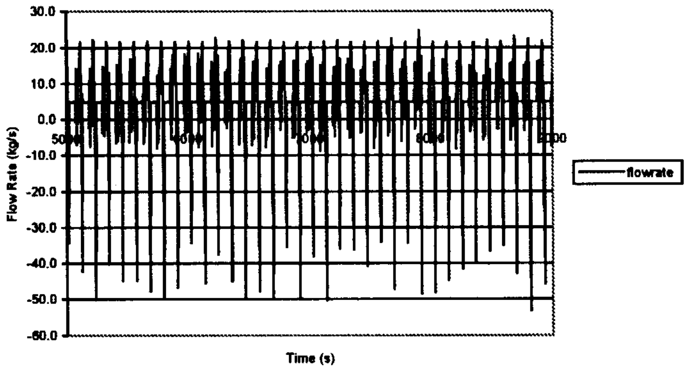
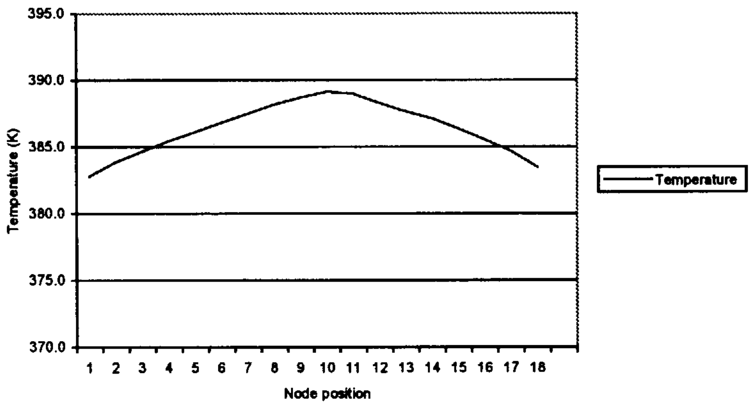


Figure A.4.3.4. Secondary side temperature distribution



4.4. Result of 75% of mass inventory LP calculation using single tube model

Figure A.4.4.1. Heat transfer rate in U-tube

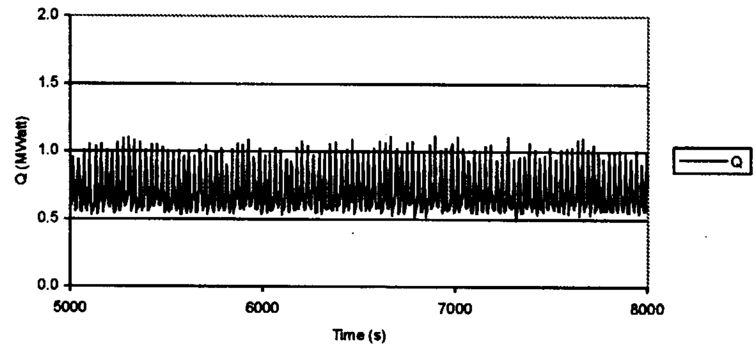


Figure A.4.4.2. U-tube flow

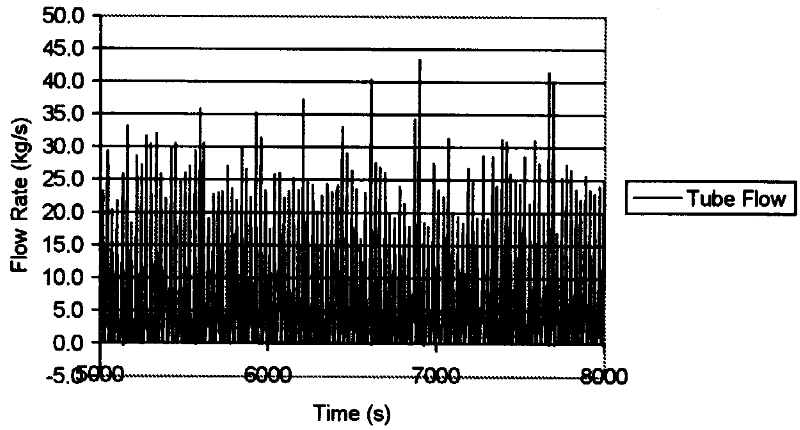
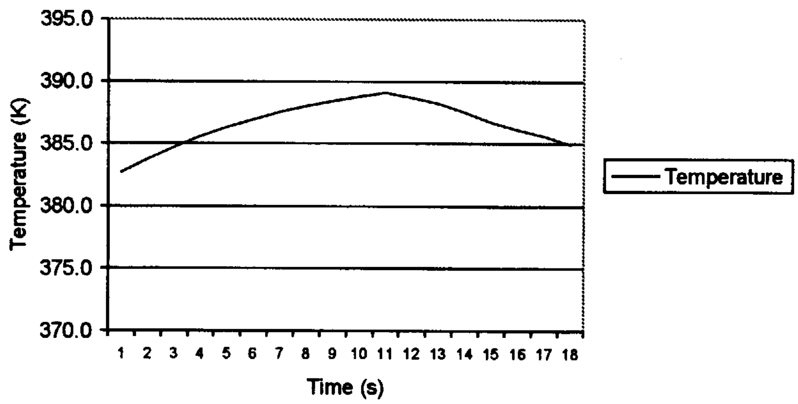


Figure A.4.4.3. Secondary side temperature distribution



4.5. Result of 100% of mass inventory HP calculation using 9 tube model

4.5.1. Uniform Forward Flow.

Figure A.4.5.1.1. Heat transfer rate in U-tube

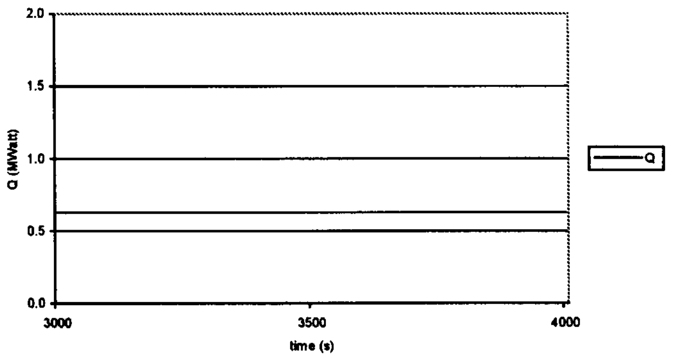


Figure A.4.5.1.2. Tube flow

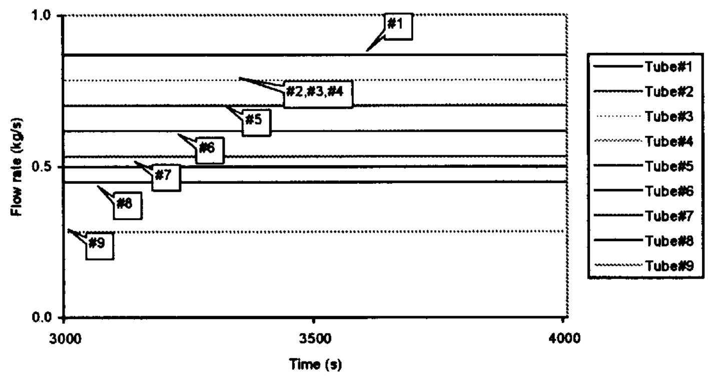


Figure A.4.5.1.3. Secondary side temperature distribution

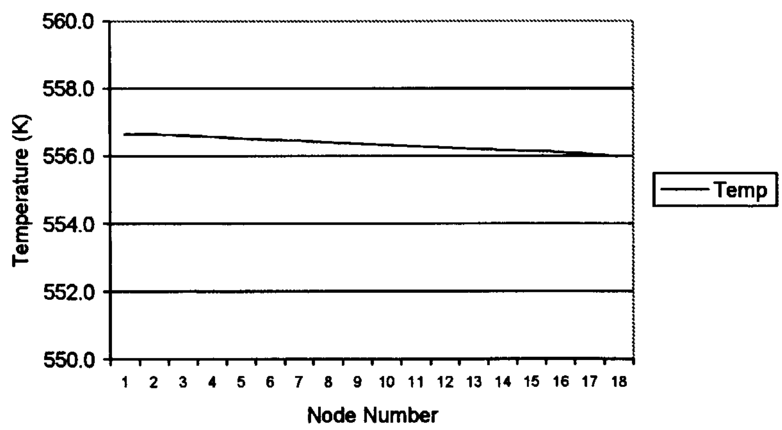
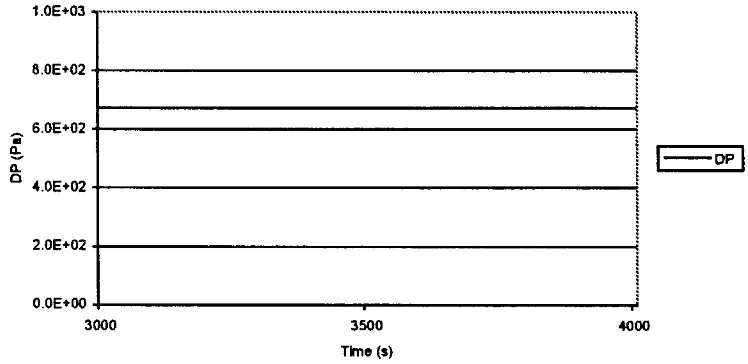


Figure A.4.5.1.4. Differential pressure



4.5.2. Short Tube Flow Reverses

Figure A.4.5.2.1. Heat transfer rate in U-tube

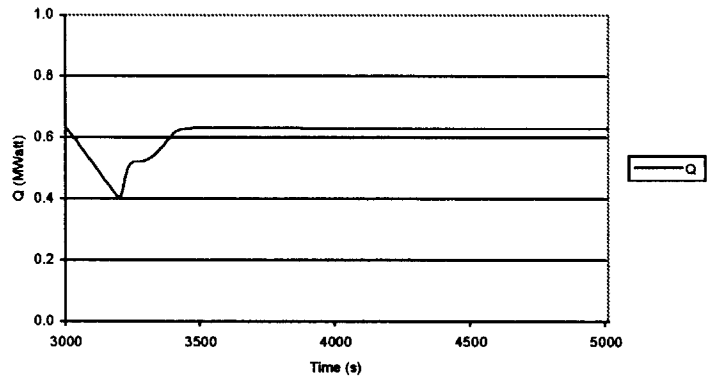


Figure A.4.5.2.2. Inlet flow

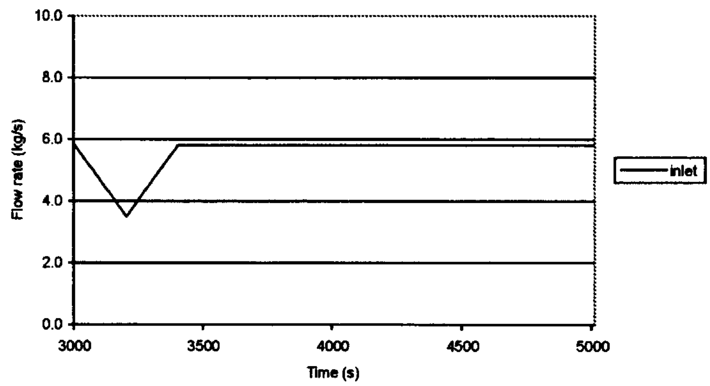


Figure A.4.5.2.3. Tube flow

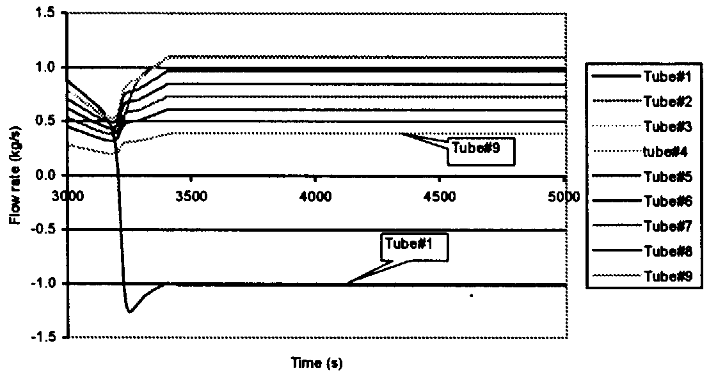
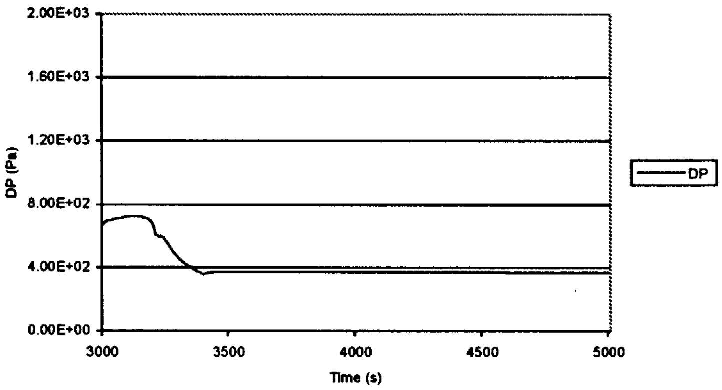


Figure A.4.5.2.4. Differential pressure



4.5.3. Long Tube Flow Reverses

Figure A.4.5.3.1. Heat transfer rate in U-tube

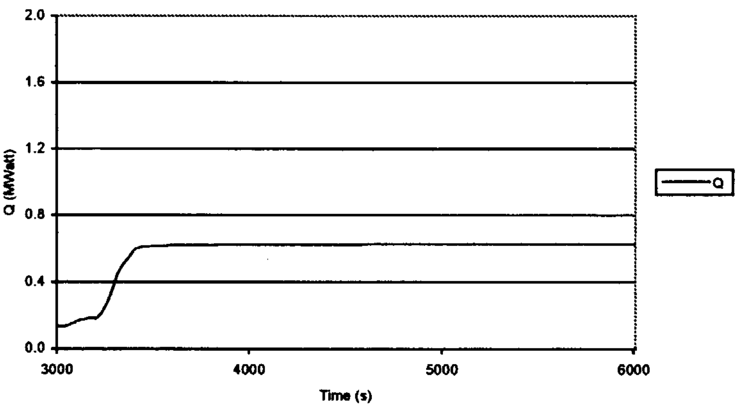


Figure A.4.5.3.2. Inlet flow

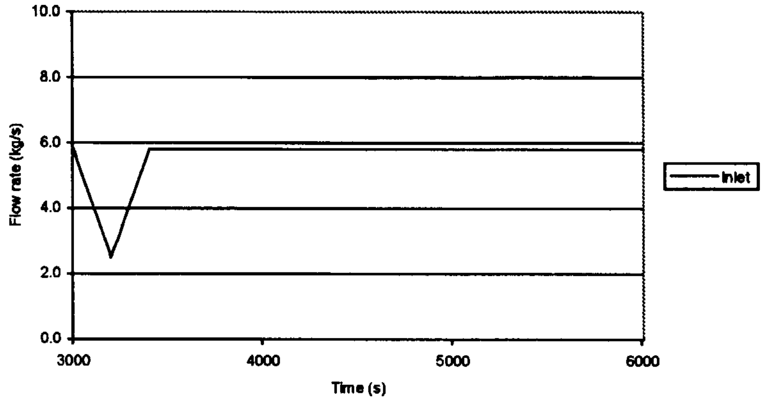


Figure A.4.5.3.3. U-tube flow

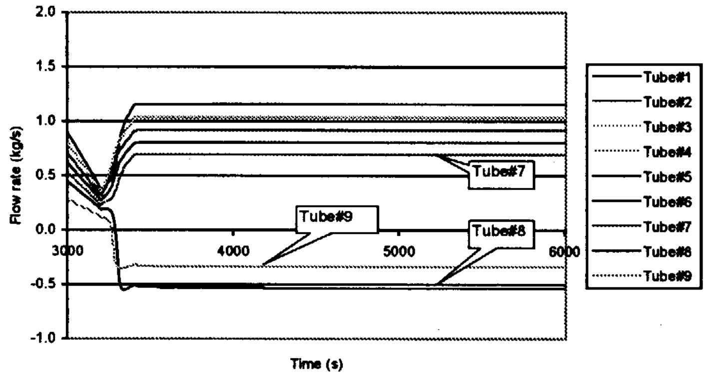


Figure A.4.5.3.4. Differential pressure

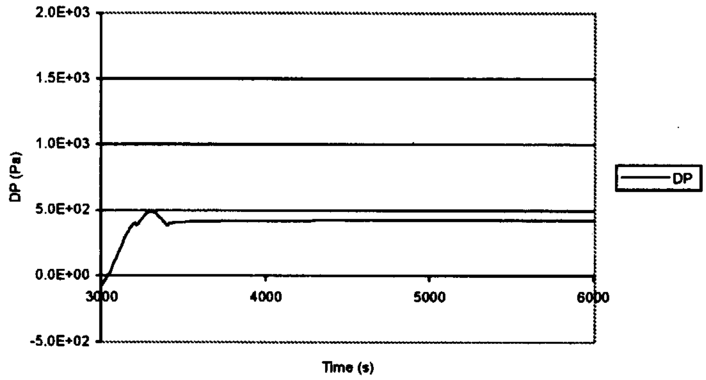
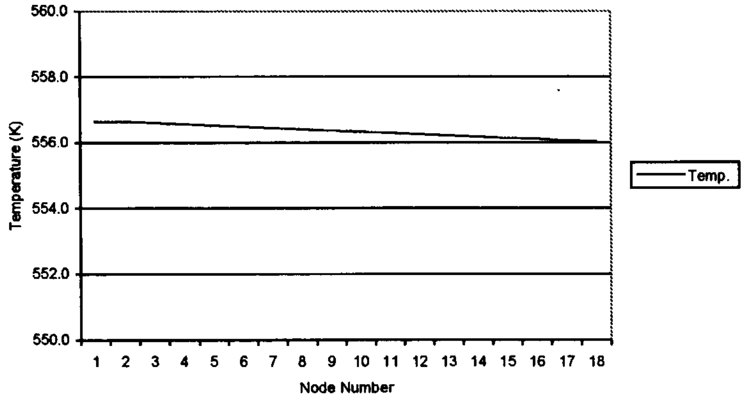


Figure A.4.5.3.5. Secondary side temperature distribution



4.6. Result of 73% of mass inventory HP calculation using 9 tube model

Figure A.4.6.1. Heat transfere rate in U-tube

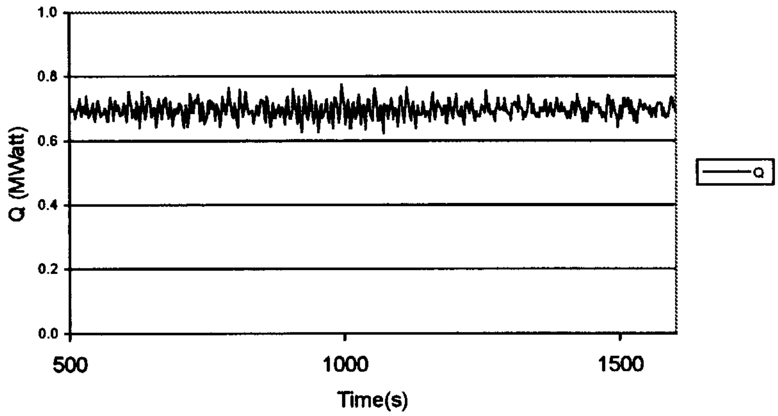


Figure A.4.6.2. Outlet flow

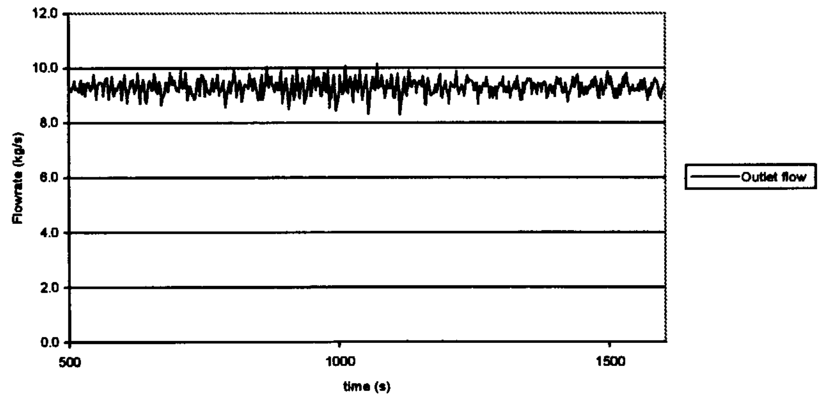


Figure A.4.6.3. Tube#1 flow

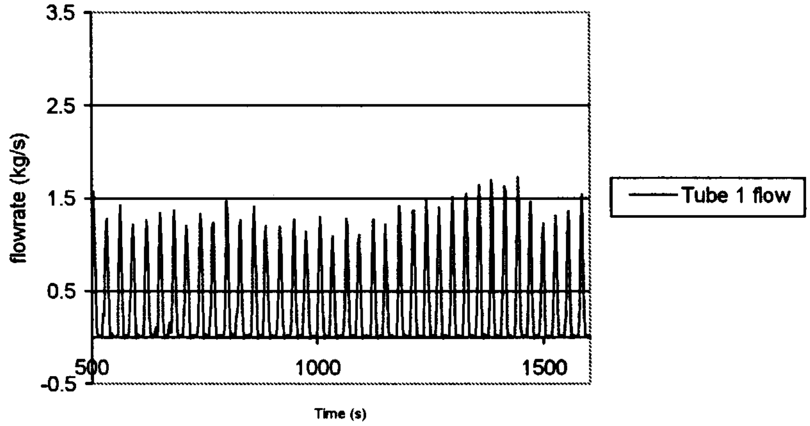


Figure A.4.6.4. Tube#2 flow

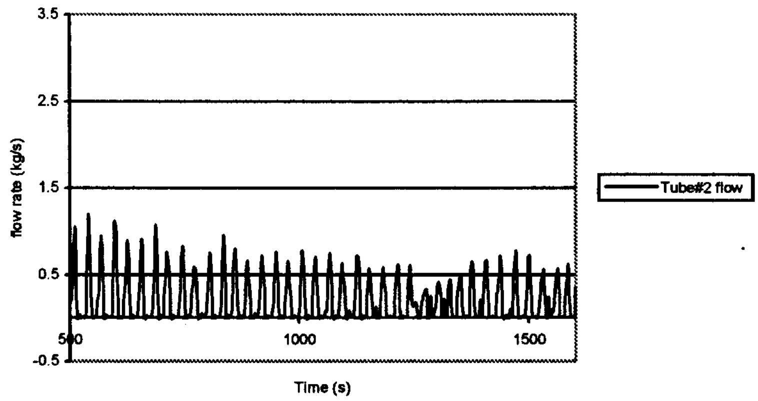


Figure A.4.6.5. Tube#3 flow

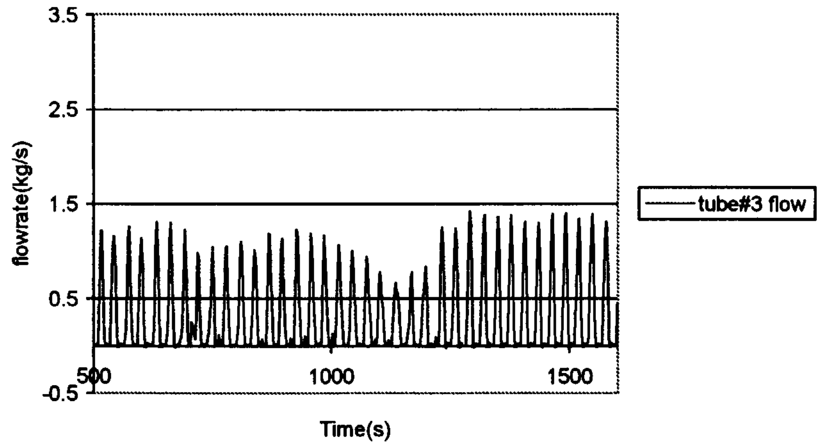


Figure A.4.6.6. Tube#4 flow

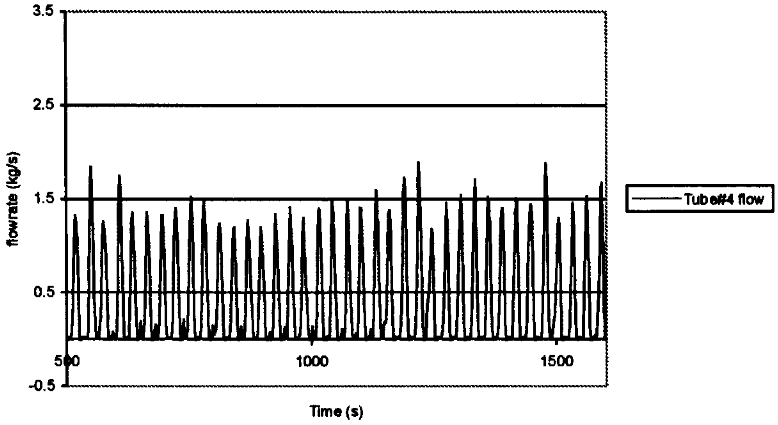


Figure A.4.6.7. Tube#5 flow

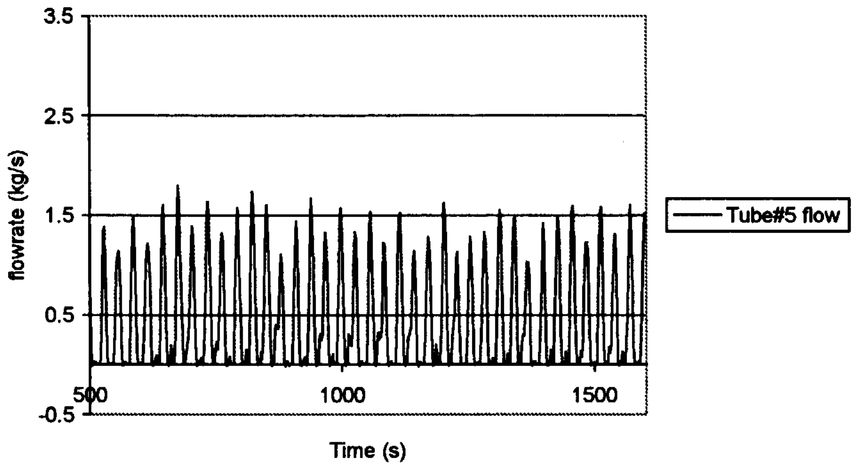


Figure A.4.6.8. Tube#6 to Tube#9 flow

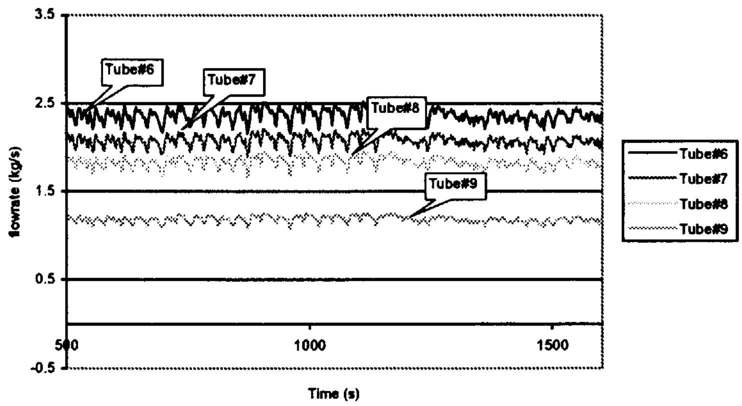


Figure A.4.6.9. Differential pressure (P out - P in)

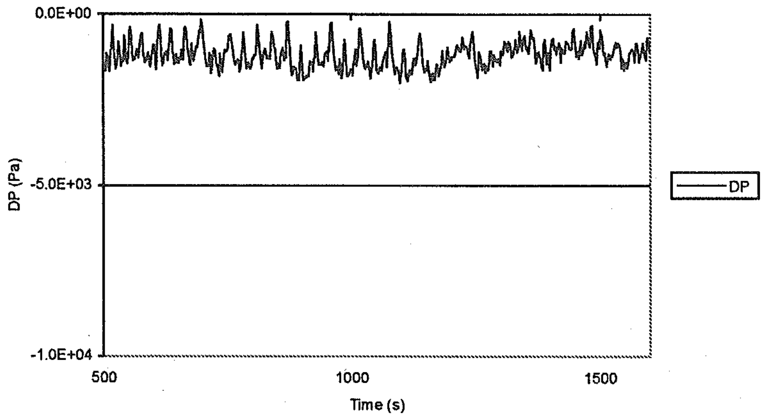


Figure A.4.6.10. Tube collapsed level (Up side)

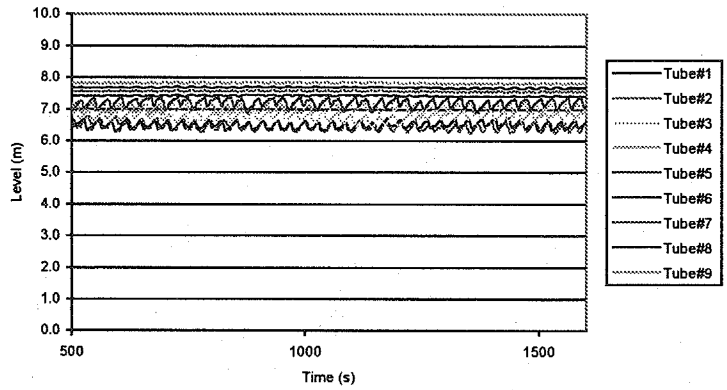
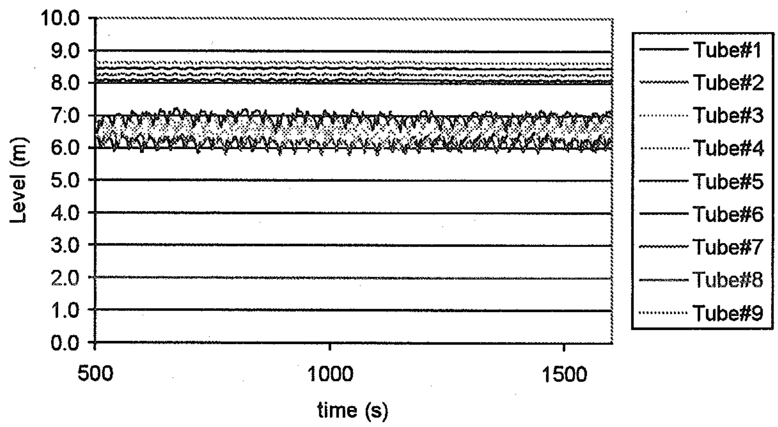


Figure A.4.6.11. Tube collapsed level (down side)



4.7. Result of 100% of mass inventory LP calculation using 9 tube model

Figure A.4.7.1. Heat transfer rate in U-tube

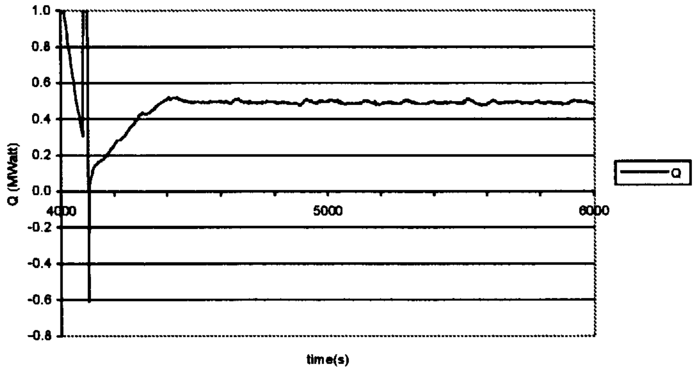


Figure A.4.7.2. U-tube flow

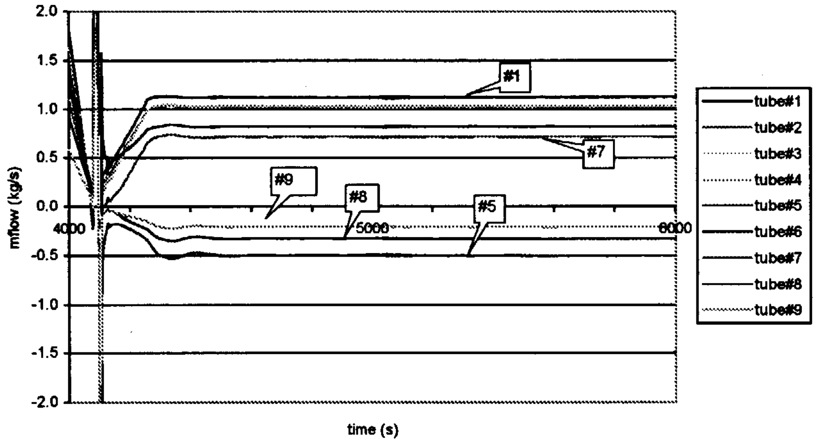


Figure A.4.7.3. Secondary side temperature distribution

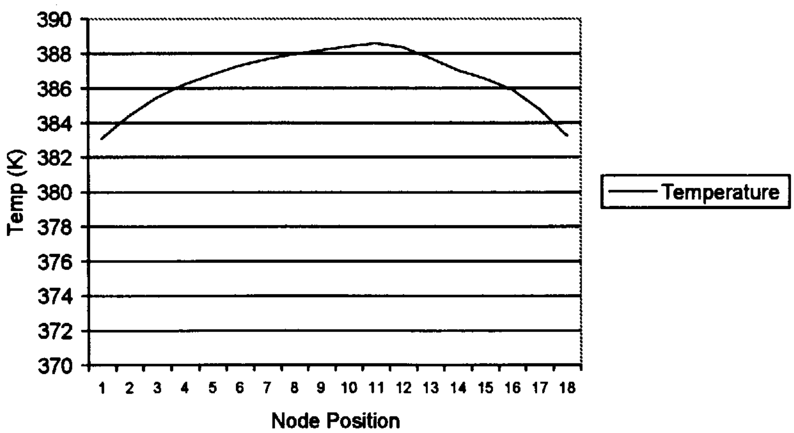
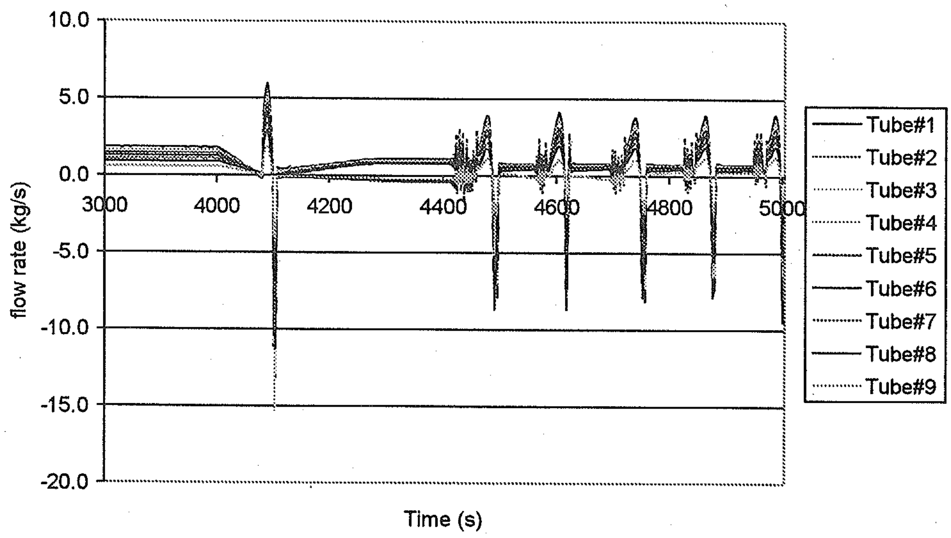


Figure A.4.7.4. Instability in U-tube flow



4.8. Result of 75% of mass inventory LP calculation using 9 tube model

Figure A.4.8.1. Heat transfer rate in U-tube

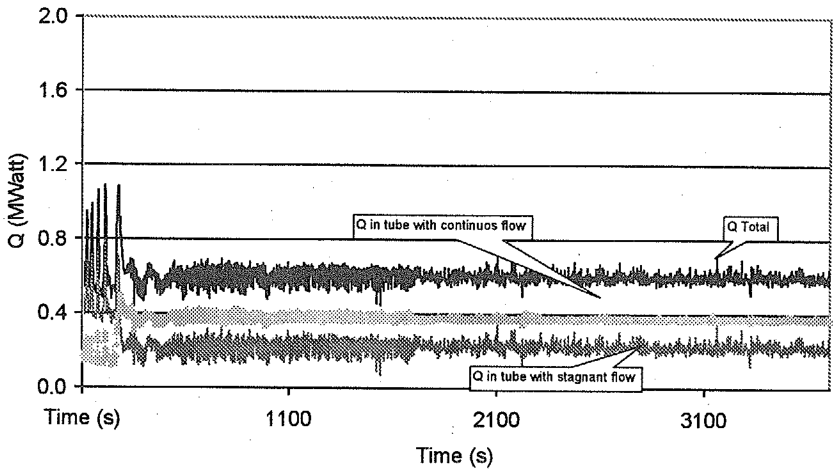


Figure A.4.8.2. Outlet flow

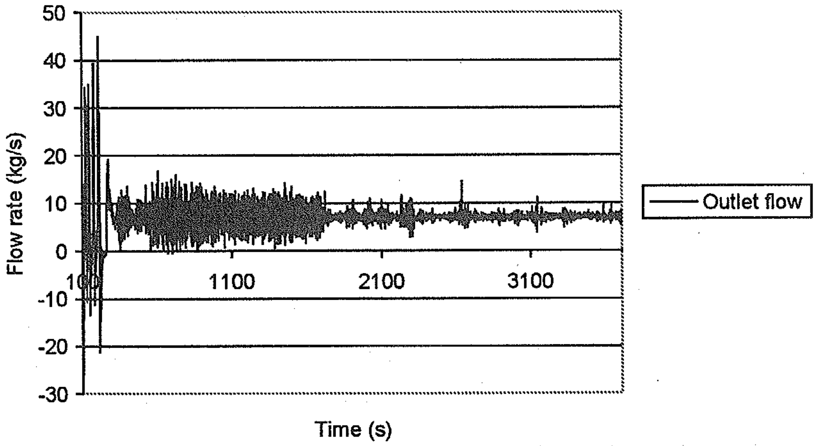


Figure A.4.8.3. Differential pressure (P out - P in)

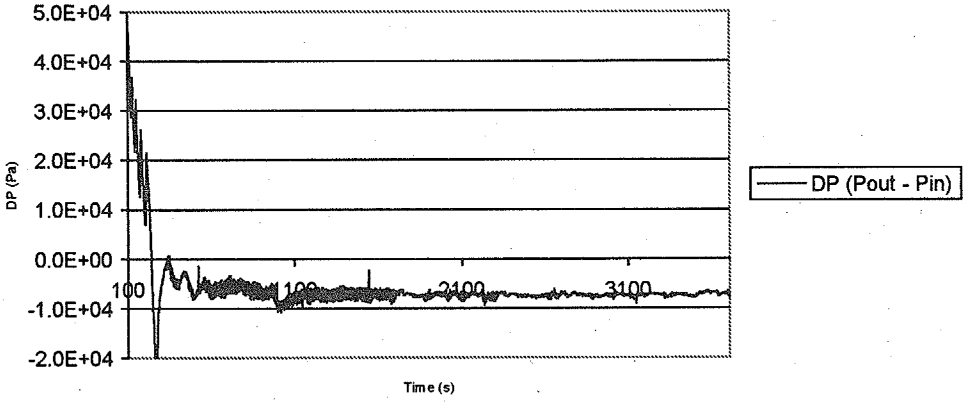


Figure A.4.8.4. Secondary side temperature distribution

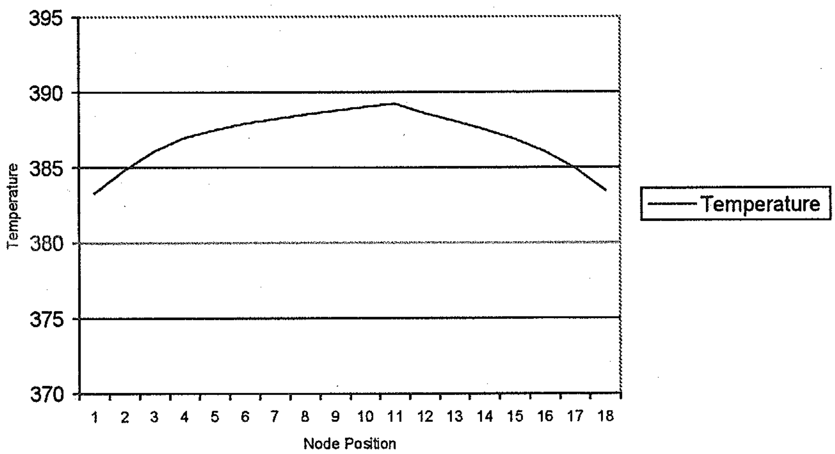


Figure A.4.8.5. Tube#2 collapsed level

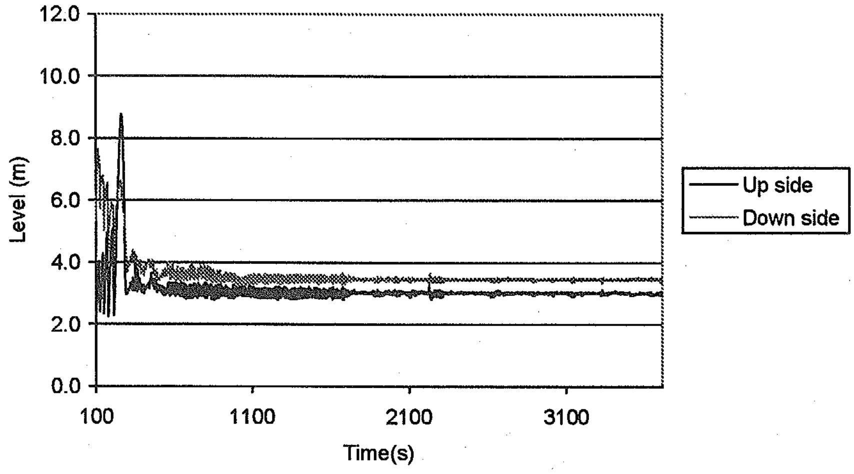


Figure A.4.8.6. Tube#3 collapsed level

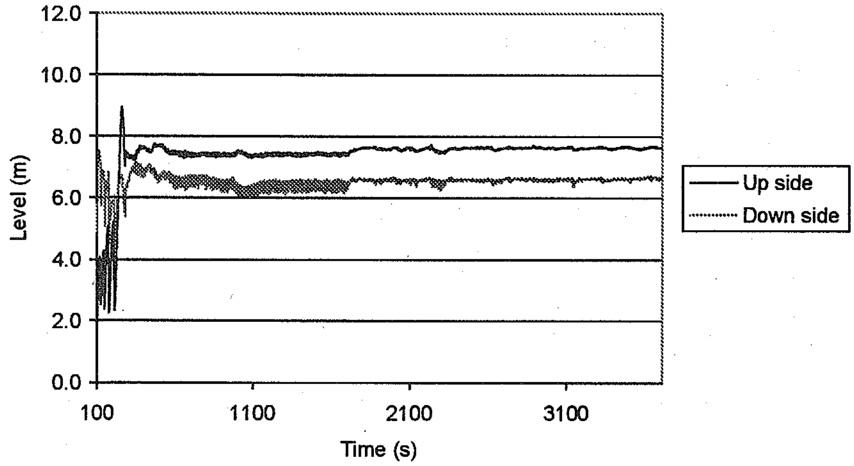


Figure A.4.8.7. Tube flow rate

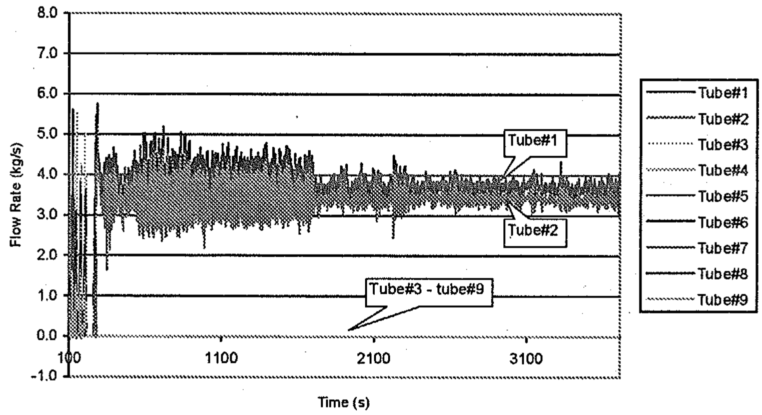


Figure A.4.8.8. Tube#5 collapsed level

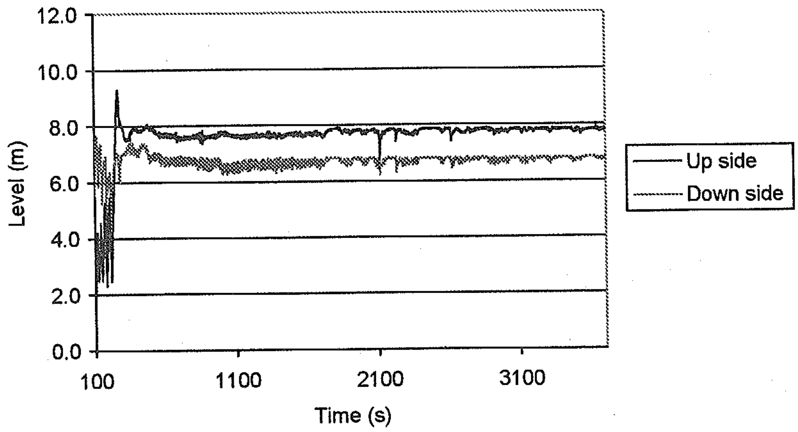


Figure A.4.8.9. Tube#8 collapsed level

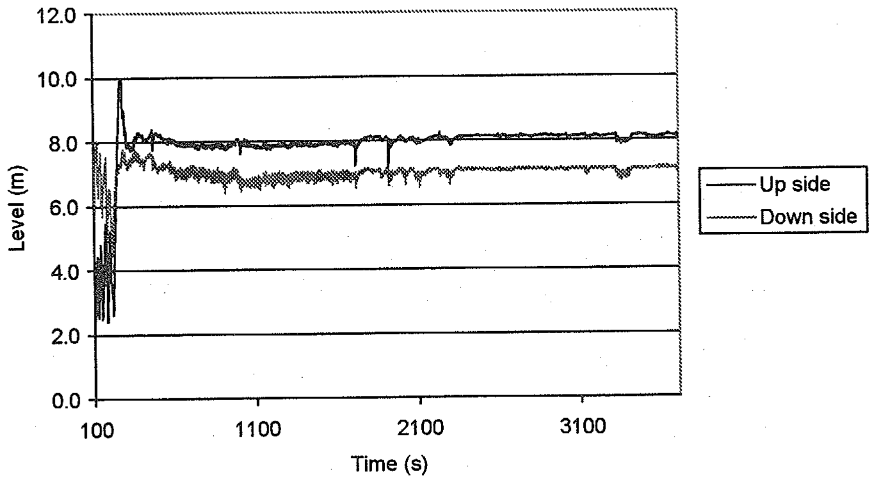


Figure A.4.8.10. Tube#6 collapsed level

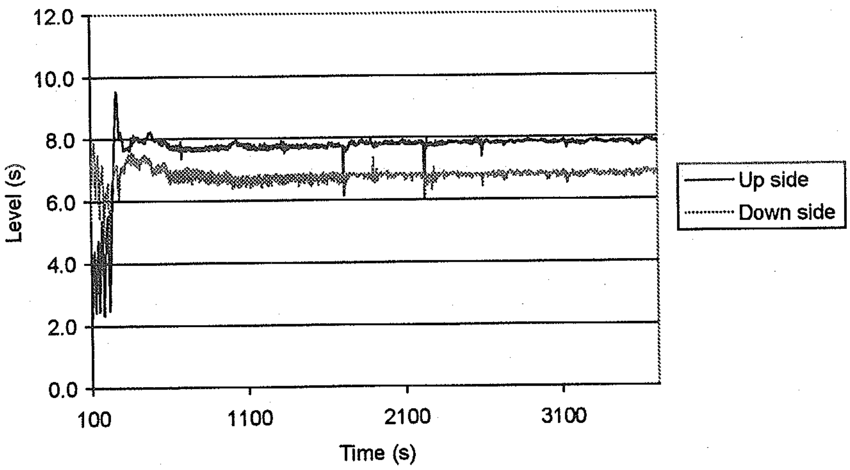


Figure A.4.8.11. Tube#1 collapsed level

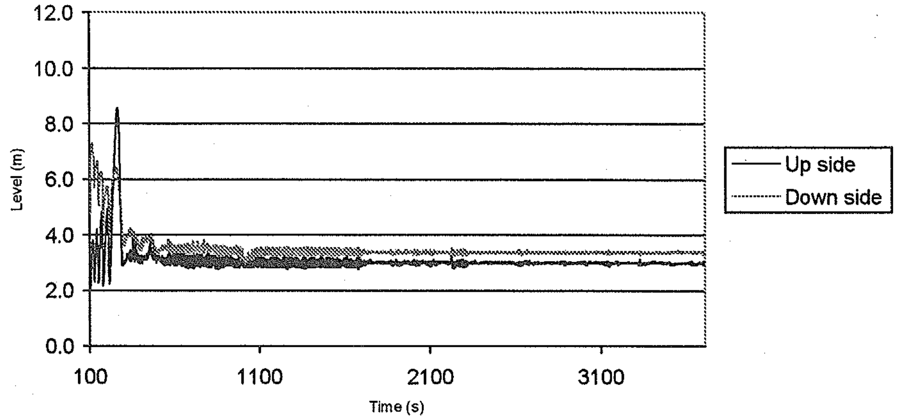


Figure A.4.8.12. Tube#7 collapsed level

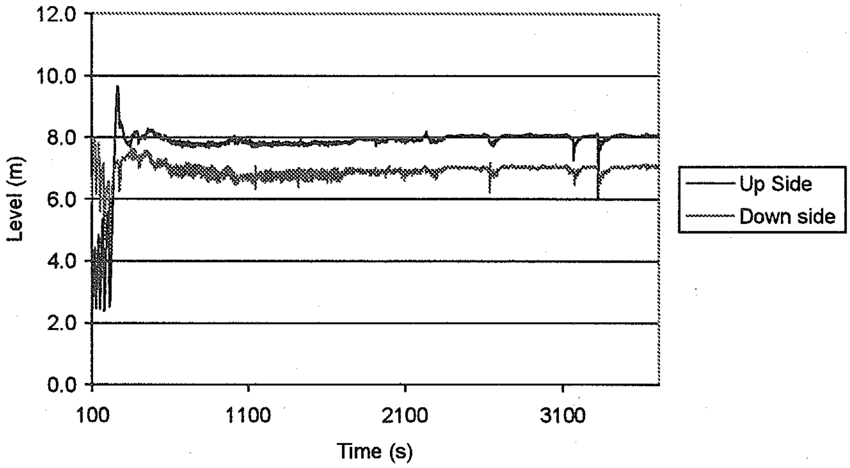


Figure A.4.8.13. Tube#4 collapsed level

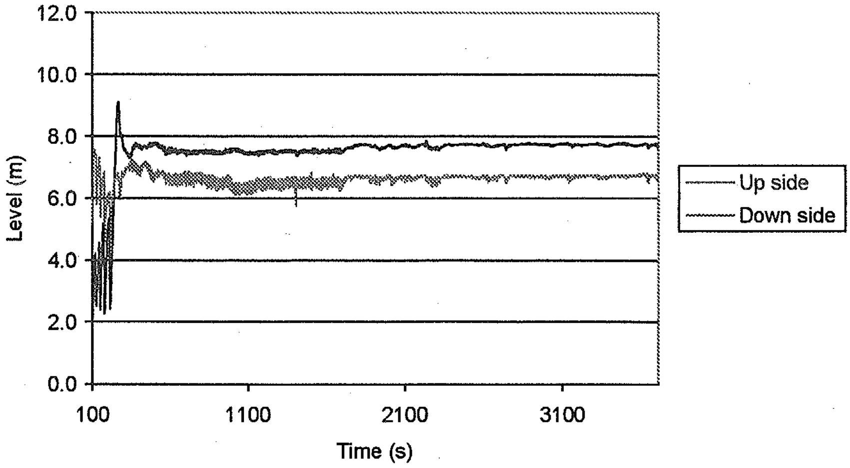
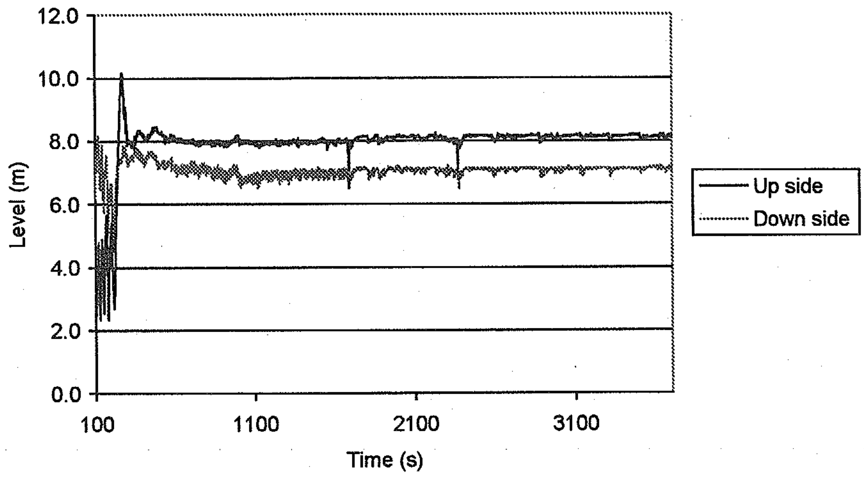


Figure A.4.8.14. Tube#9 collapsed level



4.9. Result of 100% of mass inventory HP calculation using 5 tube model

Figure A.4.9.1. Inlet flow

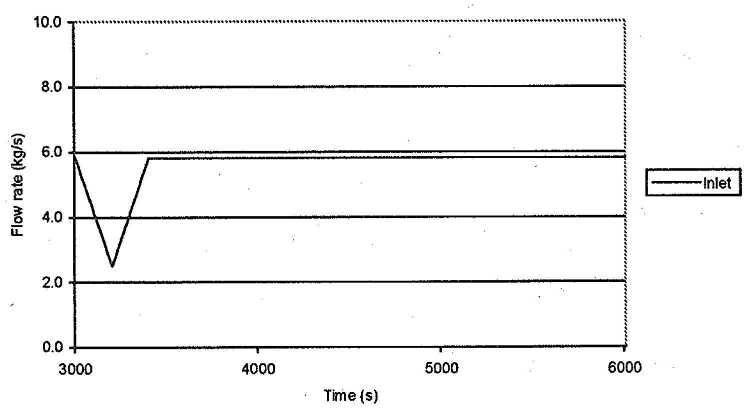


Figure A.4.9.2. Differential pressure

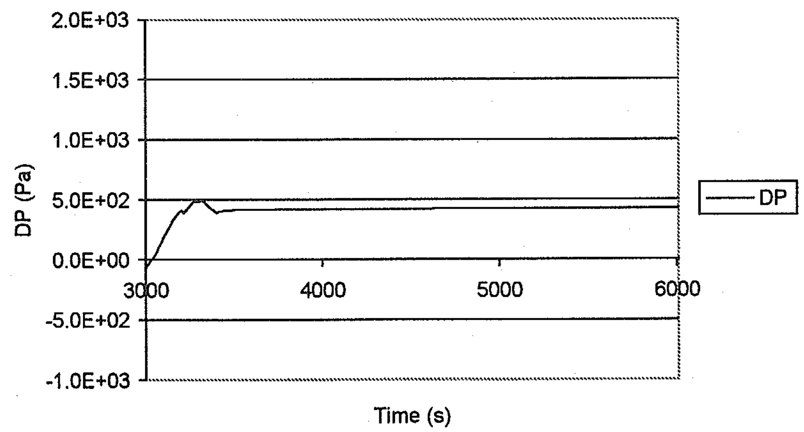
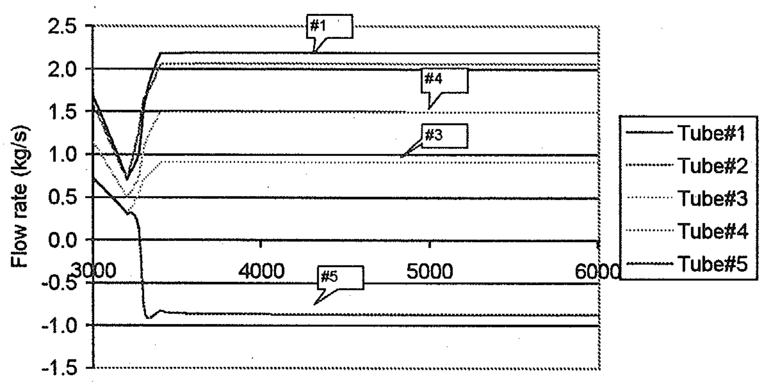


Figure A.4.9.3. Tube flow



4.10. Result of 73% of mass inventory HP calculation using 5 tube model

Figure A.4.10.1. Tube#1 flow

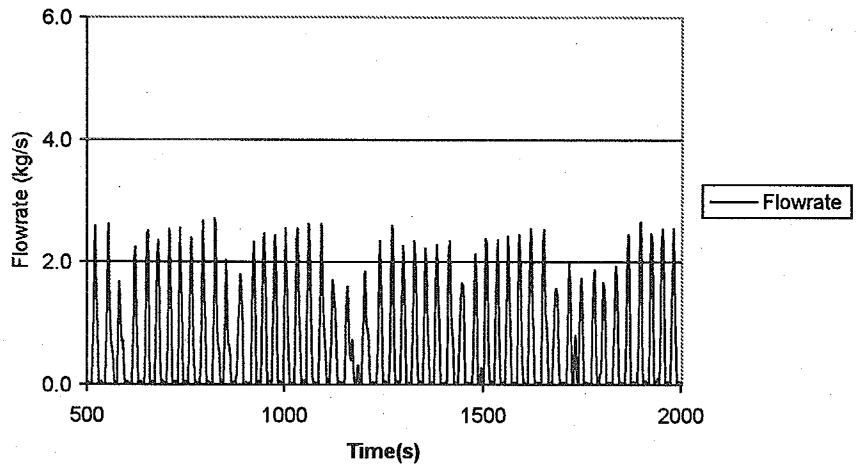


Figure A.4.10.2. Tube#2 flow

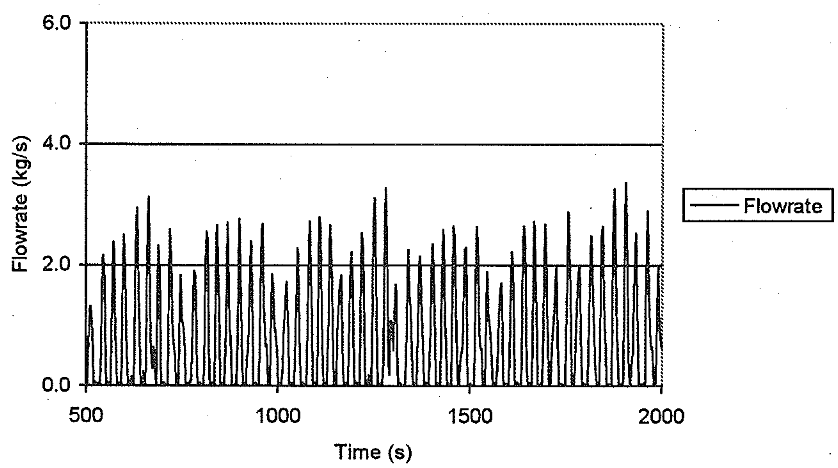


Figure A.4.10.3. Tube#3 flow

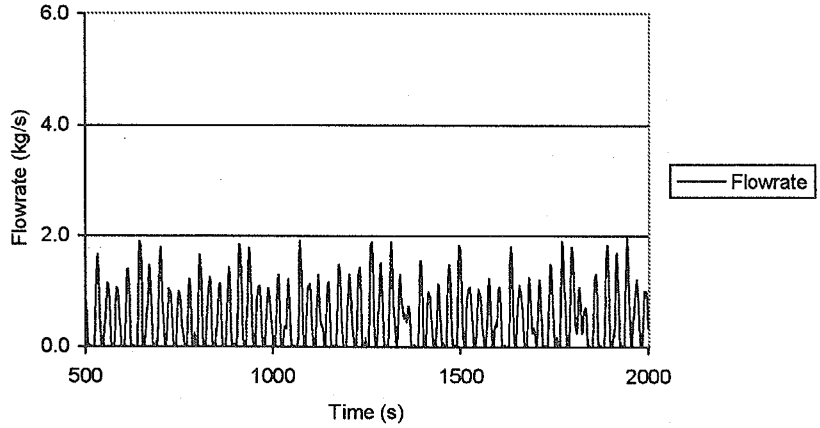


Figure A.4.10.4. Tube#4 and Tube#6 flow

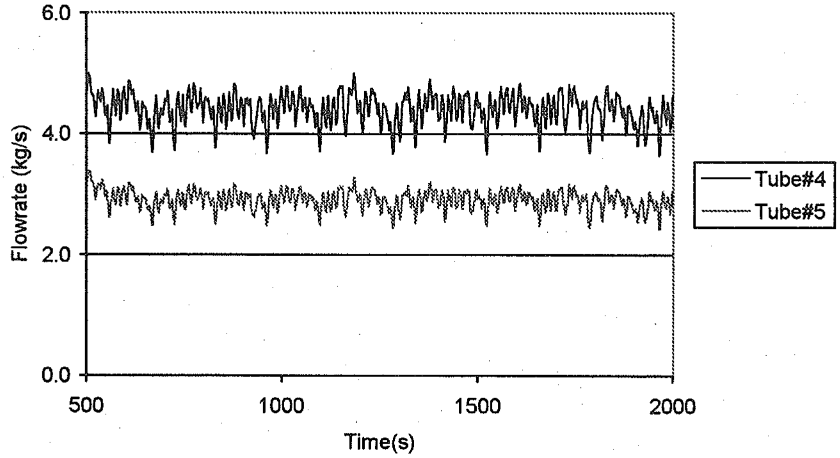
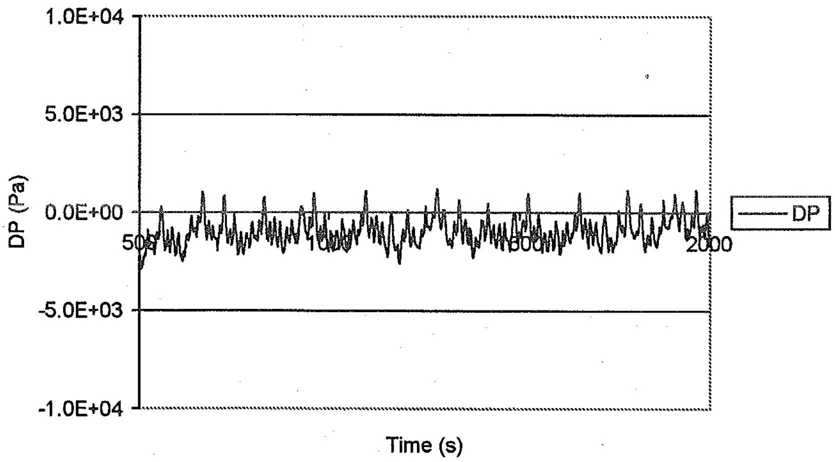


Figure A.4.10.5. Differential pressure



4.11. Result of 100% of mass inventory LP calculation using 5 tube model

Figure A.4.11.1. Heat Transfer rate in U-tube

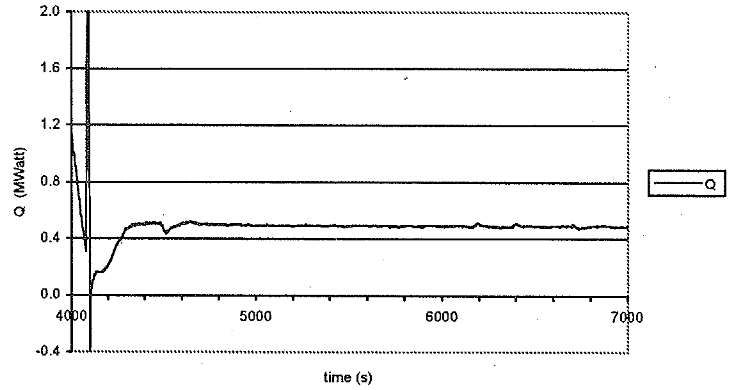


Figure A.4.11.2. Inlet flow

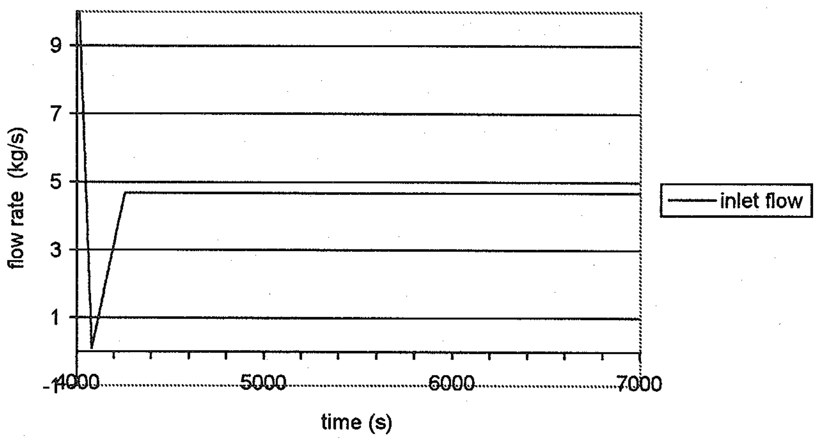
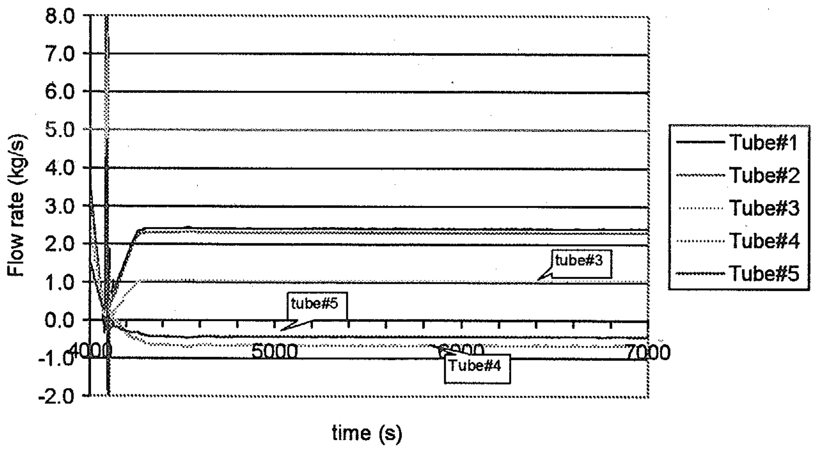


Figure A.4.11.3. U-Tube flow



4.12. Result of 75% of mass inventory LP calculation using 5 tube model

Figure A.4.12.1. U-Tube flow

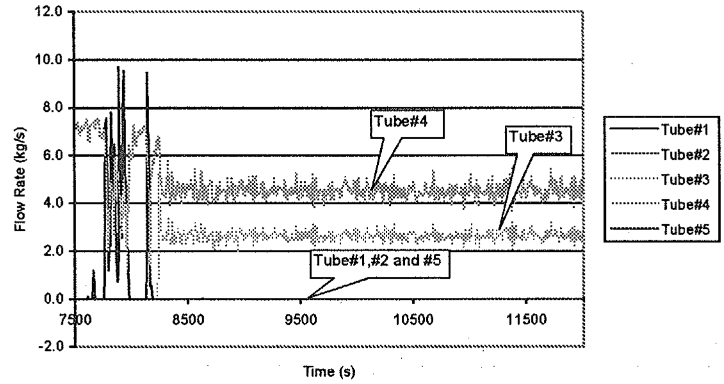


Figure A.4.12.2. Secondary side temperature distribution

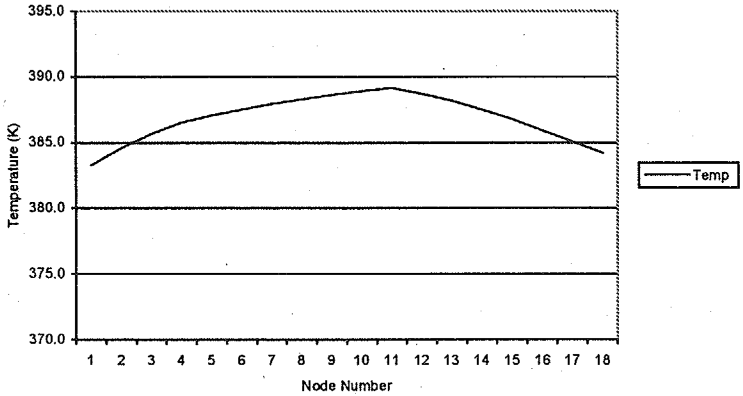
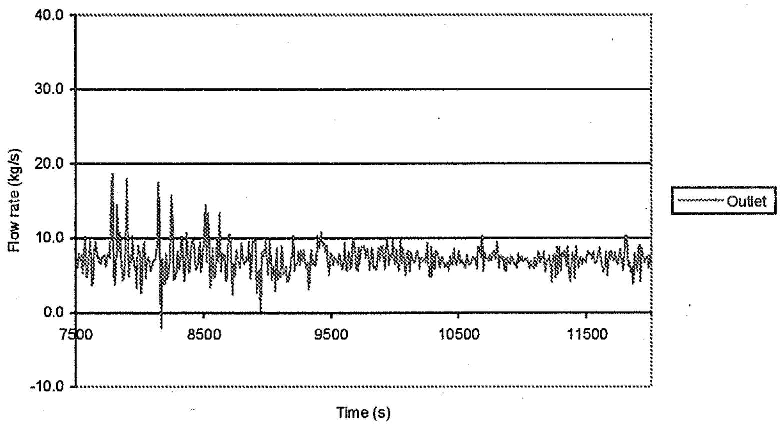


Figure A.4.12.3. Outlet flow



国際単位系 (SI) と換算表

表 1　SI 基本単位および補助単位

量	名　称	記　号
長　さ	メートル	m
質　量	キログラム	kg
時　間	秒	s
電　流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光　度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表 3　固有の名称をもつ SI 組立単位

量	名　称	記号	他の SI 単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m \cdot kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー, 仕事, 熱量	ジュール	J	$N \cdot m$
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	$A \cdot s$
電位, 電圧, 起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	$V \cdot s$
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	$cd \cdot sr$
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量当量	シーベルト	Sv	J/kg

表 2　SI と併用される単位

名　称	記　号
分，時，日	min, h, d
度，分，秒	°, ′, ″
リットル	l, L
トン	t
電子ボルト	eV
原子質量単位	u

$1\ eV = 1.60218 \times 10^{-19}\ J$

$1\ u = 1.66054 \times 10^{-27}\ kg$

表 4　SI と共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

$1\ Å = 0.1\ nm = 10^{-10}\ m$

$1\ b = 100\ fm^2 = 10^{-28}\ m^2$

$1\ bar = 0.1\ MPa = 10^5\ Pa$

$1\ Gal = 1\ cm/s^2 = 10^{-2}\ m/s^2$

$1\ Ci = 3.7 \times 10^{10}\ Bq$

$1\ R = 2.58 \times 10^{-4}\ C/kg$

$1\ rad = 1\ cGy = 10^{-2}\ Gy$

$1\ rem = 1\ cSv = 10^{-2}\ Sv$

表 5　SI 接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

（注）

1. 表1－5は「国際単位系」第5版，国際度量衡局 1985年刊行による。ただし，1 eV および 1 u の値は CODATA の 1986年推奨値によった。
2. 表4には海里，ノット，アール，ヘクタールも含まれているが日常の単位なのでここでは省略した。
3. bar は，JIS では流体の圧力を表わす場合に限り表2のカテゴリーに分類されている。
4. EC閣僚理事会指令では bar，barn および「血圧の単位」mmHg を表2のカテゴリーに入れている。

換　算　表

力	N($=10^5$dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　$1\ Pa \cdot s(N \cdot s/m^2) = 10\ P$(ポアズ)$(g/(cm \cdot s))$

動粘度　$1\ m^2/s = 10^4 St$(ストークス)(cm^2/s)

圧力	MPa(=10 bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J($=10^7$erg)	kgf・m	kW・h	cal(計量法)	Btu	ft・lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^6	3.67098×10^5	1	8.59999×10^5	3412.13	2.65522×10^6	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal = 4.18605 J（計量法）
　= 4.184 J　（熱化学）
　= 4.1855 J　(15 °C)
　= 4.1868 J（国際蒸気表）

仕事率　1 PS（仏馬力）
　= 75 kgf・m/s
　= 735.499 W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

（86年12月26日現在）

Analysis on Non Uniform Flow in Steam Generator During Steady State Natural Circulation Cooling