**FY 1993 PROGRESS REPORT ON THE ANS THERMAL-HYDRAULIC TEST LOOP
OPERATION AND RESULTS**

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CONTENTS

	Page
LIST OF FIGURES	v
LIST OF TABLES	vii
ACRONYMS	ix
ABSTRACT	xi
1. INTRODUCTION	1
2. THE NATURE OF THERMAL LIMITS	3
3. FACILITY DESCRIPTION	7
4. TEST CHANNEL DESIGN	11
5. EXPERIMENTAL PROCEDURES	15
6. DATA REDUCTION AND ANALYSIS	17
6.1 THTL BASE MODEL	17
6.2 NONUNIFORM HEAT LOSSES AND REDISTRIBUTION	18
6.3 MULTIDIMENSIONAL MODELING OF THE TEST SECTION	22
6.4 RELAP5 SIMULATION OF THE THTL SYSTEM	23
6.5 FLOW EXCURSION SENSITIVITY TO BYPASS RATIO	25
7. SCOPE OF TESTS PERFORMED	29
8. RESULTS AND DISCUSSION	33
8.1 NONDESTRUCTIVE FLOW EXCURSION TESTS	33
8.1.1 Nominal Conditions Tests	33
8.1.2 Off-nominal Conditions Tests	33
8.2 DESTRUCTIVE FE AND CHF TESTS	40
8.2.1 Burnout CHF Test	40
8.2.2 Burnout Flow Excursion Tests	42
8.3 FLOW EXCURSION ELAPSED TIME	44
8.4 SUPPORTING TESTS AND OBSERVATIONS	44
8.4.1 Pressure Drop and Temperature Measurements	44
8.4.2 Oxide Layer Buildup	46
8.4.3 "Dry" Tests for Heat Loss Determination	52
8.5 COMPARISON OF DATA TO CORRELATIONS	54
8.6 PRELIMINARY STATISTICS OF THE THTL DATA	58
9. PROPOSED APPROACH TO CORRELATIONS	61

10. FUTURE PLANS	65
11. SUMMARY AND CONCLUSIONS	67
NOMENCLATURE	69
REFERENCES	71
Appendix A. THTL BASE MODEL FOR DATA REDUCTION AND ANALYSIS (MASANORI KAMINAGA)	A-1

LIST OF FIGURES

Figure	Page
1 ANSR core assembly and fuel plates arrangement	2
2 Phenomena and criteria leading to FE instability	4
3 Advanced Neutron Source (ANS) Thermal-Hydraulic Test Loop (THTL)	8
4 Schematic diagram of the THTL primary components and instrumentation	9
5 Cross section of the channel in the THTL	11
6 THTL test section instrumentation	13
7 Apparent discrepancy between experimental and predicted heat transfer coefficient (HTC)	19
8 THTL energy loss and other possible sources of errors	20
9 Assumed and actual THTL heater wall temperature profiles	22
10 Comparison of THTL data to 3-D HEATING7 simulation (test FEN17C07)	23
11 Unheated THTL test section results: comparison of data with RELAP5 results for versions 7ac and 8k0	24
12 Heated THTL test section results for FE212A (12.15 MW/m ²) and FEN17C) (10.62 MW/m ²) compared with RELAP5 results and the Filonenko correlation	25
13 Sensitivity of bypass supply pressure drop to bypass flow ratio	27
14 Sensitivity of bypass supply pressure drop to bypass flow ratio compared to test FE212A	28
15 Flow excursion data from THTL experiments	35
16 Additional flow excursion data from THTL experiments	36
17 Decay heat and possible shutdown operations	38
18 Flow excursion data from THTL	39
19 Destructive CHF and FE tests performed in the THTL	41
20 Pressure drop vs velocity for two THTL tests	45

21	Test channel from test THTL-07 (inlet on left-hand side)	47
22	Temperatures increasing at constant power as a result of oxide buildup in THTL-11 test series (HL505A and HL507B)	49
23	Temperatures reaching equilibrium shortly after power becomes constant in a typical experiment	50
24	Oxide pattern observed near test channel exit for THTL-11	51
25	THTL test FE719B of THTL-13 series showing temperatures ranging even during constant or increased velocity	53
26	Results of conduction heat loss "dry test" for the THTL test section: (a) heavier weld at the top and (b) heavier weld at the bottom	55
27	Calibration of HEATING7 model to THTL no-flow data	56
28	Comparison of THTL FE data with correlations	57
29	Comparison of THTL FE data with the Gambill/Weatherhead correlation	59
30	Proposed modified Saha and Zuber correlation for Stanton number	62
31	Proposed modified Saha and Zuber correlation for Nusselt number	63

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	THTL test and data summary	30
2	Critical heat flux and flow excursion tests performed at the THTL	34
3	Uncertainty U factor statistics of various FE models with comparison to the FE data base	60

ACRONYMS

ANS	Advanced Neutron Source
ANSR	Advanced Neutron Source reactor
BPR	bypass ratio
CHF	critical heat flux
DNB	departure from nucleate boiling
FE	flow excursion
HTC	heat transfer coefficient
IB	incipient boiling
INEL	Idaho National Engineering Laboratory
LOCA	loss-of-coolant accident
NPA	nuclear plant analyzer
OFI	onset of flow instability
ONVG	onset of net vapor generation
CRNL	Oak Ridge National Laboratory
OSV	onset of significant void
RTD	resistance temperature device
S&Z	Saha and Zuber
T/C	thermocouple
T/H	thermal-hydraulic
THTL	Thermal-Hydraulic Test Loop
W&F	Whittle and Forgan

ABSTRACT

The Thermal-Hydraulic Test Loop (THTL) is an experimental facility constructed to support the development of the Advanced Neutron Source Reactor (ANSR) at Oak Ridge National Laboratory (ORNL). The ANSR is currently being designed to become the world's highest-flux steady-state thermal neutron source for scientific experiments. The average and peak heat fluxes in the reactor are ~ 6 and 16 MW/m^2 , respectively, with a nominal total thermal power of 300 MW. Highly subcooled heavy-water coolant (1.7 MPa and 84°C at the exit) flows vertically upward at a very high mass flux of almost $27 \text{ Mg/m}^2\text{-s}$. In a parallel fuel plate configuration as in the ANSR, the flow is subject to a potential excursive static-flow instability that can very rapidly lead to flow starvation and departure from nucleate boiling (DNB) in the "hot channel." The current correlations and experimental data bases for flow excursion (FE) and critical heat flux (CHF) seldom evaluate the specific combination of ANSR operating parameters.

The THTL facility was designed and built to provide known thermal-hydraulic (T/H) conditions for a simulated full-length coolant subchannel of the ANS reactor core, thus facilitating experimental determination of FE and CHF thermal limits under expected ANSR T/H conditions. Special consideration was given to allow operation of the system in a "stiff" mode (constant flow) and in a "soft" mode (constant pressure drop) for proper implementation of true FE and DNB experiments. The facility is also designed to examine other T/H phenomena, including onset of incipient boiling, single-phase heat transfer coefficients and friction factors, and two-phase heat transfer and pressure drop characteristics. Tests will also be conducted that are representative of decay heat levels at both high pressure and low pressure as well as other quasi-equilibrium conditions encountered during transient scenarios.

A series of FE tests with water flowing vertically upward was completed over a nominal heat flux range of 6 to 17 MW/m^2 , a mass flux range of 8 to $28 \text{ Mg/m}^2\text{-s}$, an exit pressure range of 1.4 to 2.1 MPa, and an inlet temperature range of 40 to 50°C . FE experiments were also conducted using as "soft" a system as possible to secure a true FE phenomena (actual secondary burnout). True DNB experiments under similar conditions were also conducted. To the authors' knowledge, no other FE data have been reported in the literature to date that cover such a combination of conditions of high mass flux, high heat flux, and moderately high pressure.

Comparison of these data as well as extensive data from other investigators led to a proposed modification to the Saha and Zuber correlation for onset of significant void (OSV), applied to the FE prediction. The modification takes into account a demonstrated dependence of the OSV or FE thermal limits on subcooling levels, especially in the low subcooling regime.

1. INTRODUCTION

The Thermal-Hydraulic Test Loop (THTL) is an experimental facility constructed to support the development of the Advanced Neutron Source Reactor (ANSR) at Oak Ridge National Laboratory (ORNL). The Advanced Neutron Source (ANS) is a state-of-the-art research reactor facility designed to become the world's most advanced thermal neutron flux source for scientific experiments. Therefore, the core of the ANSR must be designed to accommodate very high power densities using very high coolant mass flux and subcooling levels. Statistical/probabilistic uncertainty analysis is being performed to determine the optimal design power and provide the necessary safety margin. This analysis requires selecting the most appropriate thermal-hydraulic (T/H) correlations and developing uncertainty distribution profiles based on the best available data.

The ANSR is cooled and moderated by heavy water and uses highly enriched uranium silicide fuel. The core is composed of two concentric annular core halves, each shifted axially and radially with respect to the other (see Fig. 1). There are 684 parallel aluminum clad fuel plates (252 comprise the inner-lower core and 432 comprise the outer-upper core). Each plate is 1.27 mm thick and is arranged in an involute geometry that effectively creates an array of thin, rectangular flow channels. The coolant channels have a 1.27-mm gap width, spans of 87 and 70 mm (lower and upper core respectively), and a 507-mm heated length. Each fuel plate has 10 mm of unheated leading and trailing edges, with all the channels having common inlet and outlet plenums with nominal pressures of 3.2 and 1.7 MPa respectively. The coolant flows vertically upward at an inlet velocity of 25 m/s and a Reynolds number of 9.9×10^4 . The inlet and average outlet temperatures are 45 and 85°C respectively. The average heat flux is 5.9 MW/m² with a radial and axial maximum of 12 MW/m². A more complete description of the ANSR configuration and T/H conditions is given by Yoder et al. (1993).

The ANSR core configuration with multiparallel channels is subject to a potential static instability called flow excursion (FE), which differs from a true critical heat flux (CHF) that would occur at a fixed channel flow rate, as discussed later. The existing correlations and experimental data bases for FE and CHF seldom cover the specific combination of ANSR operating parameters. This observation is reflected in Boyd's excellent survey on subcooled flow boiling CHF (Boyd 1985) and for FE in Duffey and Hughes (1990); Lee, Dorra, and Bankoff (1992); and Rogers and Li (1992). In addition, many investigators in the past did not distinguish between FE and true CHF, which adds to the inconsistencies in the available FE and CHF data bases, since both are very complex but different phenomena. The general process of correlation evaluation and selection, as well as the correlations currently used in the ANSR T/H analysis, are discussed by Siman-Tov et al. (1991).

A THTL facility was designed and built to provide a simulated full-length coolant subchannel of the ANS reactor core, to enable experimental determination of FE and CHF thermal limits under expected ANSR T/H conditions. Determination of these two thermal limits and the relationship between them is the main objective of the THTL facility. However, the facility is also designed to examine other T/H phenomena, including onset of incipient boiling, single-phase heat transfer coefficients and friction factors, and two-phase heat transfer and pressure drop characteristics.

Although the facility's primary aim is to investigate thermal limits at the ANSR nominal conditions for normal operation and safety margin analysis, tests will also be conducted that are representative of decay heat levels at both high pressure (e.g., loss of off-site power) and low pressure [e.g., a loss-of-coolant accident (LOCA)] as well as other quasi-steady-state conditions encountered during transient scenarios. This report will discuss the initial experiments focused on the

Fig. 1. ANSR core assembly and fuel plates arrangement.

FE phenomena at ANS nominal conditions, the few true CHF experiments performed for comparison, and some off-nominal experiments primarily for decay heat removal conditions. A condensed version of the material presented in this report was presented as a paper at the 29th National Heat Transfer Conference in Atlanta, August 9-11, 1993 (Siman-Tov et al. 1993).

2. THE NATURE OF THE ADVANCED NEUTRON SOURCE REACTOR THERMAL LIMITS

The cooling channels in the ANSR fuel assembly are all parallel and share common inlet and outlet plenums, effectively imposing a common pressure drop across all the channels. This core configuration is subject to FE and/or flow instability (Ledding 1938, 1949) that may occur once boiling is initiated in any one of the channels. The FE phenomenon constitutes a different thermal limit than a true CHF or departure from nucleate boiling (DNB). In such a system, initiation of boiling in one of the channels (i.e., the hot channel) can result in flow redistribution to the other, cooler channels. This process can very rapidly lead to flow starvation, which, in turn, leads to a DNB in the hot channel at flows lower than the nominal flow rate. The FE phenomenon is in contrast to a primary DNB that occurs at a nominally constant flow rate, referred to here as a "true CHF."

The more complete way to predict the occurrence of FE is to perform flow vs pressure drop analysis of the parallel channels involved and predict the subsequent flow redistribution under constant and common pressure drop boundary conditions. Performing this prediction is quite complex because of the uncertainties involved in predicting void fractions and pressure drops in two-phase flow. In reality, after boiling starts, the flow resistance of the channel increases, leading to flow reduction in the channel. The flow reduction promotes more boiling, which, after a certain point, rapidly leads to a more severe flow starvation. Therefore, it is normally accepted that FE [also referred to as the onset of flow instability (OFI)] will most likely occur near the point where sustained net vapor first appears. This point is called the onset of net vapor generation (ONVG) point (Costa 1967) or the point of onset of significant void (OSV).

Maulbetsch and Griffith (1965) and other investigators analytically and experimentally demonstrated the conditions under which excursive instability will occur. They determined that such instability will occur "if the slope of the (demand) pressure-drop vs flow rate (or velocity) is more negative than that of the external supply system." This statement is expressed mathematically as (Maulbetsch and Griffith 1965):

$$\frac{d(\Delta P_{ext})}{dV} > \frac{d(\Delta P_u)}{dV} \quad (1)$$

Figure 2 presents a typical plot of the pressure drop vs flow rate relationship under various boundary conditions. In the case of many parallel channels between large common headers, as is the case in the ANSR, the pressure drop slope of the external supply system is practically zero and is represented in Fig. 2 by horizontal lines (A and B). Based on this observation, FE or OFI conditions were determined in most of the THTL FE experiments by detection of the test section pressure drop minimum as the flow to the test section was reduced under a constant heat flux. This method allowed for repetition of many nondestructive FE tests without experiencing an actual FE that normally causes test section failure. For confirmation and comparison, limited experiments were performed with an actual FE burnout, and some experiments were run with true CHF burnout under constant flow. To accommodate these experiments, the design of the THTL system had to respond to three separate modes of operation, as enumerated below.

1. A "soft" system was used to perform actual FE tests with burnout. In this mode, a large bypass around the test section was fully open so that the flow could split between the test section and the bypass to maintain an almost constant common pressure drop across both, thus closely simulating the ANSR configuration.

Fig. 2. Phenomena and criteria leading to FE instability.

2. A "stiff" system was used to perform true CHF tests with actual burnout at constant and known flow rates. In this mode, the bypass around the test section was completely closed to maintain a constant flow through the test section. In addition, a near-positive displacement pump that provides a nearly constant flow rate was used in the primary loop. This pump is insensitive to the system pressure drop characteristics. Small-diameter piping (to reduce volume) and a throttling valve were also used upstream of the test section inlet to enhance flow stability.
3. A modified "stiff" system was used to perform simulated FE tests without experiencing actual FE. In this mode, a closed or minimal bypass configuration, along with a significant pressure drop across the flow control valve upstream of the test section, was used to prevent actual FE or other flow instability. In this case, the potential for FE was determined by detecting the minimum pressure drop in a plot of pressure drop vs flow rate (which coincides with the ONVG point), as demonstrated by Maulbetsch and Griffith (1965), Whittle and Forgan (1967), Costa (1967),

Johnston (1988), Dougherty et al. (1989), and others. Most of the FE tests were performed using this approach.

Since the ANSR has many channels in parallel, an ideal bypass simulation in the THTL "soft" system would require a very large bypass flow ratio ("infinite bypass") and therefore an unrealistically large pump. In practice, however, a reasonable but not ideal flow ratio can provide a very close simulation with no significant error. The lowest bypass flow ratio necessary, which still provides sufficiently constant pressure drop boundary conditions, was investigated in two independent studies—one transient and one steady state. Both studies are based on models simulating the THTL as a pressure drop vs flow network to determine the sensitivity of the bypass pressure drop to changes in test section flow for a variety of bypass-to-test-section flow ratios. The first model showed that bypass ratios ≥ 4 begin to approach the response of an "infinite bypass," with absolute flow rates within 2% of the infinite bypass steady-state flow rates (Felde, Yoder, and Skrzyzke 1992). The second model showed in a preliminary way that the slope of the bypass pressure drop with the test section flow rate [supply side $d(\Delta P_{\text{ext}})/dV$ in Eq. (1)] for a typical run exceeds the slope of the test section pressure drop vs flow rate curve [demand side $d(\Delta P_{\text{u}})/dV$ in Eq. (1)] for a bypass ratio of ≥ 4 , satisfying the condition for instability [Eq. (1)]. This supply side slope becomes very small (close to horizontal) for bypass ratios in the range of 10 to 25, simulating more closely the ANSR parallel channel configuration (see Sect. 6.5 for further discussion).

Knowing which of the two types of limiting phenomena—true CHF or FE—should be used as a thermal limit for the ANSR configuration is crucial. In most cases, FE will precede true CHF in such a configuration (Waters 1966). However, the sequence of these phenomena depends on the specific conditions involved. It was demonstrated that FE will occur at heat fluxes much lower than the CHF (as low as half) at low pressure, low velocities, and low subcooling (Maulbetsch and Griffith 1965). It is noteworthy, however, that the margin between FE and CHF narrows as the level of these parameters increases, and, at a certain point, the trend may even reverse (Boyd 1988). Since ANSR normally operates at moderate pressures and very high mass flux and subcooling levels, one of the main goals of these tests is to determine the relationship between CHF and FE under ANSR conditions.

Another critical question for the ANSR design is the application of either FE or true CHF to local fuel plate conditions, such as "hot spots" and "hot streaks," that may occur on the fuel plate over a small, limited area as a result of manufacturing imperfections that cause local heat flux peaking. In addition, the effect of the hot subchannel* on these thermal limits must be addressed. Because experimental evidence indicates little mixing across the span (Costa 1967, Waters 1966, Yan and Theofanous 1992), FE in a hot subchannel can be treated as a narrow, independent subchannel in relation to the rest of the flow in the rectangular channel. Therefore, the heat flux and subcooling in each one of these subchannels can be applied independently, just as in the parallel channel configuration. The present ANSR T/H design technique applies appropriate uncertainties to each location on the fuel plate and checks the resulting heat flux against various limiting criteria, including FE and CHF. Since it is recognized that very localized boiling will not sufficiently impact the channel pressure drop to cause FE, FE is not used as a limiting criteria when the region of the fuel plate causing the limiting conditions is below a predetermined size (Yoder et al. 1993).

*A "hot subchannel" is defined here as an axial region of a certain width along the fuel plate that yields a maximum bulk coolant temperature rise. This region is also occasionally referred to as a "hot stripe."

3. FACILITY DESCRIPTION

The THTL was designed and built to provide a simulated full-length coolant subchannel of the ANS reactor core, allowing experimental determination of the thermal limits (both FE and CHF) under anticipated ANS T/H conditions. An isometric view of the facility is shown in Fig. 3, and a schematic diagram of the loop and its major components and instrumentation is presented in Fig. 4. A detailed description of the test facility is given by Felde, Yoder, and Skrzycke (1992) and by Felde et al. (1994). In the design process, special consideration was given to include the proper pump, test section bypass configuration, and system valving and piping to allow operation of the system in either stiff or soft modes, as discussed earlier.

The Moyno primary circulation pump is driven by a variable-speed motor through a gear drive. This pump and motor combination is capable of providing a wide range of flow and pressure conditions with near-positive displacement characteristics, which means that flow supply is insensitive to the loop pressure drop. Using the variable speed of the motor drive provides the capability for operating over most of the pump flow-pressure drop diagram up to $2.5 \times 10^{-3} \text{ m}^3/\text{s}$ flow and 4.1 MPa differential pressure across the pump at 750 rpm. When this pump is used in combination with the test section bypass line, a very wide range of mass flow conditions at the test section is possible. In the stiff mode, with a closed bypass, a near-constant test section mass flux in the range of 7 to 42 $\text{Mg}/\text{m}^2\cdot\text{s}$ can be used. (The maximum mass flux is limited by the overall pressure rating for the test loop.) In the soft mode, with a bypass flow ratio of 10 to 1, a maximum mass flux of 12 $\text{Mg}/\text{m}^2\cdot\text{s}$ at a near-constant bypass pressure drop can be used. At a 5 to 1 bypass flow ratio, this maximum increases to 23 $\text{Mg}/\text{m}^2\cdot\text{s}$. The approximation of the ideal bypass ratio (infinite) with a practical bypass ratio is in the nonconservative direction for FE data, but, as discussed earlier, it is believed that the approximation is sufficient from a practical point of view. Additional parametric studies will be performed to quantify the bypass ratio, and, if necessary, an additional pump will be installed parallel to the existing one to achieve even higher test section flows and bypass ratios (see discussion in Sect. 6.5).

Fig. 3. Advanced Neutron Source (ANS) Thermal-Hydraulic Test Loop (THTL).

Fig. 4. Schematic diagram of the THTL primary components and instrumentation.

4. TEST CHANNEL DESIGN

The test section and its boundary conditions were of primary interest in determining the T/H limits. A detailed description of the test channel design is given by Felde, Yoder, and Skrzycke (1992) and by Felde et al. (1994). The cross-section design, shown in Fig. 5, was similar to that used by Gambill and Bundy (1984) but was redesigned in accordance with the ANS characteristics. The test section simulated a single subchannel in the ANS reactor core with a cross section that had a full prototypic heated length (507 mm), the same flow-channel gap (1.27 mm), and the same material (aluminum) with a surface roughness ($\sim 0.5 \mu\text{m}$) reasonably close to that expected in the ANSR fuel plates. The channel span was scaled down to 12.7 mm (vs 87 and 70 mm for the upper and lower core halves in the ANSR) to limit total power requirements to the test section. The involute shape of the plates was not simulated to simplify the experimental design and operation. Other researchers have demonstrated that there is little lateral fluid mixing in such rectangular channels, even under two-phase flow conditions (Costa 1967, Waters 1966, Yan and Theofanous 1992). Furthermore, sources also maintain that span width (or span-to-gap ratio) does not have a significant effect on either CHF or FE within certain limits (Whittle and Forgan 1967 and Gambill and Bundy 1964). The test section wall thickness was 2.54 mm, dictated by the voltage/current of the power supplies. The reduced wall thickness at the curved ends was designed to reduce the heat flux and prevent the coolant bulk temperature from peaking on the curved ends of the channel, which could have led to premature burnout. The ratio of heat flux on the curved ends to that on the flat ends was 36% for the design shown in Fig. 5. Possible effects of lateral and axial heat redistribution by thermal conduction within

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- 1.27-mm x 12.7-mm rectangular channel
- Full Length - 507 mm
- Directly heated using dc current

Fig. 5. Cross section of the channel in the THTL.

the test section metal will be considered later through the use of a 3-D conduction model (see Sects. 6.2 and 6.3).

The test channel was instrumented on the back of the channel wall with type N thermocouples. The locations of these thermocouples on the test section are shown in Fig. 6. The spacing was staggered, as shown, to provide improved definition in the region close to the channel's exit, where FE or CHF was expected. Measurements at the center span were made on both sides of the channel at each axial location for redundancy. Pressure and temperature of the water were measured at the test section inlet and outlet with the pressure taps installed in the test section flanges, as shown in Fig. 6. The taps were located axially 12.7 mm from the "heated" channel at each end, which allowed a closer determination of the pressure drop across the heated region without the effects of possible condensation and dynamic pressure recovery that can occur between the end of the heated channel and the point of pressure measurement (Costa 1967).

The test channel was enclosed inside a stainless steel pressure backing and was thermally and electrically isolated from the backing by Mycalex insulation. The test channel was either welded or brazed on both ends into aluminum flanges, each 2.54 cm thick. The test section flanges were sandwiched between two 2.54-cm-thick aluminum electrical bus plates. The water connection to the test section was made concentrically inside this bus connection by a 5.08-cm flange and Teflon gasket that were fastened through the test section flange. The Teflon gasket and Micarta bolt sleeves provide electrical isolation for the piping loop. The stainless steel backing, which was in direct contact with the test section flanges at both ends, was split in the center and isolated at this point by Mycalex insulation. This design effectively separated the electrical contact requirements from the water sealing requirements of the loop interface.

Fig. 6. THTL test section instrumentation.

5. EXPERIMENTAL PROCEDURES

A detailed description of the experimental procedures and operation is given by Felde, Yoder, and Skrzyckie (1992) and by Felde et al. (1994). Prior to installation of the test channel assembly into the loop, the channel surface undergoes a surface treatment procedure similar to that used for fuel elements in the High Flux Isotope Reactor at ORNL and expected to be used for the ANSR fuel elements. This procedure involves cleaning and degreasing, followed by an acid treatment and hot water rinse. In addition, the as-fabricated flow channel gap is measured at locations along the axial length using a capacitance-type probe inserted into the channel. These data are used to improve conversion of volumetric flow measurements (made upstream from the test section) to local velocities in the channel.

Flow excursion tests (without burnout) are conducted in a stiff mode, as described earlier. These tests are initiated by controlling test section flow to a level where no boiling exists at the target heat flux level. The applied power to the test section is then raised to produce the target heat flux level. Exit pressure is automatically controlled via the system let-down valve and high-pressure makeup pump at the desired setting (nominally, 1.7 MPa). Process water flow to the secondary side of the heat exchanger is also automatically controlled to maintain the inlet bulk coolant temperature at the desired set point (nominally, 45°C).

Data are recorded continuously during these processes by the personal computer-based data acquisition system. Once the system is stabilized and data are obtained under steady-state conditions, the velocity is reduced to a lower level while monitoring the measured differential pressure across the test channel. This reduction is made through either pump speed reduction, flow control valve positioning, bypass flow adjustment, or some combination of the above, depending on the proximity of the conditions to the expected minimum. As the minimum is approached, the loop configuration is adjusted to minimize the amount of bypass flow and maximize the pressure drop across the control valve to prevent an actual excursion and channel failure. The system is allowed to stabilize at each of the selected velocity settings. Power supply and velocity adjustments are made concurrently to maintain the average heat flux constant. (This concurrent adjustment is necessary because the temperature coefficient of resistivity of the aluminum affects the current-voltage characteristics of the test channel as velocity is reduced and test channel wall temperatures increase.) Once the minimum in pressure drop has been clearly determined (by observation of increasing pressure drop as velocity is further decreased), the velocity is increased once again, and data are taken for comparison at some of the velocity points obtained during the earlier sequence.

6. DATA REDUCTION AND ANALYSIS

A number of data reduction models and analysis methods were developed to facilitate design of certain features of the experimental loop, planning the tests, analyzing the data acquired, interpreting the results, and comparing the results with existing correlations. The most important ones are discussed in the following sections.

6.1 THTL BASE MODEL

The THTL base model was developed to provide extensive data reduction capabilities, including prediction and comparison with correlations of interest. The model was simplified to steady state and a basically one-dimensional analysis, except that various "modifications" were incorporated to account for some of the multidimensional effects to the greatest extent possible. Two of the most important such effects were separation of the heat generation and thermal-fluid conditions in the flat portion of the channel from those near the two semicircular corners and the nonuniform heat losses along and across the aluminum channel itself. The model provides numerous summary tables and plots for both the data collected and the analyzed results. Most of this information is provided as a function of distance along the heated channel. A detailed description of the model's features and its logic block diagram is provided in draft form in Appendix A. This description will be supplemented with additional text describing the physical basis of the model's procedures and assumptions.

The basic model is based on single-phase forced-convection flow, focusing on the flat portion of the test channel (called "flats"), and excluding the semicircle corners (see Fig. 5). Fundamental variables required to identify the heat transfer characteristics in single-phase forced-convection heat transfer were the local heat flux (q''_{loc}), local inside surface temperature ($T_{w,loc}$) of the test section, local bulk coolant temperature (T_b), and coolant velocity (V) in the flat portion of the channel. Local heat flux on the flats (q''_{av}) was calculated based on the local temperature-dependent resistivity of the aluminum test section and the average heat flux on the flats (q''_{av}) after exclusion of heat losses, heat redistribution, and heat input in the semicircular corners. The average heat flux on the flats was determined on the basis of the total heat input (Q_{tot}) into the test channel as follows:

$$q''_{av} = Q_{tot} \left(1 - \frac{Q_{loss}}{Q_{tot}} \right) \frac{th_{al}}{L \times A_{al}} \quad (2)$$

Total heat input (Q_{tot}) is given by the product of the current (I) and the voltage (E) applied to the test section. Heat loss (Q_{loss}) is calculated by comparing the heat input (Q_{tot}) with the heat rate (Q_{cool}) transferred to the coolant:

$$\frac{Q_{loss}}{Q_{tot}} = 1 - \frac{Q_{cool}}{Q_{tot}} = 1 - \frac{\rho V A_{cs} C_p \Delta T_b}{EI} \quad (3)$$

The overall channel heat loss range of the tests was calculated to be between 5 to 12% of Q_{tot} , with the higher values being for the lower velocities. Coolant flow velocity (V) in the flats was converted from average coolant velocity (V_{av}) so that the pressure drop of the flats is equal to that of the semicircular channels.

As already described, the temperature of the test section required to identify the heat transfer characteristics is the channel surface temperature ($T_{w,in}$) on the flow side, but the thermocouples are located on the surface on the ceramic insulator side. Therefore, $T_{w,in}$ is determined from the local heat flux (q''_{loc}) on the channel flats by the following equation:

$$T_{w,in} = T_{w,out} - \frac{q''_{loc} \, th_{in}}{2k_{in}} - \frac{q''_{loc} \, th_{out}}{k_{out}} \quad (4)$$

The experimental data reduction model also includes a single-phase pressure drop calculation model. As described earlier, the test section inlet and outlet pressures were measured at the taps installed in the test section flanges, which are located axially 12.7 mm from the heated channel at each end. The pressure drop of the heated channel (ΔP_w) was converted from a measured pressure drop by excluding the pressure drops across the nonheated sections. The pressure drop across the nonheated section between the end of the test channel and the pressure tap is calculated with the Darcy friction factor using the Filonenko correlation (1954).

Other important calculations in the model include the local heat transfer coefficients based on the Petukhov correlation (1970), local incipient boiling heat flux based on the Bergles-Rohsenow correlation (1964), local FE limiting heat flux based on the Costa (1967) and Whittle and Forgan (1967) correlations, and local CHF limit based on the Gambill/Weatherhead correlation (Gambill 1963 and Weatherhead 1963), all as functions of distance along the heated channel.

6.2 NONUNIFORM HEAT LOSSES AND REDISTRIBUTION

Some temperature-measurement irregularities were apparent in some of the THTL tests performed. Because of those observations and major discrepancies consistently found between the heat transfer coefficients derived from the data vs the expected heat transfer coefficient based on forced-convection correlations such as Petukhov (see example in Fig. 7), a few series of tests were conducted specifically to investigate those issues. An energy balance block diagram, summarizing a number of possible sources of errors and including the effects of multidimensional thermal and electric fields, was prepared and is presented in Fig. 8 (percentages shown are crude approximations reflecting the order of magnitude expected).

There are a number of possible reasons for these discrepancies, which are being investigated systematically. Because the test section is made of aluminum, which has very high thermal conductivity and a strongly temperature-dependent electrical resistivity, one of the major uncertainties involved is the calculation of local heat flux at the test section midplane where the thermocouples (T/Cs) are installed. Although the total power to the test section is measured, the actual local heat flux will depend on the level of heat loss and the actual multidimensional thermal and electric field (Joule heating) distributions.

There are strong indications that heat losses and heat redistribution within the test section, both axially and in the spanwise direction, can affect considerably the local conditions in the test section. To help determine these local effects, a 3-D conduction model is being developed, which also includes simulation of the Joule heating in the test section (a strong function of temperature) and partial simulation of the fluid flow in the channel (which varies spanwise in both velocity and temperature). In the meantime, the uncertainty bounds of these effects were determined in a preliminary way by performing energy balance calculations and 1-D adjustments based on the

(a) One-dimensional isotherms.

(b) Multidimensional isotherms.

(c) Experimental vs. Petukhov heat transfer coefficient.

Fig. 7. Apparent discrepancy between experimental and predicted heat transfer coefficient (HTC).

Fig. 8. THTL energy loss* and other possible sources of errors.

assumption that the "measured" heat transfer coefficient should be quite close to the heat transfer coefficient calculated by the Petukhov correlation.

Using this technique, a "nonuniform" correction factor function was formulated for each test which was used for taking into account nonuniform axial heat losses in the test section. Another function was used to account for the spanwise redistribution of the heat out of the hotter midplane into the colder bulk fluid at the two semicircular corners of the channel. The two functions are composed of multiplying factors given along the length of the channel and bounded by the total heat losses of the test section.

This approach improved the situation on a preliminary basis but did not provide a total solution to the discrepancies found. One inherent problem is the sensitivity of the heat transfer coefficient calculations to the actual temperatures used. Because of the high fluid velocities involved, the thermal resistance of the boundary layer is relatively small (about a fifth of the total). That leaves only a small temperature drop (about 30–60°C, or even less if boiling occurs) between the interior wall and the bulk fluid temperature used for heat transfer coefficient calculations. As a result, even a small error in either the external wall temperature measured, the oxide layer thickness assumed, or the heat flux used for calculating the internal wall temperature will cause a significant error in the calculated heat transfer coefficient.

Several assumptions are associated with extracting the "measured" heat transfer coefficient from the THTL test section data. Some of these assumptions should be challenged to identify contributions to the reported differences between the measured THTL heat transfer coefficient and that predicted by conventional models. One assumption tacit to the measured heat transfer coefficients in THTL is uniform heat generation in the test section at a given cross section. The uniform heat generation assumption leads to the use of a parabolic temperature profile across the test section thickness, as shown in Fig. 9. The electrical resistivity of aluminum varies strongly with the local temperature as modeled approximately for the range of 20°C to 450°C by

$$R(T)_{\text{Al}} = [3.90 + 0.011 (T - 20)] \times 10^{-8}, \text{ ohm-m} . \quad (5)$$

The local power generation is inversely proportional to the local electrical resistivity, assuming that the voltage gradient is only a function of the axial position in the test section. Thus the actual temperature profile in the test section is not purely parabolic. More power is dissipated in the test section near the cooler wetted wall. Therefore, the slope of the actual temperature profile on the flow side of the wall is expected to be somewhat different from a purely parabolic form, as shown schematically in Fig. 9.

Simplified calculations examining the influence of temperature-dependent resistivity and conductivity were performed to determine their effect on the calculated liquid/wall interface temperature. Results were compared to the temperature of 300°C obtained using constant resistivity and conductivity in the calculations. The difference in the wetted wall temperature was $\sim 1^\circ$ for the temperature-dependent resistivity case and $< 1^\circ$ when both resistivity and conductivity $\pm$ allowed to vary with temperature. The revised profile had a slightly hotter wetted wall. This result indicates that the nonuniform power generation in the test section wall is responsible for a $< 2\%$ reduction in the temperature drop across the heater. This accounts for only about 3–5% of the current difference between the "measured" and predicted heat transfer coefficient. Other nonuniformity factors need to be taken into account, as discussed in other parts of this report.

Fig. 9. Assumed and actual THTL heater wall temperature profiles.

6.3 MULTIDIMENSIONAL MODELING OF THE TEST SECTION

In parallel to the above nonuniform correction factor approach, a 3-D conduction model using HEATING7 has been developed for the THTL test section assembly. The model includes the test section, Mycalex insulation, stainless steel casing, and top and bottom flanges. Voltage losses in the flanges and heat losses through the Mycalex insulation are also included in the model. This model does not allow a solution for the forced and natural convection on the inside and outside surfaces. Neither does it solve for the electrical field within the test section. Simplifying assumptions have been made to accommodate the lack of model capability.

The heat losses out the top, bottom, and sides of the test section assembly were calibrated using data taken for a test run without any coolant flow in the test section channel. The heat losses were also simulated in an earlier test run that included coolant flow and a nominal test section heat flux of 12 MW/m^2 . A comparison of the axial temperature distribution in the test section wall is shown in Fig. 10. The total heat losses calculated from the experiment, based on the measured electrical heat input and the enthalpy increase of the coolant, are 6.7% (however, $\sim 2\%$ is lost before entering the test section itself). The heat losses calculated in the HEATING7 simulation are only 1.3%. Although thermocouple measurement error could explain some of this difference, it is probably not the major reason for the discrepancy.

A more complete treatment of this problem requires a fully multidimensional model integrating conduction, electrical effects (Joule heating), and the fluid flow. As a first step toward such

Fig. 10. Comparison of THTL data to 3-D HEATING7 simulation (test FEN17C07).

modeling, a full 3-D integrated conduction/electrical numerical model is being pursued in which the fluid flow conditions in the channel are externally specified as boundary conditions. The simulation will also take into account the effects of the flanges, the massive electrodes, the Mycalex insulation, the stainless steel pressure backup around the test section, and the surrounding thermal boundary conditions. In a later stage, modeling of the fluid flow, especially the spanwise distribution and lateral mixing, will be addressed.

6.4 RELAP5 SIMULATION OF THE THTL SYSTEM

A preliminary RELAP5 model has been assembled to represent the THTL. Two input files exist: one to represent only the test section with appropriate inlet and exit boundary conditions and another that includes the entire loop. The primary purpose for the model is to validate RELAP5 against data taken in a prototype ANSR test channel. The model has been linked to the Nuclear Plant Analyzer (NPA) software developed at Idaho National Engineering Laboratory (INEL) as a graphical RELAP5 interface; thus, test runs can be simulated easily and in a short amount of time. INEL has supplied a

copy of RELAP5/MOD3 version 8k0. This version is the latest working version of the code and has a more accurate friction factor correlation than version 7ac, which was previously used for ANS primary coolant system transient analysis.

Results with the THTL RELAP5 model using version 8k0 match closely the data for an unheated test section, as shown in Fig. 11. However, when a case is simulated at 12 MW/m^2 heat flux, the agreement is not as good. Figure 12 shows a comparison of RELAP5 results with two different THTL tests (FE212A and FEN17C). A comparison with the Filonenko-calculated pressure drop is also shown. The RELAP5 results, which use the Colebrook correlation, do not account for the variation in viscosity across the boundary layer. The Filonenko correlation is strictly for smooth walls (zero surface roughness). One major discrepancy between the RELAP5 results and the data is the lack of an upturn minimum in the pressure drop curve at the lower velocities, although this upturn has been observed in RELAP5 results for lower test section heat fluxes.

The comparison of RELAP5 results with FE212A data is particularly interesting because the two are very close at velocities higher than 22 m/s . As the velocity is lowered, the data suddenly depart from the RELAP5 results, possibly because voids begin to form in the test channel. It is known that

Fig. 11. Unheated THTL test section results: comparison of data with RELAP5 results for versions 7ac and 8k0.

Fig. 12. Heated THTL test section results for FE212A (12.15 MW/m²) and FEN17C (10.62 MW/m²) compared with RELAP5 results and the Filonenko correlation.

RELAP5 currently does not allow any void formation until the Saha and Zuber OSV criteria (1974) are exceeded. This is a problem that is being discussed with INEL personnel. A nodalization study was performed with the THTL RELAP5 model. It was found that no difference in the pressure drop resulted when the discretization was increased by a factor of 4.

6.5 FLOW EXCURSION SENSITIVITY TO BYPASS RATIO

Since the ANSR has many channels in parallel, a complete bypass simulation for a single channel would require a very large bypass ratio and therefore an unrealistically large pumping capacity. In practice, however, a reasonable (but not ideal) lower bypass ratio can provide a very close simulation with no significant error. Figure 2, presented in Sect. 2, shows the theoretical basis for this behavior and the criteria for excursive instability in terms of the demand and supply curve pressure drop slopes. A model was developed to analyze pressure drops and flows in the THTL with the objective of determining the sensitivity of the expected true FE in a soft system to the bypass-to-test-section flow ratio and comparing it to the minimum pressure drop approach used to determine the "FE" point for a stiff system (closed bypass). The optimum selection is at a bypass flow ratio where that

sensitivity is sufficiently small that a "point of diminishing returns" is reached. The entire THTL loop, including the piping, test section, bypass, and auxiliary equipment, was modeled using a software package called TK!Solver. Figure 13 shows the sensitivity of the supply pressure drop slope to increased bypass flow ratio at realistic conditions for a specific case tested in the THTL (FE212A15). Either curve can be used to make that judgmental decision, with the percent curve (on the right) having the advantage of providing a "feel" for the relative improvement per incremental unit increase in bypass ratio. Figure 14 provides the same information in a more graphical way against the background of a plot of the actual demand pressure drop vs test section flow as generated in a specific THTL run. General observation of the results of this sensitivity analysis leads to a judgmental determination that a bypass flow ratio in the range of 10 to 25 may be satisfactory, with a bypass ratio of 15 being a good middle ground. To achieve that level of bypass ratio would require a volumetric flow rate capacity of three times that currently available. Another potential concept to achieve constant pressure drop boundary conditions on the test section is the use of accumulators at each end of the test sections, each maintaining a constant pressure by an appropriate pressurized inert gas system.

Considering the large pumping capacity called for above in the present system, it must be remembered that the need for performing such experiments is primarily for demonstrating, under realistic ANSR conditions, that true FE for a very large bypass ratio coincides with the minimum pressure drop point in a stiff system. This, however, has already been demonstrated experimentally by a number of investigators although at lower velocities and subcoolings. The theoretical justification, on the other hand, applies to ANSR conditions as well, and the trend itself was demonstrated in the THTL runs performed so far: the higher the bypass ratio, the higher is the velocity at which true FE will occur, and it will approach the velocity that corresponds to the minimum pressure drop in a stiff system (see Sect. 8.2.2). Since the ANSR has many channels in parallel, the minimum pressure drop approach should provide an upper limit to that velocity without being overly conservative.

It was recommended, therefore, not to try to demonstrate a true FE in a soft system at the ANSR nominal conditions but rather to rely on stiff system experiments to provide measurements of that thermal limit. The THTL can be used to show the applicability of the trend at those conditions as well as to demonstrate the point experimentally at lower velocities. This approach will be reconsidered separately for transient conditions, where there is an interest in determining quantitatively the duration of an actual FE process prior to burnout.

Fig. 13. Sensitivity of bypass supply pressure drop to bypass flow ratio.

Fig. 14. Sensitivity of bypass supply pressure drop to bypass flow ratio compared to test FE212A.

7. SCOPE OF TESTS PERFORMED

The THTL experimentation for the ANSR T/H correlations is still in its initial stages. The current THTL (Figs. 3 and 4) and test section designs (Figs. 5 and 6) are the result of a number of initial shakedown and benchmark tests, which led to successive modifications in both the loop and the test section design. Initial emphasis was placed on the FE phenomena at nominal conditions. The first goal was to proceed from low levels of heat flux and velocity and then extend the tests to the extremely high levels required by the ANSR operating conditions. Most of the FE experiments completed so far were within the following T/H conditions:

- coolant: light water,
- inlet coolant temperature: 45°C,
- exit coolant pressure: 1.7 MPa,
- local (exit) heat flux range: 2–16 MW/m² (goal is 17 MW/m²),
- corresponding velocity range: 2.5–20.5 m/s (goal is 25 m/s), and
- channel configuration (Figs. 5 and 6): 1.27 × 12.7 × 507 mm (rectangular).

Some experiments were performed at lower exit pressures and different inlet temperatures, as will be discussed in Sect. 8.1.2. Table 1 provides a summary of all the tests performed so far, with the key features indicated for each test. These tests fall into one or more of the following categories:

- Shakedown and benchmark tests,
- Nonpower pressure drop tests,
- Heat loss tests ("dry tests"),
- Oxide-layer and water chemistry tests,
- Nondestructive flow excursion tests,
- ANS nominal conditions,
- ANS off-nominal conditions,
- Destructive flow excursion tests, and
- Critical heat flux tests.

In the following section, the results of these tests will be discussed, starting with the thermal limit tests (e.g., shakedown and benchmark tests) and ending with some supportive tests.

Table 1. THTL test and data summary

[illegible]

Test Name	Test ID	Test Date	Test Time	Test Location	Test Results	Test Comments	Test Status	Test Date	Test Time	Test Location	Test Results	Test Comments	Test Status
Test 1	101	10/10/10	10:10	101	101	101	101	10/10/10	10:10	101	101	101	101
Test 2	102	10/10/10	10:10	102	102	102	102	10/10/10	10:10	102	102	102	102
Test 3	103	10/10/10	10:10	103	103	103	103	10/10/10	10:10	103	103	103	103
Test 4	104	10/10/10	10:10	104	104	104	104	10/10/10	10:10	104	104	104	104
Test 5	105	10/10/10	10:10	105	105	105	105	10/10/10	10:10	105	105	105	105
Test 6	106	10/10/10	10:10	106	106	106	106	10/10/10	10:10	106	106	106	106
Test 7	107	10/10/10	10:10	107	107	107	107	10/10/10	10:10	107	107	107	107
Test 8	108	10/10/10	10:10	108	108	108	108	10/10/10	10:10	108	108	108	108
Test 9	109	10/10/10	10:10	109	109	109	109	10/10/10	10:10	109	109	109	109
Test 10	110	10/10/10	10:10	110	110	110	110	10/10/10	10:10	110	110	110	110
Test 11	111	10/10/10	10:10	111	111	111	111	10/10/10	10:10	111	111	111	111
Test 12	112	10/10/10	10:10	112	112	112	112	10/10/10	10:10	112	112	112	112
Test 13	113	10/10/10	10:10	113	113	113	113	10/10/10	10:10	113	113	113	113
Test 14	114	10/10/10	10:10	114	114	114	114	10/10/10	10:10	114	114	114	114
Test 15	115	10/10/10	10:10	115	115	115	115	10/10/10	10:10	115	115	115	115
Test 16	116	10/10/10	10:10	116	116	116	116	10/10/10	10:10	116	116	116	116
Test 17	117	10/10/10	10:10	117	117	117	117	10/10/10	10:10	117	117	117	117
Test 18	118	10/10/10	10:10	118	118	118	118	10/10/10	10:10	118	118	118	118
Test 19	119	10/10/10	10:10	119	119	119	119	10/10/10	10:10	119	119	119	119
Test 20	120	10/10/10	10:10	120	120	120	120	10/10/10	10:10	120	120	120	120
Test 21	121	10/10/10	10:10	121	121	121	121	10/10/10	10:10	121	121	121	121
Test 22	122	10/10/10	10:10	122	122	122	122	10/10/10	10:10	122	122	122	122
Test 23	123	10/10/10	10:10	123	123	123	123	10/10/10	10:10	123	123	123	123
Test 24	124	10/10/10	10:10	124	124	124	124	10/10/10	10:10	124	124	124	124
Test 25	125	10/10/10	10:10	125	125	125	125	10/10/10	10:10	125	125	125	125
Test 26	126	10/10/10	10:10	126	126	126	126	10/10/10	10:10	126	126	126	126
Test 27	127	10/10/10	10:10	127	127	127	127	10/10/10	10:10	127	127	127	127
Test 28	128	10/10/10	10:10	128	128	128	128	10/10/10	10:10	128	128	128	128
Test 29	129	10/10/10	10:10	129	129	129	129	10/10/10	10:10	129	129	129	129
Test 30	130	10/10/10	10:10	130	130	130	130	10/10/10	10:10	130	130	130	130
Test 31	131	10/10/10	10:10	131	131	131	131	10/10/10	10:10	131	131	131	131
Test 32	132	10/10/10	10:10	132	132	132	132	10/10/10	10:10	132	132	132	132
Test 33	133	10/10/10	10:10	133	133	133	133	10/10/10	10:10	133	133	133	133
Test 34	134	10/10/10	10:10	134	134	134	134	10/10/10	10:10	134	134	134	134
Test 35	135	10/10/10	10:10	135	135	135	135	10/10/10	10:10	135	135	135	135
Test 36	136	10/10/10	10:10	136	136	136	136	10/10/10	10:10	136	136	136	136
Test 37	137	10/10/10	10:10	137	137	137	137	10/10/10	10:10	137	137	137	137
Test 38	138	10/10/10	10:10	138	138	138	138	10/10/10	10:10	138	138	138	138
Test 39	139	10/10/10	10:10	139	139	139	139	10/10/10	10:10	139	139	139	139
Test 40	140	10/10/10	10:10	140	140	140	140	10/10/10	10:10	140	140	140	140
Test 41	141	10/10/10	10:10	141	141	141	141	10/10/10	10:10	141	141	141	141
Test 42	142	10/10/10	10:10	142	142	142	142	10/10/10	10:10	142	142	142	142
Test 43	143	10/10/10	10:10	143	143	143	143	10/10/10	10:10	143	143	143	143
Test 44	144	10/10/10	10:10	144	144	144	144	10/10/10	10:10	144	144	144	144
Test 45	145	10/10/10	10:10	145	145	145	145	10/10/10	10:10	145	145	145	145
Test 46	146	10/10/10	10:10	146	146	146	146	10/10/10	10:10	146	146	146	146
Test 47	147	10/10/10	10:10	147	147	147	147	10/10/10	10:10	147	147	147	147
Test 48	148	10/10/10	10:10	148	148	148	148	10/10/10	10:10	148	148	148	148
Test 49	149	10/10/10	10:10	149	149	149	149	10/10/10	10:10	149	149	149	149
Test 50	150	10/10/10	10:10	150	150	150	150	10/10/10	10:10	150	150	150	150
Test 51	151	10/10/10	10:10	151	151	151	151	10/10/10	10:10	151	151	151	151
Test 52	152	10/10/10	10:10	152	152	152	152	10/10/10	10:10	152	152	152	152
Test 53	153	10/10/10	10:10	153	153	153	153	10/10/10	10:10	153	153	153	153
Test 54	154	10/10/10	10:10	154	154	154	154	10/10/10	10:10	154	154	154	154
Test 55	155	10/10/10	10:10	155	155	155	155	10/10/10	10:10	155	155	155	155
Test 56	156	10/10/10	10:10	156	156	156	156	10/10/10	10:10	156	156	156	156
Test 57	157	10/10/10	10:10	157	157	157	157	10/10/10	10:10	157	157	157	157
Test 58	158	10/10/10	10:10	158	158	158	158	10/10/10	10:10	158	158	158	158
Test 59	159	10/10/10	10:10	159	159	159	159	10/10/10	10:10	159	159	159	159
Test 60	160	10/10/10	10:10	160	160	160	160	10/10/10	10:10	160	160	160	160
Test 61	161	10/10/10	10:10	161	161	161	161	10/10/10	10:10	161	161	161	161
Test 62	162	10/10/10	10:10	162	162	162	162	10/10/10	10:10	162	162	162	162
Test 63	163	10/10/10	10:10	163	163	163	163	10/10/10	10:10	163	163	163	163
Test 64	164	10/10/10	10:10	164	164	164	164	10/10/10	10:10	164	164	164	164
Test 65	165	10/10/10	10:10	165	165	165	165	10/10/10	10:10	165	165	165	165
Test 66	166	10/10/10	10:10	166	166	166	166	10/10/10	10:10	166	166	166	166
Test 67	167	10/10/10	10:10	167	167	167	167	10/10/10	10:10	167	167	167	167
Test 68	168	10/10/10	10:10	168	168	168	168	10/10/10	10:10	168	168	168	168
Test 69	169	10/10/10	10:10	169	169	169	169	10/10/10	10:10	169	169	169	169
Test 70	170	10/10/10	10:10	170	170	170	170	10/10/10	10:10	170	170	170	170
Test 71	171	10/10/10	10:10	171	171	171	171	10/10/10	10:10	171	171	171	171
Test 72	172	10/10/10	10:10	172	172	172	172	10/10/10	10:10	172	172	172	172
Test 73	173	10/10/10	10:10	173	173	173	173	10/10/10	10:10	173	173	173	173
Test 74	174	10/10/10	10:10	174	174	174	174	10/10/10	10:10	174	174	174	174
Test 75	175	10/10/10	10:10	175	175	175	175	10/10/10	10:10	175	175	175	175
Test 76	176	10/10/10	10:10	176	176	176	176	10/10/10	10:10	176	176	176	176
Test 77	177	10/10/10	10:10	177	177	177	177	10/10/10	10:10	177	177	177	177
Test 78	178	10/10/10	10:10	178	178	178	178	10/10/10	10:10	178	178	178	178
Test 79	179	10/10/10	10:10	179	179	179	179	10/10/10	10:10	179	179	179	179
Test 80	180	10/10/10	10:10	180	180	180	180	10/10/10	10:10	180	180	180	180
Test 81	181	10/10/10	10:10	181	181	181	181	10/10/10	10:10	181	181	181	181
Test 82	182	10/10/10	10:10	182	182	182	182	10/10/10	10:10	182	182	182	182
Test 83	183	10/10/10	10:10	183	183	183	183	10/10/10	10:10	183	183	183	183
Test 84	184	10/10/10	10:10	184	184	184	184	10/10/10	10:10	184	184	184	184
Test 85	185	10/10/10	10:10	185	185	185	185	10/10/10	10:10	185	185	185	185
Test 86	186	10/10/10	10:10	186	186	186	186	10/10/10	10:10	186	186	186	186
Test 87	187	10/10/10	10:10	187	187	187	187	10/10/10	10:10	187	187	187	187
Test 88	188	10/10/10	10:10	188	188	188	188	10/10/10	10:10	188	188	188	188
Test 89	189	10/10/10	10:10	189	189	189	189	10/10/10	10:10	189	189	189	189
Test 90	190	10/10/10	10:10	190	190	190	190	10/10/10	10:10	190	190	190	190
Test 91	191	10/10/10	10:10	191	191	191	191	10/10/10	10:10	191	191	191	191
Test 92	192	10/10/10	10:10	192	192	192	192	10/10/10	10:10	192	192	192	192
Test 93	193	10/10/10	10:10	193	193	193	193	10/10/10	10:10	193	193	193	193
Test 94	194	10/10/10	10:10	194	194	194	194	10/10/10	10:10	194			

8. RESULTS AND DISCUSSION

The results of the experiments will be presented and discussed in this section. The destructive and nondestructive FE experiments and a single CHF will be discussed first, followed by the supporting experiments. Some anomalies and discrepancies in pressure drop, wall temperature, oxide buildup, and heat losses observed during some of the experiments will also be discussed. Data reduction, data analysis, correlation comparison, and conclusions will then follow.

8.1 NONDESTRUCTIVE FLOW EXCURSION TESTS

Most of the data taken in FY 1993 were targeted for determining the thermal limits near or around the ANS nominal conditions, but some were for off-nominal conditions similar to the Costa experiments or decay heat removal conditions.

8.1.1 Nominal Conditions Tests

The results of the FE tests at or around the ANS conditions are summarized in Table 2 and also represented in Figs. 15 and 16. The figures provide plots of the test section pressure drop vs velocity for constant heat fluxes as listed and for a single nonpowered case. Additional information on each run can be found in Tables 1 and 2. It was general practice to recheck a few of the pressure drop measurements as velocity was increased along the demand curve following the sequence where velocity was decreased to find the minimum. In some cases, the runs were duplicated for confirmation. The differences found in the velocities at the minimum pressure drop points were generally small, and the above-quoted velocities represent average values when multiple velocity measurements were made. However, in the high heat flux cases of 13 and 14 MW/m², pressure drops were higher when measurements were repeated for the same velocities. The heat fluxes indicated for each of these curves are nominal average values. The actual local heat fluxes close to the exit (where the FE phenomena is supposed to start) are indicated in Table 2 as the Q''_{ex} values, which are higher than the average in all cases as a result of the aluminum resistivity change with temperature. As illustrated in Figs. 15 and 16, the minimum points are clearly identifiable, and a true CHF (or the subsequent expected burnout) was not encountered before that minimum (the point where FE would occur) in any of the experiments.

Acquiring FE data at this level of heat fluxes and velocities is of significance for two reasons. First, to the authors' knowledge, no data are available for velocities higher than 10 m/s (Duffey and Hughes 1990; Lee, Dorra, and Bankoff 1992; Rogers and Li 1992) except those reported by Waters (1966) at 16 m/s in experiments supporting the Advanced Test Reactor. Second, the heat flux achieved is beyond the ANS nominal peak heat flux of 12 MW/m². The corresponding limiting velocity tested is about 17 m/s, well below the ANS nominal velocity of 25 m/s. Even at the highest local heat flux tested (test FE1050 at 14.7 MW/m² average and 16.3 MW/m² at the exit), the corresponding velocity of 20 m/s is well below the ANSR nominal operating velocities. This implies, on a preliminary basis, that a good margin exists at the ANSR operating velocity.

8.1.2 Off-nominal Conditions Tests

The THTL-13 test series focused on FE data for off-nominal conditions ranging from Pony motor flow (10% of nominal) at both low (0.17 MPa) and high (1.7 MPa) pressure to higher velocity

Table 2. Critical heat flux and flow excursion tests performed at the THTL

TSD	Test Case	q''_{avg} (MW/m ²)	q''_{exit} (MW/m ²)	V_{exit} (m/s)	ΔP_u (MPa)	P_{exit} (MPa)	$T_{bulk,exit}$ (°C)	$\Delta T_{sub,exit}$ °C	Heat Loss %
TSD-3/C	FEN17B	7.627	7.871	14.42	0.296	1.721	182.5	22.7	7.6
TSD-3/C	FEN17C	10.625	11.334	19.98	0.508	1.693	178.1	26.4	6.4
TSD-3/C	FEN20A	11.979	13.563	21.86	0.604	1.725	178.6	26.9	6.3
TSD-3/C	FEN20B	13.658	16.015	23.54	0.742	1.712	180.0	25.2	4.8
TSD-3/C	FEN30A	13.628	15.818	23.56	0.754	1.709	180.7	24.4	4.6
TSD-3/C	FED15B	11.624	12.979	19.68	0.545	1.706	181.9	23.0	5.5
TSD-3/C	FED15C	13.020	14.746	21.39	0.632	1.719	181.3	24.1	5.1
TSD-3/C	FED17A	14.412	16.108	23.52	0.747	1.685	176.8	27.7	6.1
TSD-3/C	FED28B	14.612	15.460	23.02	0.765	1.723	181.1	24.4	5.5
TSD-3/C	FE105B	9.030	9.930	15.38	0.359	1.721	173.6	31.6	6.2
TSD-3/C	FE105C	12.737	14.307	20.10	0.657	1.722	179.1	26.3	4.9
TSD-3/C	FE105D	14.760	16.320	23.08	0.919	1.707	182.5	22.6	4.4
TSD-3/D	FE114B	10.841	11.809	20.15	0.567	1.713	181.9	23.2	4.8
TSD-3/D	CF115B	11.771	12.987	19.76	0.628	1.709	186.1	18.9	4.2
TSD-3/D	CF115B*	12.752	13.682	14.53	1.262	1.860	208.7	0.2	5.0
TSD-3/E	FE210B	11.422	13.917	20.08	0.618	1.718	178.2	27.1	5.9
TSD-3/E	FE212A	12.146	13.325	19.31	0.653	1.708	185.2	19.7	5.6
TSD-3/E	FE212A*	12.611	13.594	17.78	0.785	1.727	197.4	8.0	6.0
TSD-3/F	FE318B	1.886	2.203	4.95	0.078	0.445	132.7	15.1	12.4
TSD-3/F	FE318B*	2.140	2.323	4.50	0.106	0.451	142.2	6.0	16.4
TSD-3/G	FE330A	12.009	14.010	21.15	0.577	1.709	174.7	30.3	3.6
TSD-3/G	FE331A	11.996	13.675	19.55	0.549	1.698	178.4	26.3	8.8
TSD-3/G	FE331A*	12.145	13.094	18.36	0.634	1.696	187.3	17.2	9.6
TSD-3/J	FE712B	1.668	1.901	2.89	0.033	1.695	183.1	21.1	12.2
TSD-3/J	FE713B	0.679	0.706	2.83	0.025	0.175	100.1	16.2	15.1
TSD-3/J	FE714B	4.333	4.979	8.58	0.142	1.700	174.3	30.2	6.5
TSD-3/J	FE714C	6.396	7.225	11.56	0.248	1.701	182.3	22.2	5.5
TSD-3/J	FE715B	9.195	10.846	16.59	0.440	1.709	177.0	27.9	3.1
TSD-3/J	FE719B	11.675	14.809	20.11	0.634	1.673	176.8	27.1	3.8

I. In all cases the inlet temperature = 45 °C (nominal)

II. The critical point refers to the minimum pressure drop data point for most Flow Excursion tests. The asterisk (*) symbol refers to a true destructive burnout.

III. Nomenclature:

(All values refer to the critical data point)

q''_{avg}	average nominal heat flux
q''_{exit}	local exit heat flux
V_{exit}	exit coolant velocity
ΔP_u	test section pressure drop
P_{exit}	exit pressure
$T_{bulk,exit}$	exit bulk coolant temperature
$\Delta T_{sub,exit}$	exit subcooling

Fig. 15. Flow excursion data from THTL experiments.

Fig. 16. Additional flow excursion data from THTL experiments.

flows corresponding to one, two, or three pumps operating in addition to the Pony motor. The conditions were selected to include assumed decay heat removal operating conditions at 0, 8, 16, and 24 h after shutdown for which the corresponding decay heat rates (including the corresponding peaking factors) are 0.72, 0.06, 0.043, and 0.036 MW/m² respectively (see Fig. 17). The six FE (minimum dP) tests performed are presented in Fig. 18, with the results showing that a large margin of decay heat removal capability is present in all these cases. Another reason for performing these specific tests was to provide additional data at the lower and intermediate velocity range for comparison with the three FE correlations of Costa (1967), Whittle and Forgan (1967), and Saha and Zuber (1974).

These tests were also the first FE tests performed under controlled pH conditions. Nitric acid was added to control pH at ~ 5 in a manner similar to that performed in the Corrosion Test Loop. The tests were conducted to obtain the minimum in differential pressure vs velocity under "stiff" loop operating conditions to avoid actual FE failure. In each case, the FE heat flux calculated from the Costa correlation for the given conditions was maintained constant while the velocity was incrementally reduced from its initially selected high value until it fell below the minimum pressure drop point.

The test FE712B was taken under Pony motor flow at a nominal exit pressure of 1.7 MPa. An average heat flux of 1.85 MW/m² was applied with an inlet bulk water temperature of 45°C. The velocity was initially set at 16 m/s and reduced while maintaining heat flux, exit pressure, and inlet temperature constant. Manual control of the process water flow was necessary under these low-power, low-flow conditions to limit inlet temperature variations. A minimum was observed at ~ 2.6 m/s, which was in good agreement with the Costa prediction, as discussed later.

Testing was continued with test FE713B under Pony motor flow and low-pressure conditions. An average heat flux of 0.85 MW/m² was applied with an exit pressure of 0.17 MPa and inlet bulk water temperature of 45°C. To reach the low pressures, a bypass flow around the pressure control valve to the low-pressure system was necessary. Velocity was reduced from 11 m/s in increments under constant heat flux, exit pressure, and inlet water temperature conditions until the minimum in differential pressure vs velocity was obtained. The minimum occurred at ~ 2.5 m/s, which was also in good agreement with the Costa prediction. A relatively rapid pressure drop increase was experienced at a velocity just below the minimum. Power was removed prior to failure of the test channel.

Test FE714B was at a heat flux of 5.09 MW/m², exit pressure of 1.7 MPa, and inlet temperature of 45°C. Velocity was decreased from 22 m/s to just beyond the minimum, which occurred at ~ 7.5 m/s. Velocity was then increased again to check for hysteresis in the differential pressure measurements at a few higher-velocity points. Some hysteresis was noted but not as much as has been observed in tests previously conducted without pH control. Test FE714C was taken with an applied heat flux of 7.05 MW/m², exit pressure of 1.7 MPa, and inlet temperature of 45°C. Velocity was decreased from 26 m/s to just beyond the minimum, which occurred at ~ 10 m/s. This situation is approximately equivalent to one pump operation in the ANS reactor system. Increasing the velocity to recheck some of the data points again showed very little hysteresis in the differential pressure measurement.

Another FE minimum type test was also conducted (FE715B). A heat flux of 9.54 MW/m² was applied to the test section with an exit pressure of 1.7 MPa and an inlet temperature of 45°C. Velocity was decreased in increments from 32 m/s to below the minimum in differential pressure, which occurred at ~ 14.5 m/s. Increasing the velocity to check for hysteresis again showed very little change.

Power was increased to provide a heat flux of 11.64 MW/m² for another set of FE data. However, a leak in the power supply cooling lines (inside the cabinet) forced a shutdown of the

Fig. 18. Flow excursion data from THTL.

system prior to completion of this data series. Testing was resumed following repairs to the power supply cooling line. The FE minimum type test (FE719B) at 11.64 MW/m^2 was continued, with exit pressure maintained at 1.7 MPa and inlet temperature at 45°C . The minimum occurred at $\sim 17.5 \text{ m/s}$. A check of several data points at higher velocities following the minimum showed little hysteresis in the pressure drop (which has been a consistent observation for this entire series of data). The primary difference in this test series from previous tests is the use of nitric acid addition for pH control.

Determination of the incipience of boiling (IB) and ONVG through detection of the associated boiling noise has been attempted with some level of success. A related investigation associated with cooling jackets on vacuum arc remelt furnaces is being pursued by the ORNL Metals and Ceramics Division. The experience may have provided more data and information supporting the utility of the technique for the ANSR. We intend to pursue this technique on the THTL to improve our knowledge of the phenomena occurring in the test section.

8.2 DESTRUCTIVE FE AND CHF TESTS

In addition to the above FE experiments, which are based on the minimum pressure drop (nondestructive tests), a number of destructive (actual burnout) tests were performed to compare true CHF using a "stiff" system to both destructive (actual burnout in a relatively "soft system") and nondestructive (minimum pressure drop in a "stiff" system) FE. Three destructive FE and one true CHF experiments were performed, and the results are presented in Fig. 19.

8.2.1 Burnout CHF Test

The single CHF experiment at 12 MW/m^2 (which is the nominal peak heat flux expected in the ANSR) was performed in a "stiff" system with a closed bypass line. The occurrence of CHF was clearly identified in the experiment by a rapid burnout and failure of the test channel. The CHF shows a 30% additional margin in velocity (12.3 m/s) compared to the FE velocity of 17.0 m/s (50% margin compared to the ANSR nominal velocity of 25 m/s) at the minimum pressure drop, which is clearly identifiable in Fig. 19. This large margin between CHF and FE was somewhat surprising. The CHF agrees quite well with that by Boyd (1989) taken under similar conditions but with subcooling of 65°C (compared to no subcooling in our experiment). Comparison of these THTL experimental results with either Boyd's results or ANSR nominal conditions also is not quite proper because the exit subcooling levels are much lower for the THTL experimental case. To achieve CHF with all the conditions similar to those of Boyd or nominal ANSR (including exit subcooling), a much shorter test section length is necessary; such an experiment is planned for a later stage. However, under such conditions, the expected measured CHF is even higher.

It should be noted that these results are preliminary and a number of factors must be taken into account in evaluating the data. The local heat flux at the exit end of the test section is normally higher than the channel average heat flux because the coefficient of electrical resistivity for aluminum varies with temperature. Under such conditions, it is expected that the CHF burnout will occur at or very near the end of the heated channel. Inspection of the channel after opening it showed, however, that the CHF burnout occurred about 2.5 cm upstream of the channel exit (the channel was missing from $\sim 1.5 \text{ cm}$ to 3.5 cm from the outlet end). This could possibly be due to conduction cooling effects of the relatively massive electrode flanges that form the boundary for the "heated" length (see Sect. 6.2). This cooling effect reduces the heat flux actually transferred to the coolant near the exit, and the internal wall temperatures are artificially lowered, sometimes to levels below the temperatures

Fig. 19. Destructive CHF and FE tests performed in the THTL.

observed upstream. In addition, the spanwise heat losses suggested by the oxide layer-profile observed on the test channel wall probably need to be accounted for. A 3-D conduction model is being implemented to quantify both the axial and spanwise effects better and to account for them in the data analysis (see Sect. 6.3).

Another interesting phenomenon that deserves attention was observed during the test. A point was reached during the reduction in velocity and resulting increase in void fraction at the test section outlet as the CHF point was approached where the resistance temperature device (RTD) measuring bulk exit temperature actually began showing a decrease in outlet temperature. This effect occurred as bulk temperatures approached the expected saturation temperature and might be due to the probe measuring the temperature of entrained subcooled liquid in the two-phase mixture rather than a mean bulk temperature of the two-phase coolant. A reliable mean bulk exit temperature measurement is necessary for energy balance calculations and assessment of the test section heat losses. A significant oxide layer on the channel surfaces was observed following this relatively short test. This layer is currently being measured and analyzed and will be accounted for in detailed analysis of the test results. Furthermore, future test plans will need to address water chemistry control conditions. The possible effects of inlet coolant temperature fluctuations must also be addressed, although it is not clear that a simple solution is available. As mentioned earlier, the exit pressure as the CHF point was approached was also slightly higher than the nominal 1.7 MPa used during most of the test. Modifications to the pressure control valve may provide a solution to this control problem under high vapor-generation conditions.

8.2.2 Burnout Flow Excursion Tests

Three destructive FE experiments were performed in a "soft" system but each with a different bypass ratio (BPR), as indicated in Fig. 19. The test series THTL-08 was designed to compare the nondestructive FE test (based on minimum pressure drop criteria) with an actual destructive FE in order to validate our belief that the minimum in the pressure drop vs flow rate curve of a single channel represents a true FE condition for multiple channels. This validation will require a sufficiently high bypass ratio (as yet not experimentally determined) to simulate multiple parallel channels. The test was conducted at a nominal heat flux of 12 MW/m², exit pressure of 1.7 MPa, and inlet temperature of 45°C. A nonpowered set of pressure drop vs velocity data was taken prior to applying power to the test channel. A nondestructive test (FE210A) to obtain the minimum in pressure drop vs velocity at 12 MW/m² was then conducted to provide comparison for the destructive test. Although it was intended to run the destructive test (numbered FE212A) with a bypass ratio of ~7, the maximum we can use with the present pump for that test section velocity, a problem with the dechlorination tanks (determined later) limited the bypass ratio to ~2.5. The test was conducted by opening the test section control valve and its associated bypass valve "full" open and then adjusting the manual control valve on the test section bypass line to give the maximum bypass ratio allowed by the heat exchanger. Velocity was then reduced at constant nominal heat flux, exit pressure, and inlet temperature conditions until failure of the channel occurred. Figure 19 shows the results of the destructive FE test (FE212A), which led to test section burnout at a velocity of 15.1 m/s. The low bypass ratio kept the system sufficiently "stiff" to prevent actual (destructive) FE at the minimum pressure drop point, which occurred at a velocity of 16.7 m/s.

The test series THTL-09 was designed to provide benchmark FE data under conditions similar to the original Costa (1967) data. The destructive test (FF318B) was operated with a low test section exit pressure of 0.38 MPa, an inlet coolant temperature of 40°C, and an average axial heat flux of 2.29 MW/m². The low-power conditions did cause some inlet temperature control problems, apparently because of the massive heat exchanger and low primary side mass flow. Relatively slow fluctuations

in inlet temperature were experienced, although it was possible to select data points within a reasonable fluctuating band of $\pm 3^\circ\text{C}$ from the desired set point. The minimum test section pressure drop point occurred at ~ 4.5 m/s average velocity, which is close to the minimum practical operating velocity of the loop in a stiff mode. A modified "stiff" system with a bypass flow ratio of ~ 1 was used, primarily to maintain pump speed at a reasonable level (not too low). The test channel experienced a true destructive FE at ~ 4 m/s as velocity was being reduced below the minimum point, although this was not the specific intent at this point in the run plan. Figure 19 shows the results of the THTL-09 test (FE318B) for conditions as close as possible to those of the Costa experiments. The heat flux (2.29 MW/m^2) used is the same as in Costa, but the pressure (0.38 MPa) was higher than calculated with Costa (0.17 MPa) because of loop limitations. Furthermore, the inlet temperature (40°C) was set to be lower than the Costa number (74.2°C) in order to achieve the same exit subcooling (4.3°C). As can be seen in the figure, the minimum pressure drop point was achieved at a velocity of 4.7 m/s compared to 5.4 m/s calculated with Costa. When an attempt was made to reduce the velocity further, an actual destructive FE occurred at a velocity of 4.2 m/s in spite of the fact that the system was relatively stiff with a bypass ratio of about 1.0 .

The test series THTL-10 was designed to evaluate the relationship between the minimum in the test section differential pressure vs velocity curve (using a stiff system) and an actual destructive flow excursion (using a soft system) under the ANSR maximum nominal heat flux of 12 MW/m^2 . Prior to running the destructive test, data were obtained for nonpowered pressure drop vs velocity as well as a set of data to obtain the minimum in pressure drop under powered conditions at a heat flux of 12 MW/m^2 using a stiff system. A bypass ratio of ~ 6 was obtained for the destructive test (FE331A) compared to a bypass ratio of ~ 2.6 that was used for the previous 12-MW/m^2 test (FE212A), to assess the effect of bypass flow ratio on the point of actual destructive FE. Results are discussed in more detail below. An additional set of measurements was made during this test which may prove useful in analyzing heat flux distributions in the test channel. Voltage measurements were taken at the T/C locations along the test section at a number of intervals during the test. The spring-loaded, ribbon-type T/Cs are in direct contact with the back of the channel wall and thus carry the common-mode dc voltage at that axial location on the channel wall. The differential voltage between adjacent T/Cs and the differential voltage referenced from the flange were measured to obtain an axial voltage drop distribution. These measurements proved to be very self-consistent, with the total voltage drop measured between the inlet and outlet flanges that is used to determine the total power applied to the test channel. Analysis of these results is currently being performed; it is hoped that it will provide useful input for refining the heat flux distributions and heat loss estimates.

It is interesting to compare the results of the THTL-09 test (FE318B) with those of the THTL-08 test (FE212A) and the THTL-10 test (FE331A) presented in Fig. 19, both for 12-MW/m^2 heat flux. Test THTL-08 was performed with a bypass ratio of $2.4\text{--}2.9$, whereas test THTL-10 was performed with a bypass ratio of $5.8\text{--}6.2$ (the highest possible for the loop at that velocity). The minimum pressure drop points were achieved at 17.2 and 17.6 m/s, respectively, representing a close agreement with the Costa correlation prediction. However, the actual destructive FE did not occur at the minimum point (as would be expected for a very large bypass ratio) for either of the two experiments, but rather at lower velocities of 15.6 m/s for the THTL-08 test (bypass ratio of 2.6) and 16.7 m/s for the THTL-10 test (bypass ratio of 6.1). This confirms that, to obtain an actual destructive FE near the minimum point, as would be expected for the multiple parallel channel configuration in the ANSR, a larger bypass ratio than can currently be applied in the loop or some other method of "softening" the system will be needed. As demonstrated by other researchers, the minimum pressure drop technique for determining FE conditions is more conservative since it implies a complete constant pressure boundary condition, as will be the case for an "infinite bypass." Increasing the bypass ratio from 2.6 to 6.1 gave a closer agreement with the minimum point, but higher ratios will apparently be

needed to get a closer match. Analytical studies are being performed to determine the lowest bypass ratio necessary for the ANSR conditions. On the other hand, for test THTL-09 with lower pressure, subcooling, and velocities (Costa conditions), the destructive FE occurred much closer to the minimum in spite of a lower bypass ratio of about 1. The higher sensitivity of those conditions to FE is also reflected in the larger negative slope of the dP/dV curve on the left-hand side of the minimum in test THTL-09 (similar to Costa conditions) compared to the one of test THTL-10 (similar to ANSR conditions). Another difference between the two tests is the closer agreement of the FE heat flux data with those of the Costa correlation. The measured heat flux in THTL-09 was about 12% higher than in the Costa correlation, whereas in THTL-08 and THTL-10 it was about 50% and 60% higher respectively. This is in agreement with our previous conclusion stated in the preliminary safety analysis report that the Costa correlation may be more conservative at higher velocities (and pressures).

8.3 FLOW EXCURSION ELAPSED TIME

Bounding times for FE duration from the beginning of runaway flow redistribution to test section destruction (or CHF burnout) have been estimated analytically. The pressure drop as a function of velocity (i.e., the demand curve) has been measured for a constant applied thermal flux in subcooled boiling flows by many researchers. A few such curves have been developed in the THTL designed to establish thermal limits for the ANSR. The demand curve allows a bounding calculation for the time required after the initiation of an FE to decelerate the flow in a cooling channel to values where a primary DNB would occur. Figure 20 shows a typical demand characteristic as measured in the THTL-02 series. The demand characteristic was extrapolated based on data taken by other researchers (Dormer and Bergles 1964). The analysis technique used in the evaluation assumes that the applied pressure drop across the cooling channel is maintained at the value of the pressure drop minimum. This is consistent with the conditions required at the initiation of an FE event. The increase in the pressure drop deficiency between the supply and demand curves to the left of the pressure drop minimum that was measured in the quasisteady and constant inlet mass flow case decelerates the flow in the channel during a real FE when the applied pressure drop is held constant. This preliminary analysis indicated that the flow will reduce to values where a primary DNB is to be expected in 2 to 4 ms. However, additional and more detailed studies of this issue both experimentally and analytically are planned.

8.4 SUPPORTING TESTS AND OBSERVATIONS

A few tests were performed primarily to support various assumptions and observations that will be discussed in this section. Some anomalies and discrepancies in the pressure drop, wall temperature, oxide buildup, and heat losses observed during some of the experiments will also be described.

8.4.1 Pressure Drop and Temperature Measurements

A typical test sequence includes taking a data set of pressure drop measurements across the test section as a function of velocity before powered operation and repeating this procedure after every few powered data sets. The nonpowered data set serves as a reference for the expected single-phase pressure drop under isothermal conditions. Intermittent repetition of the nonpowered operation also effectively monitors any possible accumulated channel geometry changes from previous powered operation(s).

Fig. 20. Pressure drop vs velocity for two THTL tests.

Most of the nonpowered pressure drop measurements were in good agreement with the calculated values. However in the powered tests, the pressure drop measurements were not always repeatable but showed increasing values on successive measuring cycles of the same run. This phenomenon was first observed at the 14-MW/m² heat flux level of test series THTL-06 and had not been seen at lower power levels. We have adopted the general practice of rechecking a few of the pressure drop measurements as velocity is increased back upward along the velocity curve (following the sequence where velocity is decreased to find the minimum). At the 14-MW/m² power level (FEN20B), the pressure drop showed a slight increase (about 3%) when rechecked at several different velocity points. A nonpowered sequence of pressure drop vs velocity was then taken which essentially duplicated earlier nonpowered pressure drop measurements. The test section was removed to measure the "cold" channel gap, which showed only a small change from previous measurements. The test section was then reinstalled, and measurements at the 14-MW/m² heat flux level were repeated (FEN30A). Pressure drop measurements were still higher than the original measurements. Wall temperature measurements also indicated higher values. In addition, a recheck of the pressure

measurements following the sequence to obtain the minimum showed another ratcheting upward of pressure drop and wall temperatures in each successive "cycle" (reaching a maximum pressure drop increase of about 14%). A repetition of nonpowered pressure drop and "cold" channel gap measurements following this sequence still did not provide an obvious explanation of these observed effects. A few other tests since then have shown similar behavior, indicating possible changes in surface effects, oxide layer buildup, or channel gap thickness.

Temperature measurements also presented difficulties in some cases. It was observed on occasion that T/Cs that were placed at redundant axial locations on both sides of the channel gap and therefore should theoretically show identical temperatures differed considerably from each other. In addition, T/Cs along the channel that should show a gradual temperature increase in the axial direction gave inconsistent readings. These differences were sometimes in the range of 20–30°C, which is more than can be justified by normal T/C errors. Again, possible surface effects such as oxide layer buildup (see below) or T/C connection integrity could be involved, but the cause has not yet been fully addressed.

8.4.2 Oxide Layer Buildup

Some of the anomalies in pressure drop and temperature measurements discussed above could possibly be caused by the oxide buildup, which was observed in many experiments. Figure 21 is a copy of the oxide patterns from test series THTL-07, which was a CHF-type test taken directly to channel failure and therefore operated at power for a relatively short time. A "clean" surface area with an obvious oxide layer parabolic profile is observed near the center of the axial length. The oxide layer from the inlet of the test section to this point appears as a very smooth surface layer having a gold color, with the intensity of the color increasing toward the outlet end of the test section. This probably reflects the expected trend of increased oxide deposition at higher temperatures. The "clean" area appears to have no visible oxide layer present and is possibly where the incipient boiling front is located along the channel. It is possible that the generation and collapse of the vapor bubbles in this region are eroding the surface. The oxide layer downstream of this "clean" area has a visibly rougher texture and a coloration that becomes increasingly dark toward the outlet end of the channel. The last 70 mm of the test section apparently has a more uniform layer that is darker in color. It is possible that as the boiling front moves down the test channel when velocity is decreased during the test, the oxide layer is removed by the boiling action and then begins to reform downstream of this boiling front. The oxide layer parabolic profile was observed on the test channel from THTL-06 as well, although an oxide layer still appeared to exist upstream of it. In fact, several such profiles are observable on this channel, presumably a result of the different heat flux levels that were applied to the same test channel for different cases. The profile from the last test, in which the test section flow orientation was reversed, is observed as a profile in the opposite direction from those seen for the other test conditions. This reversal of flow direction is probably also the cause for this channel's loss of the dramatic oxide color patterns seen in the CHF test (THTL-07). The apparently rougher surface observed downstream of the boiling front might also explain the measured differences in pressure drop as the test channel acquired more operating history. On the other hand, such an explanation would not be consistent with the fact that when no power is applied the pressure drop again duplicates the pretesting nonpower pressure drop. The history effects are easily observable from the color variations in the oxide layer, and actual surface roughness measurements will be made to attempt to quantify these effects. These variations may actually provide some very useful diagnostic information in terms of characterizing local effects (such as the fact that oxide film in the edges was more visible than at the center area, indicating spanwise temperature and/or boiling process variation) and determining the location of incipient boiling in the channels. It should be noted that these tests

Fig. 21. Test channel from test THTL-07 (inlet on left-hand side).

were both operated with high-purity demineralized water and no pH control. It will be of interest to operate a similar test in the near future at a controlled pH of 5.0 in order to limit the oxide formation and provide an early comparison of thermal limits with a different surface condition. The oxide formed on the channel from THTL-07 was under high-heat-flux conditions for only ~ 7 h, a relatively short time compared to the other nondestructive FE tests performed earlier.

Another apparent oxide layer anomaly was observed during test series THTL-11, which included powered operation under dry conditions as discussed in the next section. These dry tests were followed by tests under pressurized flow conditions. For the water tests, nonpowered pressure drop was initially measured as a function of velocity. This was followed by testing under subcooled, nonboiling conditions at a heat flux of 12 MW/m^2 (case HL505A). Relatively high temperatures were observed near the outlet end of the test channel under these conditions; they were attributed to oxide buildup. The last four T/Cs toward the end of the test section also showed some "irregularities" in the temperature measurements, both sequentially along the test section and as differences at equal axial positions on opposite sides of the channel. Temperatures in the last 4- to 5-cm part of the test section kept rising in time in spite of the constant power and velocity (Fig. 22). The maximum temperature rose from about 330°C to around 420°C , an increase of about 90°C within around 45 min. Other tests in the past under similar conditions showed that thermal equilibrium is achieved within just a few minutes (Fig. 23).

Following this test, the test section was reversed, so that the higher T/C axial resolution was now at the inlet of the channel (HL507B). Power was applied to the test section under subcooled conditions. As power was increased, significantly higher temperatures than expected were observed again, but this time they appeared at the inlet end of the test section. These temperatures at the lower (upstream) part of the test section were higher than downstream in spite of the gradually rising bulk fluid temperature along the channel. The first four T/Cs at the inlet end of the test section also showed "irregularities" in temperature measurement similar to those observed previously in the upright test (HL505A) but in the exit end of the test section. No time-dependent change in temperatures was observed in the upside-down case once the power was maintained constant at 6 MW/m^2 . The test was terminated at a heat flux of 6 MW/m^2 to preserve the conditions on the channel surface for posttest evaluation. The channel was sectioned following removal from the loop. A dark oxide layer was very apparent over the last 5 cm of the test channel (at the original exit end where the higher temperatures were also observed when the test section was reversed), as shown in Fig. 24. The growth of this oxide, which was later measured at $\sim 7 \mu\text{m}$, was very fast and may have been influenced by the earlier tests heated in air. Following this test series, it was decided to implement pH control measures to limit the effects of oxide buildup on the measurements. A nitric acid addition pump and associated reservoir were added to the low-pressure system to provide the necessary controls.

Test series THTL-12 was designed to provide steady-state benchmark data for evaluating heat transfer coefficients, friction factors, and conduction effects under nonboiling, subcooled conditions. Nonpowered pressure drop vs velocity data were obtained prior to powered operation for reference purposes. The powered tests were operated at a heat flux level of 5.9 MW/m^2 with velocity varying from 36 to 14 m/s (all under nonboiling conditions). This test series was the first conducted with pH control and was operated at a pH of ~ 5 . The test series produced another oxide growth phenomenon at the low end of this velocity range. A significant channel wall temperature ramp was observed following the reduction from steady-state conditions at 16 m/s to a new velocity at 14 m/s (at 5.9 MW/m^2). Before this change, measured conditions on the back wall reached new steady-state values following a velocity change within a few minutes. Equilibrium conditions were not obtained at 14 m/s, however. Instead, wall temperatures continued to increase and were still increasing when the test was terminated ~ 20 min later after a net increase of $\sim 40^\circ\text{C}$ at the exit end of the channel.

Test name : HL505A17 Record No.= 1763

Record number of data file ==> 1785

Power (kW)

Temperature (°C) No.= 1784 Time=12:59:33

Tin Tout Pin Pout Power Velocity dP Bypass ratio

Stack space = 7592

x 10 Bypass ratio (-)

x 10 Velocity (m/s)

Pressure (MPa)

Fig. 22. Temperatures increasing at constant power as a result of oxide buildup in THTL-11 test series (HL505A and HL507B).

File name : HL507931 Record No.= 5 11

Record number of data file ==> 1011

Power (kW)

Temperature (°C) No.= 1011 Time=10:45:40

Stack space = 12200

x 10 Bypass ratio (-)

x 10 Velocity (m/s)

Pressure (MPa)

Tin Tout Pin Pout Power Velocity dP Bypass ratio

Fig. 23. Temperatures reaching equilibrium shortly after power becomes constant in a typical experiment.

Fig. 24. Oxide pattern observed near test channel exit for THTL-11.

The most probable cause of the increase was a rapid buildup of oxide. It was decided to repeat the test conditions to determine if the effect would continue. Another set of nonpowered pressure drop vs velocity data was taken, and then the test sequence at a heat flux of 5.9 MW/m^2 was repeated. The same phenomenon was observed again once velocity was reduced to the 14-m/s level. The rate of temperature rise did eventually slow down as the apparent oxide film thickness increased. The test was allowed to continue until another $\sim 40^\circ\text{C}$ temperature increase was observed on the back wall. The test was then terminated at this point for removal of the test channel and sectioning to allow examination of the inside channel surface.

Initial observation of the channel surface revealed a "black" oxide layer that became very dark over the last 100 mm of the channel (outlet end). Measurements with the eddy probe indicated oxide thicknesses varying from $\sim 13 \mu\text{m}$ at 400 mm from the inlet end of the channel to $\sim 51 \mu\text{m}$ at 490 mm. Further analysis is planned for the films in order to characterize the oxide layer. In addition, the implications of this oxide growth behavior will be evaluated using comparisons with results from both the Corrosion Test Loop and the THTL experiments. It is not immediately apparent that there are any direct impacts on ANS reactor operation since the velocity at which this phenomenon occurred is well below the normal operating level. This area will also be addressed, however, as further testing is conducted. Analysis of the "black" oxide on the test channel surface from THTL-12 is described in the Corrosion Test Loop section of the August 1993 *ANS Monthly Progress Report*. This type of oxide has been consistently present since pH control through nitric acid addition was implemented just prior to THTL-12 tests. The outer oxide layer contains high concentrations of magnetite (Fe_3O_4), apparently from the stainless steel portions of the loop. No FE data were taken from this test series.

A temperature ramp was also experienced during the last data set of test series THTL-13 (Fig. 25) at the TE-107 and TE-108 T/C locations (460 mm from the beginning of the channel heated length) that eventually led to channel failure. The temperatures began increasing as velocity was reduced in the test channel and continued to increase even after velocity was brought back to nonboiling levels. Back wall temperatures in excess of 700°C (which is well above the aluminum melting temperature) were recorded prior to channel failure. It is possible that the rapid oxide buildup observed in the previous test series, THTL-12, may have occurred again, with the resulting high local temperatures then creating a positive feedback condition that leads to an elevated local heat flux. In most cases, this phenomenon starts at higher wall-to-fluid interface temperatures, but no single common triggering temperature has been determined. It is not yet clear what initiates that phenomenon, but it is clearly related to the formation of the black oxide layer that was present in this test series as well. Fortunately, these effects did not seem to influence significantly the FE results reported for the earlier data sets of this test series.

8.4.3 "Dry" Tests for Heat Loss Determination

The heat losses in the test section were normally determined by comparing the total electric energy generated in the test section with the energy absorbed by the fluid, as calculated from the flow rate and bulk fluid temperatures measured at the inlet and outlet. Most of the heat losses must be taking place through the flanges and the large electrodes connected to them. Some heat losses take place through the insulation, but this was estimated to be quite small, on the order of 1% (see Fig. 8). In addition, there were some welding differences between the flanges imposed from the fabrication of the test sections which could have affected the symmetry of the heat losses. To study these effects, a few special tests, called "dry tests," were performed heated (THTL-11), but without cooling water. The test section used was one that had leaked primarily at the test channel/flange interface and had been repaired. The repair process resulted in a larger than normal weld material buildup at this

File name : Record No.=
 Record number of data file ==>

Stack space = 12084
 x 10 Bypass ratio (-)
 x 10 Velocity (m/s)
 Pressure (MPa)

Temperature (°C) No.= 1851

Fig. 25. THTL test FE719B of THTL-13 series showing temperatures ranging even during constant or increased velocity.

interface, and this test section was used intentionally to determine the effect of this buildup on axial heat conduction into the flange and electrode area. It was not expected to simulate the actual heat losses of the normal FE test through these "dry tests," since the temperature profiles cannot be duplicated (the normal test has an almost linear increase in bulk temperature with maximum temperature at the top, whereas the dry test temperature is a parabola with the peak at about the center of the test section). However, inspection and analysis of the results (presented in Fig. 26) for two such tests show that the effects of the heavier weld are quite significant—in all cases the temperatures are lower at the T/Cs that are closer to the side of the heavier weld. Based on external surface temperatures, it was estimated that about 10% of the total heat loss (equal to heat input) in the dry tests occurred directly through the Mycalex insulation, showing that this type of loss should not be neglected.

To quantify the heat losses out the top, bottom, and sides of the test section assembly modeled, the results from the two "dry tests" were used in a HEATING7 3-D conduction model of the THTL test section assembly. The intent was to calibrate the boundary conditions in the model by matching the "dry tests" data to allow later model/data comparisons with forced cooling in the test section. Once good agreement is obtained between model results and the experimental data, a better understanding of the distribution of heat flow within the test section will result. The results of the first calibration run are shown in Fig. 27. Here the solid line represents the temperatures produced by the HEATING model, and the symbols are the data.

8.5 COMPARISON OF DATA TO CORRELATIONS

Although the final correlation of the FE data will be postponed until the remainder of the experiments is performed (by extending the heat flux and corresponding velocity ranges up to 17 MW/m² and ~25 m/s respectively), the collected data so far, including the FE tests under nonnominal conditions (THTL-13), were plotted for comparison to selected correlations in Fig. 28. The uncertainty bars for each test reflect uncertainties connected with nonuniform axial heat losses and internal spanwise heat redistribution in the test section, as discussed previously in relation to multidimensional effects. The comparisons are made with correlations by Costa (1967), Whittle and Forgan (1967), and Saha and Zuber (1974). The Costa correlation is the one currently being used for the preliminary ANSR T/H design and analysis. Whittle and Forgan (W&F) and Saha and Zuber (S&Z) correlations are widely used in the United States, with the S&Z correlation being well established in many computer codes for nuclear safety analysis. For a given coolant (water), physical properties, and geometry ($L/D = 199.6$), all three correlations can be rearranged and simplified to the same general formulation, as follows:

$$\frac{q''_{fs}}{(T_c - T_{b,fs})} = C V^n, \quad (6)$$

where $C = 1/0.0128$ and $n = 0.5$ (Costa); $C = 1/0.0382$ and $n = 1.0$ (S&Z); and $C = 1/0.0427$ and $n = 1.0$ (W&F).

In the Costa correlation, the FE heat flux is proportional to the square root of velocity, whereas both W&F and S&Z (as well as most other FE correlations) show a linear dependence. Based on this formulation, the Costa correlation will yield the same result as the W&F correlation at a velocity of 11.1 m/s and, in comparison, will be too optimistic (higher heat flux) at lower velocities and too conservative at higher velocities (33% more conservative with respect to W&F at the ANSR nominal

Fig. 26. Results of conduction heat loss "dry test" for the THTL test section: (a) heavier weld at the top and (b) heavier weld at the bottom.

Fig. 27. Calibration of HEATING7 model to THTL no-flow data.

velocity of 25 m/s). The Costa correlation will show the same trend when compared with the S&Z correlation, except that the equality will occur at 8.9 m/s. At 25 m/s, the Costa correlation will be ~40% more conservative with respect to the S&Z correlation.

Since the above correlations are based on data for relatively low velocities (maximums of 9.14, 7, and 7.66 m/s for W&F, Costa, and S&Z respectively), it is quite interesting to see the trend of our data in terms of dependence on velocity. As can be seen in Fig. 28, all three correlations seem to be generally conservative when compared with the data, with S&Z being the most accurate. Excluding three of the four data points taken with test section TSD-3/B (a possible anomaly with this test section is being investigated), the agreement with S&Z is quite good, with the correlation skirting the lower bound of the data. The nonnominal conditions data points (indicated in the figure by TSD-3/J) are in good agreement with Saha and Zuber and Whittle and Forgan correlations but show again the Costa correlation to be too conservative in the high-velocity range but (unexpectedly) somewhat optimistic at the lower velocity range. The FE heat flux dependence on velocity seems to be between 0.5 power (Costa) and 1.0 (S&Z and W&F), more nearly in the 0.8–0.9 range. This heat flux estimation is in agreement with the conclusion recently arrived at by Lee and Bankoff (1992) and Rogers and Li (1992), who relate the heat flux to the turbulent heat transfer coefficient, which is approximately proportional to the 0.6–0.8 power of velocity. As indicated before, the actual correlation of the ANSR FE data will be postponed to a later stage.

Fig. 28. Comparison of THTL FE data with correlations.

An interesting comparison of the FE data and the single CHF data point with the Gambill/Weatherhead CHF correlation is presented in Fig. 29. As can be seen, the FE data show quite a good agreement with the Gambill/Weatherhead CHF correlation, whereas the correlation is about 50% conservative in relation to the single CHF data point taken so far. This could indicate that the Gambill/Weatherhead correlation is more closely representing FE phenomena than CHF (depending on how "soft" the actual experimental system may have been). More CHF data are required (as is indeed planned) to come to any reliable general conclusion on the CHF correlation performance.

8.6 PRELIMINARY STATISTICS OF THE THTL DATA

Table 3 provides the results of an initial statistical uncertainty analysis of the THTL total FE data collected so far in comparison to the three correlations of Costa, S&Z, and W&F. The table also provides a comparison of the statistics of our data base with the same three correlations using various "filtering" criteria.

As can be seen, the standard deviations of the correlations for all the data base (including the THTL data but excluding $V < 2$ m/s) are quite large, ranging from 50% to 56%. The mean values, however, show that all three correlations are on the conservative side. The uncertainties for the THTL data only are much smaller, ranging from 18% to 30%, but the conclusion that all three correlations are generally conservative is still the same. However, two important distinctions must be made. First, there is a different trend in the lower velocity ($2 < V < 8$ m/s) range (into which most of the data base falls) than in the higher velocity ($V > 8$ m/s) range (into which most of the THTL data fall). Second, the uncertainties for low subcooling ($< 10^\circ\text{C}$) are much larger than for the rest of the data base, with a rapidly increasing trend in the extremely low subcooling values. The resulting agreement of the THTL data with S&Z is quite impressive, providing a mean of 1.02 and a standard deviation of 0.216, or 21.2%. In addition, the agreement with the S&Z correlation is quite good over the entire velocity range, whereas the Costa correlation becomes extremely conservative in the high-velocity range and somewhat optimistic in the low-velocity range. A more general discussion on the correlations, the statistical uncertainty of the data, and recommendations on which correlation to use (with some suggested modifications) is presented in the next section.

Fig. 29. Comparison of THTL FE data with the Gambill/Weatherhead correlation.

Table 3. Uncertainty U factor statistics of various FE models with comparison to the FE data base

$$U = q''(\text{experimental}) / q''(\text{correlation})$$

Case	# Data Points	Costa			S&Z			W&F (Eta)			W&F (Rw&f)		
		mean	S.D.	S.D.%	mean	S.D.	S.D.%	mean	S.D.	S.D.%	mean	S.D.	S.D.%
THTL Data	26	1.379	0.407	29.53%	1.018	0.216	21.25%	1.175	0.307	17.58%	1.018	0.076	7.43%
All Data	375	1.339	4.827	360.37%	1.599	3.000	237.61%	1.563	3.263	208.68%	1.042	0.103	9.93%
V > 2	338	1.396	5.079	363.76%	1.653	3.990	241.34%	1.900	3.400	226.59%	1.034	0.103	9.95%
2 < V ≤ 8	295	0.926	0.342	36.89%	1.349	0.563	41.70%	1.226	0.605	49.33%	1.029	0.105	10.17%
V > 8	43	4.624	13.927	301.20%	3.737	10.973	293.66%	3.384	9.274	274.10%	1.064	0.085	7.94%
V > 8; dTsub > 10	34	1.443	0.301	20.85%	1.061	0.363	34.17%	1.234	0.349	28.18%	0.998	0.065	6.47%
V > 2; dTsub > 10	276	0.916	0.334	36.51%	1.215	0.426	35.03%	1.095	0.371	33.89%	1.014	0.101	9.92%
V > 2; dTsub ≤ 10	62	3.534	11.676	330.37%	3.604	9.077	251.82%	3.303	7.693	232.95%	1.120	0.059	5.27%
2 < V ≤ 8; dTsub > 10	242	0.846	0.274	32.36%	1.227	0.445	36.25%	1.080	0.385	35.62%	1.011	0.104	10.29%
2 < V ≤ 8; dTsub ≤ 10	53	1.289	0.385	29.83%	1.906	0.698	36.60%	1.890	0.913	48.30%	1.113	0.055	4.96%
V > 2; 0 < Tsub ≤ 4	6	23.859	33.323	139.67%	19.683	25.682	131.31%	17.283	21.425	124.54%	1.218	0.012	0.98%
V > 2; 4 < Tsub ≤ 7	12	1.794	1.084	60.42%	2.313	1.052	45.49%	2.457	1.129	45.93%	1.140	0.064	5.57%
V > 2; 7 < Tsub ≤ 10	44	1.237	0.305	24.65%	1.775	0.540	30.44%	1.638	0.511	31.18%	1.102	0.046	4.18%
V > 2; 100 < L/D < 200	165	0.927	0.374	40.33%	1.285	0.578	44.96%	1.339	0.699	52.19%	1.046	0.103	9.84%

1) THTL data excludes TSD-3/B

2) THTL Data includes Non-Uniform Heat Losses & Redistribution.

9. PROPOSED APPROACH TO CORRELATIONS

As reported earlier, the THTL data collected for FE seem to support our previous assumption that the Costa correlation is overly conservative for predicting FE or OFI at the high-velocity range applicable to the ANSR nominal conditions (see Fig. 28). The S&Z correlation was considered for FE prediction instead of the Costa correlation, even though the S&Z correlation is intended for predicting local OSV or ONVG rather than OFI. As such, the S&Z correlation, when applied to the exit conditions and used for upward flow as in the ANS case, is from a phenomenological point of view a conservative representation of OFI. However, the S&Z correlation in its original form is very sensitive to the subcooling value and decreases rapidly to zero as subcooling decreases to zero, which is obviously unrealistic.

A limited investigation led to a recommended preliminary modifications to the S&Z correlation. A letter entitled "A Recommended Flow Excursion Correlation for the ANSR Analysis" from Moshe Siman-Tov to Grady Yoder, dated November 10, 1993, was drafted (Siman-Tov November 1993); it discusses alternatives to the Costa correlation for anticipating FE and recommends a new approach for predicting FE heat flux limits based on a modified S&Z correlation. The letter provides, in detail, the reasons for the switch in correlations, the basis for the recommended modifications to be used in the short term, a procedure for incorporating that approach into a general computerized subroutine, and a general recommended approach for the longer term. The THTL FE data are incorporated in the comparisons and the related statistics.

The modifications to the S&Z correlation were made in such a way that the Stanton number was held constant at the S&Z value of 0.0065 and the Nusselt number was held constant at the S&Z value of 455 for all temperatures down to 15°C subcooling. Then both were allowed to increase according to the data as subcooling decreases, since they must become infinite at zero subcooling by definition. The modified correlations are presented in Figs. 30 and 31 for the Stanton and Nusselt numbers, respectively. The modified correlations are

For $Pe > 70,000$,

$$St = 0.0065 \quad \text{for } \Delta T_{sub} > 15 \quad (7)$$

$$St(\Delta T_{sub}) = 0.04875 [(1/\Delta T_{sub}) + (\Delta T_{sub}/225)] \quad \text{for } \Delta T_{sub} < 15.$$

For $Pe < 70,000$,

$$Nu(\Delta T_{sub}) = 3412.5 [(1/\Delta T_{sub}) + (\Delta T_{sub}/225)] \quad \text{for } \Delta T_{sub} < 15 \quad (8)$$

$$Nu = 455 \quad \text{for } \Delta T_{sub} > 15.$$

For the moment, it was recommended in this letter to use, the modified correlations for Stanton number [Eq.(7)] and Nusselt number [Eq. (8)] instead of the Costa correlation used until now. Siman-Tov (November 1993) provides a detailed discussion of those recommendations and should be referred to for further details. Note, however, that these modifications to S&Z were revised later in 1994. This source also includes a discussion of the differences between "Eia formulation" and

Fig. 30. Proposed modified Saha and Zuber correlation for Stanton number.

Fig. 31. Proposed modified Saha and Zuber correlation for Nusselt number.

"R formulation," the first based on local conditions, such as in the S&Z correlation, and the second based on energy balance on the entire flow channel, such as in the W&F correlation.

The W&F correlation is being presented in two ways: one based on transforming the original W&F R factor to the "Eta" factor, as done in the correlation comparison section of this report (see Fig. 28), and the other using the original W&F R factor directly. The two forms are theoretically equivalent and can be derived from each other through the energy balance equation. Such a transformation could also be made for Costa and S&Z, both of which were originally expressed in the "Eta" form. It turned out, however, that the R factor form is not as sensitive to errors in measured fluid bulk temperature as is the Eta form for large L/D and small subcooling, whereas the reverse is true for small L/D and high subcooling. This observation and its implications (including the reason for not using the W&F correlation at all) are discussed in more detail in Siman-Tov (November 1993).

10. FUTURE PLANS

The initial focus of the THTL experimentation for the ANSR is the determination of thermal limits under ANS nominal conditions using water as the coolant. Future plans include additional experiments to be performed with the existing facility and test section design to capture the onset of incipient boiling, the single-phase heat transfer coefficients and friction factors, and the two-phase heat transfer and pressure drop characteristics.

Also under consideration are plans for nonnominal conditions experiments, including low-flow tests simulating shutdown and refueling conditions, low-pressure conditions simulating LOCA and other selected quasi-equilibrium situations encountered during transient scenarios, the effect of oxide buildup, the effects of different materials and its surface roughnesses, and the effect of heavy water on the thermal limits (CHF, FE, and IB).

Other experiments will require modifying the THTL facility, including adding new test section designs to accommodate additional requirements. This program includes a full-span, single-sided heated channel to determine the level of lateral flow mixing in the channel and confirm the effects (or lack thereof) of channel span, a two-sided half-length heated channel to test the effects of the lateral and axial heat flux distributions, and a full-span single-sided heated channel to test the effects of hot spots and hot streaks on the CHF and FE thermal limits, respectively. A more complete long-term experimental plan is currently being prepared.

In the near term, the current series of experiments will be continued to accomplish the following objectives:

- extend the current FE data to include low subcooling in the range of 1–10°C in order to determine the behavior of the FE correlation at low subcooling;
- extend the current FE experiments to achieve or exceed the ANSR nominal set point conditions, which include the nominal velocity of 25 m/s and the corresponding heat flux of $\sim 16 \text{ MW/m}^2$, using the minimum pressure drop approach (i.e., a modified stiff system with closed or minimal bypass);
- confirm (for some limited cases) that actual burnout FE (destructive FE) does indeed occur at the point of minimum pressure drop, using a soft system with open bypass;
- perform similar experiments with increased test channel span to determine the level of lateral mixing and to test the scalability of the span size;
- perform FE experiments with reduced test channel length to simulate FE at subcooling levels similar to those of the ANSR nominal conditions;
- perform selective true CHF tests to establish the relationship between true CHF and FE, using a stiff system with closed bypass and focusing on the ANS nominal operating conditions;
- establish correlations of FE and CHF as a function of the major T/H parameters of velocity, pressure, and subcooling at the range of the ANS nominal conditions (nominal set point $\pm 20\%$); and
- perform tests on the special effects of the thermal limits (oxide film, heavy water, etc.), nonnominal conditions, and other T/H phenomena, as described in the long-range plans.

11. SUMMARY AND CONCLUSIONS

1. A THTL facility was constructed with special consideration to ensure the capability to operate the loop in three different modes—stiff for CHF tests, modified stiff for nondestructive FE tests (detected by a minimum in pressure drop), and soft for actual FE burnout tests to most accurately simulate the multiple parallel channel configuration of the ANSR. The THTL includes a bypass line in parallel to the test section; a large, nearly positive displacement pump providing almost constant mass flux; a reduced piping volume upstream of the test section; and a significant pressure drop across the flow control valve upstream of the test section.
2. Although the experiments performed so far are in their initial stages, preliminary conclusions were derived by comparing the data to three well-known FE correlations: Costa (1967), Whittle and Forgan (1967), and Saha and Zuber (1974). All three correlations seem to be generally conservative when compared with the data, with the best agreement occurring with the S&Z correlation. The FE heat flux dependence on velocity seems to be somewhere between the 0.5 power (Costa) and 1.0 (S&Z and W&F), lying nearly in the 0.8–0.9 range proposed by the more recent correlations of Lee and Bankoff (1992) and Rogers and Li (1992).
3. Acquiring FE data at this level of heat flux and velocity is of great significance for numerous reasons. Most of the available FE data is in the low-velocity (<10 -m/s) range. The data reported in this report are beyond any previously available, except those reported by Waters (1966) in support of the Advanced Test Reactor. The heat flux achieved (14 MW/m^2 average and 16.2 MW/m^2 at the exit) is well beyond the ANSR nominal peak heat flux of 12 MW/m^2 , and yet the corresponding limiting velocity is 17.3 m/s —well below the ANSR nominal velocity of 25 m/s . The true CHF (or the subsequent expected burnout) was not encountered before the minimum pressure drop (FE) point in any of the experiments performed thus far. Furthermore, a true CHF velocity of 12.2 m/s at 12 MW/m^2 showed a 30% margin compared to the 17.3 m/s for the corresponding FE critical velocity and a 50% margin compared to the ANSR nominal velocity. On a preliminary basis, this result implies the existence of a good safety margin in the ANSR operating velocity for both thermal limits.
4. The S&Z correlation was modified at the lower subcooling range ($<15^\circ\text{C}$) for the ANS application to provide a better fit with the data in this range and be consistent with the fact that both the Stanton and Nusselt numbers must, by definition, be infinite at zero subcooling.
5. Some difficulties were encountered in temperature measurement, oxide layer buildup, pH control, and 3-D heat redistribution that complicated the data reduction and analysis. Those difficulties were taken into account and are being resolved as the project progresses.
6. The initial focus in the THTL experimentation for the ANSR is on thermal limit determination under ANSR nominal conditions using water as the coolant. A comprehensive test plan for the THTL facility and its various upgrades is being developed. This plan will consider all of the phenomena and effects intended to be studied in the THTL, as well as the constraints involved. Upgrades planned for the THTL facility include a full-span, single-sided heated channel and a two-sided, half-length heated channel.

7. In the near term, the current series of experiments will be continued to achieve or exceed the ANSR nominal set point conditions, which include the nominal velocity of 25 m/s and the corresponding heat flux of 16 MW/m². The final correlation of the data for FE and CHF as a function of the major T/H parameters at the ANSR conditions range will be postponed until the remainder of the experiments have been performed.

NOMENCLATURE

A	=	cross section area (m^2)
C	=	a constant [Eq. 6]
C_p	=	mean coolant specific heat ($kJ/kg \cdot K$)
D_h	=	hydraulic diameter (m)
E	=	electric voltage to test section (kV)
G	=	mass flux ($kg/m^2 \cdot s$)
I	=	electric current to test section (A)
k	=	thermal conductivity ($kW/m \cdot K$)
L	=	heated length (m)
Nu	=	Nusselt Number (-) = $\frac{q'' D_h}{k \Delta T_{mb}}$

P	=	pressure (Pa)
Pe	=	Peclet Number (-)
R	=	electrical resistance ($\mu\Omega \cdot cm$)
Q	=	heat rate (kW)
q''	=	heat flux (kW/m^2)
St	=	Stanton Number (-) = $\frac{q''}{G \cdot C_p \Delta T_{mb}}$

T	=	temperature (K)
th	=	thickness (m)
V	=	coolant velocity (m/s)
x	=	distance along channel (m)
n	=	exponential constant [Eq. 6]
ΔP	=	pressure drop (Pa)
ΔT	=	temperature difference (K)
ρ	=	coolant density (kg/m^3)

Subscripts

al	=	aluminum
av	=	average across and along the test section
b	=	bulk coolant
c	=	value at the minimum ΔP point
cool	=	coolant
cs	=	cross section of the flow
fe	=	at the flow excursion point
ele	=	electrical
ex	=	exit
ext	=	external
in	=	inside
loc	=	local

loss = losses from test section
ox = oxide film layer
s = saturated
sub = subcooling value ($T_{\text{sat}} - T_b$)
tot = total
ts = test section
w = wall

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Appendix A

THTL BASE MODEL FOR DATA REDUCTION AND ANALYSIS (MASANORI KAMINAGA)

1. Prepare *.PRN files for THTL

Following two kinds of data files are created by THTL data acquisition system (PC located downstairs).

- a. ANS1xx.PRN : Experimental data (47 data points) are collected every 10 sec. (large file)
- b. ANS2xx.PRN : Experimental data (47 data points) are collected by operator's request. (small file)

xx : random number

Example : ANS168.PRN, ANS268.PRN

Usually after an experiment above files are renamed as shown below.

a. ANS1xx.PRN → THssmdd.DAT

b. ANS2xx.PRN → THssmddA.DAT

ss : THTL experiments series number (01, 02, 03,)

m : Month (1, 2, 3, 4, 5, 6, 7, 8, 9, O, N, D)

dd : Day

Example : TH10331.DAT, TH10331A.DAT

Experimental data reduction program THTL (THTL ver1.86) needs one of above files (usually THTL uses a large file), but files must be named by the following manner.

Therefore before running THTL, you must rename above files.

a. THssmdd.DAT → ttmdyy1.PRN (large file)

b. THssmddA.DAT → ttmdyy2.PRN (small file)

If there are more than 2 files, please rename files as shown below.

c. [THssmddC.DAT → ttmdyy3.PRN (large file)]

d. [THssmddD.DAT → ttmdyy4.PRN (small file)]

tt : Type of experiment

FE : Flow Excursion

CF : Critical Heat Flux

IB : Incipient Boiling

HC : Heat Transfer Coefficient

ss : THTL experiments series number (01, 02, 03,)

m : Month (1, 2, 3, 4, 5, 6, 7, 8, 9, O, N, D)

dd : Day

yy : Year

Example : FE331931.PRN, FE331932.PRN

FE330931.PRN, FE330932.PRN, FE330933.PRN, FE330934.PRN

2. Prepare *.CFG files for THTL

File format of *.CFG files is shown below. THTL needs *.CFG files as many as *.PRN files. If there are 10 *.PRN files, you must create 10 *.CFG files. File name of *.CFG file is the same as *.PRN file except file extension of CFG.

Example file : FE331931.CFG -----

FE331931,5,0

TT117, TT115, TT113, TT111, TT109, TT107, TT105, TT—, TT101

TT118, TT116, TT114, TT112, TT110, TT108, TT106, TT104, TT102

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/G Test Section No.=131693¹⁾

gap =¹⁾ 0.1232525 Flow gap cm [0.0485250 inch]¹⁾

w =¹⁾ 1.270 Width of test channel flat cm¹⁾

thal=¹⁾ 0.254 Thickness of aluminum flats cm¹⁾

xa =¹⁾ 0.0635 Thickness of aluminum ends cm¹⁾

xb =¹⁾ 0.0381 Width of end section which has same flow gap with flat channel cm¹⁾

L =¹⁾ 50.70 Length of test channel cm [Measured length = 50.85 cm]¹⁾

thex=¹⁾ 0.0002 Estimated thickness of aluminum oxide cm¹⁾

tbulkin =¹⁾ 1 1:(TT-201A - TT-201B) 2: 2:TT-201.A 3:TT-201B¹⁾

tbulkout =¹⁾ 1 1:(TT-202A - TT-202B) 2: 2:TT-202.A 3:TT-202B¹⁾

¹⁾Comments

(1) : FE331931,5,0

FE331931 : *.PRN file name(except *.PRN file extension)

5 : First data record number of *.PRN file (usually 5)

0 : If there are two sets of comment lines in *.PRN file, please type the first record number of the second comment lines set.

See following example file !

Example file : FE331931.PRN-----

Record number -----

"03-31-1993", "09:10:08", "THTL.RTG ", , 48, "CHANNELS", 1 : Comment line 1

"CHANNEL", 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,, 47 2 : Comment line 2

"TIME", "TT-101", "TT-102", "TT-103", "TT-104", "TT-105",, 3 : Comment line 3

"HH:MM:SS", "C Deg", "C Deg", "C Deg", "C Deg", "C Deg",, 4 : Comment line 4

"09:10:10", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ... 5 : Data 1

"09:10:20", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ... 6 : Data 2

"09:10:30", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ... 7 : Data 3

"09:10:40", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ... 8 : Data 4

Example

FE330931,5,7 (or FE330931,11,0).....[FE330931,11,0] is better than [FE330931,5,7]

FE330931 : *.PRN file name(except *.PRN file extension)

5 : : First data record number of *.PRN file

7 : : The first record number of the second comment lines set.

See following example file !

ANS THTL Flow Excursion Test

Velocity Parameter

$T_{in}=45\text{ C}$, $P_{out}=1.7\text{ MPa}$

03/06/92 FE306A, FE306B
04/29/92 FE429A, FE429B

File name : NONUNI2.DAT

Non-uniform heat flux distribution difinition file "Nonuni2.dat"
1.200, 0.850, 0.750, 0.877, 1.000, 1.200, 1.500, 2.000, 2.500
Length of each elements (cm) are as follows.
8.25, 13.75, 12.0, 6.0, 4.0, 3.0, 1.5, 1.0, 1.2

File name : NONUNI3.DAT

Non-uniform heat flux distribution difinition file "Ncnuni3.dat"
0.8500606, 0.900, 0.950, 1.00, 1.123, 1.300, 1.400, 1.500, 1.600
Length of each elements (cm) are as follows.
8.25, 13.75, 12.0, 6.0, 4.0, 3.0, 1.5, 1.0, 1.2

ANS THTL Flow Excursion Test

Comparisons between measured qFE vs. qFE predicted by Costa's correlation

File name : FE11493.INP

FE114931

FE114A01, 593, FE114A02, 601, FE114A03, 606, FE114A04, 611, FE114A05, 616
FE114A06, 623, FE114A07, 628, FE114A08, 631, FE114A09, 634, FE114A10, 638
FE114A11, 642, FE114A12, 647, FE114A13, 651, FE114END,9998

FE114933

FE114B01, 473, FE114B02, 429, FE114B03, 459, FE114B04, 475, FE114B05, 491
FE114B06, 535, FE114B07, 570, FE114B08, 592, FE114B09, 602, FE114B10, 631
FE114B11, 649, FE114B12, 657, FE114B13, 683, FE114B14, 723, FE114B15, 752
FE114B16, 769, FE114B17, 799, FE114B18, 809, FE114B19, 843, FE114B20, 880
FE114B21, 942, FE114B22, 990, FE114B23,1028, FE114B24,1110, FE114B25,1156
FE114B26,1204, FE114END,9999

File name : CF11593.INP

CF115931

CF115A01, 7, CF115A02, 12, CF115A03, 20, CF115A04, 26, CF115A05, 32
CF115A06, 37, CF115A07, 43, CF115A08, 49, CF115A09, 55, CF115A10, 64
CF115A11, 66, CF115A12, 72, CF115A13, 76
CF115B01, 424, CF115B02, 461, CF115B03, 488, CF115B04, 513, CF115B05, 550
CF115B06, 579, CF115B07, 615, CF115B08, 633, CF115B09, 656, CF115B10, 697
CF115B11, 721, CF115B12, 737, CF115B13, 762, CF115B14, 772, CF115B15, 832
CF115B16, 865, CF115B17, 878, CF115B18, 900, CF115B19, 934, CF115B20, 951
CF115END,9999

File name : FE21093.INP

FE210931

FE210A01, 406, FE210A02, 411, FE210A03, 429, FE210A04, 433, FE210A05, 441
FE210A06, 446, FE210A07, 449, FE210A08, 456, FE210A09, 461, FE210A10, 466
FE210A11, 472, FE210A12, 475, FE210A13, 481, FE210A14, 485
FE210B01,1476, FE210B02,1498, FE210B03,1518, FE210B04,1541, FE210B05,1579
FE210B06,1592, FE210B07,1627, FE210B08,1641, FE210B09,1653, FE210B10,1666
FE210B11,1678, FE210B12,1699, FE210B13,1711, FE210B14,1731, FE210B15,1741
FE210B16,1753, FE210B17,1763, FE210B18,1777, FE210B19,1783, FE210B20,1811
FE210B21,1844, FE210B22,1865, FE210B23,1973, FE210END,9999

File name : FE21193.INP

FE211931

FE211A01, 406, FE211A02, 409, FE211A03, 420, FE211A04, 426, FE211A05, 436
FE211A06, 443, FE211A07, 467, FE211A08, 483, FE211A09, 487, FE211A10, 495
FE211A11, 499, FE211A12, 503, FE211A13, 505, FE211A14, 510, FE211END,9999

File name : FE21293.INP

FE212931

FE212A01, 440, FE212A02, 457, FE212A03, 484, FE212A04, 509, FE212A05, 536
FE212A06, 557, FE212A07, 673, FE212A08, 700, FE212A09, 897, FE212A10,1147
FE212A11,1523, FE212A12,1809, FE212A13,2099, FE212A14,2418, FE212A15,2811
FE212A16,3106, FE212A17,3428, FE212A18,3820, FE212A19,4057, FE212A20,4587
FE212A21,4646, FE212A22,4658, FE212END,9999

FE212A21 : FE Point

ANS THTL Flow Excursion Test

Comparisons between measured qFE vs. qFE predicted by Costa's correlation

File name : FED1792.INP

FED17921

FED17A01, 521, FED17A02, 543, FED17A03, 578, FED17A04, 587, FED17A05, 611
 FED17A06, 642, FED17A07, 669, FED17A08, 698, FED17A09, 710, FED17A10, 733
 FED17A11, 749, FED17A12, 754, FED17A13, 781, FED17A14, 815, FED17A15, 855
 FED17A16, 878, FED17A17, 905, FED17A18, 925, FED17A19, 960, FED17A20, 1008
 FED17A21, 1121, FED17A22, 1178, FED17A23, 1251, FED17A24, 1299, FED17A25, 1317
 FED17A26, 1356, FED17A27, 1372, FED17A28, 1385, FED17A29, 1407, FED17A30, 1448
 FED17B01, 1775, FED17B02, 1895, FED17B03, 1901, FED17B04, 1904, FED17B05, 1911
 FED17B06, 1930, FED17B07, 2114, FED17B08, 2121, FED17B09, 2129, FED17B10, 2136
 FED17B11, 2141, FED17B12, 2151, FED17B13, 2158, FED17B14, 2162, FED17END, 9999

File name : FED2892.INP

FED28921

FED28A01, 1580, FED28A02, 1589, FED28A03, 1594, FED28A04, 1600, FED28A05, 1606
 FED28A06, 1614, FED28A07, 1617, FED28A08, 1622
 FED28B01, 1945, FED28B02, 1977, FED28B03, 1993, FED28B04, 2006, FED28B05, 2026
 FED28B06, 2052, FED28B07, 2064, FED28B08, 2081, FED28B09, 2095, FED28B10, 2117
 FED28B11, 2134, FED28B12, 2156, FED28B13, 2172, FED28B14, 2182, FED28B15, 2199
 FED28B16, 2223, FED28B17, 2239, FED28B18, 2252, FED28B19, 2271, FED28B20, 2293
 FED28B21, 2305, FED28B22, 2328, FED28B23, 2343, FED28B24, 2359, FED28B25, 2372
 FED28B26, 2379, FED28B27, 2400, FED28END, 9999

File name : FE10593.INP

FE105932

FE105A01, 6, FE105A02, 7, FE105A03, 10, FE105A04, 12, FE105A05, 14
 FE105A06, 26, FE105A07, 30, FE105A08, 36, FE105A09, 38, FE105A10, 40
 FE105A11, 41, FE105A12, 43, FE105A13, 45, FE105A14, 46, FE105A15, 47
 FE105A16, 48
 FE105B01, 50, FE105B02, 51, FE105B03, 58, FE105B04, 59, FE105B05, 62
 FE105B06, 63, FE105B07, 68, FE105B08, 70, FE105B09, 74, FE105B10, 79
 FE105B11, 84, FE105B12, 86, FE105B13, 89, FE105B14, 91, FE105B15, 94
 FE105B16, 95, FE105B17, 97, FE105B18, 98, FE105B19, 100, FE105B20, 101
 FE105C01, 106, FE105C02, 109, FE105C03, 110, FE105C04, 114, FE105C05, 116
 FE105C06, 118, FE105C07, 119, FE105C08, 121, FE105C09, 123, FE105C10, 125
 FE105C11, 129, FE105C12, 130, FE105C13, 132, FE105C14, 135, FE105C15, 138
 FE105C16, 139, FE105C17, 143, FE105C18, 146, FE105C19, 147, FE105C20, 148
 FE105C21, 150, FE105C22, 152, FE105C23, 154, FE105C24, 155, FE105C25, 158
 FE105D01, 159, FE105D02, 160, FE105D03, 163, FE105D04, 165, FE105D05, 166
 FE105D06, 168, FE105D07, 170, FE105D08, 172, FE105D09, 176, FE105D10, 177
 FE105D11, 179, FE105D12, 180, FE105D13, 184, FE105D14, 192, FE105D15, 193
 FE105D16, 195, FE105D17, 197, FE105D18, 200, FE105D19, 201, FE105D20, 203
 FE105D21, 206, FE105D22, 207, FE105END, 9999
 FE105E01, 211, FE105E02, 213, FE105E03, 214, FE105E04, 217, FE105E05, 218
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 FE105E11, 226, FE105E12, 229, FE105E13, 230, FE105E14, 231, FE105E15, 232
 FE105E16, 233, FE105E17, 234, FE105E18, 235, FE105E19, 236, FE105E20, 237
 FE105E21, 238, FE105E22, 241, FE105E23, 242, FE105E24, 243, FE105E25, 244
 FE105E26, 246, FE105E27, 247, FE105E28, 248, FE105E29, 249
 FE105F01, 250, FE105F02, 252, FE105F03, 254, FE105F04, 257, FE105F05, 258
 FE105F06, 259, FE105F07, 260, FE105F08, 261, FE105F09, 262, FE105F10, 263
 FE105F11, 264, FE105F12, 265, FE105F13, 266, FE105FND, 9999

ANS THTL Flow Excursion Test

Heat Flux Parameter

$T_{in}=45\text{ C}$, $P_{out}=1.7\text{ MPa}$

04/16/92 FE416A

04/24/92 FE424A, FE424B

File name : FEN1992.INP

FEN19921

FEN19A01,2354, FEN19A02,2364, FEN19A03,2370, FEN19A04,2381, FEN19A05,2396
 FEN19A06,2403, FEN19A07,2409, FEN19A08,2417, FEN19A09,2424, FEN19A10,2429
 FEN19A11,2437, FEN19A12,2447, FEN19END,9999

File name : FEN2092.INP

FEN20921

FEN20A01, 552, FEN20A02, 569, FEN20A03, 583, FEN20A04, 604, FEN20A05, 620
 FEN20A06, 645, FEN20A07, 659, FEN20A08, 691, FEN20A09, 703, FEN20A10, 728
 FEN20A11, 747
 FEN20B01, 787, FEN20B02, 799, FEN20B03, 820, FEN20B04, 850, FEN20B05, 872
 FEN20B06, 893, FEN20B07, 912, FEN20B08, 931, FEN20B09, 953, FEN20B10, 965
 FEN20B11, 983, FEN20B12, 987, FEN20B13, 998, FEN20B14,1016, FEN20B15,1032
 FEN20B16,1047
 FEN20C01,1246, FEN20C02,1262, FEN20C03,1278, FEN20C04,1288, FEN20C05,1293
 FEN20C06,1307, FEN20C07,1317, FEN20C08,1327, FEN20C09,1336, FEN20C10,1352
 FEN20C11,1359, FEN20C12,1369, FEN20END,9999

File name : FEN3092.INP

FEN30921

FEN30A01, 337, FEN30A02, 347, FEN30A03, 361, FEN30A04, 385, FEN30A05, 408
 FEN30A06, 431, FEN30A07, 450, FEN30A08, 462, FEN30A09, 495, FEN30A10, 508
 FEN30A11, 531, FEN30A12, 537, FEN30A13, 567, FEN30A14, 587, FEN30A15, 631
 FEN30A16, 642, FEN30A17, 665, FEN30A18, 671, FEN30A19, 696, FEN30A20, 716
 FEN30A21, 732, FEN30A22, 745, FEN30A23, 889
 FEN30B01,1075, FEN30B02,1083, FEN30B03,1091, FEN30B04,1099, FEN30B05,1105
 FEN30B06,1115, FEN30B07,1121, FEN30B08,1126, FEN30B09,1135, FEN30B10,1142
 FEN30B11,1147, FEN30B12,1154, FEN30B13,1158, FEN30END,9999

File name : FED1592.INP

FED15921

FED15A01, 604, FED15A02, 609, FED15A03, 619, FED15A04, 627, FED15A05, 634
 FED15A06, 640, FED15A07, 648, FED15A08, 653, FED15A09, 657, FED15A10, 662
 FED15A11, 669, FED15A12, 675, FED15A13, 682, FED15A14, 686, FED15A15, 692
 FED15A16, 700
 FED15B01,1149, FED15B02,1183, FED15B03,1208, FED15B04,1224, FED15B05,1244
 FED15B06,1266, FED15B07,1273, FED15B08,1301, FED15B09,1347, FED15B10,1378
 FED15B11,1398, FED15B12,1420, FED15B13,1442, FED15B14,1450, FED15B15,1471
 FED15B16,1479, FED15B17,1503, FED15B18,1524, FED15B19,1555, FED15B20,1598
 FED15C01,1631, FED15C02,1648, FED15C03,1659, FED15C04,1685, FED15C05,1701
 FED15C06,1713, FED15C07,1735, FED15C08,1745, FED15C09,1760, FED15C10,1782
 FED15C11,1793, FED15C12,1805, FED15C13,1817, FED15C14,1827, FED15C15,1843
 FED15C16,1858, FED15C17,1867, FED15C18,1877, FED15C19,1889, FED15C20,1902
 FED15C21,1920, FED15C22,1943, FED15C23,1950, FED15C24,1975, FED15END,9999

M.Kaminaga 1/8/93

File name : FE105A.XLS

Variable parameter : Coolant velocity

January 8, 1993 12:17

Gap= 0.0484 Inch

	FE105A	FE105A01	FE105A02	FE105A03	FE105A04	FE105A05	FE105A06	FE105A07	FE105A08
Record number of data file	6	7	10	12	14	26	30	36	
Inlet temperature (°C)	44.12	44.43	44.67	44.66	44.53	45.27	45.38	45.68	
Outlet temperature Tb,out (°C)	44.90	45.13	45.29	45.32	45.13	45.67	45.77	46.07	
Inlet pressure (MPa)	4.614	4.310	4.049	3.742	3.544	3.326	3.112	2.880	
Outlet pressure (MPa)	1.713	1.708	1.718	1.676	1.703	1.710	1.706	1.701	
Power (W)	0	0	0	0	0	0	0	0	
TS power (W)	0	0	0	0	0	0	0	0	
Maximum heat flux (MW/m ²)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Average heat flux (MW/m ²)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Average coolant velocity (m/s)	37.97	35.92	34.06	32.06	30.06	28.11	26.00	23.99	
Heat loss (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
dP _{measured} (MPa)	2.901	2.602	2.331	2.066	1.841	1.616	1.406	1.179	
dP _{calculated} (MPa)	2.966	2.681	2.436	2.186	1.949	1.724	1.500	1.298	
dP _{form,calculated} (MPa)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Bypass flow ratio (-)	0.51	0.51	0.61	0.60	0.61	0.66	0.76	0.87	
Saturation temperature Ts (°C)	204.70	204.56	204.85	203.63	204.40	204.60	204.49	204.36	
q [*] ave(Ts-Tb,out) (MW/m ² °C)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
PTS _{in} (MPa)	4.544	4.246	3.991	3.690	3.497	3.285	3.076	2.849	
PTS _{out} (MPa)	1.784	1.772	1.776	1.728	1.749	1.751	1.742	1.732	
PTS _{out,cal} (MPa)	1.719	1.692	1.672	1.608	1.641	1.643	1.648	1.613	
dPTS _{measured} (MPa)	2.759	2.474	2.215	1.962	1.748	1.534	1.334	1.117	
dPTS _{calculated} (MPa)	2.825	2.553	2.320	2.082	1.856	1.642	1.428	1.236	
Saturation temp. TsTS _{out} (°C)	206.68	206.36	206.47	205.12	205.71	205.76	205.50	205.23	
	FE105A	FE105A09	FE105A10	FE105A11	FE105A12	FE105A13	FE105A14	FE105A15	FE105A16
Record number of data file	38	40	41	43	45	46	47	48	
Inlet temperature (°C)	45.62	45.40	45.21	44.92	44.79	44.45	44.17	43.85	
Outlet temperature Tb,out (°C)	45.97	45.61	45.38	45.07	44.79	44.52	44.07	43.81	
Inlet pressure (MPa)	2.739	2.577	2.410	2.284	2.148	2.038	1.964	1.916	
Outlet pressure (MPa)	1.705	1.709	1.696	1.716	1.694	1.700	1.726	1.712	
Power (W)	0	0	0	0	0	0	0	0	
TS power (W)	0	0	0	0	0	0	0	0	
Maximum heat flux (MW/m ²)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Average heat flux (MW/m ²)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Average coolant velocity (m/s)	21.99	19.97	17.93	16.05	14.04	12.07	10.09	8.01	
Heat loss (%)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
dP _{measured} (MPa)	1.034	0.869	0.714	0.567	0.454	0.339	0.238	0.204	
dP _{calculated} (MPa)	1.112	0.938	0.776	0.639	0.505	0.388	0.285	0.192	
dP _{form,calculated} (MPa)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Bypass flow ratio (-)	0.87	1.09	1.37	1.61	2.03	2.56	3.19	4.36	
Saturation temperature Ts (°C)	204.48	204.57	204.22	204.79	204.15	204.32	205.05	204.65	
q [*] ave(Ts-Tb,out) (MW/m ² °C)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
PTS _{in} (MPa)	2.713	2.555	2.391	2.268	2.136	2.029	1.957	1.911	
PTS _{out} (MPa)	1.732	1.731	1.715	1.731	1.706	1.709	1.732	1.716	
PTS _{out,cal} (MPa)	1.654	1.661	1.652	1.660	1.655	1.659	1.685	1.729	
dPTS _{measured} (MPa)	0.981	0.824	0.677	0.537	0.430	0.320	0.224	0.195	
dPTS _{calculated} (MPa)	1.059	0.894	0.739	0.608	0.481	0.370	0.271	0.182	
Saturation temp. TsTS _{out} (°C)	205.23	205.21	204.75	205.22	204.49	204.58	205.24	204.78	

File name : FE81792.INP

FE817921

FE817A01, 777, FE817A02, 875, FE817A03, 968, FE817A04, 986, FE817A05, 1003
 FE817A06, 1018, FE817A07, 1029, FE817A08, 1046, FE817A09, 1062, FE817A10, 1079
 FE817A11, 1093, FE817A12, 1111, FE817A13, 1138
 FE817B01, 1195, FE817B02, 1224, FE817B03, 1237, FE817B04, 1255, FE817B05, 1270
 FE817B06, 1284, FE817B07, 1291, FE817B08, 1303, FE817B09, 1325, FE817B10, 1350
 FE817B11, 1358
 FE817C01, 1667, FE817C02, 1696, FE817C03, 1723, FE817C04, 1743, FE817C05, 1761
 FE817C06, 1783, FE817C07, 1806, FE817C08, 1831, FE817C09, 1862, FE817C10, 1876
 FE817C11, 1887, FE817C12, 1906, FE817C13, 1922
 FE817D01, 1981, FE817D02, 2005, FE817END, 9999

File name : FE90392.INP

FE903921

FE903A01, 1676, FE903A02, 1708, FE903A03, 1801, FE903A04, 1807, FE903A05, 1822
 FE903A06, 1888, FE903A07, 1897, FE903A08, 1904, FE903A09, 1919, FE903A10, 1928
 FE903A11, 1940, FE903A12, 1946, FE903A13, 1956
 FE903B01, 2094, FE903B02, 2102, FE903B03, 2112, FE903B04, 2120, FE903B05, 2126
 FE903B06, 2132, FE903B07, 2139, FE903B08, 2143, FE903B09, 2153, FE903END, 9999

File name : FE90492.INP

FE904921

FE904A01, 1052, FE904A02, 1068, FE904A03, 1086, FE904A04, 1122, FE904A05, 1135
 FE904A06, 1151, FE904A07, 1162, FE904A08, 1180, FE904A09, 1195, FE904A10, 1204
 FE904A11, 1237, FE904A12, 1243, FE904A13, 1266
 FE904B01, 1309, FE904B02, 1323, FE904B03, 1343, FE904B04, 1361, FE904B05, 1376
 FE904B06, 1399, FE904B07, 1413, FE904B08, 1424, FE904B09, 1442, FE904B10, 1456
 FE904B11, 1461, FE904B12, 1471
 FE904C01, 1535, FE904C02, 1545, FE904C03, 1561, FE904C04, 1579, FE904C05, 1593
 FE904C06, 1611, FE904C07, 1627, FE904C08, 1639, FE904C09, 1657, FE904C10, 1665
 FE904C11, 1681, FE904C12, 1699
 FE904D01, 1728, FE904D02, 1745, FE904D03, 1758, FE904D04, 1779, FE904D05, 1786
 FE904D06, 1796, FE904D07, 1808, FE904D08, 1823, FE904D09, 1830, FE904D10, 1841
 FE904END, 9999

File name : FEN1792.INP

FEN17921

FEN17A01, 114, FEN17A02, 161, FEN17A03, 184, FEN17A04, 192, FEN17A05, 202
 FEN17A06, 206, FEN17A07, 214, FEN17A08, 221, FEN17A09, 224, FEN17A10, 234
 FEN17A11, 240, FEN17A12, 246
 FEN17B01, 778, FEN17B02, 793, FEN17B03, 809, FEN17B04, 827, FEN17B05, 844
 FEN17B06, 859, FEN17B07, 871, FEN17B08, 889, FEN17B09, 897, FEN17B10, 912
 FEN17B11, 923, FEN17B12, 933, FEN17B13, 959
 FEN17C01, 1004, FEN17C02, 1020, FEN17C03, 1030, FEN17C04, 1045, FEN17C05, 1066
 FEN17C06, 1072, FEN17C07, 1087, FEN17C08, 1100, FEN17C09, 1116, FEN17C10, 1129
 FEN17C11, 1152
 FEN17D01, 1333, FEN17D02, 1346, FEN17D03, 1355, FEN17D04, 1364, FEN17D05, 1368
 FEN17D06, 1373, FEN17D07, 1378, FEN17D08, 1384, FEN17D09, 1392, FEN17D10, 1398
 FEN17D11, 1409, FEN17D12, 1414, FEN17D13, 1432, FEN17D14, 1444, FEN17END, 9999

ANS THTL Flow Excursion Test

Velocity Parameter

$T_{in}=45 - 47$ C, $P_{out}=0.5$ MPa

03/05/92 FE305A, FE305B

04/28/92 FE428B

File name : FE212931.CFG

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FE212931,5,0
TT117, TT116, TT113, TT111, TT109, TT107, TT105, TT103, TT101
TT118, TT115, TT114, TT112, TT110, TT108, TT106, TT104, TT102
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
TSD-3/E      'Test Section No.=171892
gap = 0.123338082 'Flow gap cm [0.0485583 inch]
w = 1.270      'Width of test channel flat cm
thal= 0.254    'Thickness of aluminum flats cm
xa = 0.0635    'Thickness of aluminum ends cm
xb = 0.0381    'Width of end section which has same flow gap cm
L = 50.70      'Length of test channel cm [Measured length = N/A cm]
thox= 0.0002   'Estimated thickness of aluminum oxide cm
tbulkin = 1    '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
tbulkout = 2   '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

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File name : FE212932.CFG

```

FE212932,5,0
TT117, TT116, TT113, TT111, TT109, TT107, TT105, TT103, TT101
TT118, TT115, TT114, TT112, TT110, TT108, TT106, TT104, TT102
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
TSD-3/E      'Test Section No.=171892
gap = 0.123338082 'Flow gap cm [0.0485583 inch]
w = 1.270      'Width of test channel flat cm
thal= 0.254    'Thickness of aluminum flats cm
xa = 0.0635    'Thickness of aluminum ends cm
xb = 0.0381    'Width of end section which has same flow gap cm
L = 50.70      'Length of test channel cm [Measured length = N/A cm]
thox= 0.0002   'Estimated thickness of aluminum oxide cm
tbulkin = 1    '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
tbulkout = 2   '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

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Test Number Nomenclature

Test Name

FE408A10

Data point #10 of test "A"
run on 04/08/92 for Flow
Excursion

FE Flow Excursion
CF Critical Heat Flux
IB Incipient Boiling
HC Heat Transfer Coefficient etc.

File name : FED28921.CFG

```

FED28921,5,0
TT---, TT116, TT114, TT111, TT109, TT108, TT---, TT---, TT101
TT117, TT115, TT113, TT112, TT110, TT107, TT105, TT103, TT102
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
TSD-3/C      'Test Section No.= 141592 *** 90 degree rotated ***
gap = 0.12285218 'Flow gap cm [0.048367 inch]
w = 1.270      'Width of test channel flat cm
thal= 0.254    'Thickness of aluminum flats cm
xa = 0.0635    'Thickness of aluminum ends cm
xb = 0.0381    'Width of end section which has same flow gap cm
L = 50.70      'Length of test channel cm [Measured length = 50.75 cm]
thox= 0.0002   'Estimated thickness of aluminum oxide cm
tbulkin = 2    '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
tbulkout = 2   '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

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File name : FED28922.CFG

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FED28922,5,0
TT---, TT116, TT114, TT112, TT109, TT108, TT---, TT---, TT101
TT117, TT115, TT113, TT111, TT110, TT107, TT105, TT103, TT102
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
TSD-3/C      'Test Section No.= 141592 *** 90 degree rotated ***
gap = 0.12285218 'Flow gap cm [0.048367 inch]
w = 1.270      'Width of test channel flat cm
thal= 0.254    'Thickness of aluminum flats cm
xa = 0.0635    'Thickness of aluminum ends cm
xb = 0.0381    'Width of end section which has same flow gap cm
L = 50.70      'Length of test channel cm [Measured length = 50.75 cm]
thox= 0.0002   'Estimated thickness of aluminum oxide cm
tbulkin = 2    '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
tbulkout = 2   '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

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File name : FE105931.CFG

```

FE105931,5,0
TT118, TT116, TT113, TT111, TT109, TT108, TT106, TT104, TT102
TT117, TT115, TT114, TT112, TT110, TT107, TT105, TT103, TT101
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
TSD-3/C      'Test Section No.= 141592 *** Up side down ***
gap = 0.12285218 'Flow gap cm [0.048367 inch]
w = 1.270      'Width of test channel flat cm
thal= 0.254    'Thickness of aluminum flats cm
xa = 0.0635    'Thickness of aluminum ends cm
xb = 0.0381    'Width of end section which has same flow gap cm
L = 50.70      'Length of test channel cm [Measured length = 50.75 cm]
thox= 0.0002   'Estimated thickness of aluminum oxide cm
tbulkin = 2    '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
tbulkout = 2   '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

```

File name : FEN30921.CFG

```

FEN30921,5,0
TT118, TT115, TT113, TT111, TT110, TT108, TT106, TT104, TT102
TT117, TT116, TT114, TT112, TT109, TT107, TT105, TT103, TT101
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
TSD-3/C      'Test Section No.= 141592
gap = 0.12285218 'Flow gap cm [0.048367 inch]
w = 1.270      'Width of test channel flat cm
thal= 0.254    'Thickness of aluminum flats cm
xa = 0.0635    'Thickness of aluminum ends cm
xb = 0.0381    'Width of end section which has same flow gap cm
L = 50.70      'Length of test channel cm [Measured length = 50.75 cm]
thox= 0.0002   'Estimated thickness of aluminum oxide cm
tbulkin = 1    '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
tbulkout = 1   '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

```

File name : FEN30922.CFG

```

FEN30922,5,0
TT118, TT115, TT113, TT111, TT110, TT108, TT106, TT104, TT102
TT117, TT116, TT114, TT112, TT109, TT107, TT105, TT103, TT101
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
TSD-3/C      'Test Section No.= 141592
gap = 0.12285218 'Flow gap cm [0.048367 inch]
w = 1.270      'Width of test channel flat cm
thal= 0.254    'Thickness of aluminum flats cm
xa = 0.0635    'Thickness of aluminum ends cm
xb = 0.0381    'Width of end section which has same flow gap cm
L = 50.70      'Length of test channel cm [Measured length = 50.75 cm]
thox= 0.0002   'Estimated thickness of aluminum oxide cm
tbulkin = 1    '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
tbulkout = 1   '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

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File name : FED15921.CFG

```

FED15921,5,0
TT118, TT116, TT114, TT112, TT110, TT108, TT106, TT104, TT102
TT117, TT115, TT113, TT111, TT109, TT107, TT105, TT103, TT101
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
  2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
TSD-3/C      'Test Section No.= 141592
gap = 0.12285218 'Flow gap cm [0.048367 inch]
w = 1.270      'Width of test channel flat cm
thal= 0.254    'Thickness of aluminum flats cm
xa = 0.0635    'Thickness of aluminum ends cm
xb = 0.0381    'Width of end section which has same flow gap cm
L = 50.70      'Length of test channel cm [Measured length = 50.75 cm]
thox= 0.0002   'Estimated thickness of aluminum oxide cm
tbulkin = 2    '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
tbulkout = 2   '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

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ANS THTL Flow Excursion Test

Comparisons between measured qFE vs. qFE predicted by Costa's correlation

Rectangular channel model 'a'

File name : FEN19922.CFG

FEN19922,5,0

TT118, TT115, TT113, TT111, TT110, TT108, TT106, TT104, TT102

TT117, TT116, TT114, TT112, TT109, TT107, TT105, TT103, TT101

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/C

'Test Section No.= 141592

gap = 0.12285218 'Flow gap cm [0.048367 inch]

w = 1.270 'Width of test channel flat cm

thal= 0.254 'Thickness of aluminum flats cm

xa = 0.0635 'Thickness of aluminum ends cm

xb = 0.0381 'Width of end section which has same flow gap cm

L = 50.70 'Length of test channel cm [Measured length = 50.75 cm]

thox= 0.0002 'Estimated thickness of aluminum oxide cm

tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B

tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

File name : FEN20921.CFG

FEN20921,5,0

TT118, TT115, TT113, TT111, TT110, TT108, TT106, TT104, TT102

TT117, TT116, TT114, TT112, TT109, TT107, TT105, TT103, TT101

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/C

'Test Section No.= 141592

gap = 0.12285218 'Flow gap cm [0.048367 inch]

w = 1.270 'Width of test channel flat cm

thal= 0.254 'Thickness of aluminum flats cm

xa = 0.0635 'Thickness of aluminum ends cm

xb = 0.0381 'Width of end section which has same flow gap cm

L = 50.70 'Length of test channel cm [Measured length = 50.75 cm]

thox= 0.0002 'Estimated thickness of aluminum oxide cm

tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B

tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

File name : FEN20922.CFG

FEN20922,5,0

TT118, TT115, TT113, TT111, TT110, TT108, TT106, TT104, TT102

TT117, TT116, TT114, TT112, TT109, TT107, TT105, TT103, TT101

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/C

'Test Section No.= 141592

gap = 0.12285218 'Flow gap cm [0.048367 inch]

w = 1.270 'Width of test channel flat cm

thal= 0.254 'Thickness of aluminum flats cm

xa = 0.0635 'Thickness of aluminum ends cm

xb = 0.0381 'Width of end section which has same flow gap cm

L = 50.70 'Length of test channel cm [Measured length = 50.75 cm]

thox= 0.0002 'Estimated thickness of aluminum oxide cm

tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B

tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

ANS THTL Flow Excursion Test

Comparisons between measured qFE vs. qFE predicted by Costa's correlation

File name : FEN17921.CFG

FEN17921,11,0

TT118, TT115, TT113, TT111, TT110, TT108, TT106, TT104, TT102

TT117, TT116, TT114, TT112, TT109, TT107, TT105, TT103, TT101

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/C

'Test Section No.= 141592

gap = 0.12285218 'Flow gap cm [0.048367 inch]

w = 1.270 'Width of test channel flat cm

thal= 0.254 'Thickness of aluminum flats cm

xa = 0.0635 'Thickness of aluminum ends cm

xb = 0.0381 'Width of end section which has same flow gap cm

L = 50.70 'Length of test channel cm [Measured length = 50.75 cm]

thox= 0.0002 'Estimated thickness of aluminum oxide cm

tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B

tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

File name : FEN17922.CFG

FEN17922,5,0

TT118, TT115, TT113, TT111, TT110, TT108, TT106, TT104, TT102

TT117, TT116, TT114, TT112, TT109, TT107, TT105, TT103, TT101

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/C

'Test Section No.= 141592

gap = 0.12285218 'Flow gap cm [0.048367 inch]

w = 1.270 'Width of test channel flat cm

thal= 0.254 'Thickness of aluminum flats cm

xa = 0.0635 'Thickness of aluminum ends cm

xb = 0.0381 'Width of end section which has same flow gap cm

L = 50.70 'Length of test channel cm [Measured length = 50.75 cm]

thox= 0.0002 'Estimated thickness of aluminum oxide cm

tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B

tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

File name : FEN19921.CFG

FEN19921,5,0

TT118, TT115, TT113, TT111, TT110, TT108, TT106, TT104, TT102

TT117, TT116, TT114, TT112, TT109, TT107, TT105, TT103, TT101

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/C

'Test Section No.= 141592

gap = 0.12285218 'Flow gap cm [0.048367 inch]

w = 1.270 'Width of test channel flat cm

thal= 0.254 'Thickness of aluminum flats cm

xa = 0.0635 'Thickness of aluminum ends cm

xb = 0.0381 'Width of end section which has same flow gap cm

L = 50.70 'Length of test channel cm [Measured length = 50.75 cm]

thox= 0.0002 'Estimated thickness of aluminum oxide cm

tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B

tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

ANS THTL Flow Excursion Test

Heat Flux Parameter

$T_{in}=45\text{ C}$, $P_{out}=1.7\text{ MPa}$

04/16/92 FE416A

04/24/92 FE424A, FE424B

File name : FE903922.CFG

FE903922,5,0

TT117, TT115, TT113, TT111, TT110, TT108, TT105, TT103, TT101
 TT118, TT116, TT114, TT112, TT109, TT107, TT106, TT104, TT102
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/B 'Test Section No.= 1292
 gap = 0.12259818 'Flow gap cm [0.048267 inch]
 w = 1.270 'Width of test channel flat cm
 thal= 0.254 'Thickness of aluminum flats cm
 xa = 0.0635 'Thickness of aluminum ends cm
 xb = 0.0381 'Width of end section which has same flow gap cm
 L = 50.70 'Length of test channel cm [Measured length = 50.622cm]
 thox= 0.0002 'Estimated thickness of aluminum oxide cm
 tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
 tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

File name : FE904921.CFG

FE904921,5,0

TT117, TT115, TT113, TT111, TT110, TT108, TT105, TT103, TT101
 TT118, TT116, TT114, TT112, TT109, TT107, TT106, TT104, TT102
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/B 'Test Section No.= 1292
 gap = 0.12259818 'Flow gap cm [0.048267 inch]
 w = 1.270 'Width of test channel flat cm
 thal= 0.254 'Thickness of aluminum flats cm
 xa = 0.0635 'Thickness of aluminum ends cm
 xb = 0.0381 'Width of end section which has same flow gap cm
 L = 50.70 'Length of test channel cm [Measured length = 50.622cm]
 thox= 0.0002 'Estimated thickness of aluminum oxide cm
 tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
 tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

File name : FE904922.CFG

FE904922,5,0

TT117, TT115, TT113, TT111, TT110, TT108, TT105, TT103, TT101
 TT118, TT116, TT114, TT112, TT109, TT107, TT106, TT104, TT102
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/B 'Test Section No.= 1292
 gap = 0.12259818 'Flow gap cm [0.048267 inch]
 w = 1.270 'Width of test channel flat cm
 thal= 0.254 'Thickness of aluminum flats cm
 xa = 0.0635 'Thickness of aluminum ends cm
 xb = 0.0381 'Width of end section which has same flow gap cm
 L = 50.70 'Length of test channel cm [Measured length = 50.622cm]
 thox= 0.0002 'Estimated thickness of aluminum oxide cm
 tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
 tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

ANS THTL Flow Excursion Test

Heat Flux Parameter

$T_{in}=45\text{ C}$, $P_{out}=0.5\text{ MPa}$

04/08/92 FE408A, FE408B

04/28/92 FE428A

File name : FE817921.CFG

FE817921,5,0

TT117, TT115, TT113, TT112, TT109, TT107, TT105, TT104, TT101
 TT118, TT116, TT114, TT111, TT110, TT108, TT106, TT103, TT102
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/A 'Test Section No.= 6792
 gap = 0.1266825 'Flow gap cm [0.049875 inch]
 w = 1.270 'Width of test channel flat cm
 thal= 0.254 'Thickness of aluminum flats cm
 xa = 0.0635 'Thickness of aluminum ends cm
 xb = 0.0381 'Width of end section which has same flow gap cm
 L = 50.70 'Length of test channel cm [Measured length = 50.483 cm]
 thox= 0.0002 'Estimated thickness of aluminum oxide cm
 tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
 tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

File name : FE817922.CFG

FE817922,5,0

TT117, TT115, TT113, TT112, TT109, TT107, TT105, TT104, TT101
 TT118, TT116, TT114, TT111, TT110, TT108, TT106, TT103, TT102
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/A 'Test Section No.= 6792
 gap = 0.1266825 'Flow gap cm [0.049875 inch]
 w = 1.270 'Width of test channel flat cm
 thal= 0.254 'Thickness of aluminum flats cm
 xa = 0.0635 'Thickness of aluminum ends cm
 xb = 0.0381 'Width of end section which has same flow gap cm
 L = 50.70 'Length of test channel cm [Measured length = 50.483 cm]
 thox= 0.0002 'Estimated thickness of aluminum oxide cm
 tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
 tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

File name : FE903921.CFG

FE903921,5,0

TT117, TT115, TT113, TT111, TT110, TT108, TT105, TT103, TT101
 TT118, TT116, TT114, TT112, TT109, TT107, TT106, TT104, TT102
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0

TSD-3/B 'Test Section No.= 1292
 gap = 0.12259818 'Flow gap cm [0.048267 inch]
 w = 1.270 'Width of test channel flat cm
 thal= 0.254 'Thickness of aluminum flats cm
 xa = 0.0635 'Thickness of aluminum ends cm
 xb = 0.0381 'Width of end section which has same flow gap cm
 L = 50.70 'Length of test channel cm [Measured length = 50.622cm]
 thox= 0.0002 'Estimated thickness of aluminum oxide cm
 tbulkin = 1 '1:(TT-201A + TT-201B)/2, 2:TT-201A, 3:TT-201B
 tbulkout = 1 '1:(TT-202A + TT-202B)/2, 2:TT-202A, 3:TT-202B

ANS THTL Flow Excursion Test

Velocity Parameter

$T_{in}=45\text{ C}$, $P_{out}=1.7\text{ MPa}$

03/06/92 FE306A, FE306B
04/29/92 FE429A, FE429B

File name : DATNUM3.DAT

01/22/92, HC12292 , 0
 03/05/92, FE30592 , 1, 03/06/92, FE30692 , 0
 04/08/92, FE40892 , 1, 04/16/92, FE41692 , 1, 04/24/92, FE42492 , 1, 04/28/92, FE42892 , 0
 04/29/92, FE42992 , 0
 99/99/99 Maximum number of lines is seven and maximum number of data set for one line is four.
 01/22/92, HC122A01, (01) -----
 03/05/92, FE305A06, (01 to 07) Velocity THTL Experimental data file
 , FE305B10, (01 to 12) Velocity '12/31/92 M. Kaminaga
 03/06/92, FE306A06, (01 to 10) Velocity TSD-1
 , FE306B05, (01 to 06) Velocity
 04/08/92, FE408A08, (01 to 10) Heat flux Maximum number of data sets is 28.
 , FE408B07, (01 to 11) Heat flux If you want to input data sets
 04/16/92, FE416A05, (01 to 09) Heat flux 'more than 28 please make an another
 , FE416B06, (01 to 06) Heat flux 'data file (DATNUMx.dat : x =1 ...9).
 04/24/92, FE424A25, (01 to 27) Heat flux
 , FE424B11, (01 to 14) Heat flux FE-----x ; FE----xx : Non-heated test
 04/28/92, FE428A14, (01 to 19) Heat flux
 , FE428B11, (01 to 15) Velocity
 04/29/92, FE429A10, (01 to 13) Velocity
 , FE429B09, (01 to 09) Velocity
 99/99/99 "99/99/99" means end of data sets.
 0 '0 : End of data 1 : continue

M.Kaminaga 1/8/93

File name : FE105B.XLS

	FE105B	FE105B17	FE105B18	FE105B18	FE105B20
Record number of data file	97	98	100	101	
Inlet temperature (°C)	45.39	44.27	45.48	44.62	
Outlet temperature $T_{b,out}$ (°C)	156.26	133.77	121.04	114.59	
Inlet pressure (MPa)	2.211	2.470	2.783	2.983	
Outlet pressure (MPa)	1.703	1.701	1.699	1.723	
Power (W)	138969	138526	138861	138664	
TS power (W)	127203	128773	131104	131415	
Maximum heat flux (MW/m²)	9.982	10.026	10.097	10.075	
Average heat flux (MW/m²)	9.209	9.323	9.491	9.514	
Average coolant velocity (m/s)	16.01	19.98	24.03	25.97	
Heat loss (%)	8.5	7.0	5.6	5.2	
$dP_{measured}$ (MPa)	0.509	0.769	1.084	1.260	
$dP_{calculated}$ (MPa)	0.452	0.694	0.992	1.154	
$dP_{form,calculated}$ (MPa)	0.000	0.000	0.000	0.000	
Bypass flow ratio (-)	1.68	1.35	1.33	1.18	
Saturation temperature T_s (°C)	204.41	204.36	204.30	204.97	
$q''_{ave}(T_s - T_{b,out})$ (MW/m² °C)	0.191	0.132	0.114	0.105	
PTS_{in} (MPa)	2.196	2.448	2.752	2.947	
PTS_{out} (MPa)	1.714	1.718	1.724	1.752	
$PTS_{out,cal}$ (MPa)	1.770	1.794	1.816	1.858	
$dPTS_{measured}$ (MPa)	0.482	0.729	1.028	1.195	
$dPTS_{calculated}$ (MPa)	0.426	0.654	0.936	1.089	
Saturation temp. $T_{s,TSout}$ (°C)	204.72	204.85	205.01	205.78	

FE105B, $T_{in} = 45^\circ\text{C}$, $P_{out} = 1.7\text{ MPa}$, $q = 9.0\text{ MW/m}^2$

File name : DATNUM2.DAT

01/05/93, FE10593 , 1, 01/14/93 , FE11493 , 1, 01/15/93 , CF11593 , 0

02/10/93, FE21093 , 1, 02/11/93 , FE21193x, 1, 02/12/93 , FE21293 , 0

99/99/99 Maximum number of lines is seven and maximum number of data set for one line is four.

01/05/93, FE105Axx, (01 to 16) Velocity THTL Experimental data file

, FE105B09, (01 to 20) Velocity '12/31/92 M. Kaminaga

, FE105C10, (01 to 25) Velocity TSD-3

, FE105D11, (01 to 22) Velocity

, FE105Eyy, (01 to 29) Heat flux Maximum number of data sets is 28.

, FE105Fxx, (01 to 13) Velocity If you want to input data sets

01/14/93, FE114Axx, (01 to 13) Velocity 'more than 28 please make an another

, FE114B10, (01 to 26) Velocity 'data file (DATNUMx.dat : x =1 ...9).

01/15/93, CF115Axx, (01 to 13) Velocity

, CF115B12, (01 to 19) Velocity FE-----x ; FE-----xx : Non-heated test

, CF115B20, (20) CHF Point '<=== Just before burn out

02/10/93, FE210Axx, (01 to 14) Velocity

, FE210B10, (01 to 23) Velocity

02/11/93, FE211Axx, (01 to 14) Velocity

02/12/93, FE212A15, (01 to 22) Velocity

, FE212A21, () FE occur

99/99/99

"99/99/99" means end of data sets.

1

'0 : End of data 1 : continue

M.Kaminaga 1/8/93

File name : FE105B.XLS

Variable parameter : Coolant velocity

January 8, 1993 12:17

gap= 0.0484 inch

	FE105B	FE105B01	FE105B02	FE105B03	FE105B04	FE105B05	FE105B06	FE105B07	FE105B08
Record number of data file	50	51	58	59	62	63	68	70	
Inlet temperature (°C)	44.48	43.84	44.55	43.99	44.25	44.69	44.41	44.45	
Outlet temperature Tb,out (°C)	113.17	118.03	125.79	132.79	142.53	154.35	160.69	169.46	
Inlet pressure (MPa)	2.994	2.821	2.639	2.472	2.328	2.226	2.153	2.116	
Outlet pressure (MPa)	1.720	1.709	1.716	1.712	1.735	1.720	1.704	1.717	
Power (W)	138822	138611	139013	138697	139068	138338	138329	138836	
TS power (W)	129577	128935	128351	127781	127268	125691	125554	125433	
Maximum heat flux (MW/m²)	9.885	9.875	9.887	9.803	9.934	9.844	9.790	9.743	
Average heat flux (MW/m²)	9.381	9.334	9.292	9.251	9.214	9.099	9.090	9.081	
Average coolant velocity (m/s)	26.08	24.05	21.90	19.97	18.01	15.99	15.08	14.04	
Heat loss (%)	6.7	7.0	7.7	7.9	8.5	9.1	9.2	9.7	
dP _{measured} (MPa)	1.274	1.112	0.923	0.760	0.623	0.506	0.450	0.399	
dP _{calculated} (MPa)	1.199	1.024	0.850	0.710	0.578	0.458	0.408	0.355	
dP _{form,calculated} (MPa)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Bypass flow ratio (-)	0.74	0.74	0.88	0.95	0.96	1.25	1.41	1.60	
Saturation temperature Ts (°C)	204.90	204.59	204.79	204.67	204.48	204.90	204.43	204.82	
q _{ave} (Ts-Tb,out) (MW/m² °C)	0.102	0.108	0.118	0.129	0.149	0.180	0.208	0.257	
PTSin (MPa)	2.958	2.790	2.612	2.450	2.310	2.211	2.140	2.104	
PTSout (MPa)	1.749	1.734	1.737	1.729	1.720	1.731	1.713	1.726	
PTSout,cal (MPa)	1.824	1.822	1.810	1.779	1.765	1.779	1.755	1.770	
dPTS _{measured} (MPa)	1.209	1.056	0.875	0.720	0.590	0.480	0.428	0.378	
dPTS _{calculated} (MPa)	1.134	0.967	0.803	0.670	0.545	0.432	0.385	0.335	
Saturation temp. Ts/TSout (°C)	205.72	205.29	205.38	205.16	204.88	205.22	204.71	205.06	
	FE105B	FE105B09	FE105B10	FE105B11	FE105B12	FE105B13	FE105B14	FE105B15	FE105B16
Record number of data file	74	79	84	86	89	91	94	95	
Inlet temperature (°C)	44.42	44.39	44.45	44.08	44.84	45.06	44.56	44.88	
Outlet temperature Tb,out (°C)	173.61	178.72	184.78	190.21	185.18	179.70	174.31	170.55	
Inlet pressure (MPa)	2.100	2.101	2.124	2.131	2.113	2.100	2.112	2.098	
Outlet pressure (MPa)	1.721	1.717	1.710	1.695	1.708	1.713	1.731	1.703	
Power (W)	136154	138702	138869	138419	138502	138454	138359	138810	
TS power (W)	124258	124633	124987	124636	124576	125072	124493	125804	
Maximum heat flux (MW/m²)	9.625	9.634	9.634	9.573	9.613	9.691	9.684	9.808	
Average heat flux (MW/m²)	8.996	9.023	9.049	9.023	9.019	9.055	9.013	9.108	
Average coolant velocity (m/s)	13.47	13.01	12.50	11.99	12.46	13.03	13.44	14.01	
Heat loss (%)	10.1	10.1	10.0	10.0	10.1	9.7	10.0	9.4	
dP _{measured} (MPa)	0.379	0.383	0.414	0.438	0.405	0.388	0.381	0.395	
dP _{calculated} (MPa)	0.328	0.306	0.283	0.262	0.282	0.306	0.324	0.351	
dP _{form,calculated} (MPa)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
Bypass flow ratio (-)	1.67	1.69	1.74	1.75	1.74	1.71	1.72	1.72	
Saturation temperature Ts (°C)	204.93	204.82	204.61	204.18	204.56	204.69	205.20	204.41	
q _{ave} (Ts-Tb,out) (MW/m² °C)	0.287	0.346	0.456	0.648	0.465	0.362	0.292	0.269	
PTSin (MPa)	2.089	2.090	2.114	2.122	2.103	2.090	2.101	2.086	
PTSout (MPa)	1.729	1.725	1.717	1.701	1.715	1.720	1.739	1.711	
PTSout,cal (MPa)	1.780	1.802	1.847	1.876	1.838	1.802	1.795	1.756	
dPTS _{measured} (MPa)	0.360	0.365	0.397	0.421	0.388	0.370	0.362	0.375	
dPTS _{calculated} (MPa)	0.309	0.288	0.287	0.247	0.265	0.288	0.305	0.330	
Saturation temp. Ts/TSout (°C)	205.15	205.02	204.80	204.36	204.75	204.89	205.42	204.65	

File name : DATNUM1.DAT

08/17/92, FE81792 , 0
 09/03/92, FE90392x, 1, 09/04/92, FE90492 , 0
 11/17/92, FEN1792 , 1, 11/19/92, FEN1992x, 1, 11/20/92, FEN2092 , 1, 11/30/92, FEN3092 , 0
 12/15/92, FED1592 , 1, 12/17/92, FED1792 , 1, 12/28/92, FED2892 , 0
 99/99/99 Maximum number of lines is seven and maximum number of data set for one line is four.
 08/17/92 , FE817Axx, (01 to 11) Velocity THTL Experimental data file
 , FE817Bxx, (01 to 13) Velocity '12/31/92 M. Kaminaga
 , FE817C09, (01 to 13) Velocity TSD-3
 09/03/92 , FE903Axx, (01 to 13) Velocity
 , FE903Bxx, (01 to 09) Velocity Maximum number of data sets is 28.
 09/04/92 , FE904A09, (01 to 13) Velocity If you want to input data sets
 , FE904B09, (01 to 12) Velocity 'more than 28 please make an another
 , FE904C07, (01 to 12) Velocity 'data file (DATNUMx.dat : x =1 ...9).
 , FE904D07, (01 to 10) Velocity
 11/17/92 , FEN17Axx, (01 to 12) Velocity FE-----x ; FE----xx : Non-heated test
 , FEN17B09, (01 to 13) Velocity
 , FEN17C08, (01 to 11) Velocity
 , FEN17Dxx, (01 to 14) Velocity
 11/19/92 , FEN19Axx, (01 to 12) Velocity
 11/20/92 , FEN20A09, (01 to 11) Velocity
 11/20/92 , FEN20B09, (01 to 12) Velocity
 , FEN20Cxx, (01 to 16) Velocity
 11/30/92 , FEN30A09, (01 to 22) Velocity
 , FEN30Bxx, (01 to 13) Velocity
 12/15/92 , FED15Axx, (01 to 16) Velocity
 , FED15B11, (01 to 20) Velocity
 , FED15C13, (01 to 24) Velocity
 12/17/92 , FED17A12, (01 to 30) Velocity
 , FED17Bxx, (01 to 14) Velocity
 12/28/92 , FED28Axx, (01 to 08) Velocity
 , FED28B13, (01 to 27) Velocity
 99/99/99 "99/99/99" means end of data sets.
 1 '0 : End of data 1 : continue

M.Kaminaga 1/8/93

File name : FE105A.XLS

FED15A, $T_{in}=45\text{ }^{\circ}\text{C}$, $P_{out}=1.7\text{ MPa}$, $q=0.0\text{ MW/m}^2$

File name : FE212A01.DAT

FE212A01,02/12/93

45.649,119.009

174777.24

32.1910

3.6118,1.7002

2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 18.0, 49.0, 50.0

188.9, 199.0, 248.0, 290.7, 274.0, 285.4, 298.7, 294.8, 280.3

12.6513, 0.0, 0.0

13.9724, 0.05486938

'<FE212A01> from FE212931.PRN No.440

'02/12/93 q'= 12.65 MW/m²

'Flow Excursion Test

"10:14:35",280.2814,971.7909,294.8138,260.4666,298.7355,190.7247,285.3572,
270.2537,273.9656,254.0642,290.6982,290.7705,248.0114,239.2249,110.4004,
198.9883,188.9054,92.95473,55.81631,134.6682,60.28175,45.60622,11.98532,
44.57866,118.7704,46.71883,119.2482,1.700179,.9982151,1.891241,1.037796,
3.611815,32.09098,57.29523,57.19296,6.216249,130.4366,184.9239,4.003956,
21179.02,8.272876999999999,-62.99121,-.002706972,8.757512999999999,12.00282,
955.5228,965.6343000000001

File name : PATEDATA.DAT

"c:\qb45\program\ans0513\data\"

"c:\thtl\"

"c:\qb45\program\ans0513\out\"

"c:\qb45\program\ans0513\out\"

'Path1\$: Input Data : *.DAT, *.INP

'Path2\$: Input Data : *.PRN (Original file)

'Path3\$: Output : *.ANS (Calculation results)

'Path4\$: Ascci data : *.ASC, *.TBL (For MS-Excel etc.)

'Note : "PathData.Dat" must be saved in the same directory of the program.

THTLTX.XLS

qCHFr2	qCHF for a rectangular channel (Rectangular channel model "a") (MW/m ²)
qCHF s2	qCHF for a semicircular channel (Semicircular channel model "a") (MW/m ²)
qCHFr s2	qCHF s2 converted to a rectangular channel (MW/m ²)
qFEa	FE heat flux for an average channel (Average channel model) (MW/m ²)
qFEa	qFEa converted to a rectangular channel (MW/m ²)
qFEr1	FE heat flux for a rectangular channel (Rectangular channel model "a") (MW/m ²)
qFEr2	FE heat flux for a rectangular channel (Rectangular channel model "b") (MW/m ²)
qFEr s1	qFEs1 converted to a rectangular channel (MW/m ²)
qFEr s2	qFEs2 converted to a rectangular channel (MW/m ²)
qFEs1	FE heat flux for a semicircular channel (Semicircular channel model "a") (MW/m ²)
qFEs2	FE heat flux for a semicircular channel (Semicircular channel model "b") (MW/m ²)
qIBa	qIB for an average channel (Average channel model) (MW/m ²)
qIBr1	qIB for a rectangular channel (Rectangular channel model "a") (MW/m ²)
qIBr2	qIB for a rectangular channel (Rectangular channel model "a") (MW/m ²)
qIBa	qIBa converted to a rectangular channel (MW/m ²)
qIBr s1	qIBs1 converted to a rectangular channel (MW/m ²)
qIBr s2	qIBs2 converted to a rectangular channel (MW/m ²)
qIBs1	qIB for a semicircular channel (Semicircular channel model "a") (MW/m ²)
qIBs2	qIB for a semicircular channel (Semicircular channel model "a") (MW/m ²)
Rav	$R = (T_{bav} - t_{bulk}) / (T_{s,out} - t_{bulk})$ for an average channel (-)
Rrc1	$R = (T_{brc} - t_{bulk}) / (T_{s,out} - t_{bulk})$ for a rectangular channel (-)
Rrc2	$R = (T_{brc2} - t_{bulk}) / (T_{s,out} - t_{bulk})$ for a rectangular channel (-)
Rsc1	$R = (T_{bsc} - t_{bulk}) / (T_{s,out} - t_{bulk})$ for a semicircular channel (-)
Rsc2	$R = (T_{bsc2} - t_{bulk}) / (T_{s,out} - t_{bulk})$ for a semicircular channel (-)
TW1	Wall temperature at IB point for an average channel (Average channel model) (°C)
TW2	Wall temperature at IB point for a rectangular channel (Rectangular channel model "a") (°C)
TW3	Wall temperature at IB point for a semicircular channel (Semicircular channel model "a") (°C)
TW4	Wall temperature at IB point for a rectangular channel (Rectangular channel model "b") (°C)
TW5	Wall temperature at IB point for a semicircular channel (Semicircular channel model "b") (°C)
Vav	Velocity at FE point for an average channel (Average channel model) (m/s)
Vrc	Velocity at FE point for a rectangular channel (Rectangular channel model "a") (m/s)
Var	Vrc converted to an average channel (m/s)
Vsc	Velocity at FE point for a semicircular channel (Semicircular channel model "a") (m/s)
Vas	Vsc converted to an average channel (m/s)

THTLTXT.XLS

Xex2	Exit quality (-)
OTHERS	
Asmall	Area after contraction (small area)
Alarge	Area before contraction (large area)
calflo	Average coolant velocity (m/s)
CF%	= 0 : Circular channel (-) [Channel configuration] = 1 : Rectangular channel (-) [Channel configuration]
CI	Current through test channel (amps) See SUB Volts
Cond	Conductivity (W/cm K)
Cond	H2O Saturated liquid thermal conductivity (W/m K) or (W/cm K)
Cp	H2O Saturated liquid specific heat (kJ/kg K) or (J/g K)
Density'n	Coolant density at TS inlet (g/cm ³) [Based on tbulkln]
Densityrcex	Coolant density at TS exit (g/cm ³) [Based on tbulkex(INEle)]
Densityscex	Coolant density at TS exit (g/cm ³) [Based on tbulkex(INEle)]
DH	Equivalent hydraulic diameter (m) or (cm)
dL	Channel length (m)
dP	Friction loss (MPa)
DynVisc	H2O Saturated liquid dynamic viscosity (Pa s) or (g/cm s)
F\$	File name currently used in this program
FCFG\$	Configuration file name (*.CFG)
FD	Filonenko friction factor (-) [Darcy friction factor]
Filenam\$	Original fi FE305921)
Fi\$	Inputted file name
FLAGTAV%	Iteration flag. 0 (Converged) or 1 (Not converged)
FLAGT3%	Iteration flag. 0 (Converged) or 1 (Not converged)
FLAGTW%	Iteration flag. 0 (Converged) or 1 (Not converged)
H, HPE	Heat transfer coefficient (kW/m ² K) or (W/cm ² K)
HTCm	Measured heat transfer coefficient (kW/m ² K) or (kW/m ² C)
IDatNum	Data file number (1, 2, 3 ...).
IDdate\$	Test date [ex. 920904]
IDHTC%	= 0 : CHF or qIB is calculated by using measured heat transfer coefficient. = 1 : CHF is calculated by using heat transfer coefficient calculated by Petukhov.
IFLAG	Flag for unit conversion 0 or 1
IFRAME	= 1 : Call SUB Frame
IMessage	= 1 to 5 See SUB Message
INE	If INE > 2, calculation is not converged. (-) See SUB FEVEL
IPOSITION	Y\$ position for print out to the screen
ISTATUS	= 0 Initial Y\$="N", = 1 Initial Y\$="Y"
Iteratpress	Iteration flag for pressure drop calculation (dPTSrc = dPTSc)
Iteratpress1	Iteration flag for pressure drop calculation
JJ1	Data number [JJ1=1 to JMAX] [for IFMODE=1]
K	Resistance coefficient for contraction or enlargement
KA	Thermal conductivity of aluminum (W/cm K)
Lele	Length of elements (cm) See SUB Volts
LiqDen	H2O Saturated liquid density (kg/m ³) or (g/cm ³)
loss	Heat losses (-)
losssc	Heat losses from the rectangular channel to semicircular channel (-)
LtnHt	H2O Latent heat of vaporization (kJ/kg)
Lx	Distance from inlet of channel (m)
Mmin	Minimum Coolant velocity ratio for semicircular
Mmax	Maximum M channel (Vsc = M1 * Vrc)
N%	= 0 : Output ==> CRT = N : Output ==> File #N

THTLTXT.XLS

NonuniF\$	Non-uniform heat loss distribution data file name (-)
P	Local pressure (MPa)
P1	Test section inlet pressure (MPa)
P2	Test section outlet pressure (MPa)
Pin	Measured test section inlet pressure (MPa)
Pout	Measured test section outlet pressure (MPa)
Power	Measure TS power [I x V] (W)
Position\$	Record number of file which we want to get
Pr	Prandtl number (-)
PreNum%	Prediction calculation number for ICALCMODE=3
Psat	H2O Saturation pressure (MPa)
qCHFc	Critical heat flux (MW/m ²)
qflux	Local heat flux (KW/m ²) or (W/cm ²)
qIBc	Incipient boiling heat flux (MW/m ²)
qrc	Average heat flux on flats (MW/m ²)
qrcmax	Maximum heat flux on flats (MW/m ²)
P, R#	Resistivity (Micro-ohm-cm) for Al-6061 See SUB Volts
Resist	Resistivity (Micro-Ohm cm) 'or Al-6061 See SUB Alprop
Rho	Density
Rohm	Resistance for heated length Lele (ohm) See SUB Volts
rec\$	Record number of data file (-)
Sftens	H2O Surface tension (N/m) or (kg/s ²)
T	Temperature (°C)
T3	Interface temperature (°C)
TAV	Average wall temperature of TS flats (°C)
tbulk	Bulk coolant temperature (°C)
tbulkin	Measured TS inlet temperature (°C)
tbulkout	Measured TS outlet temperature (°C)
theta	Angle of divergence (DEG.)
TIB	Wall temperature at incipient boiling (°C)
tmeas	Test section back-wall surface temperature (°C)
trendtype\$	= 1 : Type 1 Standard type = 2 : Type 2 Displays both Selected temperatures and Un-selected temperatures = 3 : Type 3 Displays Selected temperatures only = 4 : Type 4 Displays Un-selected temperatures only = 5 : Type 5 Displays Tin, Tout, Power, Pin, Pout, Velocity, dP, Bypass ratio
Tsat	Saturation temperature (°C)
tspwr	Test section power including heat losses (W)
Twall	Inner wall surface temperature of flats (°C)
V	Voltage across test channel length (volts) See SUB Volts
VapDen	H2O Saturated vapor density (kg/m ³)
velocity	Coolant velocity (m/s)
VIS	Dynamic viscosity
Vmin0	Minimum velocity for iteration (m/s) See SUB FEVEL
Vmax0	Maximum velocity for iteration (m/s) See SUB FEVEL
Y\$	= "Y" or "N"
xls%	IF VAL(MID\$(DatNam\$(JJ1), 7, 2)) < VAL(MID\$(DatNam\$(JJ1 - 1), 7, 2)) THEN xls% = 0
Following values are calculated at the channel exit See THTLsub3.bas	
qCHF	qCHF for a average channel (Average channel model) (MW/m ²)
qCHF	qCHF converted to a rectangular channel (MW/m ²)
qCHF	qCHF for a rectangular channel (Rectangular channel model "a") (MW/m ²)
qCHF	qCHF for a semicircular channel (Semicircular channel model "a") (MW/m ²)
qCHF	qCHF converted to a rectangular channel (MW/m ²)

THLTXT.XLS

	=3 : Heat Transfer Coefficient (HTC), $T_{w,in}$, q_{lB} , q_{FE} , q_{CHF} and so on are predicted based on inputted coolant velocity V_{rc} , heat flux on flats, inlet coolant temperature and outlet pressure.
IDATA	=0 : Show both raw data and calculation results. =1 : Show raw data only (No calculation). (For ICALCMODE = 0, 1, 2 (Not for ICALCMODE = 3))
IDH	=0 : Constant heat loss along the channel. =1 : Non-uniform heat loss along the channel.
IDPres	=0 : V_{sc}/V_{rc} is constant (0.630 for TSD-1, 0.7413 for TSD-3). =1 : V_{sc}/V_{rc} is calculated based on dP of both RC and SC channel.
IDtbulkin	tbulkin ==> 1 : $(TT-201A+TT201B)/2$, 2 : TT201A, 3: TT201B
IDtbulkout	tbulkout==> 1 : $(TT-202A+TT202B)/2$, 2 : TT202A, 3: TT202B
IDTS	Test section ID (1, 2, 3...)
IDTS\$	Test section ID (TSD-1, TSD-2, TSD-3)
IFP	Data point indicator [If number = record then IFP=1 else IFP=0.]
IFMODE	File extension (file type) indicator ; 1 *.INP, 2 *.PRN, 3 *.DAT
IFNL	File name length
IMAKE	=0 : Standard calculation mode. =1 : Make data file *.DAT (ICALCMODE = 0,1,2). =2 : Make data file *.asc for Microsoft EXCEL. =3 : Make data file *.tbl for Microsoft EXCEL.
INele	Number of elements in length L [=CINT(Nele)]
L	Length of test channel (cm)
L11	Distance from inlet of channel at $T_b=T_s$ (cm)
L12	Distance from inlet of channel at $T_b=T_s$ (cm)
loss	Heat loss (-)
M	Coolant velocity ratio for semicircular channel ($V_{sc} = M1 * V_{rc}$)
M1	Coolant velocity ratio for semicircular channel ($V_{sc} = M1 * V_{rc}$)
massfluxav	Mass flux in the average channel (g/cm^2s)
massfluxrc	Mass flux in the rectangular channel (g/cm^2s)
massfluxsc	Mass flux in the semicircular channel (g/cm^2s)
Nele	Number of elements in length L
Peri	Perimeter of test channel (m)
Perirc	Perimeter of rectangular (flats) channel (m)
Perisc	Perimeter of semicircular (ends) channels (m)
Pin	Measured TS inlet pressure (MPa)
Pinold	Measured TS inlet pressure (MPa) [10 sec before]
Pout	Measured TS outlet pressure (MPa)
Poutold	Measured TS outlet pressure (MPa) [10 sec before]
Powerold	Measured TS power (W) [10 sec before]
PTSin	TS inlet pressure (MPa)
PTSout	TS outlet pressure (MPa)
PTSoutsc	TS outlet pressure (MPa) [Semicircular channel]
PBFlin	Blind flange inlet pressure (MPa)
PBFout	Blind flange outlet pressure (MPa)
Poutcal	Calculated TS outlet pressure (MPa)
PTShinconv	TS inlet pressure (Heated length inlet, Measured converted) (MPa)
PTShoutconv	TS outlet pressure (Heated length outlet, Measured converted) (MPa)
PTSoutconv	Measured converted TS outlet pressure (MPa)
PBFoutconv	Measured converted blind flange outlet pressure (MPa)
PTShout	TS outlet pressure (Heated length outlet, Calculated) (MPa)
PTShinsec	TS inlet pressure (MPa) [Semicircular channel]
PTShoutsc	TS outlet pressure (MPa) [Semicircular channel]
Fath1\$	Directory path name for input (*.dat) files.

THTL.TXT.XLS

Path2\$	Directory path name for input (*.pm) files.
Path3\$	Directory path name for output (*.ans, *.IB, *.CHF, *.FE) files.
Path4\$	Directory path name for output (*.asc, *.tbl) files.
qCHFexit	Critical heat flux at TS exit (MW/m ²)
qFEexit	Flow excursion heat flux at TS exit (MW/m ²)
qIBexit	Incipient boiling heat flux at TS exit (MW/m ²)
qCHFjaeri	Critical heat flux at TS exit (MW/m ²) [JAERI correlation]
qendflux	Average heat flux on ends (W/cm ²)
qfluxnom	Average heat flux on flats (W/cm ²)
qfluxlocmax	Maximum heat flux on flats (W/cm ²)
qfluxav	Average heat flux, if q\$="Converted" then "Converted" else "Measured" (kW/m ²)
qfluxrc	Average heat flux for flats, if q\$="Converted" then "Converted" else "Measured" (KW/m ²)
Qloss	Heat flux losses [=0] (W/cm ²)
qratio	Heat flux ratio for ends (qsc = qratio * qrc)
q\$	"Converted" or "Calculated"
record%	Record number of file
record\$	Record number of file
T3max	Maximum TS inner surface temperature (°C)
Tbav	Tb converted to an average channel (Average channel model) (°C)
Tbrc	Tb converted to a rectangular channel (Rectangular channel model "a") (°C)
Tbrc2	Tb converted to a rectangular channel (Rectangular channel model "b") (°C)
Tbsc	Tb converted to a semicircular channel (Semicircular channel model "a") (°C)
Tbsc2	Tb converted to a semicircular channel (Semicircular channel model "b") (°C)
Tbsc	Tb converted to a semicircular channel (Semicircular channel model "a") (°C)
TbrcConv	Tb converted to a rectangular channel (°C) See SUB qIBqC:HFqFE
tbulkinold	Measured TS inlet temperature (°C) [10 sec before]
tbulkoutold	Measured TS outlet temperature (°C) [10 sec before]
thal	Thickness of aluminum flats (cm)
thox	Thickness of aluminum oxide film (cm)
tm%	Time (X axis) for trend graph (x 10 sec)
tmc%	End of X axis (x 10 sec)
test\$	Test name [ex. FE115B01]
tsdate\$	Test date [ex. 09/04/92]
TT\$	Name of selected thermocouples "TT117, TT115, ..., TT101"
num.ber%	Current record number of data file
vel	Measured average coolant velocity at TS inlet (m/s)
velrc	Coolant velocity in the rectangular channel at TS inlet (cm/s)
velsc	Coolant velocity in the semicircular channels at TS inlet (cm/s)
velcx	Average coolant velocity at TS exit (m/s)
velrcex	Coolant velocity in the rectangular channel at TS exit (cm/s)
velscex	Coolant velocity in the semicircular channels at TS exit (cm/s)
velavex1	Average coolant velocity at TS exit (m/s)
velrcex1	Coolant velocity in the rectangular channel at TS exit (m/s)
velscex1	Coolant velocity in the semicircular channel at TS exit (m/s)
velrcex2	Average coolant in the rectangular channel velocity at TS exit (m/s)
velrcex2	Average coolant in the semicircular channel velocity at TS exit (m/s)
Ver\$	Version number of THTL experimental data reduction program.
VerDate\$	Last modification date of THTL experimental data reduction program.
w	Width of test channel flat (cm)
WY	Width of Y1 axial (-)
WY2	Width of Y2 axial (-)
xa	Thickness of aluminum ends (cm)
xb	Width of end section which has same flow gap with flat channel (cm)
Xex1	Exit quality (-)

THLT.TXT.XLS

CHF()	Critical heat flux calculated by Gambill-w/Weatherhead's correlation (MW/m ²)
CI()	Current through each aluminum element (amps)
datNam\$()	Test number [Example : FE318A01]
Datrec\$()	Record number of file "Filenam\$()"
Dat()	Raw data from an original data file [from data acquisition system]
Densityav()	Coolant density at the location of thermocouple in the average channel (g/cm ³)
Densityrc()	Coolant density at the location of thermocouple in the rectangular channel (g/cm ³)
Densitysc()	Coolant density at the location of thermocouple in the semicircular channel (g/cm ³)
dP()	Friction loss of i-th element in the rectangular channel (MPa)
dPsc()	Friction loss of i-th element in the semicircular channel (MPa)
FLAGT3%()	Iteration flag for T3 (-)
FLAGTAV%()	Iteration flag for TAV (-)
FLAGTW%()	Iteration flag for Twall (-)
Floss()	Factor for axial heat loss distribution (-)
h()	Heat transfer coefficient based on measured temperature (W/cm ² .K) [for rectangular (flat) channel]
Hcal()	Heat transfer coefficient calculated by Petukhov & Popov (W/cm ² .K) [for rectangular (flat) channel]
Image1()	integer array to hold a screen image [upper half] (-)
Image2()	Integer array to hold a screen image [lower half] (-)
ITC()	11(light cyan) or 3(cyan) [Print out color] (-) See SUB TSdata [=1 : Selected thermocouple, =3 : Non-selected thermocouple]
KA()	Thermal conductivity of each aluminum element (W/cm.K)
Lele()	Length of each element (cm)
Locat()	Distance between inlet of the channel and the location of thermocouple (cm)
P()	Pressure at the location of thermocouple in the rectangular channel (MPa)
Psc()	Pressure at the location of thermocouple in the semicircular channel (MPa)
Ploc()	Pressure at the location of thermocouple in the rectangular channel (MPa) [Based on measured pressure]
PColor%()	Measured temperature's plot color (-) See SUB SelectTemp
= 12	Selected measured temperature
= 11	Non-selected measured temperature
= 4	Selected temperature which is calculated by interpolation or extrapolation.
= 3	Non-selected temperature which is calculated by interpolation or extrapolation.
qFE()	Flow excursion heat flux calculated by Costa's correlation
qflxloc()	Local heat flux for flats (W/cm ²)
qflxold()	Local heat flux for flats (W/cm ²)
qflxlocends()	Local heat flux for ends (W/cm ²)
qIB()	Incipient boiling heat flux calculated by Bergles/Rohsenow's correlation (MW/m ²)
qppp()	Local power density for flats (W/cm ³)
R()	Resistivity of each aluminum element (ohm.cm)
Rohm()	Resistance for each aluminum element (ohm)
STN%()	Thermocouple number [1 to 18] (-) See SUB TSdata
T3()	Inner wall surface (oxide surface) temperature for flats (°C) [calculated from measured back surface temperature, local heat flux]
TAV()	Average aluminum temperature of flats (°C)
Tb()	Local bulk coolant temperature at the end of each element in the average channel (°C) [Based on uniform heat flux]
tbulk()	Local bulk coolant temperature at the location of thermocouple in the average channel (°C)
tbulkrc()	Local bulk coolant temperature at the location of thermocouple in the rectangular channel (°C)
tbulks()	Local bulk coolant temperature at the location of thermocouple in the semicircular channel (°C)
tbulkel()	Local bulk coolant temperature at the end of each element in the average channel (°C)
tbulkelrc()	Local bulk coolant temperature at the end of each element in the rectangular channel (°C)
tbulkelrc()	Local bulk coolant temperature at the end of each element in the semicircular channel (°C)

THTLTXT.XLS

Tex()	Measured buck wall surface temperature (°C)
Texold()	Measured buck wall surface temperature (°C) [10 sec before]
TH\$()	Name of selected thermocouples [TT-118, TT-117..., TT-101] See SUB TSdata
tmeas()	Back wall surface temperature for flats (°C)
Tsat()	Saturation temperature at the each axial calculation point (°C) [Based on measured Pressure, Ploc()]; Interpolation between PTShsinconv and PTShoutconv]
Tsatcal()	Saturation temperature at the each axial calculation point (°C) [Based on P()]
Tsatcalsc()	Saturation temperature at the each axial calculation point (°C) [Based on Psc()]
Twall()	Aluminum inner wall surface temperature of flats (°C)
Twdummy()	Dummy wall temperature [Not used in the calculation]
V()	Voltage across each aluminum element (volts)
vel()	Local coolant velocity in the average channel (m/s)
velrc()	Local coolant velocity in the rectangular channel (m/s)
versc()	Local coolant velocity in the semicircular channel (m/s)
Xbo()	Boundary of each element (cm)
XL()	Location of each thermocouples (cm)

COMMON SHARED

Acs	Cross-sectional area of test section (cm ²)
Aflow	Flow area of test channel (cm ²)
Afrc	Flow area of rectangular (flats) channel (cm ²)
Afsc	Flow area of semicircular (ends) channel (cm ²)
Ahrc	Heated area of rectangular (flats) channel (m ²)
Ahsc	Heated area of semicircular (ends) channels (m ²)
badrec%	Bad record number of original data file (-)
calfloold	Measured buck wall surface temperature (°C) [10 sec before]
Condux	Thermal conductivity of aluminum oxide (W/cm K)
DHY	Equivalent hydraulic diameter of test channel (cm)
DHYrc	Equivalent hydraulic diameter of rectangular (flats) channel (cm)
DHYsc	Equivalent hydraulic diameter of semicircular (ends) channels (cm)
DUMT\$	Time (hh : mm : ss)
dPfric	Total friction loss of test section (MPa)
dPformin	Test section inlet loss (MPa)
dPformout	Test section outlet loss (MPa)
dPdvin	Dynamic pressure loss at TS inlet (MPa)
dPdout	Dynamic pressure loss at TS outlet (MPa)
DPzin	Head of test section inlet pipe (MPa)
DPzout	Head of test section outlet pipe (MPa)
dPzsum	Total test section head (MPa)
dPcal	Calculated pressure drop of TS (MPa)
dPTSh	Calculated pressure drop of TS heated length (MPa)
dPTShconv	Measured converted pressure drop of TS heated length (MPa)
dPTShsc	Calculated pressure drop of TS heated length (MPa) [Semicircular channel]
gap	Flow gap of test channel (cm)
IC	Title bar color (-)
ICALCMODE	Calculation mode (-) =0 : Tw,in is calculated based on measured external temperature. qCHF and qIB are calculated based on measured HTC. =1 : Tw,in is calculated based on measured external temperature. qCHF and qIB are calculated based on HTC calculated by Petukhov. =2 : Heat Transfer Coefficient (HTC), Tw,in, qIB, qFE, qCHF and so on are predicted based on an experimental condition.

FUNCTION KEYS

THULFLO3.XLS

7501

Recede to determine local pressure

A-45

FUNCTION KEYS

880

Iterate to determine local pressure

880

THLFL02XLS

TMFL02.xls

890

Iterate to determine local pressure

H

Iterate to determine local heat flux

G

Calculate bulk at the end of element (Rectangular channel)
 $T = \text{bulk}(I-1)$; IF $T \geq T_{\text{sat}}$ THEN $T = T_{\text{sat}}$
 $\text{bulk}(I) = \text{bulk}(I-1) + ((q_{\text{doc}}(I) \cdot 2 \cdot W \cdot L_{\text{ele}}(I)) / (A_{\text{fc}} \cdot \text{massflux} \cdot C_p))$
 $T = (\text{bulk}(I-1) + \text{bulk}(I)) / 2$; IF $T \geq T_{\text{sat}}$ THEN $T = T_{\text{sat}}$
 $\text{bulk}(I) = \text{bulk}(I-1) + ((q_{\text{doc}}(I) \cdot 2 \cdot W \cdot L_{\text{ele}}(I)) / (A_{\text{fc}} \cdot \text{massflux} \cdot C_p))$
 IF $\text{bulk}(I) \geq T_{\text{sat}}$ THEN $\text{bulk}(I) = T_{\text{sat}}$
 Calculate bulk at the location of each thermocouple (Node=9) or center of the element (Node=20)
 $\text{bulk}(I) = \text{bulk}(I-1) + ((\text{bulk}(I) - \text{bulk}(I-1)) \cdot A_{\text{ele}}(I)) \cdot (L_{\text{loc}}(I) - X_{\text{bc}}(I-1))$
 IF $\text{bulk}(I) \geq T_{\text{sat}}$ THEN $\text{bulk}(I) = T_{\text{sat}}$

Call H2OProp(T, ..., Cp, ...)

Call H2OProp(T, ..., Cp, ...)

Calculate bulk at the end of element (Semicircular channel)
 $T = \text{bulk}(I-1)$; IF $T \geq T_{\text{sat}}$ THEN $T = T_{\text{sat}}$
 $\text{bulk}(I) = \text{bulk}(I-1) + ((q_{\text{docends}}(I) \cdot \text{Perisc} \cdot 100 \cdot L_{\text{ele}}(I)) / (A_{\text{fc}} \cdot \text{massflux} \cdot C_p))$
 $T = (\text{bulk}(I-1) + \text{bulk}(I)) / 2$; IF $T \geq T_{\text{sat}}$ THEN $T = T_{\text{sat}}$
 $\text{bulk}(I) = \text{bulk}(I-1) + ((q_{\text{docends}}(I) \cdot \text{Perisc} \cdot 100 \cdot L_{\text{ele}}(I)) / (A_{\text{fc}} \cdot \text{massflux} \cdot C_p))$
 IF $\text{bulk}(I) \geq T_{\text{sat}}$ THEN $\text{bulk}(I) = T_{\text{sat}}$
 Calculate bulk at the location of each thermocouple (Node=9) or center of the element (Node=20)
 $\text{bulk}(I) = \text{bulk}(I-1) + ((\text{bulk}(I) - \text{bulk}(I-1)) \cdot A_{\text{ele}}(I)) \cdot (L_{\text{loc}}(I) - X_{\text{bc}}(I-1))$
 IF $\text{bulk}(I) \geq T_{\text{sat}}$ THEN $\text{bulk}(I) = T_{\text{sat}}$

Call H2OProp(T, ..., Cp, ...)

Call H2OProp(T, ..., Cp, ...)

$\text{vel}(I) = \text{massflux} / \text{Density}(I)$
 $\text{Velrc}(I) = \text{massflux} / \text{Densityrc}(I)$
 $\text{Velsc}(I) = \text{massflux} / \text{Densitysc}(I)$

Call H2OProp(bulk(I), Densityrc(I), ...)

Call H2OProp(bulk(I), Densityrc(I), ...)

Call H2OProp(bulk(I), Densitysc(I), ...)

TS back surface temperature

IF $\text{ICALCMODE} = 2 \text{ OR } 3$ Yes
 $\text{Innes}(I) = T_{\text{wall}}(I) + ((q_{\text{doc}}(I) \cdot \text{Thal}) / (2 \cdot K_A)) - (\text{Gloss} \cdot \text{Thal} / K_A)$

No
 $T_3(I) = T_{\text{wall}}(I) - ((q_{\text{doc}}(I) - \text{Gloss}) \cdot \text{Thal} / \text{Conduct})$
 IF $T_3(I) \geq T_{3\text{max}}$ THEN $T_{3\text{max}} = T_3(I)$
 $H(I) = (q_{\text{doc}}(I) - \text{Gloss}) / (T_3(I) - \text{bulk}(I))$

Inner (Oxide) surface temperature

Measured heat transfer coefficient for rectangular channel

Yes
 NEXT I (IF $I \leq \text{Node}$)

No
 $\text{velrc} = \text{massflux} / \text{Densityrc}$
 $\text{velsc} = \text{massflux} / \text{Densitysc}$
 $\text{BNN} = 0$

Call H2OProp(bulk(I), Densityrc, ...)

Call H2OProp(bulk(I), Densityrc, ...)

Call H2OProp(bulk(I), Densitysc, ...)

FOR JJ=1 TO Node

IF $(\text{ABS}(\text{q}_{\text{doc}}(\text{JJ}) - \text{q}_{\text{docold}}(\text{JJ})) / \text{q}_{\text{doc}}(\text{JJ})) < 0.0001$ Yes

890

K

J

3000

A.S.I

THMLFLO1.XLS

THTL 1.88

File name: FE330B05

Date= 03/30/93

Time= 16:46:30

No. = 515

U = 31.952(m/s)

Pin = 3.6459(MPa)

Pout= 1.6876(MPa)

dP = 1.9583(MPa)

Tin = 43.84(°C)

Tout= 43.44(°C)

TSp = 3(W)

Flux= 0.000(MW/m²)[45]

TI-101= 37.43(°C) TI-102= 36.43(°C) Gap = 0.0485 (in)

TI-103= 33.66(°C) TI-104= 36.92(°C) PTSout,cal= 1.5714 (MPa)

TI-105= 37.21(°C) TI-106= 36.00(°C) dPTS,cal = 2.0238 (MPa)

TI-107= 37.13(°C) TI-108= 36.65(°C) dPTS = 1.8569 (MPa)

TI-109= 36.12(°C) TI-110= 36.12(°C) PTSin = 3.5952 (MPa)

TI-111= 36.81(°C) TI-112= 36.33(°C) PTSout = 1.7383 (MPa)

TI-113= 36.66(°C) TI-114= 35.21(°C)

TI-115= 36.29(°C) TI-116= 35.48(°C)

TI-117= 37.23(°C) TI-118= 36.07(°C)

TE-120= 30.03(°C)

IP= 1 M= 0.7413 IP1= 3

TS flow = 9.008 (GPM) 34.096 (LPM) Temperature (°C)

Byp flow = 3.015 (GPM) 11.412 (LPM) 500.0

Byp flow : TS flow = 0.33 : 1.00

Ts,out= 203.97 (°C) [Based on Pout]

Pout[32-30]= 1.7006 (MPa)

dP [30]= 1.9453 (MPa)

U [33]= 31.990 (m/s)

Power [38]= 3 (W)

Save calculation results? (Y/N) ==> N

Use <Space Bar> and/or <Enter>

DC Power Supply= 0.003 (KW)

1-dPTS/dPTS,cal= 8.248 (%)

Wall temperature
Coolant temperature
Pressure

Fig.19

- F2 : Re-show this screen (Fig.19).
 F3 : Short cut.
 F4 : Show thermocouple location and TS configuration (Fig.12).
 F5 : Show pressure-drop and measured temperatures (Fig.13).

IHTL Ver 1.86 04/02/93 0
 FE330B05 Test date : 03/30/93
 Rectangular channel $U_{rc,in} = 32.97$ (m/s) Semicircular channel $U_{sc,in} = 24.44$ (m/s)
 $U_{rc,ex} = 32.97$ (m/s) $U_{sc,ex} = 24.44$ (m/s)

Element No.	Tb (°C)	dP,cal (MPa)	P,cal (MPa)	Tsat+ (°C)	Urc (m/s)	Element No.	Tb (°C)	dP,cal (MPa)	P,cal (MPa)	Tsat+ (°C)	Usc (m/s)
1	43.84	0.3285	3.495	242.42	32.97	1	43.84	0.3066	3.505	242.58	24.44
2	43.84	0.5475	3.036	234.47	32.97	2	43.84	0.5111	3.077	235.20	24.44
3	43.84	0.4778	2.398	221.71	32.97	3	43.84	0.4460	2.481	223.50	24.44
4	43.84	0.2389	2.076	214.32	32.97	4	43.84	0.2230	2.182	216.82	24.44
5	43.84	0.1593	1.919	210.29	32.97	5	43.84	0.1487	2.033	213.21	24.44
6	43.84	0.1195	1.759	205.99	32.97	6	43.84	0.1115	1.884	209.39	24.44
7	43.84	0.0597	1.679	203.73	32.97	7	43.84	0.0558	1.810	207.39	24.44
8	43.84	0.0398	1.639	202.56	32.97	8	43.84	0.0372	1.773	206.36	24.44
9	43.84	0.0478	1.599	201.38	32.97	9	43.84	0.0446	1.735	205.32	24.44

 $dP_{formin} = 0.0000$ (MPa) $dP_{dvin} = 0.0000$ (MPa) $P_{out,cal} = 1.5207$ $P_{out} = 1.6876$
 $dP_{formout} = 0.0000$ (MPa) $dP_{dvout} = 0.0000$ (MPa) $dP,cal = 2.1252$ $dP = 1.9583$
 $dP_{form} = 0.0000$ (MPa) $dP_{fric} = 2.1200$ (MPa) $1-dP/dP,cal = 7.854$ (%)
 $dP_{zsum} = 0.0052$ (MPa) $PTS_{Fin} = 3.6459$ (MPa) $PTS_{Fout} = 1.5207$ (MPa)
 $P_{in} = 3.6459$ $P_{in} = 3.6459$

Following results are converted to TS heated length inlet or outlet.
 $PTS_{out} = 1.7383$ (MPa) $PTS_{out,cal} = 1.5714$ (MPa) $PTS_{in} = 3.5952$ (MPa)
 $dPTS = 1.8569$ (MPa) $dPTS,cal = 2.0238$ (MPa) $1-dPTS/dPTS,cal = 8.248$ (%)
 $dPTS_{src} = 2.1252$ (MPa) $dPTS_{sc} = 1.9841$ (MPa) $(1-dPTS_{src}/dPTS_{sc}) = -7.113$ (%)
 Calculate again (Y/N) ==> Y * : Including TS-flange region
 Use <Space Bar> and/or <Enter> + : Based on P,cal

Fig.20

- F2 : Go to Fig.19.
 F4 : Show thermocouple location and TS configuration (Fig.12).
 F5 : Show pressure-drop and measured temperatures (Fig.13).

Test name : FE331A10 Record No.= 1110
 Record number of data file ==> 1110

Stack space = 8512

Temperature (°C) No.= 1110 Time=11:40:03

Fig.17

F1 : Show digital data and go to data reduction.
 F10 : Go to next data point.

(Trend type = 4)

Test name : FE331A10 Record No.= 1110
 Record number of data file ==> 1119

Stack space = 7932
 x 10 Bypass ratio (-)
 x 10 Velocity (m/s)
 Pressure (MPa)

Temperature (°C) No.= 1110 Time=11:40:03

Tin Tout Pin Pout Velocity dP Bypass ratio

Fig.18

F1 : Show digital data and go to data reduction.
 F10 : Go to next data point.

(Trend type = 5)

Test name : FE331A10 Record No.= 1110
 Record number of data file ==> 1110

Stack space = 10012

Temperature (°C) No.= 1110 Time=11:40:03

Fig.15

F1 : Show digital data and go to data reduction.
 F10 : Go to next data point.

(Trend type = 2)

Test name : FE331A10 Record No.= 1110
 Record number of data file ==> 1110

Stack space = 9084

Temperature (°C) No.= 1110 Time=11:40:03

Fig.16

F1 : Show digital data and go to data reduction.
 F10 : Go to next data point.

(Trend type = 3)

Fig.13

- F2 : Go to Fig.4.
 F3 : Short cut.
 F4 : Show thermocouple location and TS configuration (Fig.12).
 F6 : Input "Heat loss", loss (%)
 F7 : Input "Heat loss to the semicircular channel (heat re-distribution)", loss_{sc} (%).
 F8 : Redo from start.
 F9 : Input "Oxide thickness", thox (cm)

Test name : FE331A01 Record No.= 761
Record number of data file ==> 5
Trend graph type 1, 2, 3, 4==>? 2

Stack space = 12240

Type 1 : Standard type
Type 2 : Displays both Selected temperatures and Un-selected temperatures
Type 3 : Displays Selected temperatures only
Type 4 : Displays Un-selected temperatures only
Type 5 : Displays Tin, Tout, Power, Pin, Pout, Velocity, dP, Bypass ratio

Fig.14

F8 + Enter : Redo from start

THIL Ver 1.86 04/02/93 0

Flow Excursion (FE) heat flux and velocity predicted by Costa Correlation

THIL Test No. : FE331A10 Converted Heat loss = 8.087 (%)

Channel	Measured heat flux	Velocity at FE	Tb	Corresponding average velocity
Average channel	10.912 (MW/m ²)	15.356 (m/s)	169.17 (°C)	15.356 (m/s)
Rectangular channel	12.333 (MW/m ²)	23.607 (m/s)	172.32 (°C)	22.875 (m/s)
Semicircular channel	4.223 (MW/m ²)	0.646 (m/s)	137.58 (°C)	0.845 (m/s)

Coolant velocities are calculated based on a measured heat flux on flats.

Channel	Velocity at channel exit	Heat flux at FE	Tb	Corresponding heat R flux on flats (-)
Average channel	20.354 (m/s)	12.564 (MW/m ²)	169.17(°C)	14.200 (MW/m ²) 0.776
Rectangular channel	21.084 (m/s)	11.656 (MW/m ²)	172.32(°C)	11.656 (MW/m ²) 0.796
Semicircular channel	1.060 (m/s)	20.384 (MW/m ²)	137.58(°C)	59.527 (MW/m ²) 0.577

Urc=Usc=Uav

Rectangular channel	20.527 (m/s)	10.112 (MW/m ²)	176.24(°C)	10.112 (MW/m ²) 0.820
Semicircular channel	19.316 (m/s)	30.418 (MW/m ²)	116.22(°C)	88.833 (MW/m ²) 0.443

Heat fluxes are calculated based on a measured average coolant velocity.

Inlet coolant temperature Tin = 45.75 (°C)
 Outlet coolant temperature Tout = 169.17 (°C) Tout,c = 169.17 (°C)
 Outlet coolant pressure* PTSout= 1.717 (MPa) Xex,1* = 0.000 L11= 0.0 (cm)
 Saturation temperature* Ts,out= 204.81 (°C) Xex,2* = 0.000 L12= 0.0 (cm)
 Measured heat flux on flats qrc = 12.332 (MW/m²) qrcmax = 13.316 (MW/m²)
 Measured average coolant velocity U = 18.50 (m/s)

* at the Test Section (heated length) outlet.

Save calculation results? (Y/N) ==> N

Use <Space Bar> and/or <Enter>

Fig.11

- F2 : Go to Fig.4.
- F3 : Short cut.
- F4 : Show thermocouple location and TS configuration (Fig.12).
- F5 : Show pressure-drop and measured temperatures (Fig.13).
- F6 : Input "Heat loss", loss (%)
- F7 : Input "Heat loss to the semicircular channel (heat re-distribution)", loss_{sc} (%).
- F8 : Redo from start.
- F9 : Input "Oxide thickness", thox (cm)

THIL Tset Section Instrumentation

THIL Tset Section Configuration

Tset name : FE331A10 TS design : TSD-3
Tset date : 03/31/93

Aflow = 0.17785D-04 (m²) DHY = 2.3101D-03 (m)
Afrc = 0.15653D-04 (m²) DHYrc = 2.4651D-03 (m)
Afsc = 0.21323D-05 (m²) DHYsc = 1.5806D-03 (m)

Al = 0.15614D-01 (m²) vel = 18.499 (m/s)
Ahrc = 0.12878D-01 (m²) velrc = 19.091 (m/s)
Ahsc = 0.27358D-02 (m²) velsc = 14.152 (m/s)

Acs = 0.69209D-04 (m²)
qratio = 0.34242 (-)

Stack space = 10438
Press <Enter> to continue

Fig.12

- F2 : Go to Fig.4.
F3 : Short cut.
F5 : Show pressure-drop and measured temperatures (Fig.13).
F6 : Input "Heat loss", loss (%)
F7 : Input "Heat loss to the semicircular channel (heat re-distribution)", loss_{sc} (%).
F8 : Redo from start.
F9 : Input "Oxide thickness", thox (cm)

THIL Ver 1.86 04/02/93 0
 Critical Heat Flux (CHF) predicted by Gambill - Weatherhead Correlation
 THIL Test No. : FE331A10 Heat loss = 8.087 (%)

Channel	Velocity at channel exit	Critical heat flux (CHF)	Corresponding heat flux on flats
Average channel	20.354 (m/s)	15.832 (MW/m ²)	17.894 (MW/m ²)
Rectangular channel	21.084 (m/s)	15.390 (MW/m ²)	15.390 (MW/m ²)
Semicircular channel	15.059 (m/s)	10.415 (MW/m ²)	53.778 (MW/m ²)
U _{rc} =U _{sc} =U _{av}			
Rectangular channel	20.527 (m/s)	14.350 (MW/m ²)	14.350 (MW/m ²)
Semicircular channel	19.316 (m/s)	25.048 (MW/m ²)	73.149 (MW/m ²)

Heat fluxes are calculated based on a measured average coolant velocity.

Inlet coolant temperature T_{in} = 45.75 (°C)
 Outlet coolant pressure* P_{Tsout} = 1.717 (MPa)
 Saturation temperature* T_{s,out} = 204.81 (°C)
 Measured heat flux on flats q_{rc} = 12.332 (MW/m²) [Average]
 Measured heat flux on flats q_{rcmax} = 13.316 (MW/m²) [Maximum]
 Measured average coolant velocity U = 18.50 (m/s)

* at the Test Section (heated length) outlet.

Save calculation results? (Y/N) ==> N
 Use <Space Bar> and/or <Enter>

Fig.9

F2 : Go to Fig.4.
 F3 : Short cut.
 F4 : Show thermocouple location and TS configuration (Fig.12).
 F5 : Show pressure-drop and measured temperatures (Fig.13).
 F6 : Input "Heat loss", loss (%)
 F7 : Input "Heat loss to the semicircular channel (heat re-distribution)", loss_{sc} (%).
 F8 : Redo from start.
 F9 : Input "Oxide thickness", thox (cm)

THIL Ver 1.86 04/02/93 0
 Incipient Boiling (IB) heat flux predicted by Bergles-Rohsenow Correlation
 THIL Test No. : FE331A10 Heat loss = 8.087 (%)

Channel	Velocity at channel exit	IB heat flux	T_w	Corresponding heat flux on flats
Average channel	20.354 (m/s)	6.740 (MW/m ²)	213.04 (°C)	7.618 (MW/m ²)
Rectangular channel	21.084 (m/s)	6.329 (MW/m ²)	212.79 (°C)	6.329 (MW/m ²)
Semicircular channel	15.059 (m/s)	9.880 (MW/m ²)	214.76 (°C)	28.853 (MW/m ²)
$U_{rc}=U_{sc}=U_{av}$				
Rectangular channel	20.527 (m/s)	5.502 (MW/m ²)	212.26 (°C)	5.502 (MW/m ²)
Semicircular channel	19.316 (m/s)	15.605 (MW/m ²)	217.29 (°C)	45.573 (MW/m ²)

Heat fluxes are calculated based on a measured average coolant velocity.

Inlet coolant temperature $T_{in} = 45.75$ (°C)
 Outlet coolant pressure* $P_{TSout} = 1.717$ (MPa)
 Saturation temperature* $T_{s,out} = 204.81$ (°C)
 Measured heat flux on flats $q_{rc} = 12.332$ (MW/m²) [Average]
 Measured heat flux on flats $q_{rcmax} = 13.316$ (MW/m²) [Maximum]
 Measured average coolant velocity $U = 18.50$ (m/s)

* at the Test Section (heated length) outlet.

Save calculation results? (Y/N) ==> N
 Use <Space Bar> and/or <Enter>

Fig.10

F2 : Go to Fig.4.
 F3 : Short cut.
 F4 : Show thermocouple location and TS configuration (Fig.12).
 F5 : Show pressure-drop and measured temperatures (Fig.13).
 F6 : Input "Heat loss", loss (%)
 F7 : Input "Heat loss to the semicircular channel (heat re-distribution)",
 loss_{sc} (%).
 F8 : Redo from start.
 F9 : Input "Oxide thickness", th_{ox} (cm)

THTL Ver 1.86 04/02/93 0
 FE331A10 Test date : 03/31/93 Steady State Calculations Heat loss= 8.087 (%)
 Calculation model : Rectangular channel (Zero mixing) $U_{rc,in} = 19.09$ (m/s)
 $U_{rc,ex} = 21.08$ (m/s)

Element No.	HTC (W/cm ² K)	HTC,cal (W/cm ² K)	qCHFcal (MW/m ²)	HTC/HTC,cal (-)	dP,cal (MPa)	P,cal (MPa)	Tsat+ (°C)	Urc (m/s)	P (MPa)	Tsat (°C)
1	14.187	12.382	38.143	1.146	0.0910	2.271	218.87	19.14	2.270	218.85
2	14.190	13.338	33.072	1.064	0.1525	2.143	215.87	19.41	2.138	215.76
3	13.580	14.783	24.495	0.919	0.1318	1.965	211.47	19.97	1.955	211.22
4	15.306	15.203	22.389	1.007	0.0680	1.875	209.13	20.35	1.863	208.82
5	18.683	15.352	23.522	1.217	0.0462	1.828	207.89	20.56	1.817	207.58
6	18.583	15.484	20.729	1.200	0.0352	1.782	206.61	20.79	1.771	206.32
7	19.526	15.546	20.109	1.256	0.0177	1.758	205.96	20.91	1.748	205.68
8	21.262	15.575	20.768	1.365	0.0119	1.746	205.62	20.98	1.737	205.36
9	23.356	15.604	21.587	1.497	0.0143	1.734	205.29	21.04	1.725	205.04

Pin = 2.3177 P_{in} = 2.3177
 dP_{formin} = 0.0000 (MPa) dP_{dvin} = 0.0000 (MPa) P_{out,cal} = 1.7094 P_{out} = 1.7010
 dP_{formout} = 0.0000 (MPa) dP_{dout} = 0.0000 (MPa) dP,cal = 0.6083 dP = 0.6167
 dP_{form} = 0.0000 (MPa) dP_{fric} = 0.6033 (MPa) 1-dP/dP,cal = -1.376 (%)
 dP_{zsum} = 0.0050 (MPa) PTS_{fin} = 2.3177 (MPa) PTS_{fout} = 1.7094 (MPa)

Following results are converted to TS heated length inlet or outlet.

PTS_{out} = 1.7171 (MPa) PTS_{out,cal} = 1.7255 (MPa) PTS_{in} = 2.2987 (MPa)
 dPTS = 0.5816 (MPa) dPTS,cal = 0.5732 (MPa) 1-dPTS/dPTS,cal = -1.460 (%)
 Ts_{TSout} = 204.81 (°C) Ts_{TSout+} = 205.05 (°C) + : Based on P,cal

Stack space = 11074

Press <Enter> to continue

Fig.7

F2	: Go to Fig.4.
F3	: Short cut.
F4	: Show thermocouple location and TS configuration (Fig.12).
F5	: Show pressure-drop and measured temperatures (Fig.13).
F6	: Input "Heat loss", loss (%)
F7	: Input "Heat loss to the semicircular channel (heat re-distribution)", loss _{ssc} (%).
F8	: Redo from start.
F9	: Input "Oxide thickness", thox (cm)

THIL Ver 1.86 04/02/93 0
 FE331A10 Test date : 03/31/93 Steady State Calculations Heat loss= 8.087 (%)
 Rectangular channel $U_{rc,in}$ = 19.09 (m/s) Semicircular channel $U_{sc,in}$ = 14.15 (m/s)
 $U_{rc,ex}$ = 21.08 (m/s) $U_{sc,ex}$ = 15.06 (m/s)

Element No.	qflux (MW/m ²)	Tb (°C)	P,cal (MPa)	Tsat+ (°C)	Urc (m/s)	Element No.	qflux (MW/m ²)	Tb (°C)	P,cal (MPa)	Tsat+ (°C)	Usc (m/s)
1	10.991	51.40	2.271	218.87	19.14	1	3.764	49.82	2.274	218.94	14.18
2	11.692	78.14	2.143	215.87	19.41	2	4.004	69.10	2.156	216.20	14.31
3	12.854	118.15	1.965	211.47	19.97	3	4.402	98.04	1.997	212.30	14.57
4	13.123	139.12	1.875	209.13	20.35	4	4.494	113.27	1.917	210.25	14.74
5	12.996	149.58	1.828	207.89	20.56	5	4.450	120.90	1.876	209.17	14.84
6	13.271	160.03	1.782	206.61	20.79	6	4.544	128.54	1.834	208.04	14.93
7	13.316	165.29	1.758	205.96	20.91	7	4.560	132.40	1.813	207.47	14.99
8	13.243	167.91	1.746	205.62	20.98	8	4.535	134.33	1.802	207.17	15.01
9	13.169	170.51	1.734	205.29	21.04	9	4.509	136.24	1.791	206.88	15.04

Rectangular channel (Heated section)

PTSin = 2.2987 (MPa)

PTSout,cal= 1.7255 (MPa)

dPTS,cal = 0.5732 (MPa)

dPTSrc* = 0.6083 (MPa)

Massflux = 18.883D+03 (kg/m²s)

Massfluxav= 18.297D+03 (kg/m²s)

(1-dPTSrc/dPTSsc)* = -10.780 (%)

Semicircular channel (Heated section)

PTSin = 2.2998 (MPa)

PTSout,cal= 1.7836 (MPa)

dPTS,cal = 0.5162 (MPa)

dPTSsc* = 0.5491 (MPa)

Massflux = 13.998D+03 (kg/m²s)

* : Including non-heated sections

+ : Based on P,cal

Stack space = 11074

Press <Enter> to continue

Fig.8

- F2 : Go to Fig.4.
- F3 : Short cut.
- F4 : Show thermocouple location and TS configuration (Fig.12).
- F5 : Show pressure-drop and measured temperatures (Fig.13).
- F6 : Input "Heat loss", loss (%)
- F7 : Input "Heat loss to the semicircular channel (heat re-distribution)", loss_{sc} (%).
- F8 : Redo from start.
- F9 : Input "Oxide thickness", thox (cm)

Fig.5

- F2 : Go to Fig.4.
- F3 : Short cut.
- F4 : Show thermocouple location and TS configuration (Fig.12).
- F5 : Show pressure-drop and measured temperatures (Fig.13).
- F6 : Input "Heat loss", loss (%)
- F7 : Input "Heat loss to the semicircular channel (heat re-distribution)", loss_{sc} (%).
- F8 : Redo from start.
- F9 : Input "Oxide thickness", thox (cm)

IHTL Ver 1.86 04/02/93 0
 FE331A10 Test date : 03/31/93 Steady State Calculations Heat loss= 8.987 (%)
 Tin = 45.75 (°C) Tout = 169.17 (°C) Pin = 2.318 (MPa) Pout = 1.701 (MPa)
 Power = 185353 (W) TSpower = 170364 (W) Uav,in = 18.50 (m/s) Ratio Usc/Urc = 0.7413
 Voltage across TS = 9.3635 (V) Current = 19795.1 (A) Uav,ex = 20.35 (m/s)
 Al Wall thickness = 0.2540 (cm) Ends(xa) = 0.0635 (cm) Urc,ex = 21.08 (m/s)
 Oxide thickness = 0.0002 (cm) TS length = 50.700 (cm) Usc,ex = 15.06 (m/s)
 Power to flats is 158.81 (kW) Ratio Pf/TSpower = 0.9322 Flow gap = 0.1233 (cm)
 Power to ends is 11.55 (kW) Heat flux ratio = 0.3424 Tout,rc/C = 172.32 (°C)
 qIB calculated by B/R's correlation = 10.630 (MW/m²) [at the channel exit]
 qFE calculated by Costa's correlation = 11.656 (MW/m²) [at the channel exit]
 qCHF calculated by Gambill's correlation = 22.083 (MW/m²) [at the channel exit]
 qCHF calculated by JAERI's correlation = 14.304 (MW/m²) [at the channel exit]
 Average Heat flux of flats = 12.332 (MW/m²) (Tout,av)cal = 169.17 (°C)
 Maximum Heat flux of flats = 13.316 (MW/m²) (Tout,rc)cal = 172.32 (°C)
 Average Heat flux of ends = 4.223 (MW/m²) 1-dT/(dT,av)cal = -0.00 (%)
 Calculation model : Rectangular channel (Zero mixing) Urc,in = 19.09 (m/s)

Element No.	qflux (MW/m²)	Tbulk (°C)	Tinter (°C)	Twall (°C)	Tavg-al (°C)	Tmeas (°C)	Urc (m/s)	Volts (V)	Location (cm)	qIBcal (MW/m²)
1	10.991	51.40	128.87	138.64	189.39	214.76	19.14	1.358	2.50	25.737
2	11.692	78.14	160.54	170.93	224.08	250.66	19.41	2.408	14.00	21.381
3	12.854	118.15	212.80	224.23	281.61	310.29	19.97	2.310	30.00	14.144
4	13.123	139.12	224.86	236.53	294.94	324.14	20.35	1.179	38.00	12.298
5	12.996	149.58	219.14	230.69	288.61	317.56	20.56	0.778	42.00	12.891
6	13.271	160.03	231.44	243.24	302.22	331.71	20.79	0.596	46.00	10.477
7	13.316	165.29	233.49	245.33	304.49	334.06	20.91	0.299	48.00	9.803
8	13.243	167.91	230.19	241.96	300.84	330.27	20.98	0.198	49.00	10.084
9	13.169	170.51	226.89	238.60	297.19	326.47	21.04	0.237	50.00	10.442

Fig.6

- F2 : Go to Fig.4.
 F3 : Short cut.
 F4 : Show thermocouple location and TS configuration (Fig.12).
 F5 : Show pressure-drop and measured temperatures (Fig.13).
 F6 : Input "Heat loss", loss (%)
 F7 : Input "Heat loss to the semicircular channel (heat re-distribution)", loss_{ssc} (%).
 F8 : Redo from start.
 F9 : Input "Oxide thickness", thox (cm)

Test name : FE331A10 Record No.= 1110
 Record number of data file ==> 1110

Stack space = 11618
 x 10 Bypass ratio (-)
 x 10 Velocity (m/s)
 Pressure (MPa)

Temperature (°C) No.= 1110 Time=11:40:03

Tin Tout Pin Pout Velocity dP Bypass ratio

Fig.3

F1 : Show digital data and go to data reduction.
 F10 : Go to next data point.

(Trend type = 1)

File name: FE331931 Heat loss [losssc] = 0.00 (%) DC Power Supply=185.353 (KW)
 Date= 03/31/93 (Heat loss to s.c. channel) 1-dPTS/dPTS,cal= -1.460 (%)
 Time= 11:40:03 TT-101=326.47(°C) TT-102=312.41(°C) Gap = 0.0485 (in)
 No. = 1110 TT-103=271.69(°C) TT-104=307.85(°C) PTSout,cal= 1.7255 (MPa)
 U = 18.499(m/s) TT-105=334.06(°C) TT-106=304.17(°C) dPTS,cal = 0.5732 (MPa)
 Pin = 2.3177(MPa) TT-107=331.71(°C) TT-108=326.23(°C) dPTS = 0.5816 (MPa)
 Pout= 1.7010(MPa) TT-109=317.56(°C) TT-110=308.63(°C) PTSin = 2.2987 (MPa)
 dP = 0.6167(MPa) TT-111=324.14(°C) TT-112=321.01(°C) PTSout = 1.7171 (MPa)
 Tin = 45.75(°C) TT-113=310.29(°C) TT-114=290.11(°C) Tw,max = 233.49 (°C)
 Tout= 169.17(°C) TT-115=250.66(°C) TT-116=252.05(°C) Tout,cal= 169.17 (°C)
 TSp= 170364(W) TT-117=214.76(°C) TT-118=217.00(°C) Calc. coolant temp.
 Flux= 12.031(MW/m²)[45] Inner wall temp. Wall temperature
 Heat loss= 8.087(%) TE-120=169.68(°C) HTC,calculated Coolant temperature
 *Including heat loss M= 0.7413 IP1= 3 HTC,measured Pressure
 TS flow = 5.215 (GPM) 19.741 (LPM) Temperature (°C) Pressure (MPa)
 Byp flow =29.129 (GPM)110.261 (LPM) 500.0
 Byp flow : TS flow = 5.59 : 1.00
 Average Heat flux of flats*=12.332 400.0
 Maximum Heat flux of flats*=13.316
 Average Heat flux of ends *= 4.223 300.0
 Ts,out= 204.81 (°C) [Based on PTSout] 200.0
 Ts,out= 204.35 (°C) [Based on Pout] 100.0
 Pout[32-30]= 1.7023 (MPa)
 dP [30]= 0.6154 (MPa)
 U [33]= 18.522 (m/s)
 Power [38]= 185353 (W)
 Stack space = 11074
 Press <Enter> to continue

Fig.4

- F2 : Re-show this screen (Fig.4).
- F3 : Short cut.
- F4 : Show thermocouple location and TS configuration (Fig.12).
- F5 : Show pressure-drop and measured temperatures (Fig.13).
- F6 : Input "Heat loss", loss (%)
- F7 : Input "Heat loss to the semicircular channel (heat re-distribution)", losssc (%).
- F8 : Redo from start.
- F9 : Input "Oxide thickness", thox (cm)

Appendix A

```

THTL Ver 1.86 04/02/93 0
Input IMAKE      ==> 0      IMAKE = 0 : Standard calculation mode
Input ICALCMODE   ==> 0      = 1 : Make data file *.DAT (ICALCMODE = 0,1,2)
Input IDATA       ==> 0      = 2 : Make data file *.asc for Microsoft EXCEL
Input IDPres      ==> 0      = 3 : Make data file *.tbl for Microsoft EXCEL
Input IDH         ==> 0
Input lossssc (%) ==> 0.00 lossssc : Heat loss to the semicircular channel.
                                (Heat loss (W) =  $t_{spwr}$  (W) * lossssc /100)
ICALCMODE = 0 :  $T_{w,in}$  is calculated based on measured external temperature.
                 $q_{CHF}$  and  $q_{IB}$  are calculated based on measured HTC.
            = 1 :  $T_{w,in}$  is calculated based on measured external temperature.
                 $q_{CHF}$  and  $q_{IB}$  are calculated based on HTC calculated by Petukhov.
            = 2 : Heat Transfer Coefficient (HTC),  $T_{w,in}$ ,  $q_{IB}$ ,  $q_{FE}$ ,  $q_{CHF}$  and so on
                are predicted based on an experimental condition.
            = 3 : Heat Transfer Coefficient (HTC),  $T_{w,in}$ ,  $q_{IB}$ ,  $q_{FE}$ ,  $q_{CHF}$  and so on
                are predicted based on inputed coolant velocity  $U_{rc}$ , heat flux
                on  $\phi_{lats}$ , inlet coolant temperature and outlet pressure.
IDATA            = 0 : Show both raw data and calculation results.
            = 1 : Show raw data only (No calculation).
                For ICALCMODE = 0, 1, 2 (Not for ICALCMODE = 3)
IDH              = 0 : Constant heat loss along the channel
            = 1 : Non-uniform heat loss along the channel
IDPres           = 0 :  $U_{sc}/U_{rc}$  is constant (0.630 for TSD-1, 0.7413 for TSD-3).
            = 1 :  $U_{sc}/U_{rc}$  is calculated based on dP of both RC and SC channel.
                                ■ : Standard
                                ■ : Optional
                                <Redo from start [F8 + Enter key]>

```

Fig.1

```

F8 + Enter      : Redo from start
[F8             : Redo from start]

```


THL Ver 1.86 04/02/93 0
 Input data file name ==>? <Enter : Next>

Stack space = 12240

Date	File name	Date	File name	Date	File name	Date	File name
01/05/93	: FE10593	01/14/93	: FE11493	01/15/93	: CF11593		
02/10/93	: FE21093	02/11/93	: FE21193	02/12/93	: FE21293		
03/18/93	: FE31893	03/29/93	: FE32993	03/30/93	: FE33093	03/31/93	: FE33193

■ : Blank, 1, 2...

Date	File name (Data No.)	Parameter	Date	File name (Data No.)	Parameter
01/05/93	: FE105Axx (01 to 16)	Velocity		FE212A21 ()	FE occur
	FE105B09 (01 to 20)	Velocity	03/18/93	: FE318Axx (01 to 08)	Velocity
	FE105C10 (01 to 25)	Velocity		FE318B10 (01 to 12)	Velocity
	FE105D11 (01 to 22)	Velocity		FE318B12 ()	FE occur
	FE105Eyy (01 to 29)	Heat flux	03/29/93	: FE329Axx (01 to 17)	Velocity
	FE105Fxx (01 to 13)	Velocity	03/30/93	: FE330A09 (01 to 15)	Velocity
01/14/93	: FE114Axx (01 to 13)	Velocity		FE330Axx (01 to 17)	Velocity
	FE114B10 (01 to 26)	Velocity	03/31/93	: FE331A13 (01 to 16)	Velocity
01/15/93	: CF115Axx (01 to 13)	Velocity		FE331A16 ()	FE occur
	CF115B12 (01 to 19)	Velocity			
	CF115B20 ()	CHF Point			
02/10/93	: FE210Axx (01 to 14)	Velocity			
	FE210B10 (01 to 23)	Velocity			
02/11/93	: FE211Axx (01 to 14)	Velocity			
02/12/93	: FE212A15 (01 to 22)	Velocity			

Non-powered case

<Redo from start [F8 + Enter key]>

Fig.2

F8 + Enter : Redo from start
 Enter : Next page

- a. Run THTL.EXE (THTL Ver 1.86)
- b. Use **IMAKE = 3** (Make data file *.asc for Microsoft EXCEL)
 Please use other calculation options as follows.
ICALCMODE= 1 (Must be 1).
IDATA= 0 (Must be 0).
IDPres = 0 or 1 (You had better use IDPres = 0, because if you use IDPres=1, it takes much longer calculation time. When you use IDPres=1, calculation results would be different.)
IDH= 0 or 1
losssc = 0.0 (You can input losscc greater than 0.0.)

See Appendix A Fig.1

- c. Use *.DAT file as input of THTL.
 Example
 Input data file name ==>? FE212A15

See Appendix A Fig.2

8. Create *.XLS files for each run using "Microsoft EXCEL"

- a. Run EXCEL
- b. Open previous *.XLS file.
 Example : Open "FE212A.XLS".
- c. Open *.ASC file which was created by THTL (THTL Ver1.86). When you open *.ASC file, please use Text file option -- Column Delimiter : Comma, File Origin : DOS or OS/2(PC-8).
- d. Copy contents of *.ASC file to *.XLS file. During copy procedure, please use Paste special -- Paste : Value, Operation : Non.
- e. Save file using Save as command.

FE331A16, () FE occur ' <=== Just before FE occur'
 99/99/99 "99 99 99" means end of data sets.³⁾
 1 '0 : End of data 1 : continue³⁾

³⁾Comments

_____ : Added or modified.

(1) : 01/05/93, FE10593 , 1, 01/14/93, FE11493 , 1, 01/15/93, CF11593 , 0

01/05/93, FE10593 , 1,..... : Test date, *.INP file name without file extension, 1 or 0.

[0 : End of this line, 1 : Continue]

Maximum number of data sets per one line is 4.

Maximum line number of this kind of data is 7.

(2) : 99/99/99

99/99/99

: End of data sets

(3) : 01/05/93 , FE105Axx, (01 to 16) Velocity

01/05/93 , FE105Axx, (01 to 16) Velocity :Test date, *.DAT file name of FE point (CHF point etc) [xx for non-powered case], Comments (maximum 20 characters).

Maximum number of this kind of data set is 28.

(4) : 99/99/99

99/99/99

: End of data sets

(5) : 1

1

: =1 There is an another data file.

Example : In this case, this file name is "DATNUM2.DAT",

"1" means there is an another file which has a name of

"DATNUM3.DAT"

=0 End of data. There is no additional data file.

5. Run THTL.EXE to create *.DAT files

THTL does not always require *.DAT files, but it is convenient to have *.DAT files. Because if you don't have *.DAT files, you always have to use *.PRN (original data file from data acquisition system) files. *.PRN files take much more disk space compared with *.DAT files.

a. Run THTL.EXE (THTL Ver 1.86)

b. Use IMAKE = 1 (Make data file *.DAT (ICALCMODE= 0, 1, 2)

Please use other calculation options as follows.

ICALCMODE= 0, 1 or 2.

IDATA= 0 (Must be 0.)

IDPres = 0 or 1 (You had better use IDPres = 0, because if you use IDPres=1, it takes much longer calculation time.)

IDH= 0 or 1 (You had better to use IDH=0.)

losssc = 0.0 (You can input losscc greater than 0.0.)

See Appendix A Fig.1

c. Use *.INP file as input of THTL.

Example

Input data file name ==>? FE21293

"FE21293" means "FE21293.INP"

See Appendix A Fig.2

Example file : FE331A01.DAT -----

FE331A01,03/31/93

45.766,119.3260⁴⁾173932.07⁴⁾31.9718⁴⁾3.2299,1.6996⁴⁾2.5. 14.0. 30.0. 38.0. 42.0. 46.0. 48.0. 49.0. 50.0⁴⁾188.0. 214.6. 238.4. 250.8. 252.2. 272.3. 272.6. 272.2. 271.8⁴⁾12.5904. 0.0. 0.0⁴⁾13.5014. 0.05817148⁴⁾

'<FE331A01> from FE331931.PRN No.761

'03 31 93 q' = 12.59 MW m² 4)'Flow Excursion Test'⁴⁾

"11:16:09",271.7766,261.1698,223.471,255.4702,272.6203,248.264,272.2504,267.2599,
 252.2466,243.7286,250.8207,242.8829,238.4149,224.7005,214.622,215.995,187.9803,
 190.6747,114.8467,158.3855,69.73944,45.4178,11.45599,44.78102,119.265,46.75005,
 119.3871,1.699605,2.867204,1.528749,.4164757,3.229878,32.01028,56.86305,163.038,
 6.194012,151.947,184.6749,3.600999,20948.93,8.416278,-56.40644,-.007018312,8.839281,
 11.98666,103.8443,150.3831

⁴⁾ THTL does not use these data for data reduction using *.DAT files. (These data are not used for calculation.)

6. Run THTL.EXE to create *.ASC files for "Microsoft EXCEL"

a. Run THTL.EXE (THTL Ver 1.86)

b. Use **IMAKE = 2** (Make data file *.asc for Microsoft EXCEL)

Please use other calculation options as follows.

ICALCMODE= 0 or 1.(No effects against *.ASC files).**IDATA= 0** (Must be 0).

IDPres = 0 or 1 (You had better use IDPres = 0, because if you use IDPres=1, it takes much longer calculation time. When you use IDPres=1, calculation results would be different.)

IDH= 0 or 1**losssc = 0.0** (You can input losscc greater than 0.0.)

See Appendix A Fig.1

c. Use *.INP file as input of THTL.

Example

Input data file name ==>? FE21293

"FE21293" means "FE21293.INP"

See Appendix A Fig.2

7. Run THTL.EXE to create *.TBL files for "Microsoft EXCEL"

Usually *.tbl files are made for only FE point (a data point which has minimum pressure drop across the test section).

If there are two or more source files, files format of *.INP file will change to the following file format..

Example file 2 : FE331931.INP -----

FE330931

FE330A01,1564, FE330A02,1586, FE330A03,1618, FE330A04,1658, FE330A05,1683
FE330A06,1720, FE330A07,1779, FE330A08,1803, FE330A09,1845, FE330A10,1877
FE330A11,1935, FE330A12,1954, FE330A13,1971, FE330A14,1984, FE330A15,2008
FE330END,9998

FE330933

FE330B01, 492, FE330B02, 496, FE330B03, 505, FE330B04, 512, FE330B05, 515
FE330B06, 518, FE330B07, 521, FE330B08, 524, FE330B09, 528, FE330B10, 531
FE330B11, 534, FE330B12, 538, FE330B13, 540, FE330B14, 546, FE330B15, 548
FE330B16, 555, FE330B17, 559, FE330END,9999

(1) : FE330931

FE330931 : Source file (*.PRN) name 1 (First source file name)

(2) : FE330A01,1564, FE330A02,1586, FE330A03,1618,

FE330A01,1564,..... : Data point name, Record number,

At the end of the first data set series, "xxxxxxx, 9998" must be inputted. xxxxxxx has no meanings, therefore you can type any letter. In this case, FE330END is used. Maximum number of data set per one source file is 100.

(3) : FE330933

FE330933 : Source file (*.PRN) name 2 (Second source file name)

(4) : FE330B01, 492, FE330B02, 496, FE330B03, 505,

FE330B01, 492,..... : Data point name, Record number,

At the end of the file, "xxxxxxx, 9999" must be inputted. xxxxxxx has no meanings, therefore you can type any letter. In this case, FE330END is used. Maximum number of data set per one source file is 100.

4. Modify DATNUM*.DAT file

Add new file names to DATNUM*.DAT file.

Before modification : DATNUM2.DAT -----

01/05/93, FE10593 , 1, 01/14/93, FE11493 , 1, 01/15/93, CF11593 , 0

02/10/93, FE21093 , 1, 02/11/93, FE21193x, 1, 02/12/93, FE21293 , 0

03/18/93, FE31893 , 1, 03/29/93, FE32993x, 1, 03/30/93, FE33093 , 0

99/99/99 *Maximum number of lines is 7 and maximum number of data set for one line is 4.²⁾

01/05/93 , FE105Axx, (01 to 16) Velocity 'THTL Experimental data file²⁾

, FE105B09, (01 to 20) Velocity '12.31.92 M. Kaminaga²⁾

, FE105C10, (01 to 25) Velocity 'TSD-3²⁾

, FE105D11, (01 to 22) Velocity

, FE105Eyy, (01 to 29) Heat flux 'Maximum number of data sets is 28.²⁾

, FE105Fxx, (01 to 13) Velocity	'If you want to input data sets
01/14/93, FE114Axx, (01 to 13) Velocity	'more than 28 please make an another
, FE114B10, (01 to 26) Velocity	'data file (DATNUMx.dat : x = 1 ... 9). ²⁾
01/15/93, CF115Axx, (01 to 13) Velocity	
, CF115B12, (01 to 19) Velocity	'FE-----x : FE-----xx : Non-heated test ²⁾
, CF115B20, () CHF Point	'-=== Just before burn out ²⁾
02/10/93, FE210Axx, (01 to 14) Velocity	
, FE210B10, (01 to 23) Velocity	
02/11/93, FE211Axx, (01 to 14) Velocity	
02/12/93, FE212A15, (01 to 22) Velocity	
, FE212A21, () FE occur	'<=== Just before FE occur ²⁾
03/18/93, FE318Axx, (01 to 08) Velocity	
, FE318B10, (01 to 12) Velocity	
03/29/93, FE329Axx, (01 to 17) Velocity	
03/30/93, FE330A09, (01 to 15) Velocity	
, FE330Bxx, (01 to 17) Velocity	
99/99/99	""99 99 99"" means end of data sets. ²⁾
1	'0 : End of data 1 : continue ²⁾

²⁾Comments

After modification : DATNUM2.DAT -----

01/05/93, FE10593 , 1, 01/14/93, FE11493 , 1, 01/15/93, CF11593 , 0
 02/10/93, FE21093 , 1, 02/11/93, FE21193x, 1, 02/12/93, FE21293 , 0
 03/18/93, FE31893 , 1, 03/29/93, FE32993x, 1, 03/30/93, FE33093 , 1, 03/31/93, FE33193 , 0
 99/99/99 'Maximum number of lines is 7 and maximum number of data set for one line is 4.³⁾

01/05/93 , FE105Axx, (01 to 16) Velocity	'THTL Experimental data file ³⁾
, FE105B09, (01 to 20) Velocity	'12 31 92 M. Kaminaga ³⁾
, FE105C10, (01 to 25) Velocity	'TSD-3 ³⁾
, FE105D11, (01 to 22) Velocity	
, FE105Eyy, (01 to 29) Heat flux	'Maximum number of data sets is 28. ³⁾
, FE105Fxx, (01 to 13) Velocity	'If you want to input data sets
01/14/93, FE114Axx, (01 to 13) Velocity	'more than 28 please make an another
, FE114B10, (01 to 26) Velocity	'data file (DATNUMx.dat : x = 1 ... 9). ³⁾
01/15/93, CF115Axx, (01 to 13) Velocity	
, CF115B12, (01 to 19) Velocity	'FE-----x : FE-----xx : Non-heated test ³⁾
, CF115B20, () CHF Point	'-=== Just before burn out ³⁾
02/10/93, FE210Axx, (01 to 14) Velocity	
, FE210B10, (01 to 23) Velocity	
02/11/93, FE211Axx, (01 to 14) Velocity	
02/12/93, FE212A15, (01 to 22) Velocity	
, FE212A21, () FE occur	'<=== Just before FE occur ³⁾
03/18/93, FE318Axx, (01 to 08) Velocity	
, FE318B10, (01 to 12) Velocity	
03/29/93, FE329Axx, (01 to 17) Velocity	
03/30/93, FE330A09, (01 to 15) Velocity	
, FE330Bxx, (01 to 17) Velocity	
<u>03/31/93, FE331A13, (01 to 16) Velocity</u>	

Example file : FE330931.PRN-----	Record number -----	
"03-30-1993", , "09:10:08", , "THTL.RTG " , , 48, "CHANNELS", 1		: Comment line 1-1
"CHANNEL", 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,, 47	2	: Comment line 1-2
"TIME", "TT-101", "TT-102", "TT-103", "TT-104", "TT-105",	3	: Comment line 1-3
"HH:MM:SS", "C Deg", "C Deg", "C Deg", "C Deg", "C Deg",	4	: Comment line 1-4
"09:10:10", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ...	5	: Data 1
"09:10:20", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ...	6	: Data 2
"03-31-1993", , "09:10:28", , "THTL.RTG " , , 48, "CHANNELS", 7		: Comment line 2-1
"CHANNEL", 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,, 47	8	: Comment line 2-2
"TIME", "TT-101", "TT-102", "TT-103", "TT-104", "TT-105",	9	: Comment line 2-3
"HH:MM:SS", "C Deg", "C Deg", "C Deg", "C Deg", "C Deg",	10	: Comment line 2-4
"09:10:32", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ...	11	: Data 3
"09:10:42", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ...	12	: Data 4
"09:10:52", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ...	13	: Data 5
"09:10:62", 20.27098, 20.47091, 20.57772, 21.27202, 20.68454, ...	14	: Data 6

(2): TT117, TT115, TT113, TT111, TT109, TT107, TT105, TT---, TT101
 TT117, TT115, TT113, : Selected thermocouples for data reduction. TS temperatures measured by these thermocouples are used for data reduction. (from bottom to top.)
 "TT---" means that a temperature at the location of this thermocouple is calculated by interpolation using measured temperatures of TT105 and TT101.

(3): TT118, TT116, TT114, TT112, TT110, TT108, TT106, TT104, TT102
 TT118, TT116, TT114, : Un-selected thermocouples for data reduction.

(4): 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
 2.5, 14.0, 30.0, : Location of selected thermocouples. (from bottom of the test section).

(5): 2.5, 14.0, 30.0, 38.0, 42.0, 46.0, 48.0, 49.0, 50.0
 2.5, 14.0, 30.0, : Location of un-selected thermocouples. (from bottom of the test section).

(5): TSD-3/G
 TSD-3/G : Test section number used in the program

(6): gap 0.1232525
 gap 0.1232525 : Test section flow channel gap (cm)
 [column 6 to 20] (Measured value)

(7): w 1.270
 w 1.270 : Width of test channel flat (rectangular channel) (cm)
 [column 6 to 20]

(8): thal 0.254

- thal = 0.254 : Thickness of aluminum flats (cm)
[column 6 to 20]
- (9) : xa = 0.0635
xa = 0.0635 : Thickness of aluminum ends (cm)
[column 6 to 20]
- (10) : xb = 0.0381
xb = 0.0381 : Width of end section which has the same flow channel gap of the
flat channel (cm) [column 6 to 20]
- (11) : L = 50.70
L = 50.70 : Length of test channel (cm)
[column 6 to 20]
- (12) : thox = 0.0002
thox = 0.0002 : Estimated thickness of aluminum oxide cm
[column 6 to 20]
- (13) : tbulk_{in} = 1
tbulk_{in} = 1 : = 1:(TT-201A + TT-201B)/2, = 2:TT-201A, = 3:TT-201B
[column 11 to 20]
- (14) : tbulk_{out} = 1
tbulk_{out} = 1 : = 1:(TT-202A + TT-202B)/2, = 2:TT-202A, = 3:TT-202B
[column 11 to 20]

3. Prepare *.INP file for THTL

File format of *.INP files is shown below. *.INP file contains information about data point name and data record number.

Example file 1 : FE331931.INP -----

FE331931

FE331A01, 761, FE331A02, 776, FE331A03, 791, FE331A04, 801, FE331A05, 816
FE331A06, 830, FE331A07, 851, FE331A08, 876, FE331A09, 965, FE331A10,1110
FE331A11,1340, FE331A12, 1471, FE331A13,1657, FE331A14,1808, FE331A15,1927
FE331A16,2008, FE331END,9999

(1) : FE331931

FE331931 : Source file (*.PRN) name

(2) : FE331A01, 761, FE331A02, 776, FE331A03, 791,

FE331A01, 761,..... : Data point name, Record number,

At the end of file, "xxxxxxx, 9999" must be inputted. xxxxxxxx has no meanings, therefore you can type any letter. In this case, FE331END is used. Maximum number of data set is 100.

Appendix B
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Appendix B. PREVIOUS DISTRIBUTION

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