ASSESSMENT OF FUEL COOLING UNDER NATURAL CIRCULATION CONDITIONS IN INTACT LOOP FOR LOCA SCENARIOS IN GENTILLY 2**

P. GULSHANI
AECL
2251 Speakman Drive
Mississauga, Ontario
L5K 1B2

H. HUYNH
Hydro Quebec
1155 Rue Metcalfe, 8th floor
Montreal, Quebec

ABSTRACT

Thermosyphoning experiments in the multiple-channel RD-14M facility have shown that, under certain two-phase conditions in a multiple-channel facility, the coolant in some of the channels may flow opposite or reverse to the nominal forward direction. Subsequently, void from the inlet headers may enter the inlet feeders of the channels where the flow is in the forward direction or void from the outlet headers may enter the outlet feeders of the channel where the flow is in the reverse direction. (In this paper, these two phenomena are referred to respectively as inlet feeder draining and outlet feeder voiding.) This void would reduce the feeder hydrostatic head and, therefore, the channel flow. The resulting channel two-phase flow would eventually stratify exposing the upper fuel elements and part of the pressure tube to steam. These fuel elements and part of the pressure tube would heat up.

Based on these results, Hydro Quebec proposed design modifications to Gentilly 2 to avoid high loop void conditions in postulated accident scenarios with loss of forced coolant circulation. SOPHT simulations of LOCA scenarios indicated that these design changes reduce significantly the intact loop void in most of the scenarios. For a few scenarios of low probability (i.e., in the multiple failure category), the intact loop void could still be sufficiently high for a short period of time to raise concern for fuel cooling. For these few LOCA scenarios, an assessment of fuel and fuel channel cooling under natural circulation conditions in the intact loop was made.

This paper presents the models that were developed and used for this assessesment and the results of this assessement.

INTRODUCTION

Earlier network themalhydraulic code simulations of thermosyphoning in the reactor using a single channel per core pass indicated that two-phase thermosyphoning effectively removed the decay heat up to a high (about 40%) loop integrated void fraction. Above this void, thermosyphoning would break down causing fuel heatup. This behaviour was confirmed by experiments in the single-channel per pass RD-14 test.

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However, a number of two-phase thermosyphoning experiments conducted in the multiple-channel RD-14M facility indicated that heatup of the upper fuel element simulators (FES) in some of the individual channels could occur at a much lower loop void (at about 10%) and at a relatively high thermosyphoning flow than that in a single-channel per pass facility.

Analysis of the RD-14M two-phase thermosyphoning experiments (References 1 to 6) revealed that oscillatory loop conditions caused the flow to reverse in some of the channels at low (about 7% and higher) loop void. This channel flow reversal caused the outlet feeder of these channels to become water-filled and the inlet feeders of these channels to become two-phase-filled. Subsequently, void appeared in the outlet feeders of these channels. This void reduced the reverse flow, and, eventually, caused channel flow to stratify and the upper FES to heat up. In three of the experiments, this heatup occurred at low (about 10%) loop void. In some of the other experiments, this heatup occurred at higher (about 20% or higher) loop void and after void had appeared in the inlet feeders of the channels where the flow was still in the forward direction.

Based on the understanding derived from this study of the RD-14M experiments and analysis of LOCA scenarios in Gentilly 2 (Reference 7), Hydro Quebec proposed (in Reference 7) design changes to avoid high-loop-void natural circulation conditions in the intact loop following a LOCA in the other loop or in a steam line.

SOPHT simulations of LOCA scenarios indicated (Reference 7) that these design changes reduce significantly the intact loop void in most of the scenarios. For a few scenarios of low probability (i.e., in the multiple failure category), the intact loop void could still be sufficiently high for a short period of time to raise concern for fuel cooling and fuel channel integrity. This paper assesses fuel and fuel channel cooling under natural circulation conditions in the intact loop for these few LOCA scenarios.

The paper describes the models BENDORY, TALSMALL, and AMPTRACT that were developed and used to predict the two phenomena described above (namely, inlet and outlet feeder voiding and any resulting fuel heatup). The paper presents the methodology used to assess fuel cooling and fuel channel integrity under natural circulation conditions in the intact loop for the accident scenarios in Gentilly 2. The results of this assessment are presented and discussed.

MODELS AND CODES

This section presents briefly the models BENDORY, TALSMALL, and AMPTRACT that were developed to predict any fuel and fuel channel heatup resulting from either the inlet or outlet feeder voiding phenomenon. A CATHENA channel model was also used for predicting the inlet feeder voiding process. Detailed derivation of BENDORY and comparison of the predictions of these models with the results of RD-14M thermosyphoning experiments are given elsewhere.

BENDORY: **a model for predicting bubble growth, breakup, and entrainment, outlet feeder two-phase down-flow, and channel voiding under oscillatory thermosyphoning conditions**

The model BENDORY was developed to explain and predict voiding of a given outlet feeder of a channel assembly and the resulting stratified channel flow conditions following flow reversal in this channel assembly. The stratified channel void fraction and steam flow predicted by BENDORY was used in the model AMPTRACT (developed previously in References 8, 9, 10) to compute fuel and pressure tube temperature distributions. (Note that BENDORY can also be used to predict inlet feeder voiding which may occur following channel flow reversal and thermosyphoning breakdown and the resulting two-phase conditions in the connected inlet header.)

Briefly (more detail is presented below), BENDORY assumes that, following flow reversal in a given channel assembly, voiding of the outlet feeder of the channel assembly may occur due to entrainment of steam bubbles from the connected outlet header into the outlet feeder. This theory is similar to that proposed in Reference 1. It appears that, for the conditions of concern here, voiding of the outlet feeder is not caused by water flashing in the outlet feeder itself as proposed in Reference 2.

Channel flow reversal may occur under oscillatory (and other) primary heat transport system conditions as explained in References 1 to 6.

The assumptions and approximations in BENDORY and the model derivation are briefly as follows:

i. BENDORY models only the channel assemblies and the connected inlet and outlet headers, i.e., inlet and outlet headers, feeders and end fittings, and the fuel channels.

ii. BENDORY assumes that the flow has reversed in one of the channel assemblies below the headers, i.e., the flow direction in this assembly is from the outlet to inlet header. The flow in the other assemblies is in the nominal forward direction. This situation is depicted in Figure 1.

iii. BENDORY assumes that the inlet-to-outlet header differential pressure (i.e., inlet header minus outlet header pressure) is oscillating sinusoidally with a given amplitude and frequency according to

$$\Delta p_{HH} = p_{o} \cos(\omega t) \qquad (1)$$

iv. The response to eq. (1) of the flow in the channel assemblies is determined below. In particular, the flow oscillations in the reverse-flow channel assembly is determined to be 180 degrees out-of-phase with those in the forward-flow channel assemblies.

v. BENDORY assumes that, following flow reversal in a given channel assembly, the reverse flow entrains (or drags) steam bubbles in the outlet header into the outlet feeder of this channel assembly as depicted in Figure 1.

vi. The entrained steam bubbles mentioned in the item (v) above come from the outlet feeder(s) (Refer to Figure 1): (a) where the flow is in the forward direction, and (b) which are located in the same bank of outlet feeders connected to this outlet header (i.e., connected to the outlet header at the same axial location) as the outlet feeder with reverse flow). Steam bubbles entering the outlet header from the outlet feeders in the other feeder banks (i.e., upstream of this feeder bank) cannot be dragged into and, therefore, do not enter the outlet feeder with reverse flow because, for the low thermosyphoning flow of concern here and for the spatial separation of the adjacent feeder banks on the reactor outlet header, these bubbles have sufficient time to rise to the top of the outlet header as depicted in Figure 1.

vii. Mass flow of steam entrained into an outlet feeder with reverse feeder flow is given by:

$$W_{g} = \chi_{OH} W \qquad (2)$$

where W = the outlet feeder reverse flow and χ_{OH} = outlet header quality at the axial location of the this feeder. For non-zero entrained steam flow W_{g}, two conditions must be satisfied:

reverse feeder water velocity > *steam bubble rise velocity*

and (3)

reverse feeder water flow ≥ *outlet header water flow*, W_F, *at this axial location*

The outlet header axial flow W_F is equated to the sum of the forward flows in the feeders in this feeder bank and those in the upstream feeder banks. Therefore, W and W_F are 180 degrees out-of-phase with each other.

The steam bubbles that are entrained into a reverse-flow outlet feeder are dragged downwards by the reverse flow. These bubbles coalesce with those which are already in the outlet feeder. These large bubbles cannot be dragged out of the feeder into the end fitting and channel and, therefore, remain in the feeder. (Note that the buoyancy force increases with bubble size. Therefore, a larger bubble requires a larger water drag force and, therefore, higher water velocity to be pulled down.) The resulting time evolution of void fraction in the outlet feeder is determined from eq. (2) and an integration of the mass conservation equation:

$$\frac{\partial}{\partial t}\left(A\rho_g\alpha\right) = -\frac{\partial}{\partial z}W_g \tag{4}$$

where A = feeder flow area, α = feeder void fraction, and ρ_g = steam density

viii. W and W_F are determined from eq.(4) and the following momentum balance on the flow through inlet and outlet feeders and end fittings, and channel between the inlet and outlet headers:

$$0 = \Delta p_{HH} + \Delta p_F + \Delta p_{EF} + \Delta p_{CH} + gH(\rho_{IF} - \rho_{OF}) \tag{5}$$

where a small contribution from fluid inertia is ignored, H = vertical distance of channel below the header, and Δp with a subscript is the friction pressure drop along inlet and outlet feeders (F), end fittings (EF), and channel (CH), and Δp_{HH} = pressure difference between the inlet and outlet headers given in eq. (1). The oscillation amplitude p_o in eq.(1) is about 12- 18 kPa as predicted by codes.

The feeder fluid densities in eq.(5) are given by:

$$\rho = \rho_g\alpha + \rho_l(1-\alpha) \tag{6}$$

where α is either inlet (IF) or outlet (OF) feeder void fraction and is determined below. The outlet header quality χ_{OH} in eq.(2) and α are inter-related below.

Eqs.(1) to (6) determine the flows W and W_F, and reverse-flow outlet feeder and channel void fractions as functions of time, channel power, heat loss, channel inlet fluid subcooling, oscillation amplitude and frequency, and header, feeder, and other loop component geometry.

The void fraction α in eq.(6) is determined as follows.

For a channel assembly with reverse flow, the outlet feeder void fraction is given by eq.(4). The inlet feeder void fraction is equal to that at the end of the fuel channel. This void fraction is computed using the homogeneous flow assumptions.

For a channel assembly with forward flow, the inlet feeder void fraction is zero (i.e., it is water-filled). The outlet feeder void fraction is equal to that at the exit of the fuel channel. This void is computed using the homogeneous flow assumptions.

However, under depressurizing heat transport system conditions, heat flow from the feeder superheated water increases the bubble size from its size at the time of its release from the fuel sheath surface. This increases the void fraction along the outlet feeder. Outlet feeder void fraction also increases due to any bubble breakup. As a bubble grows, flow turbulence deforms and breaks up this bubble if it grows beyond a certain size corresponding to the critical value of the local Weber number, i.e., corresponding to forced oscillation of the bubble at its lowest natural frequency (Reference 11). After each breakup, the bubble continues to grow in the superheated water along the outlet feeder and suffers further breakups. These processes are repeated until the exit of the feeder at the connected outlet header is reached. These processes determine the void fraction and bubble diameter at the end of theoutlet feeder(s). BENDORY accounts for these processes in evaluating the void fraction and bubble diameter at the end of the outlet feeder(s).

This void is equated to the void fraction in the outlet header at the axial location of the outlet feeder with reverse flow. This void fraction and outlet header quality χ_{OH} in eq. (2) are inter-related using the homogeneous flow assumptions except that this void fraction is reduced by a factor F_v because only a fraction of the steam bubbles entering the outlet header from the same-bank forward-flow outlet feeders can be entrained by the reverse flow . Presently, the factor F_v is treated as an adjustable parameter fitted to the RD-14M tests, but it may be computed from first principles. The factor F_v determines the rate of increase of the outlet feeder void fraction but it does not significantly alter the outlet feeder void fraction at which the channel two-phase flow stratifies. Therefore, the value of F_v does not significantly change the conclusions drawn about fuel heatup.

TALSMALL: a model for predicting inlet-feeder water draining

Inlet feeder water draining may occur following channel flow reversal (which brings a two-phase fluid into the connected inlet header) and thermosyphoning breakdown. Under these conditions, the steam and water phases in the inlet header separate. This separation exposes to steam the inlet feeder nozzles at the inlet header. Consequently, the water in these feeders begin to drain into the connected fuel channels. This draining reduces the hydrostatic head in the inlet feeders and, therefore, the channel flows.

The model TALSMALL was developed previously (References 8 and 9) to predict inlet feeder water draining and eventual stratified channel flow conditions including channel void fraction and steam flow.

However, TALSMALL was not used in the analysis in this paper because it is argued below that inlet feeder water draining would not occur in any of the accident scenarios in Gentilly 2.

AMPTRACT: a model for predicting fuel and pressure tube heatup under stratified channel flow conditions

AMPTRACT was developed previoulsy (Reference 10). In a given channel axial plane and for given stratified channel void fraction and power level, AMPTRACT computes steam and fuel element temperatures and the temperature distribution around the pressure tube circumference as functions of time.

CATHENA

CATHENA is a general-purpose two-fluid thermalhydraulic code. Presently, it does not appear feasible to use CATHENA to simulate the outlet-feeder voiding phenomenon. CATHENA was not used to predict inlet feeder water draining in the analysis in this paper for the reasons presented above.

METHODOLOGY FOR FUEL AND FUEL CHANNEL COOLING ASSESSMENT

The following methodology was used to assess multiple-channel natural circulation phenomena and fuel and pressure tube cooling for the conditions prevailing in the intact loop following a LOCA in the other loop with subsequent automatic pump trip or loss of class IV power in Gentilly 2.

SOPHT was used to simulate a number of small and large break LOCA scenarios in Gentilly 2 with the modifications proposed in Reference 7. The results of these simulations were reviewed to select those scenarios where the intact loop void was sufficiently high and the loop flow was sufficiently low. These conditions would raise concern for fuel and pressure tube cooling due to either inlet-feeder water draining or outlet-feeder bubble entrainment phenomenon. This review indicated that the design modifications proposed in Reference 7 for Gentilly 2 reduce to a few the accident scenarios where oscillatory two-phase thermosyphoning conditions can exist and only at intact loop void fraction less than 18%.

In particular, the review indicated that, due to emergency coolant injection and/or heavy water feed, the inlet header coolant would remain, on the average, subcooled in all of the accident scenarios even for flow reversal in a large number of channels. Therefore, inlet feeder water draining would not occur for any of the accident scenarios in Gentilly 2. Therefore, no prediction of this phenomenon for the accident scenarios in Gentilly 2 is necessary and none was performed.

For the outlet feeder voiding phenomenon, the following methodology was used.

BENDORY and AMPTRACT models were used to assess fuel and fuel channel cooling in Gentilly 2 for the outlet feeder voiding phenomenon.

The accident scenarios of concern for fuel cooling in the intact loop for this phenomenon were selected according to the following criteria.

Loop conditions needs to be oscillatory (out-of-phase oscillations) to induce channel flow reversal and to periodically reduce outlet header axial flow. These conditions require core boiling and a loop integrated void fraction larger than 4% and less than a certain value depending on the loop pressure. This range of loop void was predicted by the model MMOSS-I (References 5 and 6).

Axial flow in an outlet header at the location of the feeder bank where the flow has reversed must be sufficiently low or must become periodically sufficiently low. This requires that: (a) the feeder bank be an stagnation plane (for example, be located at a closed end of an outlet header), (b) the oscillation amplitudes be sufficiently high, and (c) flow has reversed in one-half or more than one-half of the number of feeders in the feeder bank.

The analysis used the following approach.

The parameters (such the oscillation frequency, loop pressure, and channel inlet coolant temperature) needed as input to BENDORY and AMPTRACT were taken from the SOPHT predictions (Reference 7).

To upper-bound the predicted fuel and pressure tube temperatures, channel O6 was chosen to examine channel assembly reverse flow behaviour and fuel and pressure tube heatup following entrainment of steam bubbles into the O6 outlet feeder. This channel has the highest channel and bundle powers.

To compute forward flow in the outlet feeder which is located in the same feeder bank as O6, channel O10 was used. That is, it is assumed that, in the axial location of this feeder bank.: (a) the flow in O6 would reverse, (b) the flow in O10 would remain in the forward direction, (c) the loop conditions and, in particular, inlet-to-outlet header differential pressure would be oscillatory, and (d) the outlet header axial flow at the axial location of this feeder bank would periodically become very low.

However, for the reactor outlet header geometry, the conditions in item (d) above would be unlikely to occur and would significantly overpredict fuel and pressure tube temperatures for the reasons discussed below.

ANALYSIS RESULTS FOR ACCIDENT SCENARIOS

The above methodology was used to predict fuel and pressure tube temperatures for the outlet feeder voiding phenomenon in the intact loop for the few LOCA scenarios in Gentilly 2 mentioned above. This section presents the analysis results for a dual failure large LOCA scenario.

Outlet feeder flow

Figure 2 shows O6 outlet-feeder reverse flow (solid curve) and outlet header local axial flow (dashed curve) predicted by BENDORY. The feeder flow is oscillatory with a period of about 65 seconds (which is an input from SOPHT). The mean value of the feeder reverse flow decreases as more steam bubbles are entrained into the outlet feeder from the outlet header in each half of the oscillation cycles when: (i) the outlet header pressure is increasing, (ii) the axial header flow is decreasing, and (iii) the feeder reverse flow is higher than the header axial flow. Eventually and near each oscillation trough, the corresponding channel flow periodically deceases below stratification threshold flow. Therefore, the channel two-phase flow periodically stratifies for a short time. This stratification changes the flow hydraulic resistance. This change coupled with variation in the flow due to the flow oscillations generates high frequecy flow oscillations in each half of oscillation cylce observed in Figure 2.

Eventually, about 450 seconds after the start of first bubble entrainment, channel two-phase flow falls permanently below the stratification threshold flow and the flow permanently stratifies. The flow then becomes steady since it is now too low to entrain steam bubbles into the feeder and the feeder down-flow water velocity equals bubble rise velocity.

Outlet feeder and channel void fraction

Figure 3 shows outlet feeder void (dotted curve) predicted by BENDORY. The feeder void increases during each half of an oscillation cycle and remains constant during the other half cycle. Eventually (after about 450 seconds), the feeder void increases to a limiting value (about 0.48) and remains constant thereafter.

Figure 3 shows channel void fraction (solid curve) predicted by BENDORY for stratified channel flow conditions. The channel void fraction increases rapidly and periodically for a short time during each half of an oscillation cycle when the channel flow decreases below flow stratification threshold. The stratified channel void fraction indicates rapid and periodic channel flow transitions between mixed and stratified flow regimes before the flow stratifies permanently causing channel void fraction to rapidly increase to about 0.5 (about 450 seconds after the start of outlet feeder bubble entrainment).

Fuel temperature

Figure 4 shows highest power-rated fuel element temperature predicted by AMPTRACT at the center of channel O6 and for stratified channel flow conditions. This calculation used channel void fraction predicted by BENDORY (in Figure 3) and assumed that the fuel was initially at the saturation temperature (i.e., the fuel stored heat has been removed by an initial high flow). The predicted fuel temperature increases to a limiting temperature of about 600 °C due to good steam cooling. (Note that time zero in Figure 4 is the time at which the channel flow first stratifies permanently, i.e., at about 450 seconds after the start of first bubble entrainment into the outlet feeder.)

At this temperature, no significant fuel sheath strain is expected (Reference 12).

However, in the accident scenario, the limiting temperature would not be reached, i.e., the limiting temperature is highly overpredicted and it would unlikely exceed the saturation temperature, for the reasons discussed below.

Pressure tube temperature

Figure 5 shows the AMPTRACT-predicted temperature distribution transient around the pressure tube circumference in the axial plane of highest power-rated fuel element. The calculation used the channel void fraction predicted by BENDORY.

At a given time, the pressure tube temperature is maximum at the top of the tube and decreases to the saturation temperature at the channel water level. At a point on the pressure tube circumference above the water level, the temperature increases with time. In particular, at the top of the pressure tube, the temperature reaches the limiting value of about 535 °C.

At these temperatures, no significant pressure tube strain occurs. Note that these predicted temperatures are overly conservative as discussed below.

DISCUSSIONS AND CONCLUSIONS

This paper conservatively assesses fuel and fuel channel cooling in the intact loop for LOCA scenarios with loss of forced circulation of the primary coolant in Gentilly 2 with the proposed system design modifications. The assessment used the model AMPTRACT that was developed previously, and the model BENDORY that was developed specifically for this assessment.

BENDORY was developed and used to model outlet-feeder voiding phenomenon and compute:

- Bubble entrainment from an outlet header into an outlet feeder with reverse flow under oscillatory header-to-header differential pressure conditions. BENDORY also computes the resulting reduction in the reverse flow and channel flow stratification, and stratified channel void fraction and steam flow, and

- Steam bubble growth (due to any loop depressurization and the resulting water superheating) and bubble breakup in a forward-flow outlet feeder.

AMPTRACT was used to compute fuel and pressure tube temperatures under stratified channel flow conditions using channel void fraction and steam flow predicted by BENDORY.

The results of SOPHT simulations of accident scenarios with loss of forced coolant circulation in Gentilly 2 with the proposed design modifications were reviewed. This review identified those scenarios where the intact loop void was predicted to be high for a significantly long time when the loop flow was low and the loop conditions were oscillatory. The loop conditions in these scenarios were selected to evaluate fuel and fuel channel cooling for the inlet-feeder water draining and outlet-feeder voiding phenomena described above. That is, these conditions were used in BENDORY to evaluate fuel and fuel channel cooling.

Assuming flow reversal in channel O6, BENDORY predicts that outlet feeder bubble entrainment reduces channel flow sufficiently to eventually (after 200 seconds or more) cause the channel flow to stratify. At this time, channel void fraction rapidly increases to about 0.5 or less. For channel conditions after the start of channel flow stratification predicted by BENDORY, AMPTRACT predicts that good steam cooling limits the highest power-rated fuel element temperature to about 600 °C or less. At this temperature no significant sheath strain is predicted.

The above evaluation of fuel temperature is highly conservative (that is, the fuel temperature is highly overpredicted), for the following reasons.

The limiting fuel temperature is reached in about 700 seconds or more after the start of channel flow stratification and heatup. That is, in about 900 seconds or more after the start of outlet feeder steam entrainment or low loop flow conditions. However, the SOPHT simulations of the accident scenarios predict that there is significant void in the intact loop for about 400 seconds or less. Furthermore, appropriate operator action to mitigate the accident consequences can be credicted after 15 minutes. It follows that, in these scenarios, the fuel does not have time to heat up significantly above the saturation temperature and that the limiting temperature of 600 °C predicted by AMPTRACT is overly conservative.

The BENDORY/AMPTRACT prediction for the reactor is also conservative for the following additional reasons.

Most of the feeder banks on a reactor outlet header have three or five feeder nozzles. Therefore, the flow at the axial location of any of these feeder banks would unlikely be sufficiently low to allow steam bubble entrainment into an outlet feeder with reverse flow unless this feeder bank is located at an outlet header flow-stagnation plane and the flow would reverse in more than one of the outlet feeders in this bank.

The feeder bank located at one of the closed ends of a reactor outlet header has two feeder nozzles. At the location of this feeder bank, outlet header axial flow could be sufficiently low and the flow could be forward in one of the feeders and reverse in the other feeder. However, channels connected to these outlet feeders (namely B12 and D12) have lower power than channel O6. Therefore, using channel O6 instead of B12 or D12 would significantly overpredict fuel and pressure tube temperatures.

Furthermore, SOPHT predicts that continued D_2O feed to the inlet headers in Gentilly 2 generally increases the intact loop inventory in each of the accident scenarios. The increasing loop inventory would reduce the likelihood of outlet header steam bubble entrainment into an outlet feeder. This beneficial effect is not credicted in the analysis.

It is concluded that, for the conditions predicted following a LOCA scenario with subsequent loss of forced primary coolant circulation in Gentilly 2, no significant fuel heatup and no significant sheath strain would occur in the intact loop with the proposed design modifications.

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TABLE I

ACCIDENT SCENARIOS AND INTACT LOOP THERMOSYPHONING CONDITIONS FOR ASSESSING FUEL COOLING IN GENTILLY 2 FOR OUTLET AND INLET FEEDER VOIDING PHENOMENA

Accident scenario	Initial/final channel pressure (MPa)	Maximum loop integrated void fraction	Inlet header void fraction	Header-to-header differential pressure (kPa)	Oscillation period (s)	Channel inlet fluid temperature (° C)
100% RIH/ROH breaks with loss of class IV power.	2.3/0.7	less than 0.16	0.0	mean = 0.0 oscillation amplitude = 12 kPa	65.0	150
20% RIH break with loss of loop isolation	0.79/0.38	between 0.2 and 0.8 for 250 seconds	spikes of void of about 5-second duration for 250 seconds	"	"	120
2.5% and 5.0% RIH breaks with loss of crash cooldown.	2.82/3.56	less than 0.15	0.0	"	"	230
2.5% and 5.0% RIH breaks with loss of injection.	0.83/0.6	less than 0.18	0.0	"	"	145
5% RIH break with total loss of ECCS.	2.91/2.61	less than 0.11	0.0	"	"	220

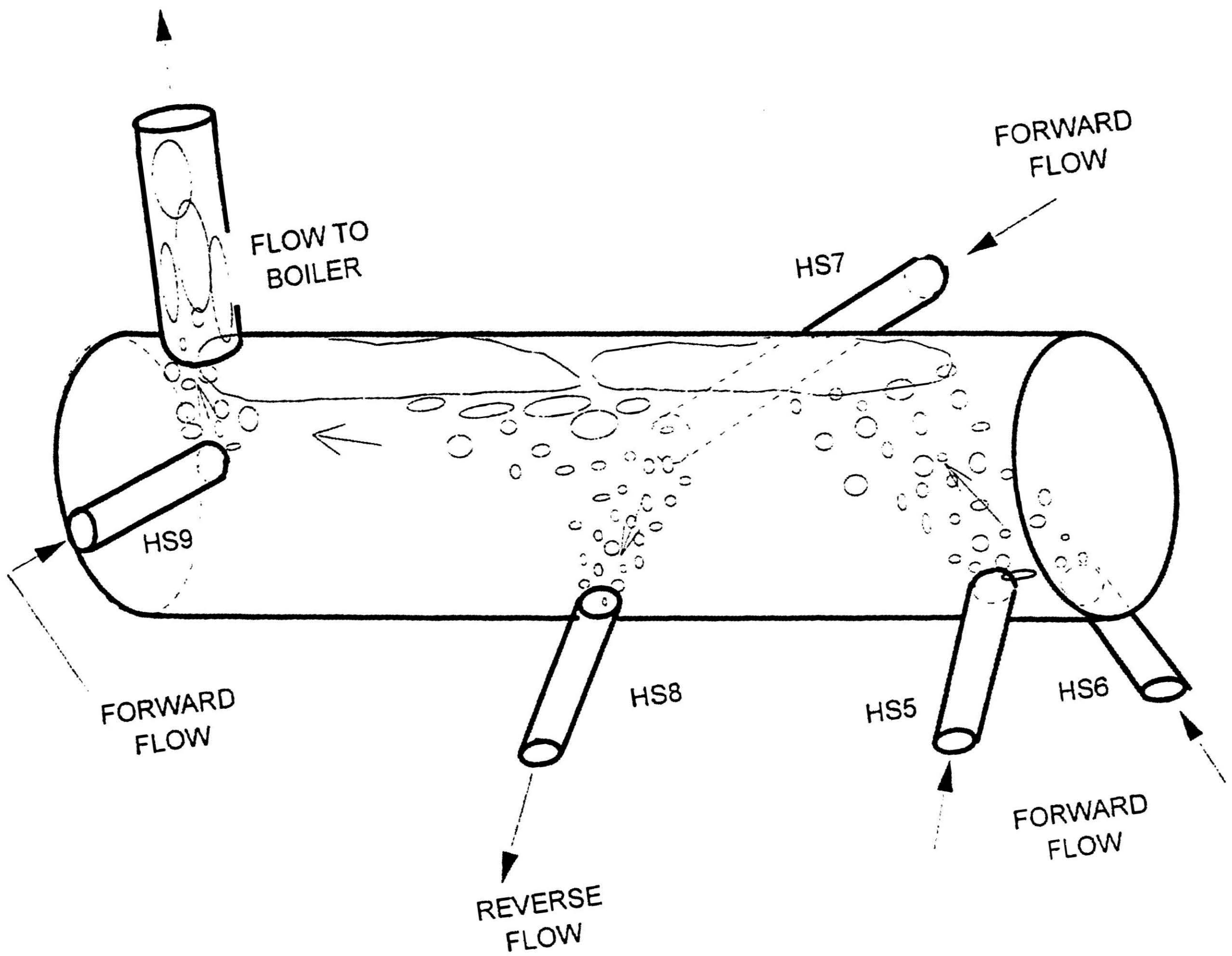

FIGURE 1: CONCEPTUAL TWO-PHASE FLOW PATTERN IN OUTLET HEADER SHOWING BUBBLE ENTRAINMENT WITH REVERSE OUTLET FEEDER FLOW

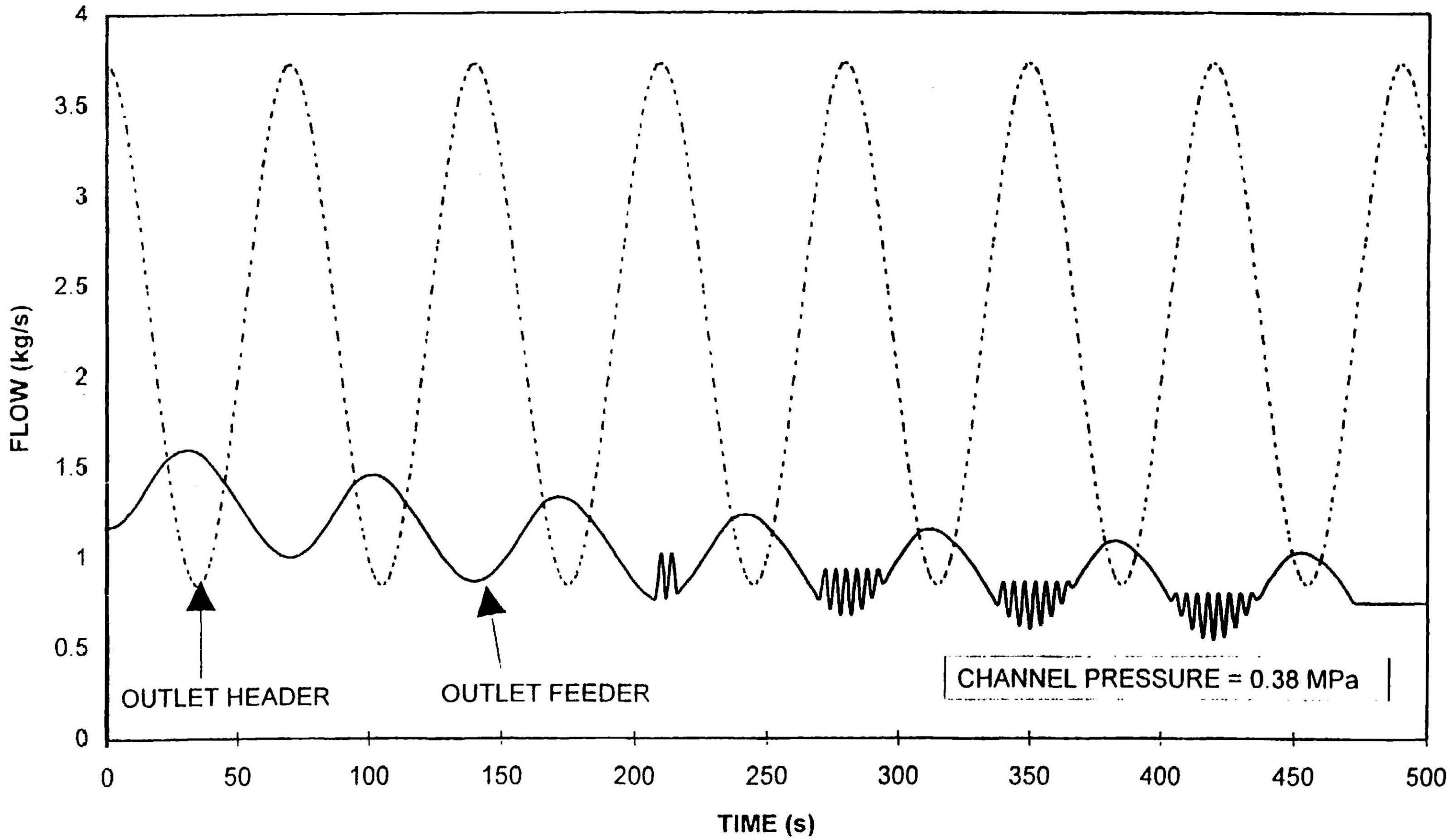

FIGURE 2 : REVERSE OUTLET FEEDER FLOW AND OUTLET HEADER FLOW AT AXIAL LOCATION OF REVERSE-FLOW OUTLET FEEDER PREDICTED BY BENDORY FOR A DUAL FAILURE LARGE LOCA SCENARIO IN GENTILLY 2

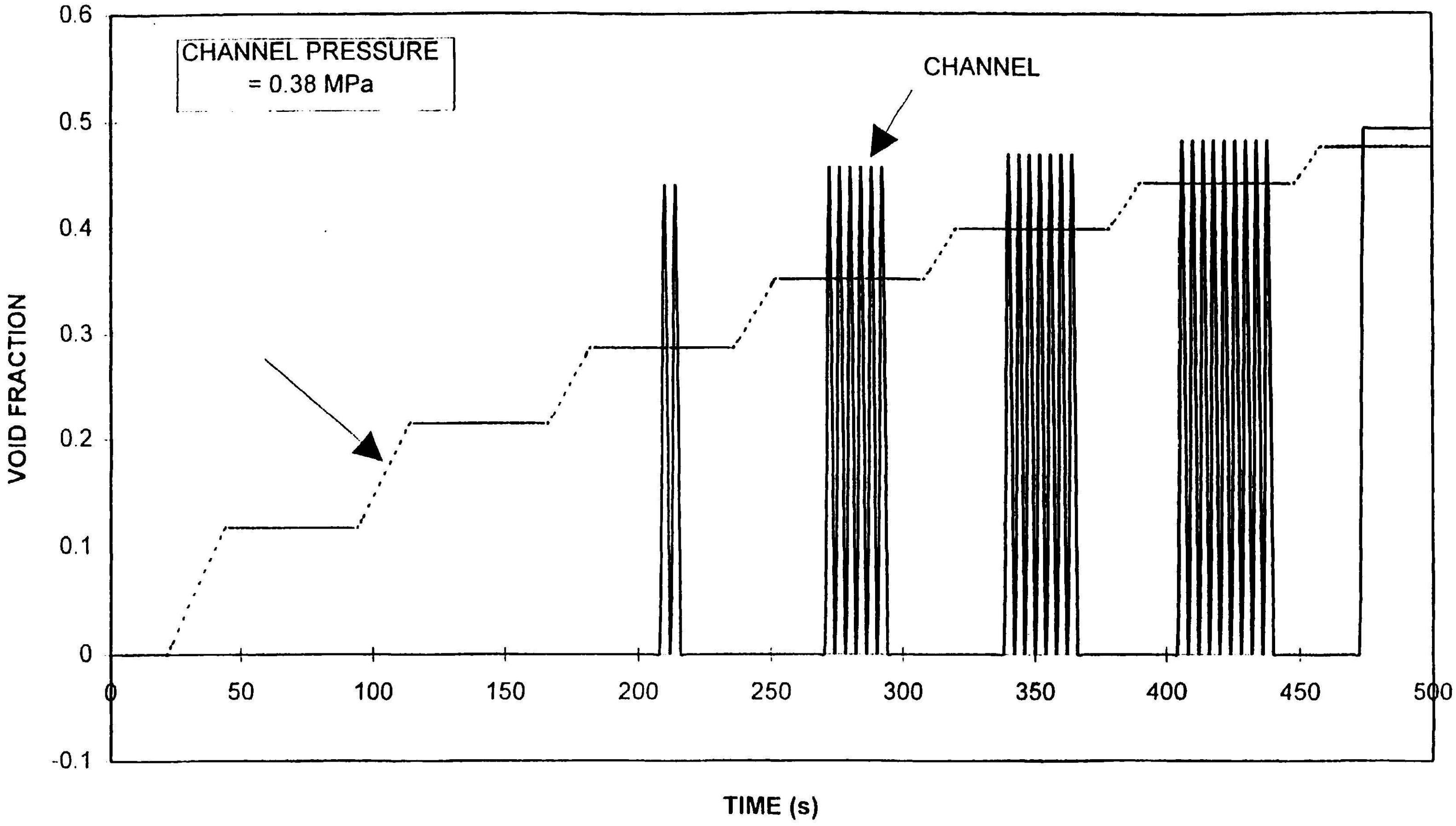

FIGURE 3 : VOID FRACTION IN REVERSE-FLOW OUTLET FEEDER AND FUEL CHANNEL PREDICTED BY BENDORY FOR A DUAL FAILURE LARGE LOCA SCENARIO IN GENTILLY 2

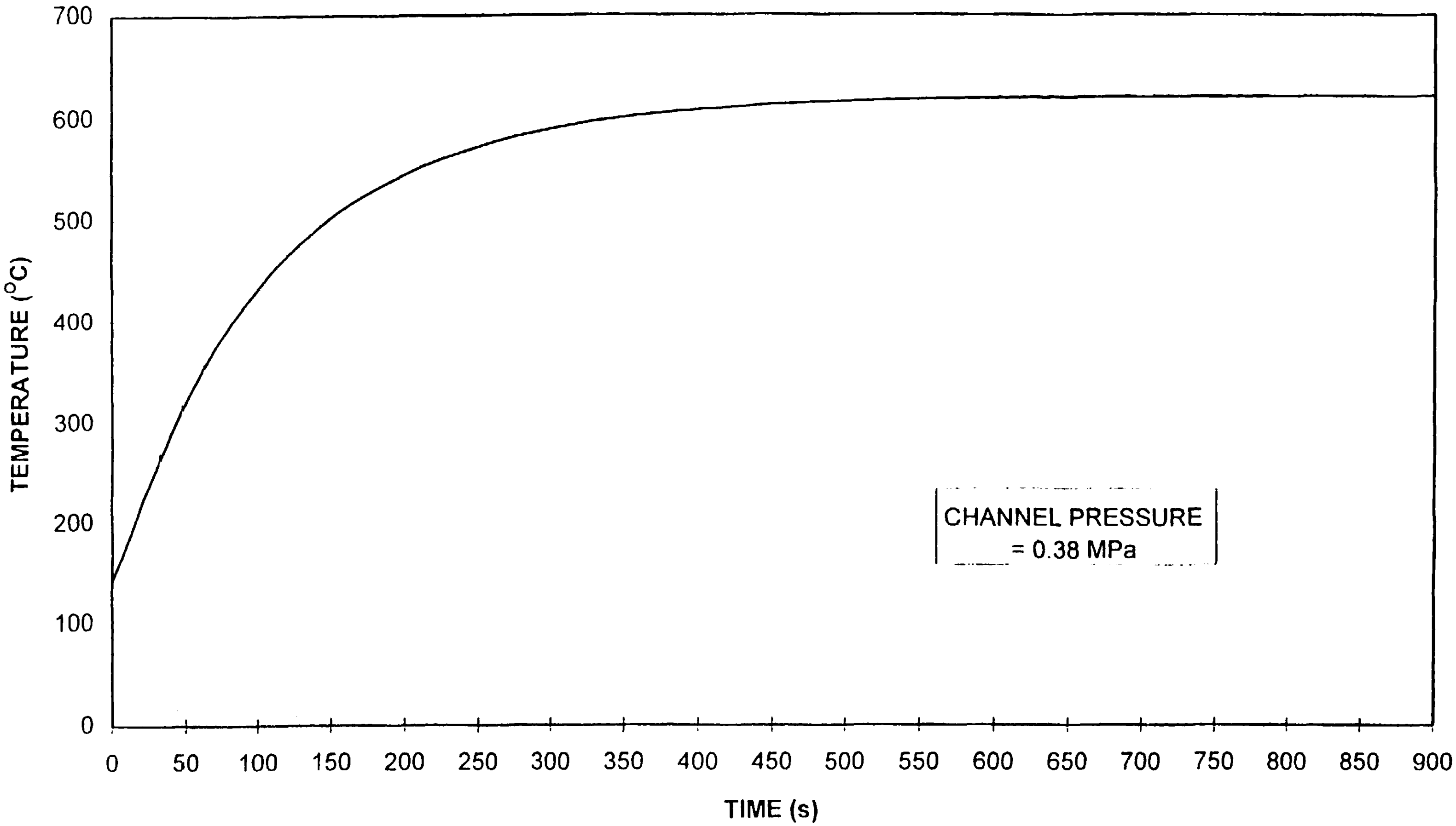

FIGURE 4 : FUEL TEMPERATURE PREDICTED BY AMPTRACT/BENDORY FOR STRATIFIED CHANNEL O6 FOLLOWING OUTLET FEEDER VOIDING FOR A DUAL FAILURE LARGE LOCA SCENARIO IN GENTILLY 2

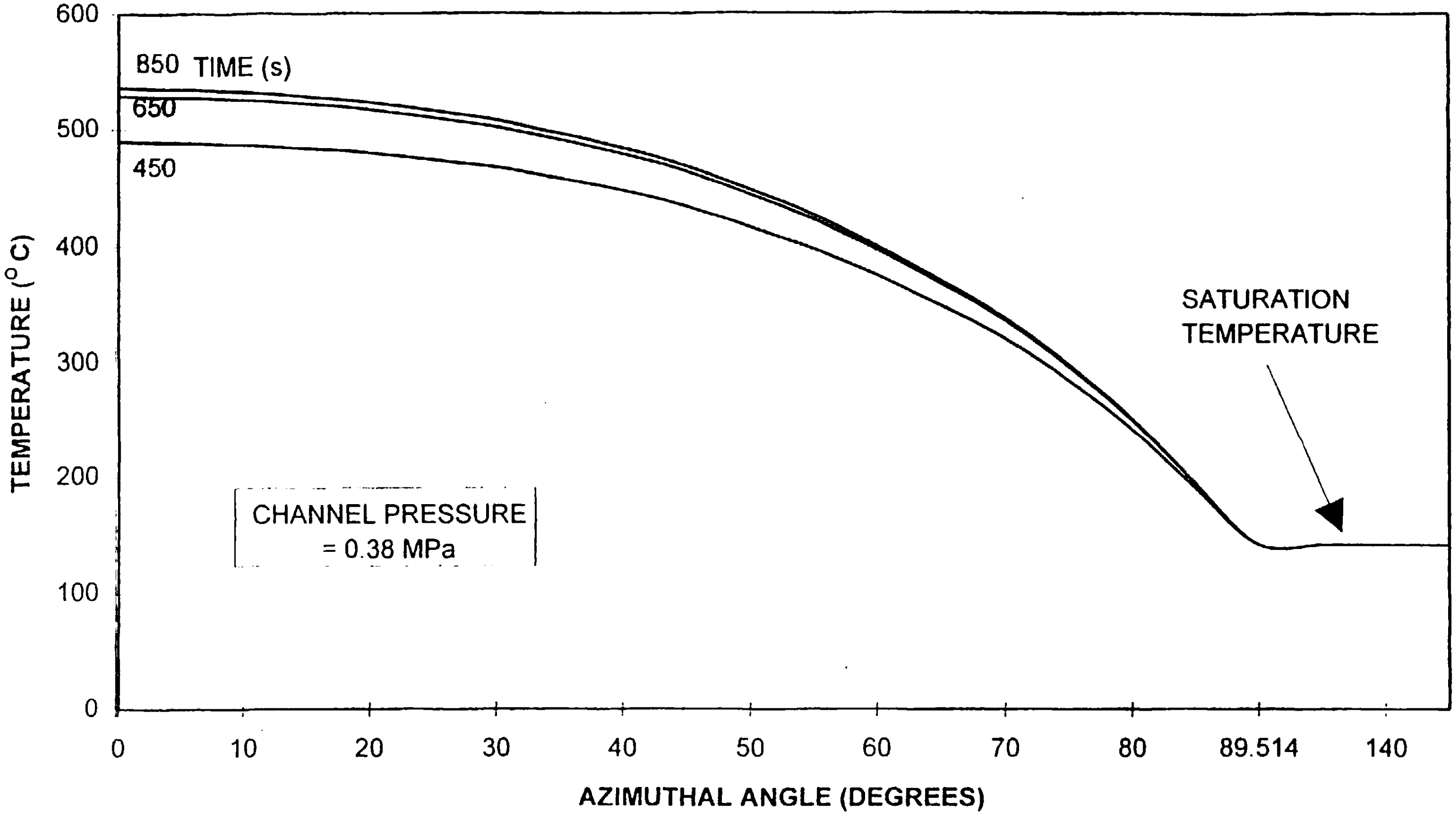

FIGURE 5: PRESSURE TUBE CIRCUMFERENTIAL TEMPERATURE TRANSIENT PREDICTED BY AMPTRACT/BENDORY FOR STRATIFIED CHANNEL 06 FOLLOWING OUTLET FEEDER VOIDING FOR A DUAL FAILURE LARGE LOCA SCENARIO IN GENTILLY 2