MODELLING INLET OR OUTLET FEEDER VOIDING AND FUEL SIMULATOR COOLING UNDER NATURAL CIRCULATION CONDITIONS IN THE RD-14M LOOP**

by

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ABSTRACT

To better understand thermosyphoning behaviour in CANDU, a number of two-phase thermosyphoning experiments were conducted in the multiple-channel RD-14M test facility. Above some loop void fraction in these experiments, the flow permanently reverse direction in some of the simulated fuel channel assemblies. Following flow reversal in these assemblies, the assembly outlet feeders became water-filled. Subsequently, void appeared in some of these outlet feeders causing the fuel element simulators (FES) to heat up. At higher loop void fraction in some of the tests, similar voiding occurred in the forward-flow inlet feeders.

This paper presents models, dubbed BENDORY and TALSMALL, which were developed to explain and predict feeder voiding and FES temperature behaviour observed in the RD-14M tests.

BENDORY models partial voiding of an initially water-filled reverse-flow outlet feeder under oscillatory low void loop. BENDORY assumes that, for certain conditions, reverse outlet feeder flow entrains steam bubbles of sufficiently small size from the connected outlet header into the feeder. The paper presents some of the RD-14M test results to justify this and other model assumptions.

TALSMALL was developed previously to model water draining in a forward-flow inlet feeder following steam -water phase separation in the connected inlet header. This phase separation exposed the inlet feeder nozzles to steam causing the feeder water to drain.

The channel conditions predicted by BENDORY and TALSMALL were used in the model AMPTRACT developed previously to predict FES temperature.

The comparison of BENORY/TALSMALL/AMPTRACT/CATHENA predictions and of the RD-14M test results presented in this paper forms part of a validation basis for these models which were used to predict fuel and fuel channel cooling under natural circulation conditions in the intact loop for accident scenarios in the Gentilly 2 plant.

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ACKNOWLEDGEMENT

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INTRODUCTION

Following loss of pumped primary circuit coolant flow in CANDU, a mode of natural circulation flow, called thermosyphoning, would transport the decay heat from the horizontal multiple fuel channels to the boilers above the core. The density difference of the coolant in the core inlet and outlet piping maintains this unidirectional natural circulation flow of either water or steam-water mixture over the top of the boiler U-tubes. For voided loop conditions, thermosyphoning flow is referred to as two-phase thermosyphoning.

Previous studies used single-channel models or facilities to examine the effectiveness of two-phase thermosyphoning to remove the core decay heat. These investigations indicated that thermosyphoning was effective up to a high loop void fraction.

To better understand two-phase thermosyphoning behaviour in the multiple-channel CANDU, a number of two-phase thermosyphoning experiments were conducted in the multiple-channel RD-14M test facility. These experiments indicated that, for certain conditions, the flow in some of the individual channels permanently changed direction (References 1 to 6). As a consequence of this channel flow reversal and the resulting phenomena, the range of the loop void fraction over which thermosyphoning effectively removed the heat generated in the channels was significantly smaller in RD-14M than that in the single-channel test facilities (References 1,2,3,5, and 6).

To judge the applicability of the RD-14M test results to CANDU, the physical mechanism for the observed phenomena observed in RD-14M needs to be understood and modelled. These models can then be applied to the conditions in CANDU. The models BENDORY, TALSMALL, and AMPTRACT were developed to predict some of the key phenomena observed in the RD-14M thermosyphoning tests. These models were then used to predict fuel cooling under natural circulation conditions for the accident scenarios in Gentilly 2 (Reference 7). This paper presents a comparison of the BENDORY/TALSMALL/AMPTRACT/CATHENA preditions with some of the the RD-14M test results.

RD-14M TEST FACILITY

The RD-14M test facility (Figure 1) is a scaled-down, full-elevation representation of the CANDU heat transport system with most of the major components. In each of the two passes, there are five horizontal electrically heated simulated fuel channels each connected to inlet and outlet feeder pipes. The feeder pipes connect to various positions around and along horizontal inlet and outlet header manifolds. These headers connect to the steam generators. This paper uses the terminology: channel to refer to a simulated fuel channel, channel assembly to refer to a channel-inlet-outlet-feeder combination, pass to refer to each half of the primary heat transport circuit containing the five channel assemblies, and FES to refer to a fuel element simulator.

RD-14M THERMOSYPHONING EXPERIMENTS

A number of two-phase thermosyphoning experiments were conducted in RD-14M at various loop integrated void fraction (or coolant inventory), channel power, and secondary side pressure. For given channel power and secondary side pressure, the primary circuit void fraction was increased intermittently by draining fluid from the loop.

PHENOMENA IN RD-14M EXPERIMENTS

The RD-14M tests exhibited the following phenomena, among others. (Some of these and other phenomena are described in References 1 to 6.)

At about 4% and higher void fraction in some of the tests, the thermosyphoning (i.e., above-header) and channel flows, the inlet-header-minus-outlet header pressure, and other loop parameters became oscillatory.

At about 7% and higher loop void fraction in some of the tests, the flow permanently reversed direction in some of the channel assemblies in each pass. In each of these channel assemblies, the flow reversal filled the outlet feeder with water and the inlet feeder with a two-phase mixture.

At about 10% and higher loop void fraction in some of the tests, the reverse flow in some of the outlet feeders began to decrease. Subsequently, void appeared in the lower parts of these outlet feeders and the temperature of the upper FESs in the channels connected to these feeders increased above the saturation temperature. These tests were finally terminated on high (600 °C) FES temperature.

At about 18% and higher loop void fractions in some of the tests, the thermosyphoning flow stopped. Subsequently, the forward flow in the inlet feeders began to decrease in succession. Shortly afterwards, void appeared in the lower parts of these inlet feeders and the temperature of the FESs in the connected channels increased above the saturation temperature. These tests were finally terminated on high (600 °C) FES temperature.

MODELLING OUTLET FEEDER VOIDING PHENOMENON

The RD-14M test results were studied to explain the physical process which produced void in an outlet feeder causing the reverse flow in this feeder to decrease. From this study it was inferred that the reverse outlet-feeder flow entrained steam bubbles from the connected outlet header into the feeder. A mathematical model, dubbed BENDORY, was developed for this entrainment process to predict the behaviour in the outlet feeder and channel void and flow and FES temperature transient observed in the RD-14M tests.

BENDORY was developed using the following approach.

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 at least 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 illustrated in Figure 2.

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:

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

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 from the outlet header into the outlet feeder of this channel assembly as illustrated in Figure 2.
This assumption was inferred from the results of the RD-14M tests as follows.

It is clear that the presence of steam in the outlet feeder reduced the hydrostatic head and, therefore, the reverse flow in the feeder. There are two possible sources for this steam.

One possibility is that it was generated within the feeder when the loop depressurization superheated the feeder water and the water flashed into steam. (In many of the tests, the feeder flow reduced during loop inventory draining and the resulting loop depressurization.) A number of test evidences indicates that this possibility is unlikely. Specifically, in test T8810, the reverse flow in an (initially water-filled) outlet feeder began to decrease over 400 seconds before the start of a loop inventory draining and the resulting loop depressurization. Furthermore, following flow reversal in HS11 and HS14 in test T8810, the flow in HS11 decreased but that in HS14 never decreased during a loop depressurization. More such test evidences that rule out feeder-water flashing as a possible mechanism for the outlet feeder voiding are presented below.

Therefore, the only other possibility is that the steam entered (i.e., was entrained into) the outlet feeder from the outlet header. A number of test evidences supports this inference and these evidences are presented below.

vi. The entrained steam bubbles mentioned in the item (v) above come from the outlet feeder(s) (refer to Figure 2): (a) where the flow is in the forward direction, and (b) which are located in the same bank of outlet feeders (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 forward-flow 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 the reverse flow because, for the low thermosyphoning flow of concern here and for the spatial separation of the adjacent feeder banks on the RD-14M outlet header, these bubbles have sufficient time to rise to the top of the outlet header as is depicted in Figure 2.

The assumption in the item (b) above is supported by the observations that: (c) following flow reversal in HS9 and HS14 in test T8810, the outlet feeder flow in these channels never decreased, and (d) No other feeder nozzles are connected to the outlet header in the same axial location as that of the either HS9 or HS14 outlet feeder (as Figure 2 illustrates).

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

$$W_{g} \; = \; \chi_{OH} \; W \tag{2}$$

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:

$$\begin{gathered} \textit{reverse feeder water velocity} \quad > \quad \textit{steam bubble rise velocity} \\ \text{and} \\ \textit{reverse feeder water flow} \quad \geq \quad \textit{outlet header water flow}, W_F, \textit{at this axial location} \end{gathered} \tag{3}$$

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. Generally, W_F is larger than W. However, under oscillatory loop conditions, W_F can become periodically less than W facilitating periodic steam bubble entrainment into a reverse-flow outlet feeder.

The second condition in eq. (3) is inferred from the following observation. The differential pressure along a reverse-flow outlet feeder is a measure of the amount of steam in the feeder. In the RD-14M tests, this differential pressure decreased periodically and only during an oscillation half cycle when the outlet feeder forward flows were decreasing (as is demonstrated below). During the other half of the oscillation cycle, the differential pressure either remained constant or increased particularly later on in the testing. This last observation implies that in this oscillation half cycle, steam bubbled out of the feeder into the outlet header. This observation and inference support the first condition in eq. (3).

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 larger 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 the void fraction in the reverse-flow 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 the 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 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 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 in this channel assembly is equal to that at the end of the 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 FES 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 8). 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.

The above processes determine the void fraction and bubble diameter at the end of the forward-flow outlet feeder(s). BENDORY accounts for these processes in evaluating the void fraction and bubble diameter at the end of the forward flow outlet feeder(s).

This void is equated to the void fraction in the outlet header at the axial location of the outlet feeder with the 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 which is the fraction of the steam bubbles entering the outlet header from the same-bank forward-flow outlet feeders that can be entrained by the reverse flow. Presently, the factor F_v is treated as a parameter evaluated from the RD-14M test results, 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 limiting outlet feeder void fraction at which the channel two-phase flow permanently stratifies. Therefore, the value of F_v does not affect the main conclusions drawn about FES heatup.

TALSMALL: a model for inlet feeder water draining

Inlet feeder water draining may occur following channel flow reversal (which brings a steam and water mixture into an 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 drains into the connected channels. This draining reduces the hydrostatic head in the inlet feeders and, therefore, the channel flows. Inlet feeder water draining occurred in channel HS9 in the RD-14M thermosyphoning test T8808.

The model TALSMALL was developed previously (References 9 and 10) to predict inlet feeder water draining and the resulting stratified channel flow conditions including channel void fraction and steam flow.

TALSMALL was used to compute the channel two-phase flow pattern resulting from inlet feeder water draining in the test T8808.

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

AMPTRACT was developed previoulsy (References 9, 10, and 11). 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.

The channel void fraction predicted by BENDORY and TALSMALL was used in AMPTRACT to compute FES temperature under stratified channel flow conditions.

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 used to predict inlet feeder water draining in the test T8808.

COMPARSION OF BENDORY/AMPTRACT PREDICTIONS AND TEST RESULTS

BENDORY was used to predict the outlet feeder voiding phenomenon in the RD-14M test T8809. BENDORY used the following test parameters as input: Channel-inlet coolant temperature, channel power, loop heat loss, and inlet-to-outlet header differential pressure oscillation amplitude and frequency, and RD-14M channel assembly geometry.

At about 7% loop void fraction in test T8809, the flow in channel HS8 reversed permanently and, at about 10% void fraction, the upper FES in HS8 began to heat up. BENDORY was used to predict HS8 outlet feeder voiding and the resulting channel flow behaviour. BENDORY was also used to predict the flow and void fraction in HS5, HS6, and HS7 when the flow in these channels were in the forward direction. Note that HS7 and HS8 outlet feeders are connected to the outlet header #7 in the same feeder bank, i.e., axial location, as illutstrated in Figure 2.

Figure 3 shows the reverse flow in the HS8 outlet feeder and the flow in the outlet header at the axial location of HS8 outlet feeder nozzle predicted by BENDORY. The predicted flows are oscillatory with a 65 second period. In Figure 35, the outlet feeder flow is 180° out-of-phase with the outlet header axial flow so that when the feeder flow is increasing, the header flow is decreasing. When the outlet feeder flow has become greater than outlet header axial flow, steam bubbles are entrained into the outlet feeder according to one of the model requirements in eq. (4). (This happens in each half of an oscillation cycle.) This entrainment reduces the hydrostatic head in the outlet feeder and, therefore, the mean feeder flow.

Eventually and near each oscillation trough, the corresponding channel flow periodically decreases below the flow stratification threshold and the flow briefly stratifies. This stratification changes the flow hydraulic resistance. This change coupled with the oscillations in the flow generates the high frequency oscillations in each half cycle observed in Figure 3.

About 1300 seconds after the start of first bubble entrainment, the outlet feeder reverse flow decreases to a minimum and subsequently remains constant when the feeder flow permanently becomes too low to entrain steam bubbles from the outlet header into the outlet feeder. Consequently, this entrainment stops according to first model requirement in eq. (3). Therefore, BENDORY predicts a certain minimum non-zero value for the feeder reverse flow due to the self-limiting characteristics of the bubble entrainment process as expressed by the conditions in eq. (3).

Figure 4 compares the differential pressure along HS8 outlet feeder predicted by BENDORY (solid curve) and observed (dashed curve) in the RD-14M test T8809 after the flow had reversed in this feeder. For the purpose of comparison, the time, in BENDORY, at which steam bubbles are first entrained from the outlet header #7 into HS8 outlet feeder is chosen to coincide as closely as possible with the start of the decrease in the observed feeder differential pressure. For this purpose also, the initial value of the predicted differential pressure (when the feeder was water-filled) is chosen to coincide as closely as possible with that observed in the test. (Note that, due to zero shift in the instrument reading, the initial value of the measured differential pressure in Figure 4 is not representative.)

The predicted differential pressure in Figure 4 decreases only in each half of an oscillation cycle as does the flow in Figure 3 and for the same reasons.

Figure 4 shows that the behaviour and the value of the feeder differential pressure predicted by BENDORY (solid curve) agree reasonably well with those (dashed curve) observed in the test T8809.

Figure 5 compares the volumetric flow predicted by BENDORY and observed in HS8 outlet feeder in the test T8809. As is noted in Figure 5, the outlet feeder flow has reversed. The predicted and observed flows agree reasonably well except for a systematic shift in the oscillation phase. This phase shift can be removed by a more accurate choice of the time at which steam bubbles are first entrained into the outlet feeder.

Figure 6 compares the fuel element simulator temperature predicted by AMPTRACT, using the channel void fraction predicted by BENDORY, and the temperature observed near channel HS8 exit in the test T8809. The predicted temperature increases above the saturation value to a limiting value of about 600 °C. This limiting value is achieved due to the self-limiting nature of the outlet feeder voiding process and, therefore, a partially water-filled channel and the resulting good steam cooling of the FESs. Figure 6 shows that the predicted and observed temperatures agree reasonably well.

COMPARISON OF TALSMALL/AMPTRACT PREDICITONS AND TEST RESULTS

TALSMALL was used to predict water draining in forward-flow HS9 inlet feeder following channel flow reversal and thermosyphoning breakdown in the RD-14M test T8808. TALSMALL used the following test parameters as input: Channel power, loop heat loss, header-to-header pressure difference, and the RD-14M channel assembly geometry.

Figure 7 compares HS9 inlet feeder volumetric flow predicted by TALSMALL and observed in the RD-14M test T8808. The flow initially decreases rapidly (within 80 seconds) to a small value and subsequently slowly (within 350 seconds) to zero. TALSMALL (conservatively) overpredicts the reduction in the flow.

Figure 8 compares the FES temperature predicted by AMPTRACT, using the channel void fraction predicted by TALSMALL, and the temperature observed near channel HS9 exit in the test T8808. The predicted temperature increases above the saturation value to about 612 °C. This temperature value is achieved due to good steam cooling of the FES in the test (before the inlet feeder inventory has decreased significantly). Figure 8 shows that the predicted and observed temperatures agree reasonably well.

COMPARISON OF CATHENA PREDICTIONS AND TEST RESULTS

Figure 9 compares the HS9 inlet feeder flow predicted by CATHENA and observed in the RD-14M test T8808. CATHENA predicts that the flow decreases to zero much faster than that observed in the test.

Figure 10 compares FES sheath temperature predicted by CATHENA and observed in the test T8808. CATHENA overpredicts the final temperature by about 200 °C and the predicted temperature continues to rise after this time.

DISCUSSIONS AND CONCLUSIONS

Above a certain loop void fraction in the RD-14M two-phase thermosyphoning experiments, the flow permanently reversed in some of the channel assemblies. In this flow reversal, the outlet feeders in these channel assemblies became water-filled. Subsequently, void appeared in some of the outlet feeders. In some of the tests at high loop void fraction, the water began to drain down in some of the inlet feeders of the channel assemblies with forward flows.

This paper provides physical explanations for the inlet and outlet feeder voiding phenomena in these tests. These explanations are inferred from a study of the test results. The paper also presents models, BENDORY and TALSMALL, developed to predict the feeder void and flow behaviour in these tests.

BENDORY was developed to predict the void and flow behaviour in an outlet feeder of a channel assembly following sustained flow reversal in this channel assembly. BENDORY assumes that the reverse outlet feeder flow entrains steam bubbles of sufficiently small size from the outlet header into the connected outlet feeder. These bubbles come only from the forward-flow outlet feeders which are located in the same feeder bank as the one with the reverse flow. The reverse feeder flow entrains steam bubbles only if the feeder velocity is higher than bubble rise velocity and if the feeder flow is higher than the outlet header axial flow.These conditions may be satisfied under oscillatory loop conditions. Under these conditions, bubbles are entrained into the feeder only periodically.

Steam bubble entrainment reduces the feeder hydrostatic head and, therefore, the feeder and channel flow. This entrainment is self-limiting, i.e., bubble entrainment ceases and, therefore, the feeder flow stops decreasing if the feeder flow becomes lower than that needed to satisfy the two conditions mentioned above.

The simulator fuel channel conditions predicted by BENDORY was used in the model AMPTRACT to predict the fuel and presssure tube temperatures.

The predictions of BENDORY/AMPTRACT agree reasonably well with the RD-14M test results. BENDORY predicts that, for the outlet feeder voiding process, the FES temperature increase is limited due to the self-limiting characteristic of the entrainment process. This limiting temperature is the temperature at which the RD-14M tests were terminated on high temperature power trip signal.

TALSMALL was developed previously to describe forward-flow inlet feeder voiding, called inlet feeder water draining, which may occur following channel flow reversal and thermosyphoning breakdown. TALSMALL/AMPTRACT and CATHENA predict conservatively the results results of an RD-14M test where inlet feeder water draining occurred.

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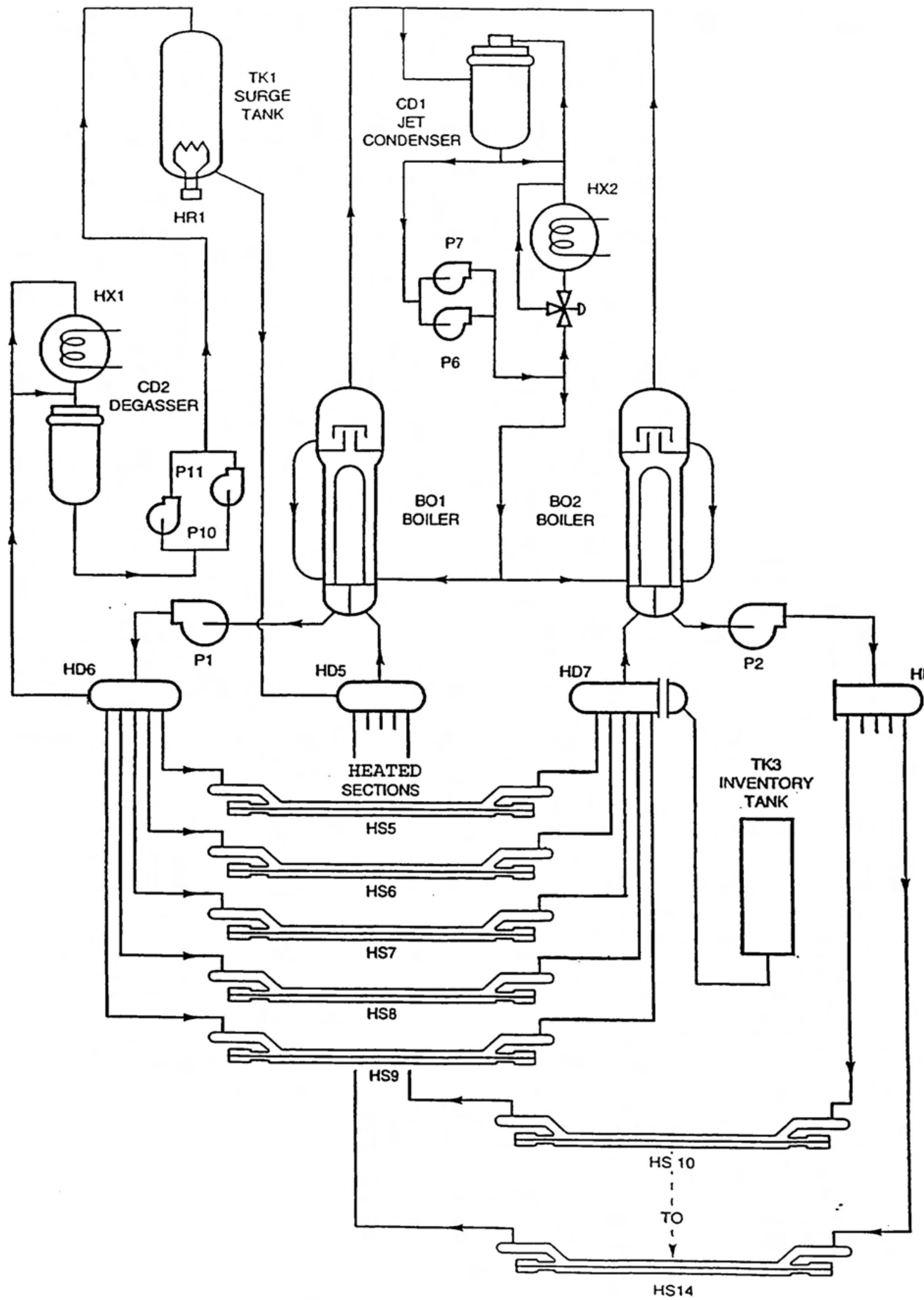

FIGURE 1 : RD-14M TEST FACILITY SCHEMATICS

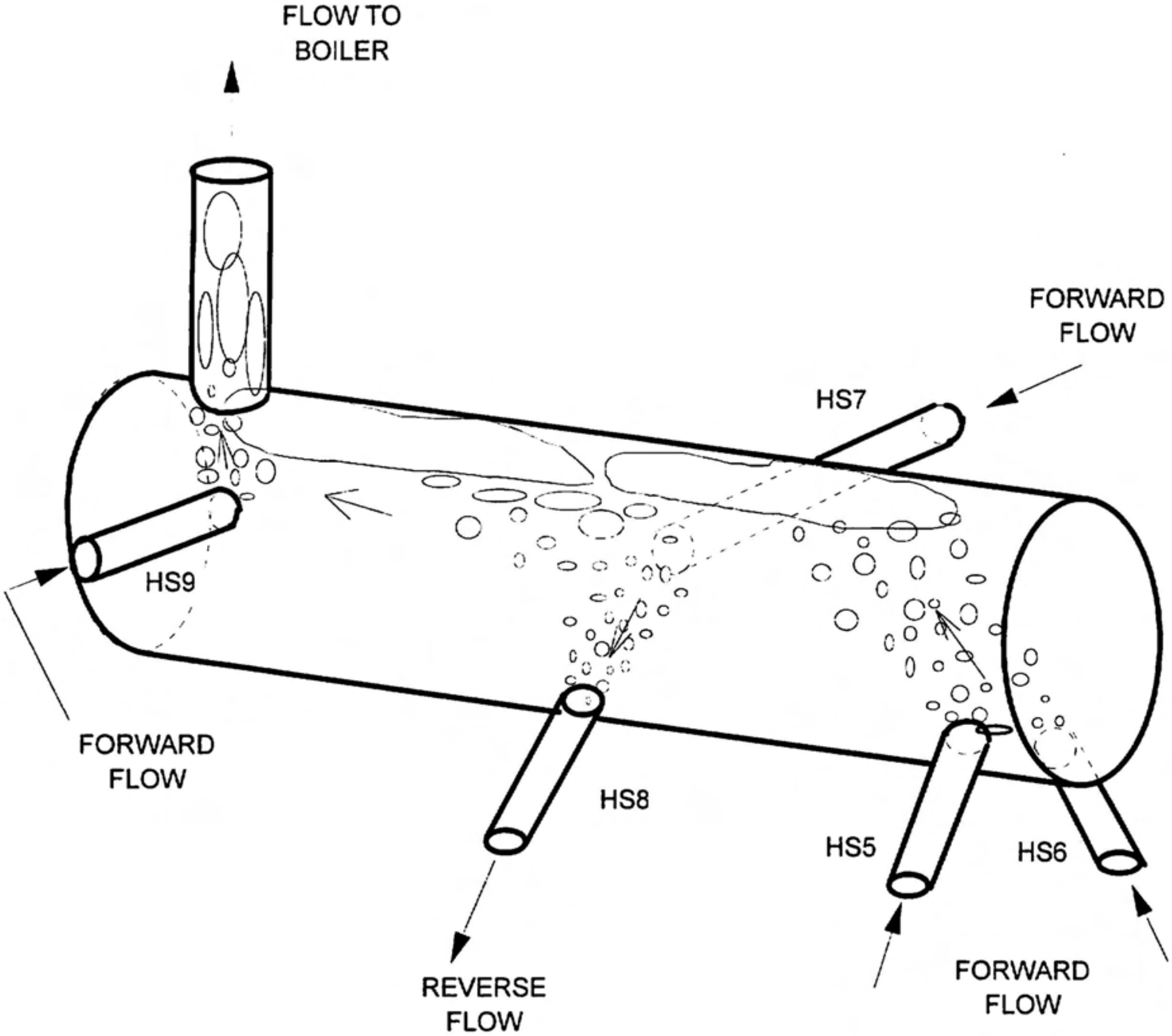

FIGURE 2: CONCEPTUAL TWO-PHASE FLOW PATTERN IN RD-14M OUTLET HEADER SHOWING BUBBLE ENTRAINMENT WITH REVERSE OUTLET FEEDER FLOW

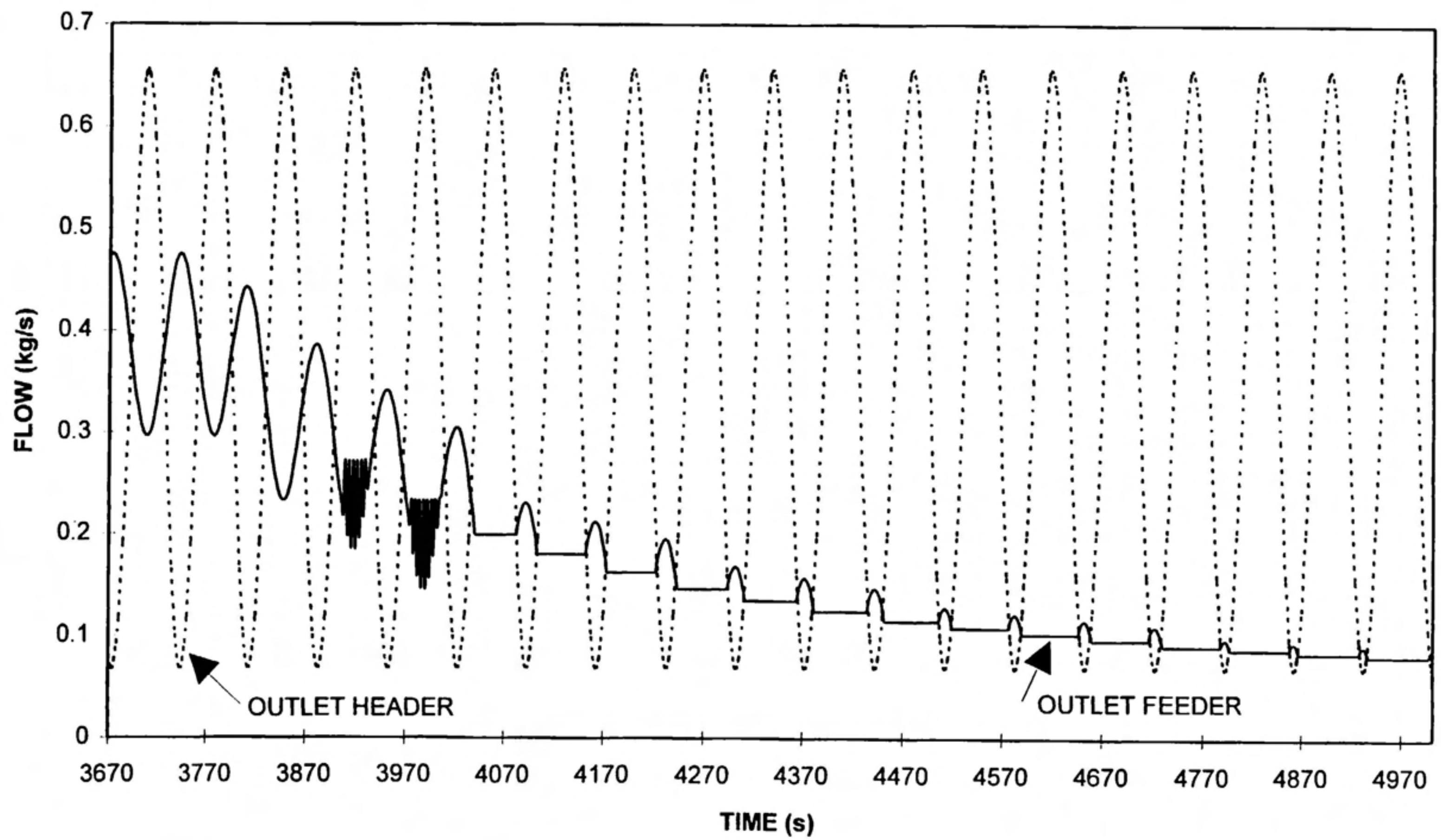

FIGURE 3: REVERSE FLOW IN HS8 OUTLET FEEDER AND OUTLET HEADER FLOW AT AXIAL LOCATION OF HS8 OUTLET FEEDER PREDICTED BY BENDORY FOR CONDITIONS IN RD-14M TEST T8809

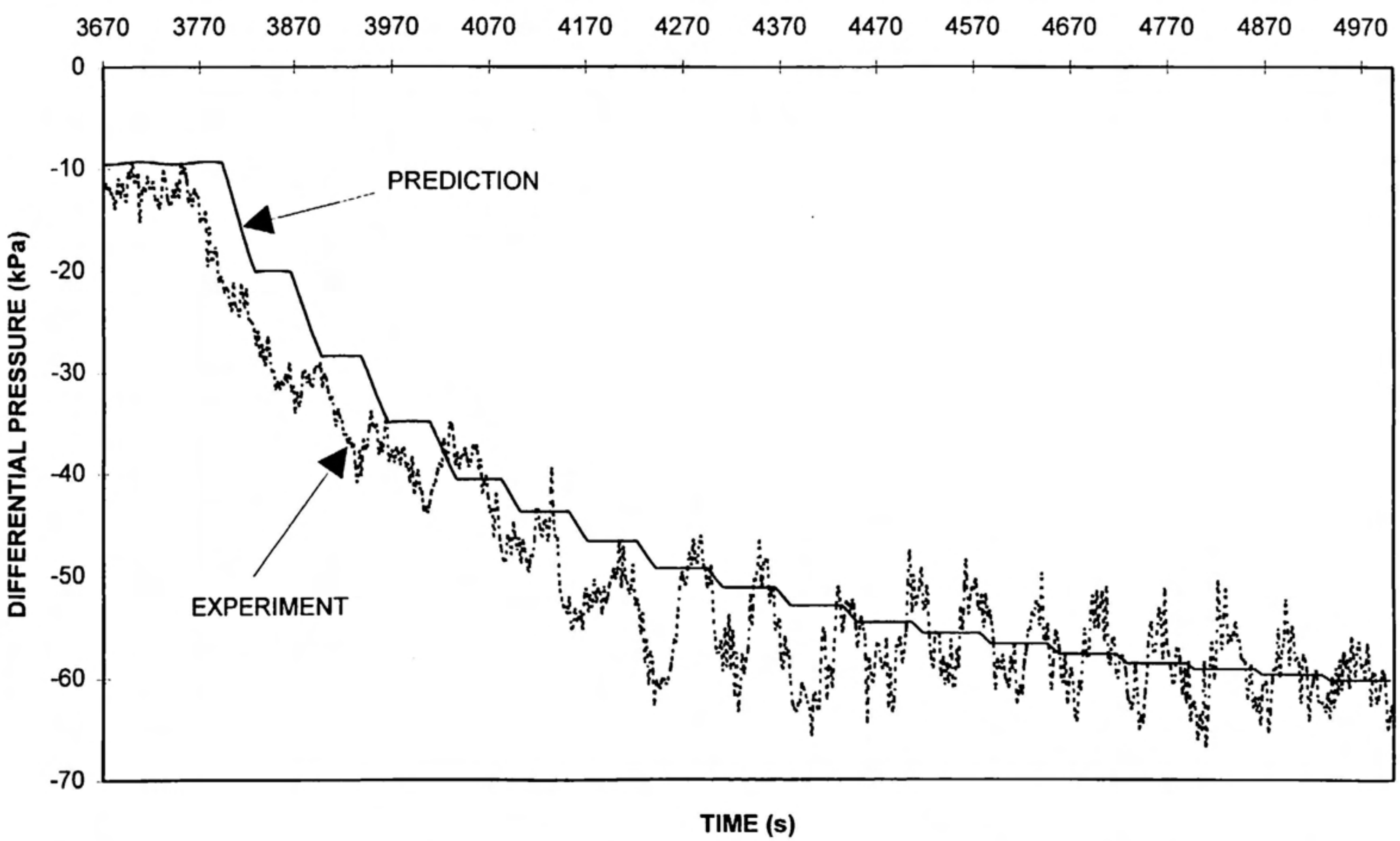

FIGURE 4 : PRESSURE DIFFERENCE BETWEEN HS8 CHANNEL OUTLET AND OUTLET HEADER #7 ALONG HS8 OUTLET FEEDER PREDICTED BY BENDORY AND OBSERVED IN RD-14M TEST T8809

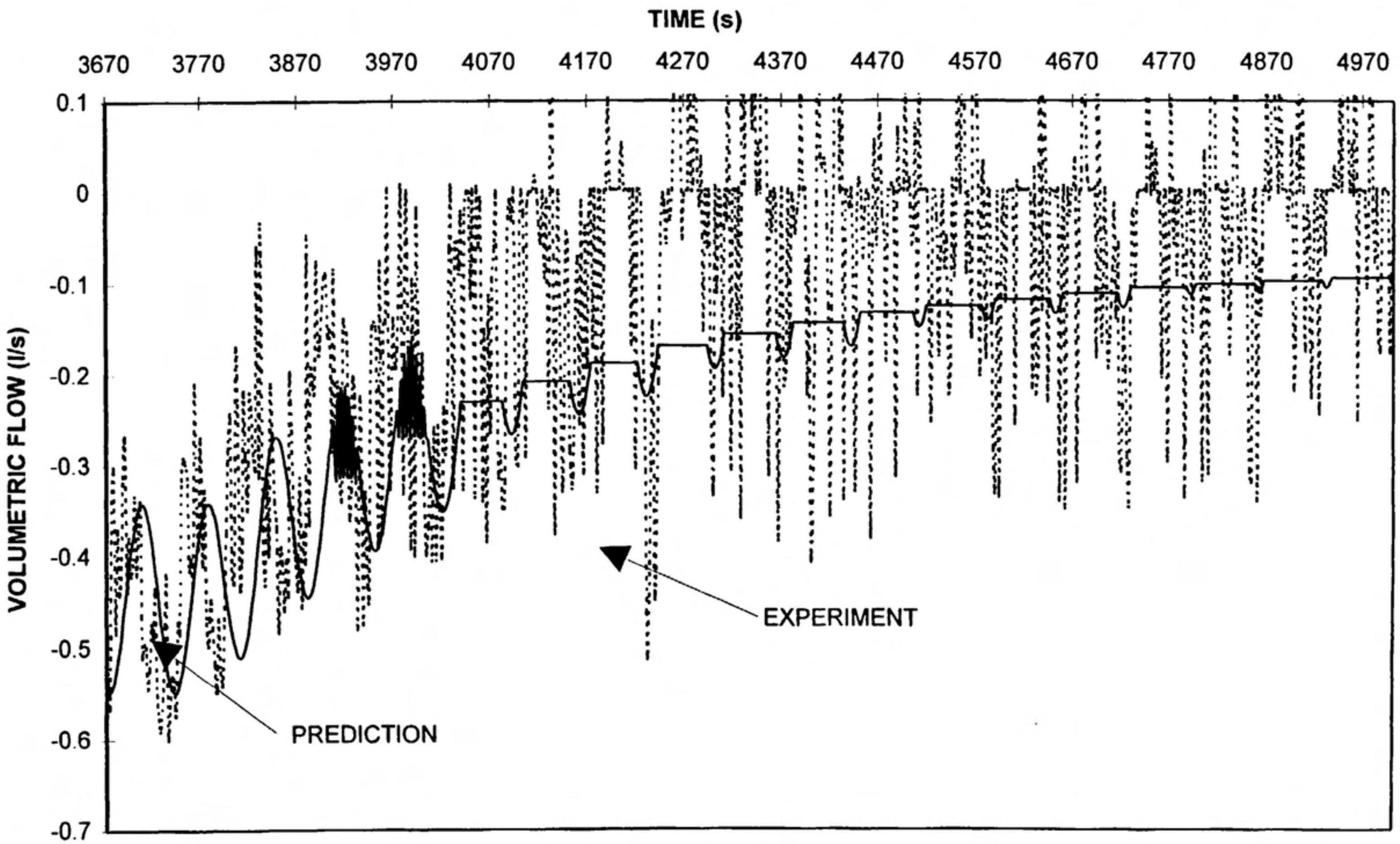

FIGURE 5 : HS8 OUTLET FEEDER FLOW PREDICTED BY BENDORY AND OBSERVED IN RD-14M TEST T8809

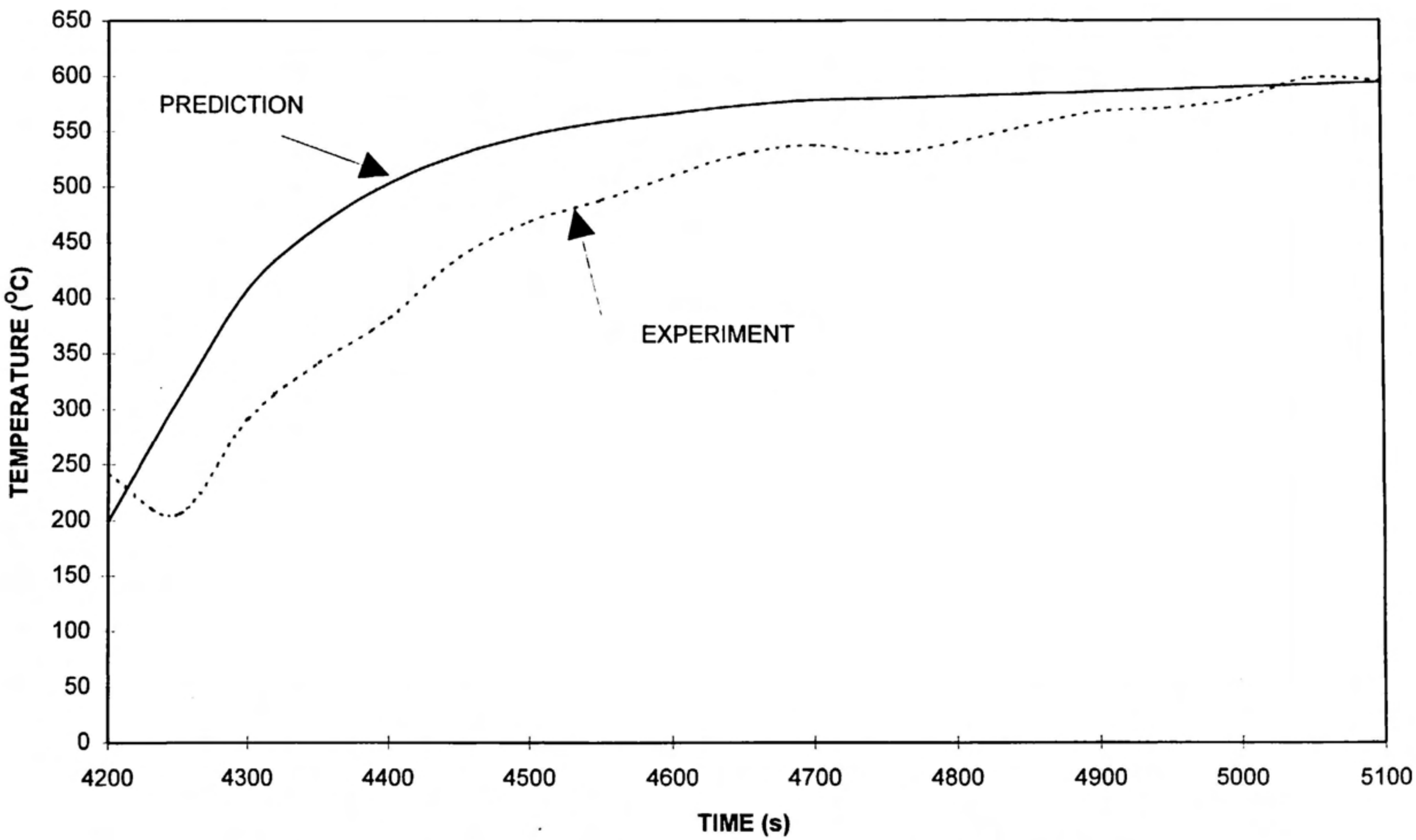

FIGURE 6 : FUEL ELEMENT SIMULATOR TEMPERATURE NEAR CHANNEL HS8 EXIT PREDICTED BY AMPTRACT/BENDORY AND OBSERVED IN RD-14M TEST T8809

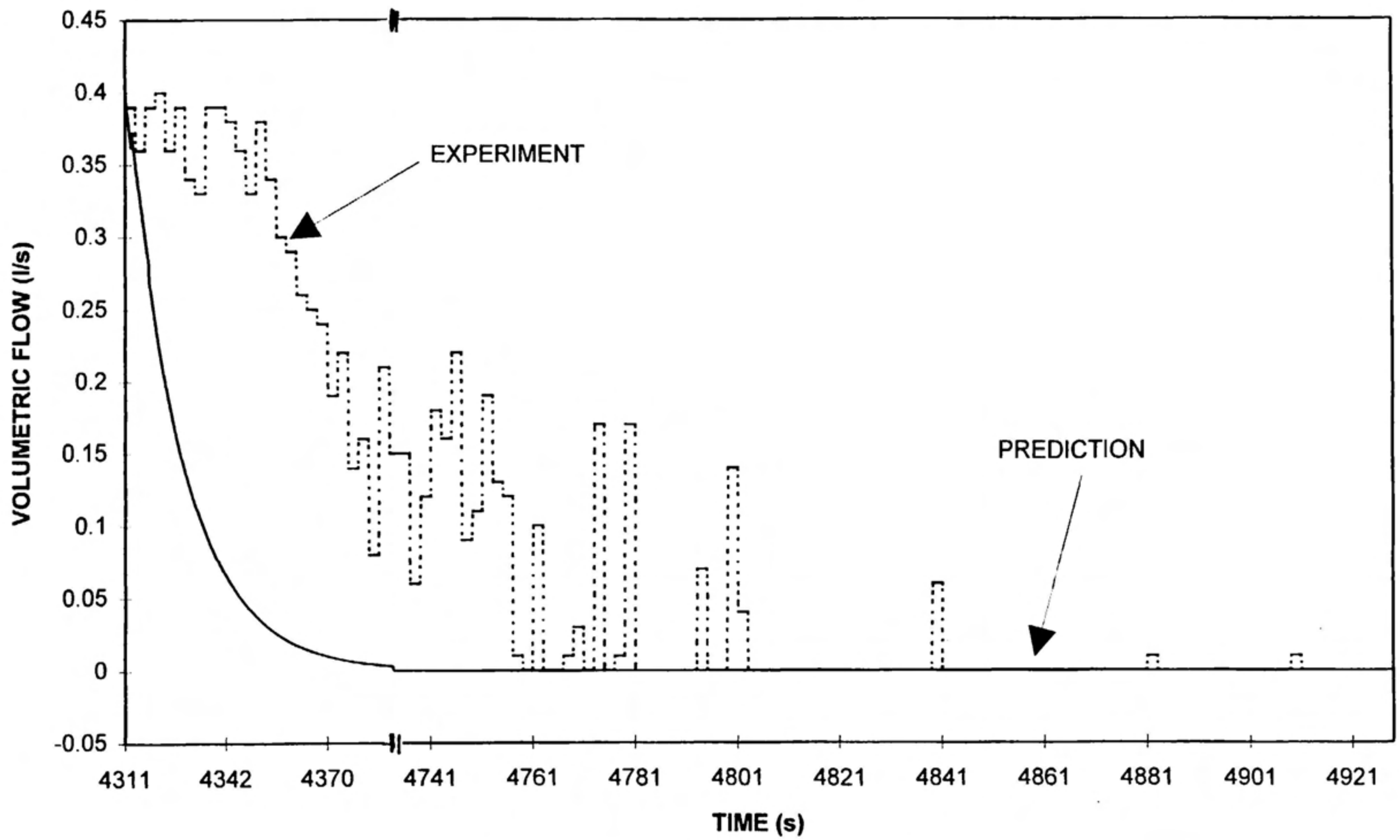

FIGURE 7 : HS9 INLET FEEDER FLOW PREDICTED BY TALSMALL AND OBSERVED IN RD-14M TEST T8808

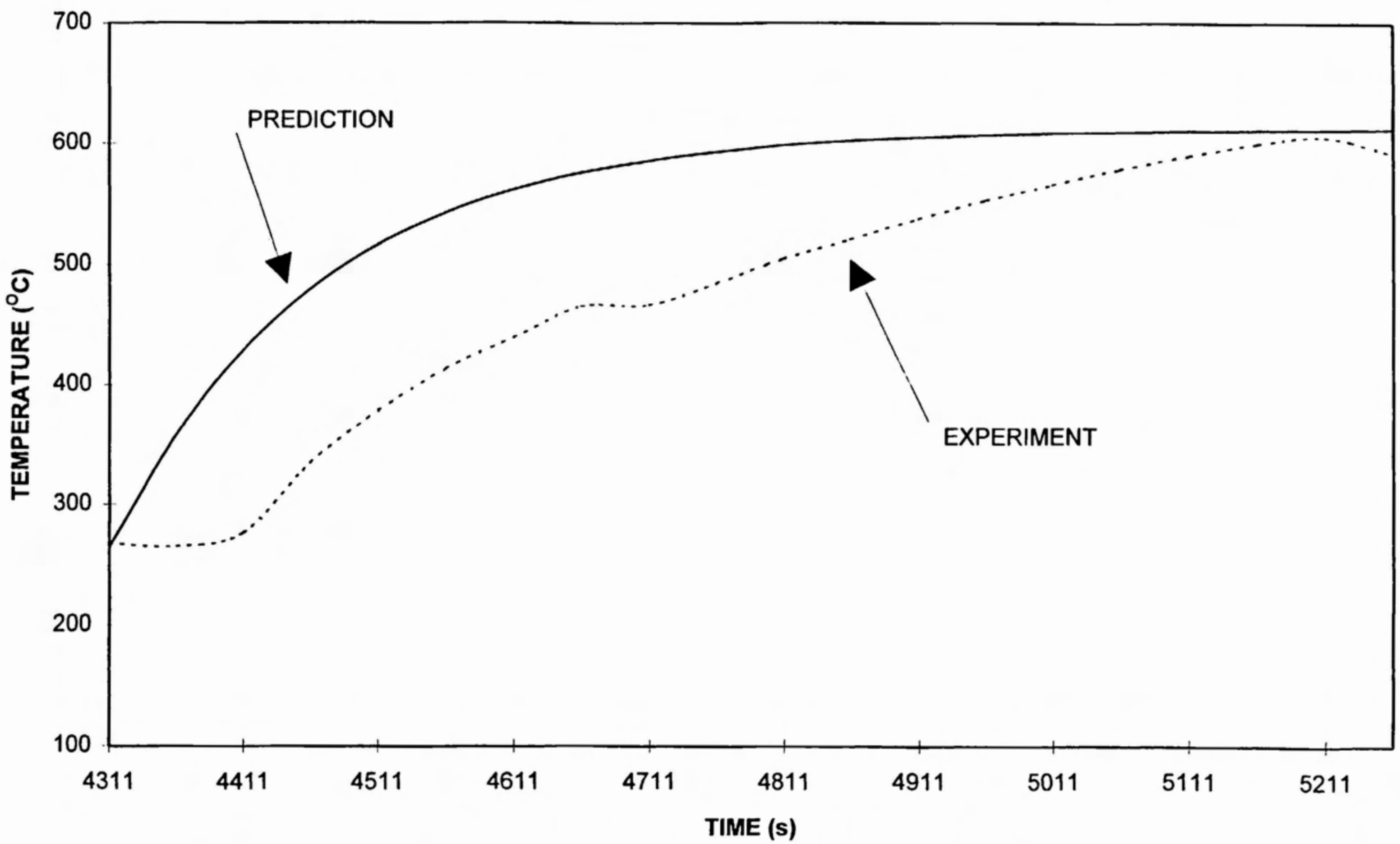

FIGURE 8 : FUEL ELEMENT SIMULATOR TEMPERATURE NEAR CHANNEL HS9 EXIT PREDICTED BY AMPTRACT/TALSMALL AND OBSERVED IN RD-14M TEST T8808

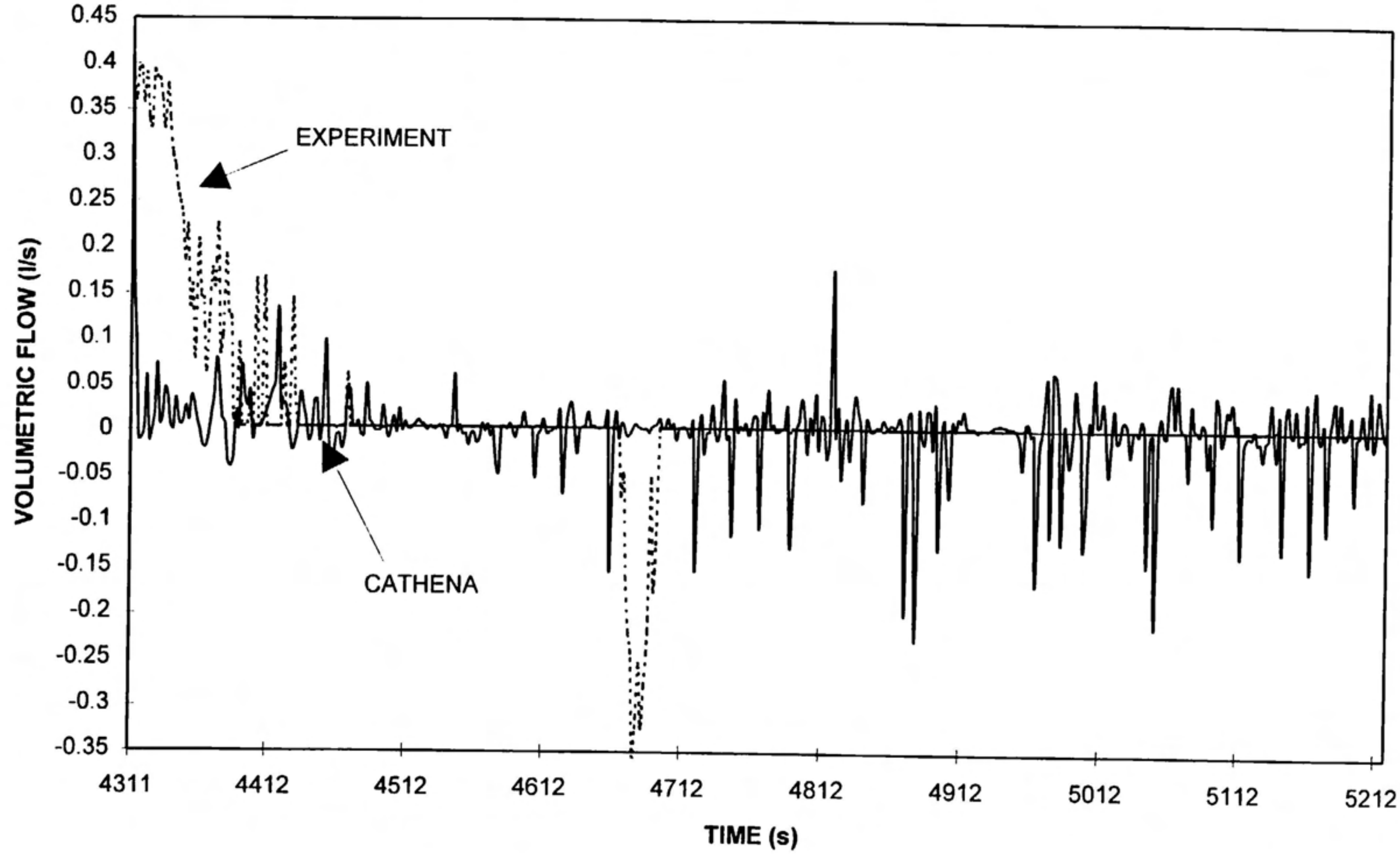

FIGURE 9 : HS9 INLET FEEDER FLOW PREDICTED BY CATHENA AND OBSERVED IN RD-14M TEST T8808

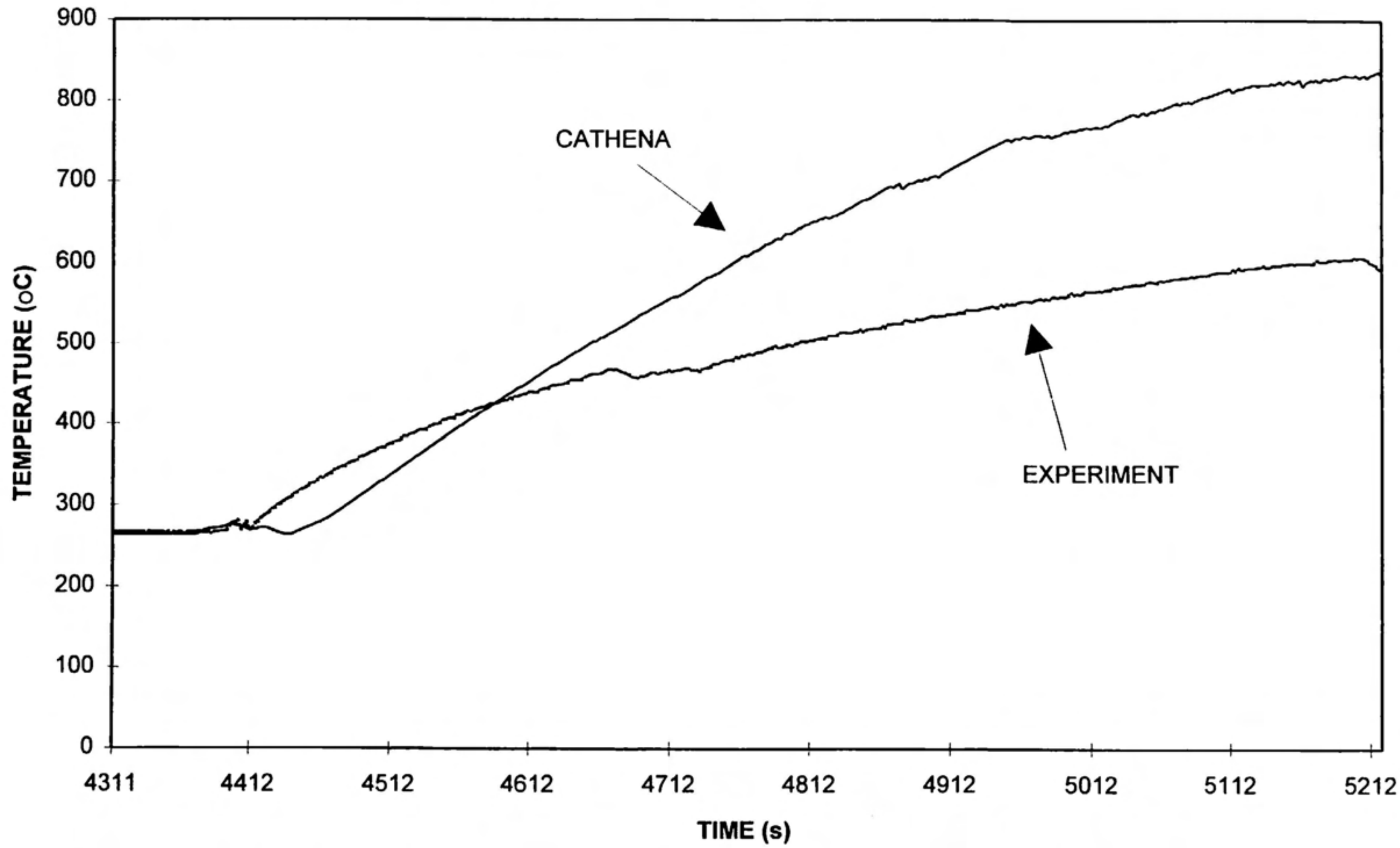

FIGURE 10 : FES SHEATH TEMPERATURE PREDICTED BY CATHENA AND OBSERVED IN RD-14M TEST T8808