UNITED STATES
NUCLEAR REGULATORY COMMISSION
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April 6, 1994

Project No. 679

APPLICANT: ATOMIC ENERGY OF CANADA LIMITED TECHNOLOGIES

PROJECT: PREAPPLICATION REVIEW OF THE CANDU 3 REACTOR DESIGN

SUBJECT: SUMMARY OF MEETING HELD WITH AECLT AT A VISIT TO THE PICKERING NUCLEAR STATION AND TO THE CANDU TEST FACILITY AT SHERIDAN PARK AND AT WHITESHELL LABORATORY TO DISCUSS TOPICS RELATED TO THE THERMAL HYDRAULIC MODELING OF CANDU 3 DESIGN.

March 8 through 10, 1994, B. Boyack, D. Siebe, from Los Alamos National Laboratory (LANL), and D. Carlson and D. Scaletti from NRC met with Atomic Energy of Canada Technologies (AECLT) regarding the CANDU 3 design.

On the morning of March 8, 1994, the staff visited the Pickering Nuclear Generating Station and the Darlington Nuclear Generating Station simulator which is located at the Pickering site. Pickering is an 8-unit site operated by Ontario Hydro. The staff toured Pickering B and then observed a couple of transients (a large break LOCA) on the Darlington simulator. In the afternoon the staff visited the CANDU test facility at Sheridan Park. Sheridan Park is an AECL CANDU test facility. The staff met with V. Snell to brief him on the purpose of the Whiteshell visit. Following the meeting, the staff had an opportunity for a short visit to the Sheridan Park test facility. The staff had the opportunity to see the prototype of the CANDU 3 single ended refueling machine, high-pressure flow test rig, on-going robotics development, and a full scale mock-up of a portion of a CANDU header and feeder piping and associated end fittings.

On March 9 and 10, 1994, the staff visited the AECL Research facility at Whiteshell Laboratory in Manitoba, Canada to discuss the thermal-hydraulic modeling of CANDU 3 using the CATHENA code, and to visit the RD-14M integral test facility. The test facility is used to represent all CANDUs; however, it is not specific to any one CANDU design, therefore specific plant transients are not run on RD-14M.

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Enclosure 1 is a detailed meeting summary provided by LANL for these meetings. Included in this enclosure isa copy of the Whiteshell meeting agenda and a list of attendees. Enclosure 2 is a copy of the presentation viewgraphs.

Original signed by:

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ENCLOSURE 1

Los Alamos
NATIONAL LABORATORY
memorandum
Technology & Safety Assessment
TSA-12, Reactor Design & Analysis

To/MS: M. W. Cappiello, TSA-12, MS K551
From/MS: B. E. Boyack, TSA-12, MS K551 BEB
D. A. Siebe, TSA-12, MS K551 BEB for
Phone/FAX: 7-2023, 5-3167
Symbol: TSA-12-94-97
Date: March 14, 1994

Trip Report: Meetings With AECL— March 8-10, 1994

On March 8-10, 1994, we participated in meetings with staff of the Atomic Energy Canada Limited (AECL). The objective of the meetings was for Los Alamos to obtain sufficient information about AECL test programs that we could successfully complete Task 3 of FIN W6155, CANDU3 Audit Code Development. For Task 3, Los Alamos is to develop a draft work plan for assessing the TRAC code against the AECL experimental data base for the Canadian Deuterium Uranium (CANDU) reactor. The US participants in the meetings were Don Carlson, USNRC/RES, Dino Scaletti, USNRC/NRR, and Don Siebe and Brent Boyack of Los Alamos National Laboratory. Bob Curtis of AECL Technologies, Inc. accompanied us. Visits on Tuesday, March 8, 1994, were to the Pickering Nuclear Station outside Toronto and AECL offices and laboratories at Sheridan Park at Mississauga, also outside Toronto. The meetings on March 9-10, 1994, where held at the Whiteshell Laboratories, some 110 kilometers outside Winnipeg. The AECL CANDU design activities are conducted at Sheridan Park and in Saskatoon, Saskatchewan. The AECL CANDU research activities are primarily conducted at the Whiteshell Laboratories.

<u>Summary Items</u>

1. The presentations prepared by AECL at Whiteshell Laboratories were responsive to our stated meeting objectives. We have a complete set of presentation materials available. AECL confirmed that none of the presentation materials contain proprietary materials.

2. Information was received about separate effect (fundamental), component, and integral test data produced by the AECL. We were able to collect sufficient information and to complete our Task 3 planning and documentation for an assessment program supporting TRAC development and assessment for CANDU applications.

3. We developed an understanding of the AECL approach to demonstrating the adequacy of CATHENA for CANDU3. AECL explicitly rejects the concept that the RD-14M facility is "prototypic" of any CANDU reactor. This is contrary to US practice where facility prototypicality is promoted. The AECL does state that information from RD-14M improves "understanding of underlying physical phenomena governing behavior." The CATHENA adequacy logic consists of the following elements. First, closure models and correlations having appropriate pedigree, applicability, and fidelity are used. These are based, in part, on CANDU specific geometries and tests, e.g., horizontal fuel channels. Second, full-size component tests are conducted for CANDU-unique components, i.e., the fuel channel, headers, and end fittings. Although atypicalities exist, efforts are made to characterize them. CATHENA is assessed against data from the component facilities and modified as necessary until acceptable assessment results are obtained. AECL has devoted significant resources to the component test program. In this regard, the AECL component test program is similar to the Westinghouse-sponsored AP600 component test program. Third, a broad spectrum of

integral tests are run in the RD-14M integral test facility. CATHENA is assessed against RD-14M data to demonstrate that the code successfully integrates the various component models and successfully predicts the integral behavior of the integral facility. Fourth, AECL argues that (a) full scale models of the CANDU components have been validated, (b) the models have been successfully integrated into the CATHENA code as demonstrated by successful assessment calculations of integral phenomena in a reduced scale facility that, although, it is not prototypic of any given CANDU reactor, simulates the key systems, components, processes, and phenomena, and (c) the governing equations for mass, momentum, and energy automatically scale to full reactor size. It should be noted that there are some RD-14M specific correlations that are used for different applications, e.g., the CATHENA "pipe" component accesses different two-fluid correlations for an empty pipe of circular cross section, square channel, 7-rod bundle, and 37-rod bundle.

4. We learned that the CANDU reactor does not operate with void at the fuel channel outlet under typical conditions. Some CANDUs are designed so that they may be operated with fuel channel outlet voiding to compensate for steam generator degradation as the plant ages. It is anticipated that some CANDU reactors will operate with exit channel voiding during some portion of the plant lifetime. This was a new insight for us. As a consequence, the spectrum of normal operating conditions from which faulted conditions can arise must consider subcooled channel exit conditions. We were informed that the Pickering reactors explicitly forbid operation with channel outlet voiding.

5. The AECL staff at Whiteshell Laboratory have a research focus. They do not, evidently, focus on the plant. They do not, for instance, exercise the CATHENA code by performing CANDU plant calculations. Rather than couple their activities to the support of licensing activities, they seem to explicitly decouple. This is evidenced, for example, by strongly maintaining that plant transients will not be simulated in integral test facilities such as RD-14M. It is also evidenced by the focus on a number of bounding phenomena that can apparently only arise during very low probability events that may not be within the design basis. At a future time, it would be most helpful to arrange a meeting with the Sheridan Park/Saskatoon staff that are preparing Chapter 15 of the Safety Analysis Report (SAR) so that an improved perspective of AECL's safety philosophy can be obtained.

Tuesday, March 8, 1994

In the morning we visited the Pickering Station of Ontario Hydro. We received a brief orientation before proceeding to tour parts of the facility that included the Pickering control room, spent fuel storage area, turbine building, and simulator facility. The Pickering site contains eight CANDU reactors of two vintages. The four Pickering A units were brought into operation during the 1970s. The four Pickering B units were brought into operation during the 1980s. Each unit has a net electrical output of about 542 MWe and the total site generation is about 4300 MWe. This is about 20% of the electrical power consumed in Ontario Province. This is a big facility. The main corridor of which the reactors for all eight units lie is 2/3 km. For multiple reactor sites, the AECL and Ontario Hydro have found it cost effective to provide a site vacuum building that operates at about 1 psi and at 1/2 capacity can absorb and condense the steam released from a large-break loss-of-coolant accident (LBLOCA). The 25 foot diameter ducting providing the interface between the containment and the vacuum building is sealed by a plate with pinned louvers. The pins fail when the containment pressure reaches a design level following the LBLOCA. In contrast, the CANDU3 will have a large dry containment.

The Pickering A units have two shutdown systems, safety rods that drop under gravity (spring assisted) and the insertion of negative reactivity as the heavy water in the calandria tank is drained. The Pickering B units also have two systems. A rodded system similar to that in the Pickering A units is one system. The second is the injection of gadolinium nitrate into the calandria tank moderator. Similar shutdown systems are planned for the CANDU3 reactor.

We were informed that the amount of heavy water in the CANDU reactors was approximately one metric ton per MWe and the replacement rate was between 1 and 1-1/2 % per year. Currently, spent fuel is stored under water in a pool located below the control room. However, the spent fuel pool can accept approximately another 1-1/2 years of fuel. The Atomic Energy Control Board (AECB), the Canadian licensing authority similar to the NRC, has licensed dry containers (concrete) for on-site storage on site. The decay heat is markedly reduced after being stored in the spent fuel pool for five years and cooling by natural circulation is possible. The concrete containers are lowered into the pool and the spent fuel is loaded into the container. The container is raised above the pool and water drained from the container, following which the container drys and is sealed (welded). The containers are to be stored in a building under construction within the site boundary. Ontario Hydro is reviewing if it is possible to store the containers outside. Within the next several years, the Canadians will begin the process of reviewing a proposal for underground, long-term storage of spent fuel in granite about one km below ground. The spent fuel would be shipped and stored in the dry concrete containers used for short-term storage on site.

There are two turbine units, one each for Pickering A and B. During our tour of the simulator (next paragraph), we were informed that a main steam line break would cause the death of anyone in the turbine building, either by the high temperature steam or by suffocation as air is displaced by steam.

The site simulator is used to train operators for several plants (e.g., Pickering and Darlington). We were given a brief overview of the control panel and then a LBLOCA was run at 1/8th actual speed. Even at this slowed speed, everything happened quickly. The simulation was then run at full speed. Both shutdown systems were activated within a count of two. The sound annunciators and all the warning lights went on just as quickly. The pressurizer pressure dropped very fast. All major events happened so fast that one could see that only automatic systems could deal with such an event. The person giving the demonstration said that the first thing experienced operators did when an event went off was to stand up and put their hands in their pockets while they took the time to try and understand what was happening. Less experienced operators were often intent on trying to force an action. I was surprised that the demo was for a LBLOCA since the demonstration was to be real time and our codes calculate so much slower than real time for this event. Some of the simulator development staff were brought in to answer our questions. They informed us that the computer simulation was indeed calculating the scenario and not operating in the playback mode. However, during these fast transients, mass, momentum and energy are not conserved. Rather, the simulation attempts to track the deficits and then correct on the run so that the simulation never gets too far from reality. The simulator results have been checked against the Ontario Hydro code, SOPHT. Ontario Hydro, which is Canada's largest nuclear utility, has done its own thermal-hydraulic code development. As fast transients unfold so fast and there is little operator intervention, this approach is deemed to be sufficiently accurate for the simulator. The simulator is used as part of the government required operator certification process.

Our afternoon meetings were held in Sheridan Park, Mississauga, Ontario, Canada.

At Sheridan Park, we met with Victor Snell, Director of Safety and Licensing for AECL Technologies, Inc. AECL Technologies, Inc. is the AECL organization incorporated in the US (Delaware) to submit the CANDU3 certification request. Our meeting with Snell was primarily to explain the information being sought by the NRC and Los Alamos during this trip. To that end, Don Siebe and I had prepared two discussions. These were entitled "Los Alamos Perspectives on Visit to AECL" (Boyack and Siebe) and "Confirmatory Thermal-Hydraulic Research" (Siebe and Boyack). Our discussions centered around the presentation materials although we did not give formal presentations. I believe the presentations were well received. Snell commented on the fact that we had prepared and said that this did not happen very often.

Snell wanted to understand the role the NRC codes would play in the confirmatory research process. Evidently, he had this question because the earlier pre-application effort by the NRC and the Idaho National Engineering Laboratory had utilized the AECL code suite. Dino Scaletti informed Snell that at present the NRC intent was to modify the NRC's code(s) and use them for the NRC's confirmatory analysis efforts. Snell was particularly interested that the NRC was considering modifying the NRC's codes for coupled thermal-hydraulic and multidimensional neutronic calculations. We informed him that a limited capability to perform such calculations already existed in the Los Alamos developed TRAC code and that the effort to incorporate this capability in NRC's version of TRAC was incremental rather than full. Snell stated that coupling thermal-hydraulic and neutronic phenomena was important for accident scenarios such as the LBLOCA. Snell asked how we intended to validate the code. I mentioned use of data from our Savannah River effort and a more standard light water reactor rod withdrawal event for which data exists. However, I consider my response to be incomplete and plan to pursue the definition of benchmarking the coupled code further.

Snell was particularly interested in our perception of the schedule for code development. I responded that Los Alamos had prepared a moderately detailed plan based upon a four-year program with approximately three years involved in code development. I asked Snell if this seemed reasonable and he responded that it was marginally reasonable but that more time might be required. He said that if our answer had been one or two years, he would have considered our estimates to be unrealistic. Snell asked us to compare the efforts for developing and benchmarking and assessing the thermal-hydraulic and multidimensional features of the code. Don Siebe and I responded that the Los Alamos estimate for the neutronic effort was about one-quarter the thermal-hydraulic effort. Snell said that he thought this estimate was low. Snell offered to have NRC and Los Alamos staff meet with AECL staff to pursue this matter in more detail.

We also touched on developmental and integral code assessment. Snell stated that all experimentally derived data would be obtained from Whiteshell. He explained that all requests must go from Los Alamos to NRR (Dino Scaletti) and that these requests would then be forwarded to Snell who would arrange for the AECL response. Snell further noted that any information that might be of sufficient detail to support the design of a reactor must be delivered government to government. Thus, the CATHENA code was transferred in this manner. Apparently, none of the experimental data would fall into this category. However, this data is all proprietary as it belongs to the CANDU Owners Group (COG) and proprietary restrictions must be observed. We described our desire to perform calculations of plant events (e.g., Wolsong) and code-to-code benchmarks for accident sequences presented by AECL Technologies, Inc. in the Safety Analysis Report accident analysis section. Snell said that all plant calculations were performed by staff at Sheridan Park rather than at Whiteshell.

We then briefly toured parts of the research laboratory at Sheridan Park. This tour was short (about 45 minutes) and it would have been helpful to have more time to absorb insights and ask questions at the displays and test rigs. Nevertheless, insights were obtained that may be helpful during future modeling and analysis efforts. We were able to see both display and actual refueling machines. We were instructed in the high pressure flow through the pressure tube. The larger part of the flow is inside the pressure tube but the flow passes through holes in the pressure tube and into an annulus before passing onto the exit fitting. In the CANDU3 pressure tubes the holes will be located closer to the exit fitting than for other CANDU reactors. A single removable plug provides the pressure boundary at the end of the pressure tube. We had the opportunity to see a 37-rod fuel assembly, including the end fittings and the pressure pads that keep the rods separated. There was a full-scale mockup of portions of the header and feeder piping. The feeder tubes are attached to the horizontal header tubes at several heights with attachments at the centerline being the highest attachment point and 10 to 15 degrees from the vertical the lowest attachment point. There was a third attachment level between the high and low. The header diameter appeared to be 12 to 15 inches.

Wednesday, March 9, 1994

The agenda for our meetings at the Whiteshell Nuclear Energy Research Establishment is provided as Attachment 1. The meeting attendance list is provided as Attachment 2. The focus of discussions on the first day of meetings at Whiteshell were Los Alamos presentations describing confirmatory research objectives and our specific meeting objectives and AECL presentations describing separate effect (fundamental) and component tests. We also toured the RD-14M integral test facility at the end of the day.

Both Los Alamos presentations appeared to be well received. The AECL personnel were interested in the Phenomena Identification and Ranking (PIRT) effort conducted by Los Alamos for a LBLOCA in a CANDU reactor. We explained that the PIRT should be revisited several times as our knowledge of the CANDU reactor and its transient behavior become better understood. We described how the PIRT focuses on key systems, components, processes and phenomena and how this information can be used to allocate limited resources to code development and code assessment activities that will deliver the greatest value. We feel that it is desirable that our Task 1 report by Don Siebe, "CANDU 3 Thermal-Hydraulic Transient Phenomena," LA-UR-94-402, be provided to AECL, if possible, to foster a dialogue with AECL staff about our initial PIRT. We have asked Don Carlson to determine if the LA-UR-94-402 can be provided to the AECL and he has agreed to pursue this matter. AECLwanted to better understand our emphasis on plant counterpart. This interest became clearer during our discussions of March 10. A primary value of counterpart calculations for the RD-14M experimental facility and the CANDU3 reactor is the insight regarding how well RD-14M simulates actual plant behavior. However, AECL clearly states that it does not perform experiments to determine CANDU accident and transient response. In effect, then, AECL looks to its CATHENA code to characterize the transient and accident behavior of CANDU reactors. This is one area where AECL philosophy clearly departs from the current approach to scaled integral tests in the United States.

Dave Richards provided an overview presentation at the start of the AECL presentations. The stated objective of the experimental program was to "provide experimental information on the thermal-hydraulic aspects of [CANDU] system behavior under postulated upset and accident conditions. Develop an understanding of relevant thermal-hydraulic phenomena through analysis of experiments, model development, and model validation". Experiments are conducted to foster understanding and to support development and assessment of component models and integral codes. Separate effect (fundamental) experiments focus on counter-current two-phase flow in piping systems and flows in reduced scale headers. Component experiments are the CWIT, LASH, Header Flow Visualization, End Fitting Characterization, Pump Behavior, and Steam Separator Characterization tests. Integrated experiments are conducted in the RD-14M facility. AECL emphasizes that RD-14M doesn't represent any specific reactor. An end point is the incorporation of the experimental knowledge in the CATHENA code. This code is based upon a two fluid model and contains CANDU specific component models. AECL bases its demonstration of CATHENA adequacy on the incorporation of component models validated using full-scale component tests and the demonstration that the integrated code predicts behavior of RD-14M. With this foundation, the applicability of CATHENA to CANDU reactors is based upon the scaling inherent in the governing equations for mass, momentum and energy that exist in CATHENA.

CATHENA development was described by Bruce Hanna. An extensive bibliography was included with the presentation handout. The basis for the constitutive relations, including flow maps and heat transfer models and component models was described. The fuel channel high temperature transients program was described by Brock Sanderson. The associated pressure tube slumping, contact with the calandria tube, and heat transfer processes are associated with beyond design basis accidents in the US but are treated as a design basis accident in Canada. The design of the ECC trains do have a common point where a single failure could totally disable ECC, and this may explain why these events are treated as design basis events in Canada. This was noted in a trip report by Ralph Meyer and Louis Shotkin of NRC documenting their November 1993 meeting at Whiteshell. From the discussion it became clear that models related to pressure tube sagging and ballooning and conduction to the calandria tubes and moderator are not needed for LOCA analyses where ECC is assumed to operate.

The Cold-Water Injection Test (CWIT) program was described by Janusz Kowalski. This program studies two-phase phenomena that may occur in CANDU reactor feeders and channels under accident conditions and provides a data base for the development and verification of the channel emergency coolant injection models in CATHENA. The facility is located at Stern Labs west of Toronto. The facility contains a full-scale model of a CANDU reactor channel-feeder system. Once again, Dave Richards emphasized that the tests are not reactor specific. The presentation included a description of the facility, facility instrumentation, and tests performed. Test objectives, data report citation, the experimental procedure, test conditions, and use or non-use of the data for CATHENA validation were covered in the presentation materials. This was precisely the information Los Alamos needs at this time to support completion of our Task 3 report. The AECL are currently focusing on analysis of CWIT test results and analysis reports will be produced. We found out that less analysis is being performed for the RD-14M tests (see meeting notes for March 10). Via questions and answers we were able to ascertain the applicability or inapplicability of various CWIT tests for our TRAC assessment planning. Most of the tests simulate transients although there was one series of tests that were specifically designed to obtain quasi-steady information on mixed/stratified flow regime transitions. Tests from this test series should be appropriate for developmental assessment.

The Large-Scale Header (LASH) program was described by J. Buell. The facility is locate at Stern Labs in Hamilton, Ontario which is near Toronto. This program studies phenomena that may occur in a CANDU header/feeder system under two-phase flow conditions and blowdown/refill conditions. The data from the program is used to improve understanding of flow behavior, identify phenomena, support the development of header models, and provide a data base for code validation. The general content and value of the presentation was similar to that for the CWIT facility. Another facility exists at Whiteshell which is constructed from transparent materials to facilitate visualization of flow regimes. We will seek the opportunity to visit and see this facility in operation on a subsequent visit to the Whiteshell Laboratory. Buell stated that the final report that he has been preparing for this test program should be completed in "3 or 4 months."

The End-Fitting Characterization program was described by Janusz Kowalski. This program characterizes the flow resistance of a CANDU end fitting under single- and two-phase flow conditions. The data from this program is used to improve understanding of flow behavior, examine processes such as the participation of water in the stagnant space of the end fitting in fuel cooling for some accident scenarios, and provide a data base for code validation. The general content and value of the presentation was similar to that for the CWIT facility.

A brief presentation describing the Critical Heat Flux (CHF) Test Facility, also at Stern Labs, and program concluded our day of presentations. The objective of the CHF experiments is to characterize dryout conditions in simulated CANDU reactor fuel assemblies under steady and transient conditions and to provide a data base for CANDU-specific correlation development. The CHF behavior of an electrically heated, 37-element fuel bundle simulator is characterized in the facility. This presentation did not contain a bibliography.

Paul Ingham led a tour of the RD-14M test facility. A tour of such facilities is always of interest because one gets a sense of the size and complexity of the facility. Ingham emphasized that up-to-date documentation of the facility configuration and procedures is maintained and displayed the documentation to us.

Thursday, March 10, 1993

The focus of discussions on the second day of meetings at Whiteshell was the RD-14/RD-14M integral test facilities. As the Whiteshell discussions progressed, the AECL philosophy for demonstrating CATHENA code adequacy became more clear. Our current understanding of the AECL philosophy is provided as Summary Item 3. During the wrap-up session for our Whiteshell meetings, Los Alamos stated its understanding of the AECL CATHENA adequacy assessment approach. We were informed by the AECL participants that our summary was correct in essential details.

A continuing challenge for the NRC and Los Alamos will be to accurately characterize the CANDU3 key systems, components, processes and phenomena for a spectrum of accident scenarios. Such an effort is necessary to ensure that limited resources are applied to the highest priority efforts for the NRC's confirmatory analysis codes. During the course of this meeting, we certainly gained valuable insights. However, structuring these insights and approaching completeness will take additional time and effort. One source of challenge arose from the nature of the AECL testing philosophy. Testing is not explicitly and strongly linked with accident sequences in many cases. We were told that the AECL test program frequently moved to the limits of severity in examining phenomena. Thus, frequently we would hear about phenomena from the experimental program staff that would later be characterized by the AECL licensing staff as associated with sequence frequencies characteristic of beyond design basis events or residual risk events (frequency unquantified).

The history and design of the RD-14/14M facility was described. We were told that scaling laws consistent with those derived by Ishii and Kataoka were developed and applied to the design of the RD-14M facility We were provided with a copy of a 1986 paper by Ingham, Krishnan, Sergejewich and Ardon that described the "Scaling Laws for Simulating the CANDU Heat Transport System." This paper was presented at the 2nd International Conference on Simulation Methods in Nuclear Engineering held October 14-16, 1986, in Montreal, Canada. Limitations of the scaling effort and scaling compromises were described. The presentation handout describes the limitations and the scaling compromises. The new channel, end fitting, feeder and header designs required for the RD-14M (multichannel) facility were emphasized. The RD-14M test matrix was described as having three major areas of focus at present. These areas are (1) natural circulation, (2) small, critical and large break LOCAs, and (3) flow stability studies. Critical breaks are those breaks where the fluid momentum, pumping forces, and pull toward the break balance in such a way that flow stagnation develops in channels in the core immediately after the break opening. This produces the largest heatup during the blowdown phase of any of the LOCA cases. There are two types of natural circulation studies. The first set of studies are named "partial inventory" by AECL and focus on the quasi-static behavior of RD-14M as the inventory of the primary is drained. We were provided with a figure comparing the natural circulation flow rate versus fraction of primary inventory for RD-14M and Semiscale. The second set of studies are named "transition to thermosiphoning" and these events simulate the transients arising from loss of forced cooling with fraction of primary inventory as one significant parameters. AECL defined the term "thermosiphoning" to mean loss of forced cooling or natural circulation. The flow stability tests focused on determining the degree to which the header interconnect piping reduced the potential for primary system flow oscillations.

For each of the areas studied, AECL described the test matrix, test procedure, and instrumentation. This information will assist Los Alamos in the preparation of the Task 3 report that is to contain a TRAC assessment plan. Some reproducibility tests have been conducted. Good agreement was reported for tests with forced phenomena, e.g., LOCA events. When forces in the system are smaller, e.g., natural circulation tests, subtle balances occur and phenomenological branch points may exist. Several such cases were described in the presentation but changes to the facility had been made in these cases. For two 1993 tests in which there is no facility changes, reproducibility as measured by the natural circulation flow rate was good. AECL reported that facility documentation, including engineering drawings, are updated and maintained to describe the current design.

Typically, data reports are prepared for each integral test. However, the level of analysis performed on the integral tests is variable. Brief quick look and analysis reports have been prepared for the natural circulation tests. Analyses of other experimental series have not been routinely prepared and/or documented. The preparation of additional analysis reports would be a positive development. Currently, the fraction of RD-14 and RD-14M tests used for CATHENA analyses is small. Analysis and documentation of these experiments is a natural consequence of assessment activities. Evidently, however, many tests are not thoroughly analyzed, or, if the analyses have been performed, they are not documented. For example, only about 8% of the RD-14M LOCA tests have been analyzed and none of the flow stability tests.

The RD-14M is atypical of CANDU in several ways. First, AECL is unable to keep the primary coolant pumps operating following LBLOCA transients. This is contrary to the planned CANDU3 operational procedures. Evidently, the pumps trip when inlet voiding is large and the pumps over-speed. Second, CANDU3 will have four reactor coolant pumps and the associated piping. The RD-14M facility has only two such pumps and associated piping. Third, essentially all available electrical power is needed to operate the simulated fuel channels at steady state conditions (about 11 MWe). For LBLOCA events, voiding increases the channel power above the 100% point for a period of time and this process cannot be simulated when all 10 fuel channels are operating. It may be possible to run some LBLOCA transients with several channels valved out so that this feature of the LBLOCA can be simulated. In addition to the atypicalities just described, we believe that the failure to measure break flows for LOCA events is a significant shortcoming. AECL stated that existing analytical break flow models should be sufficiently accurate that the absence of this measurement is not serious. We have not found that to be the case in our assessment activities. For code assessment purposes, we have found it necessary to characterize both the coolant inventory and coolant distribution as a function of time. We do not believe that reliance on analytical models to predict break flow is the appropriate approach.

AECL is well along in developing a relational database for experimental information. The database for the RD-14M is nearing completion. The database information includes test specific information, instrument lists, instrument calibration information, failed/faulty/disregarded instrumentation, loop configuration history, memoranda, and publications. The experimental data is not included in the relational data base. A demonstration of the database was given. The database was loaded on a notebook computer and operated well in the demonstration. Work has begun on a entering data for the CWIT program.

AECL described its validation program for CATHENA. All validation results are reported in the Compendium of CATHENA Validation Cases. The original issue of this document included validation efforts through 1989. The Compendium has been recently updated to include assessment calculations prepared through January 1, 1993. The draft document has been provided to AECL customers for review and comment. All validation work is reported in CANDU Owner Group reports using a standardized format. All validation assessments are performed using reference versions of the CATHENA code. We inquired about CATHENA modeling of the RD-14M steam generator secondaries. AECL stated that this was a challenge because multidimensional phenomena were being modeled with a one dimensional code. The one dimensional model has been evolving over a period of time. AECL feels that there are some gaps in the validation base and is working to eliminate these. LBLOCA tests for the RD-14M facility were mentioned. Some model development is continuing, specifically models for a generalized tank, level swell, generalized [break] discharge, and a two-dimensional header were mentioned. Additional assessments may be required for these models.

At the conclusion of the meeting, the US delegation thanked the AECL for its efforts to fulfill the meeting objective. In a letter to R. Meyer dated October 20, 1993 (letter N-12-93-546), one of us (Boyack) had provided a list of questions for AECL regarding the AECL integral test programs. At the end of the present meeting, we were able to report to the AECL that it had provided the needed information with sufficient detail that Los Alamos could complete its currently contracted planning efforts for the NRC.

Attachment 1

FINAL AGENDA

NRC Visit to Whiteshell

Wednesday, Mar. 9, 1993 Bldg 300 Front Conference Room

09:30 NRC and Los Alamos Overview Presentation

10:30 Thermalhydraulic Program (DJR)

11:00 Separate Effects and Component Tests (BNH, DBS, JEK, JRB)
- CANDU-specific closure models and correlations (BNH)
- High-Temperature Fuel Channel Behaviour Tests (DBS)

12:00 Lunch, Cafeteria

13:00 Separate Effects and Component Tests cont'd (DBS, JEK, BNH)
- Cold Water Injection Tests (JEK)
- Large Scale Header Tests (JRB)
- End-Fitting Characterization Tests (JEK)
- Critical Heat Flux Tests (JEK)

15:00 Tour of RD-14M Test Facility

Thursday, Mar. 10, 1993 Bldg 300 Front Conference Room

08:30 RD-14/RD-14M Integral Test Facilities (PJI, TVS, AJM, JPM)
- History
- Facility Descriptions and Scaling
- Instrumentation
- Experimental Test Matrix and Rationale
- Reproducibility of Results
- Non-Representative Components

12:00 Lunch, Cafeteria

13:00 RD-14/RD-14M Integral Test Facilities (cont'd)
- Heat and Mass Losses
- Documentation (Facility Geometry, Test Conditions, Instrumentation and Test Results)
- Key Test Results Used for CATHENA Validation (JPM)

15:00 Wrapup Discussion and NRC Summary

Attachment 2

Attendance List
March 10-11, 1994
Whiteshell Atomic Energy Research Establishment

Name	Affiliation
Dino Scaletti	USNRC/NRR/PDAR
Donald Carlson	USNRC/RES/DSR
Magay El-Hawary	AECB, Ottawa
Vinh Q. Tang	AECB, Ottawa
Chris Harwood	AECB, Ottawa
J. E. Kowalski	AECL/WL
Bruce N. Hanna	AECL/WL
Paul J. Ingham	AECL/WL
David J. Richards	AECL/WL
James Mallory	AECL/WL
Brock Sanderson	AECL/WL
Ajit Muzumdar	AECL/WL
John R. Buell	AECL/WL
Scott D. Grant	AECL/CANDU
Robert T. Curtis	AECL Technologies, Inc.
Don Siebe	LANL
Brent E. Boyack	LANL

ENCLOSURE 2

CATHENA
A CANDU Thermalhydraulics Code

B.N. Hanna

Code Development Section

Whiteshell Laboratories

Pinawa, Manitoba

- OUTLINE
  - background
  - CANDU specific thermalhydraulic models
  - CANDU specific heat transfer models

AECL EACL

CATHENA

- Two-fluid non-equilibrium thermalhydraulic model
- Gas phase can include up to 4 noncondensable components
- H_2O and D_2O properties included
- Comprehensive solid heat transfer models
  - radial conduction
  - 2-D radial and circumferential conduction
  - solid-solid radiation heat transfer
  - solid-solid contact conduction
- Component models such as point-reactor kinetics, valves, tanks and pumps
- A flexible set of control system models specified through the input file

AECL EACL

CANDU Specific Features

- Thermalhydraulic Models
  - Constitutive Relations
  - Component Models
- Wall Heat Transfer Models
  - geometry considerations
  - heat transfer coefficients

AECL EACL

CANDU Specific Thermalhydraulic Models

- Constitutive Relations
  - Flow regime map in horizontal fuel bundles
    - stratification criteria were developed from two sources
    - RD-13 experiments - (7-element bundle)
    - stability limit given geometry of fuel bundle (analytical)
    - validated with CWIT flow stratification experiments (37-element) (eg. CWIT-1164)
  - Flow regime map for countercurrent flow in horizontal feeders
    - stratification criteria developed from WL feeder flooding experiments - and Ardron and Banerjee model
    - validated with CWIT feeder refill experiments

CANDU Specific Thermalhydraulic Models

- Constitutive Relations
  - Interface friction correlation for stratified flow regime (with/without fuel bundle) developed from RD-13 experiments
    - Kowalski correlation
  - Orifice correlations for CANDU feeder orifices
    - correlations based on single-phase liquid flow experiments conducted at SPEL
  - Vapour/liquid entrainment correlations for flow from a header to a feeder nozzle
    - developed from experiments in the Large-Scale Header Facility (LASH)

CANDU Specific Thermalhydraulic Models

- Component Models
  - Pump curves for RD-14 facility from pump characterization experiments conducted at Westinghouse Canada Limited (now Stern Labs) - (COG-92-349, COG-91-13 and CWAPD-421)
  - Pump curves for full-scale CANDU pumps
    - » tables based on ANC modelling assumptions are installed for Wolsong-2 pumps
    - » pump curves based on full-scale (Darlington) pump experiments conducted at Ontario Hydro installed in MOD-3.5a code

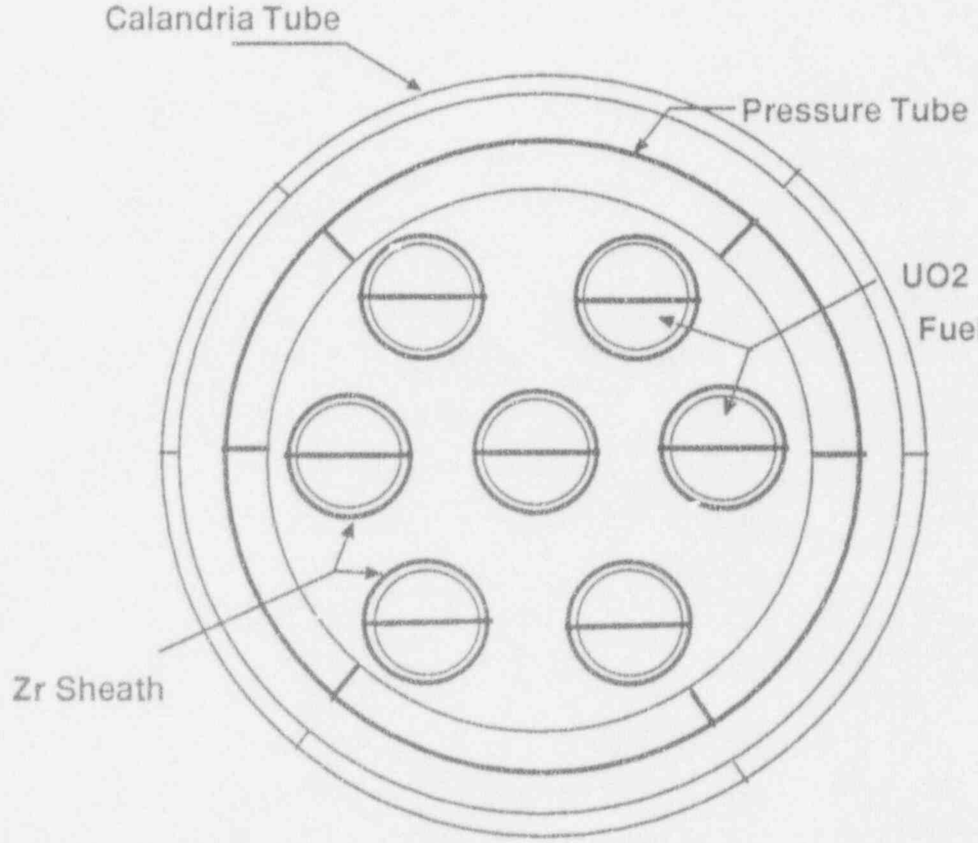
AECL EACL

CANDU Specific Thermalhydraulic Models

- Component Models
  - Valve models
    - models in CATHENA not specific to CANDU
    - require ability to model a variety of valves including rupture disks (ECI system), liquid relief valves (feed-bleed system) and control valves (boiler pressure-level control)
  - Pressurizer/ECI tanks
    - models in CATHENA not specific to CANDU
    - require ability to model a variety of tanks with control systems and multiple pipe connections, and wall heat transfer models

CANDU Geometry Heat Transfer Models

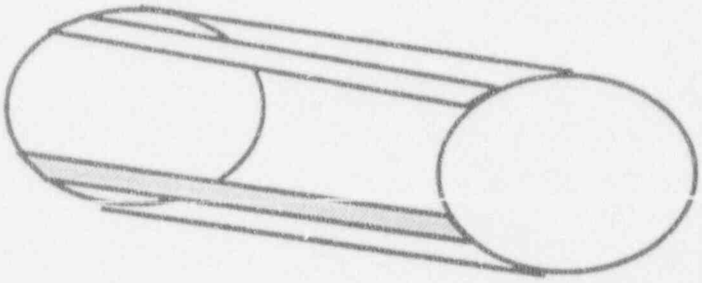
- Multiple walls surrounding fuel
  - fuel, gap, sheath, pressure tube, gap, calandria tube and calandria



AECL EACL

CANDU Geometry Heat Transfer Models

- Connection to Flow Regime Map



Separated Flow:

Liquid/gas contact for the surfaces

▨ wet dry

▨ wet dry

Mixed Flow:

Liquid/gas contact the same for all surfaces

▨ = ▨

AECL EACL

CANDU Specific Heat Transfer Models

- Fuel bundle CHF correlations
  - H_2O and D_2O Groeneveld CHF fuel bundle tables including Boiling-Length-Average (BLA) model
  - H_2O and D_2O Groeneveld CHF tube tables for other locations
- Fuel channel deformation model
  - Zr creep rates from small scale experiments at WL (Shewfelt and Godin)
    - » validated against channel delta-T experiment conducted at WL (SAB)
    - » includes criteria for pressure-tube failure and/or contact with calandria

CANDU Specific Heat Transfer Models

- Circumferential Conduction
  - important in determining temperature distribution in the pressure tube or in modelling rewetting and heat transfers in horizontal feeders during refilling under low header-to-header pressure drop conditions
- Solid-Solid contact conductance
  - heat transfer between fuel (bearing pads), pressure tube and calandria tube with heat rejection to the D_2O calandria

CANDU Specific Heat Transfer Models

- Radiation heat transfer
  - radiative heat transfer modelling required since this is a major contributor to heat transfer from fuel to pressure tube and rejection to the calandria for some conditions
- Zr-Steam reaction models
  - a number of Zr-steam reaction rate models are available - validation against WL (CAB) experiments
    - » modelling must also include steam starvation within the fuel channel
- Fuel-Channel Temperature Stratification
  - at low flow rates fluid temperature stratifies from top to bottom of the fuel bundle
  - influences pressure deformation under stratified flow conditions

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①

FUEL CHANNEL HIGH TEMPERATURE TRANSIENTS PROGRAM:

INTRODUCTION

BROCK SANDERSON

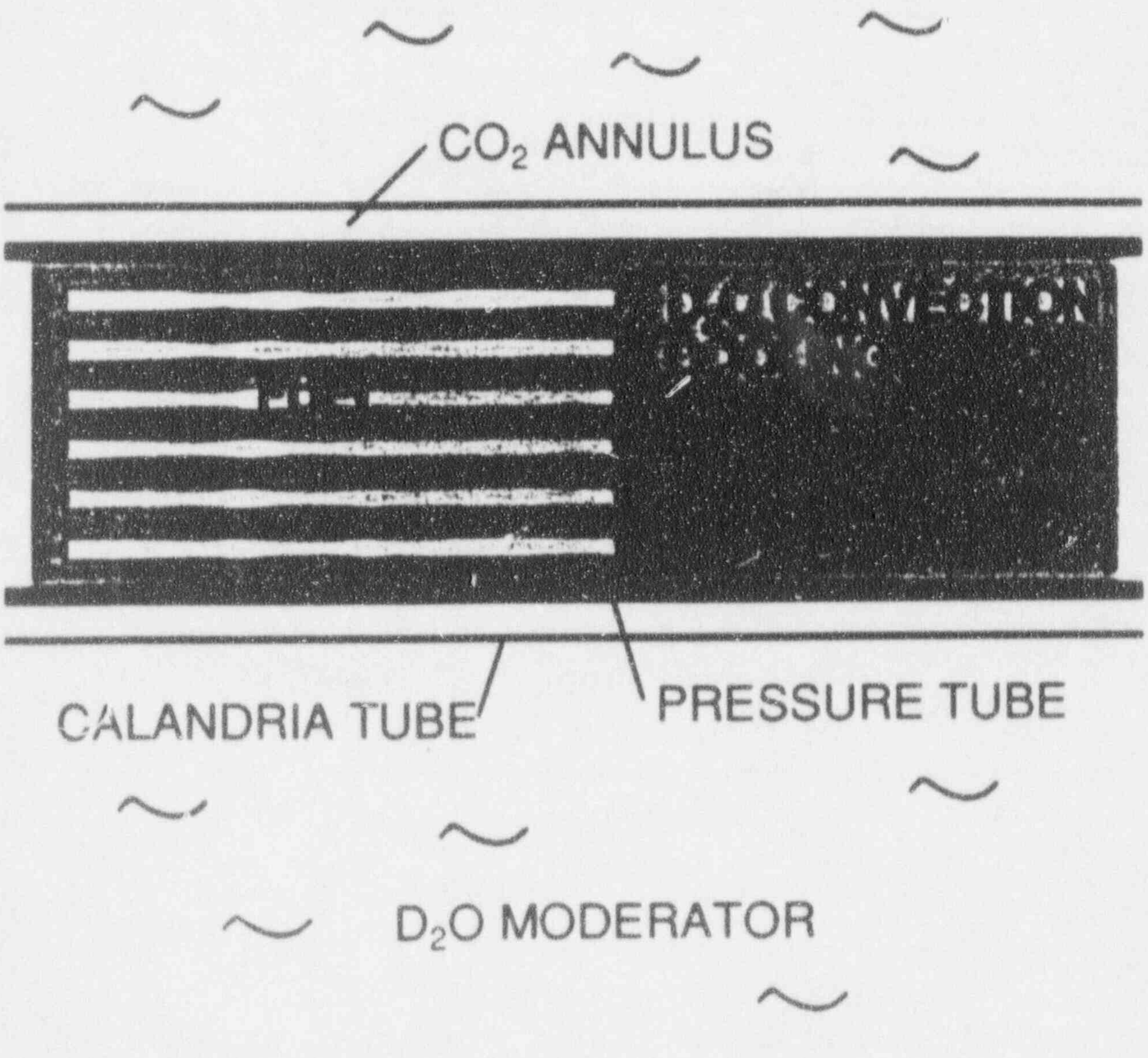
Containment Analysis Branch
Whiteshell Laboratories
AECL Research

FUEL CHANNEL BEHAVIOUR DURING ACCIDENTS

PROGRAM OBJECTIVE:

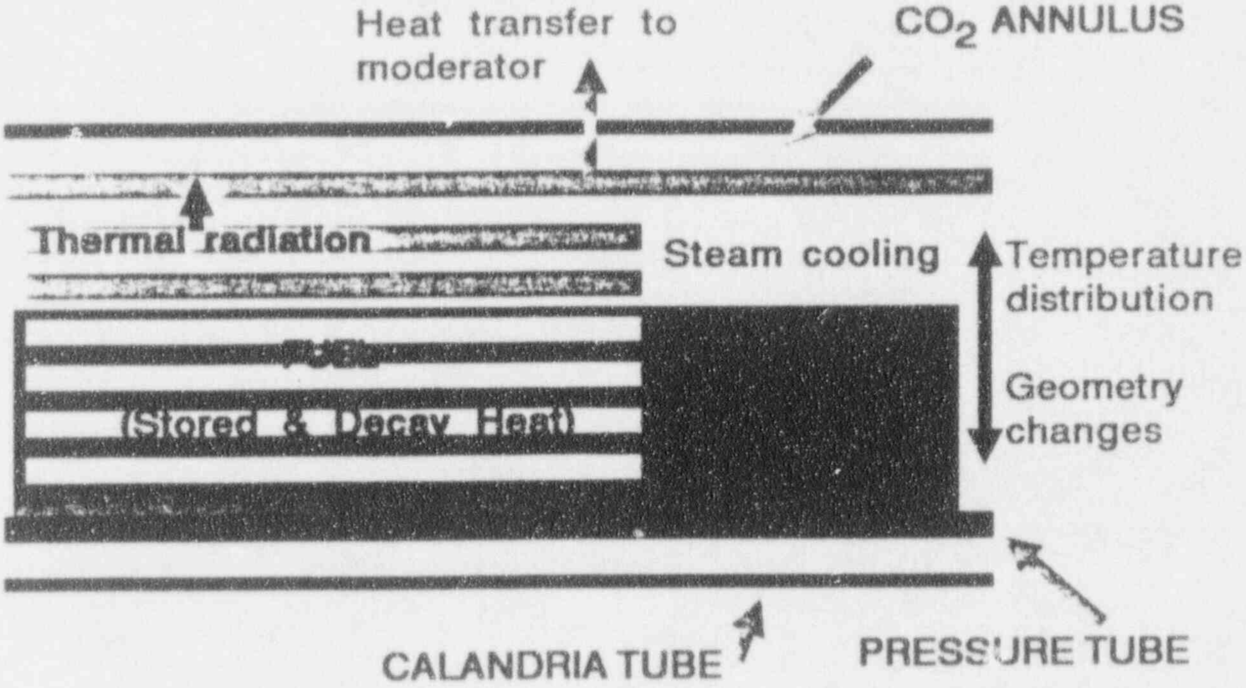
TO PROVIDE AN EXPERIMENTAL AND THEORETICAL BASIS FOR UNDERSTANDING, DETERMINING AND IMPROVING THE SAFETY BEHAVIOUR OF CANDU FUEL CHANNELS FOR A VARIETY OF POSTULATED ACCIDENTS IN CANDU PLANTS.

Fuel Channel Behaviour
Normal Operating Conditions

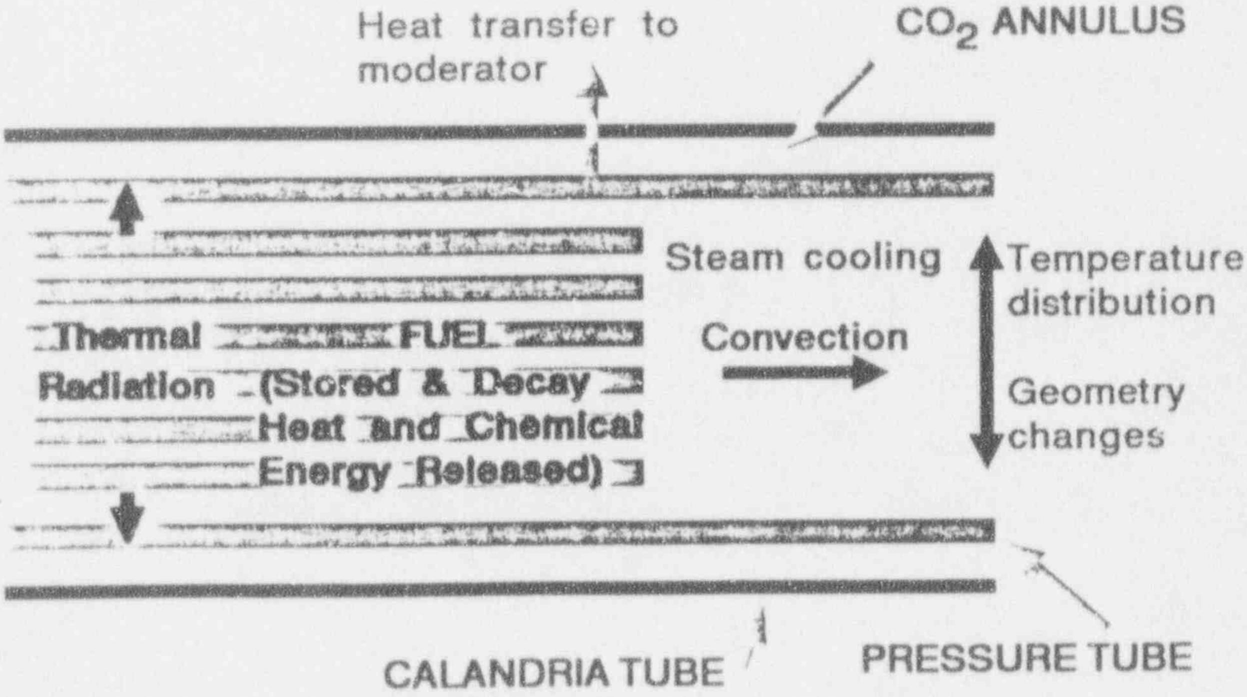


FUEL CHANNEL BEHAVIOUR

LOCA/LOECC (Stratified Flow)

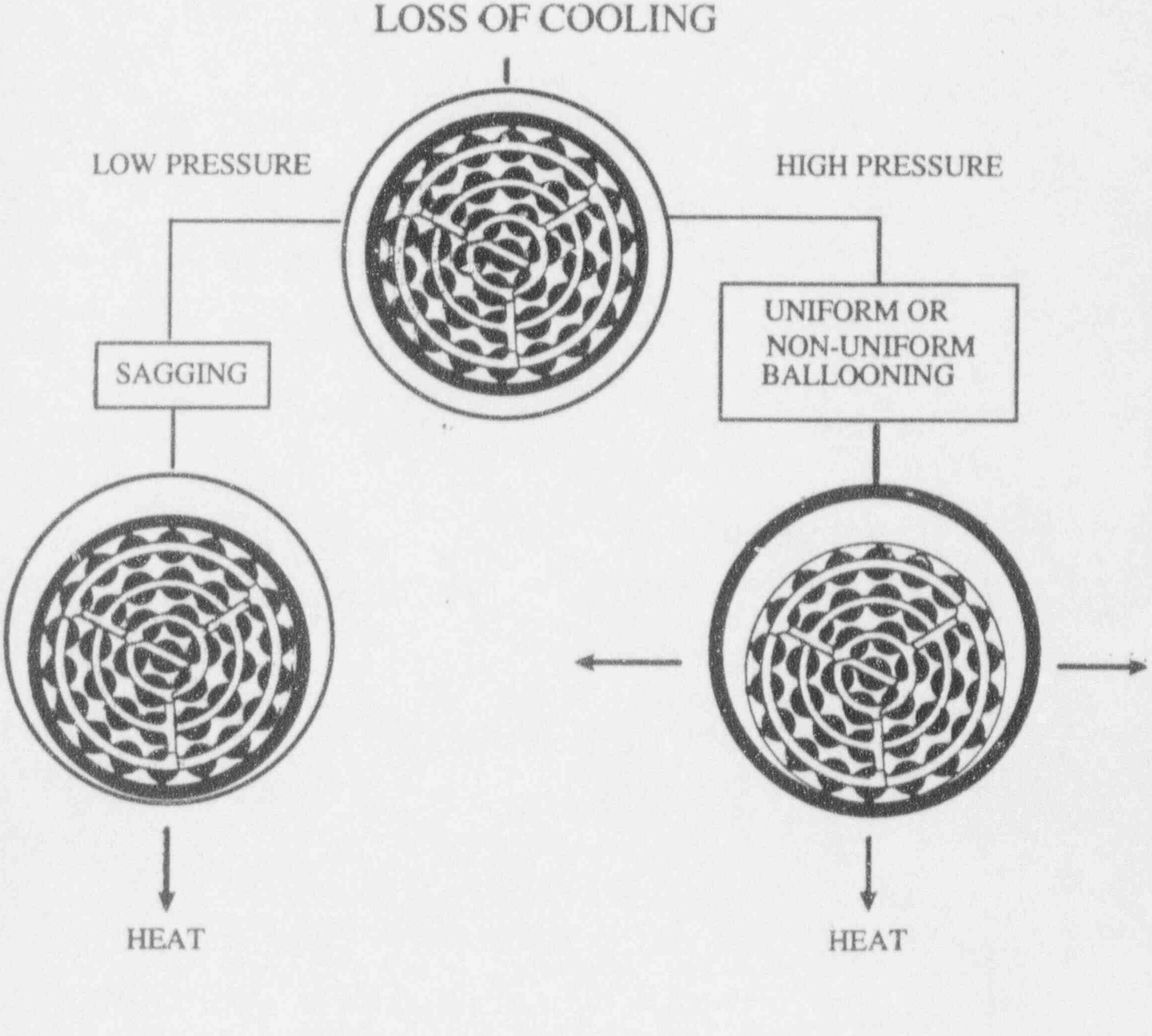


LOCA/LOECC (Channel Voided)



FC2.GEM

HTT PRESSURE TUBE BEHAVIOUR



LOSS OF COOLING

LOW PRESSURE

HIGH PRESSURE

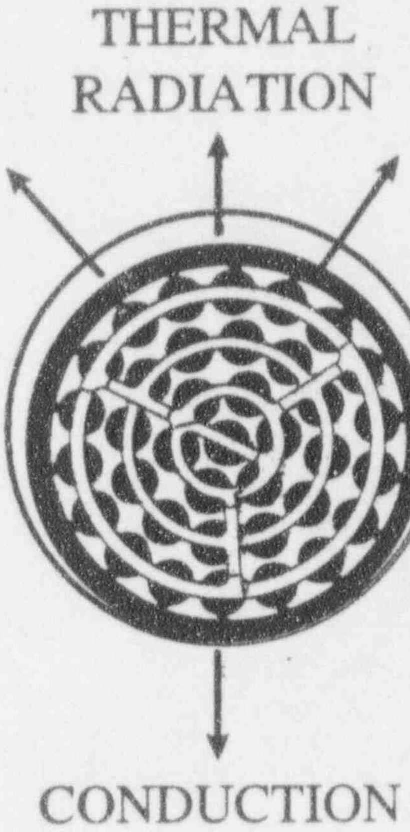
SAGGING

UNIFORM OR NON-UNIFORM BALLOONING

HEAT

HEAT

LOW PRESSURE



SAG INTO CONTACT ALONG BOTTOM OF PT/CT

IF HEAT REMOVAL IS POOR, POTENTIAL FOR FUEL MELTING AND HIGH FISSION PRODUCT RELEASE

IF HEAT REMOVAL IS GOOD, FUEL GEOMETRY IS MAINTAINED

RESULTS TO DATE SUGGEST THAT HEAT REMOVAL IS SUFFICIENT TO MAINTAIN COOLABLE FUEL GEOMETRY

HIGH PRESSURE NON-UNIFORM BALLOONING OF PT

PT/CT CONTACT:

- EFFECTIVE USE OF MODERATOR AS A HEAT SINK

PT FAILS BEFORE CT CONTACT:

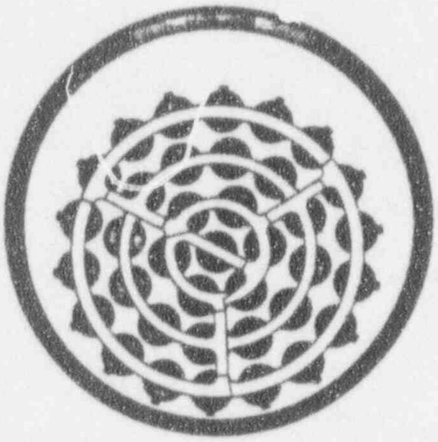
- CAUSED BY ΔT IN PT
- CT HEATS UP, POTENTIAL FOR FILM BOILING
- FP RELEASE TO ANNULUS

BOTH PT AND CT FAIL:

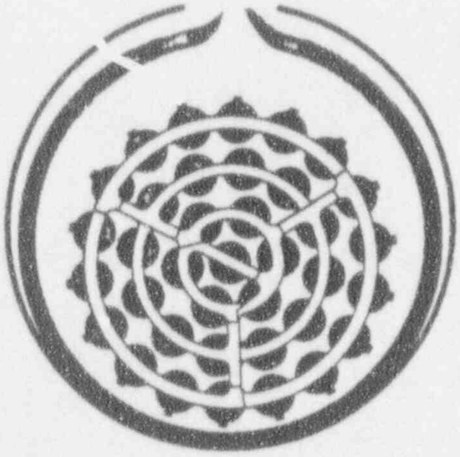
CAUSED BY FILM BOILING ON CT AND INTERNAL PRESSURE

HIGH PRESSURE

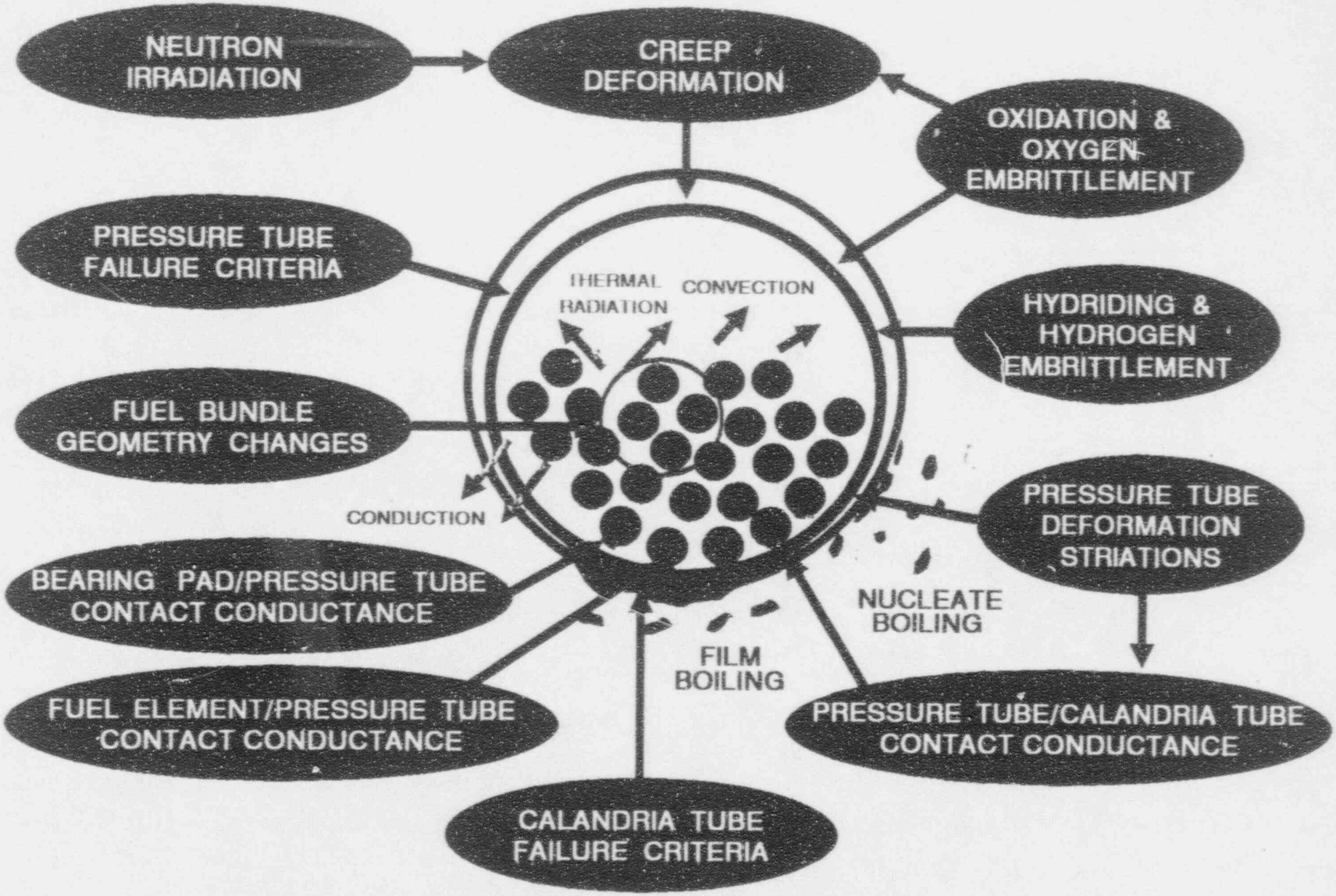
UNIFORM BALLOONING OF PT



CT IN NUCLEATE BOILING:
EFFECTIVE USE OF
MODERATOR AS A
HEAT SINK



CT IN FILM BOILING:
RESTRICTED HEAT FLOW
TO THE MODERATOR
POTENTIAL FOR FUEL
CHANNEL FAILURE



NEUTRON IRRADIATION

CREEP DEFORMATION

OXIDATION & OXYGEN EMBRITTLEMENT

PRESSURE TUBE FAILURE CRITERIA

THERMAL RADIATION

CONVECTION

HYDRIDING & HYDROGEN EMBRITTLEMENT

FUEL BUNDLE GEOMETRY CHANGES

CONDUCTION

PRESSURE TUBE DEFORMATION STRIATIONS

BEARING PAD/PRESSURE TUBE CONTACT CONDUCTANCE

NUCLEATE BOILING

FILM BOILING

FUEL ELEMENT/PRESSURE TUBE CONTACT CONDUCTANCE

PRESSURE TUBE/CALANDRIA TUBE CONTACT CONDUCTANCE

CALANDRIA TUBE FAILURE CRITERIA

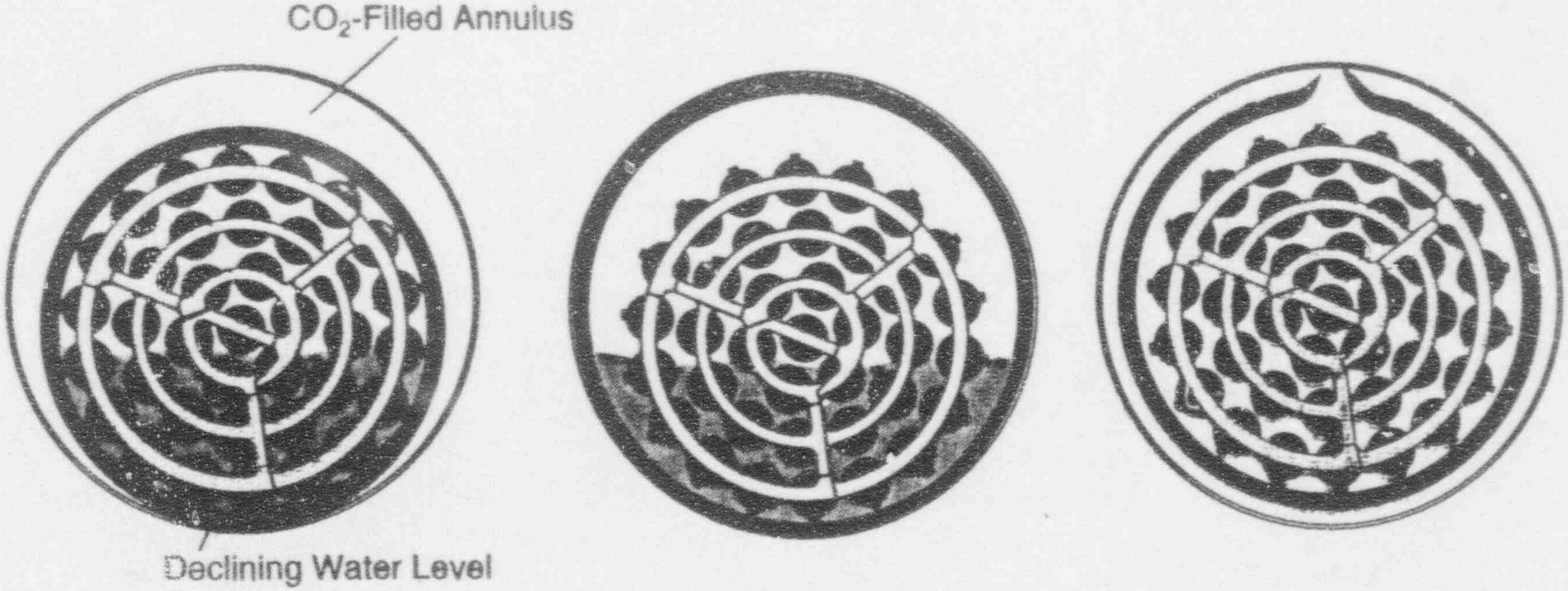
Heat Source: Decay heat and zirconium-steam reaction

Heat Sink: Moderator

MAJOR THRUSTS OF PROGRAM

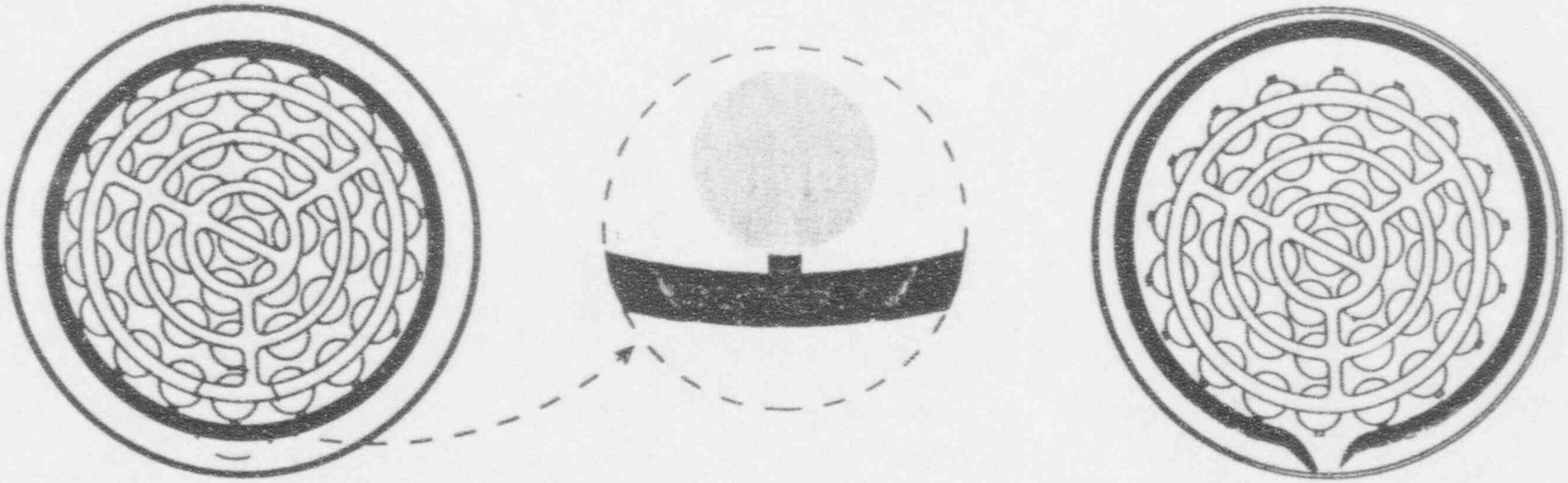
1. Pressure Tube Behaviour
2. Calandria Tube Behaviour
3. End-of-life Channel Behaviour
4. Validation of Fuel Channel Models
5. (Mitigation)

Pressure-Tube Circumferential Temperature Distribution Experiments (WPIR 0481)



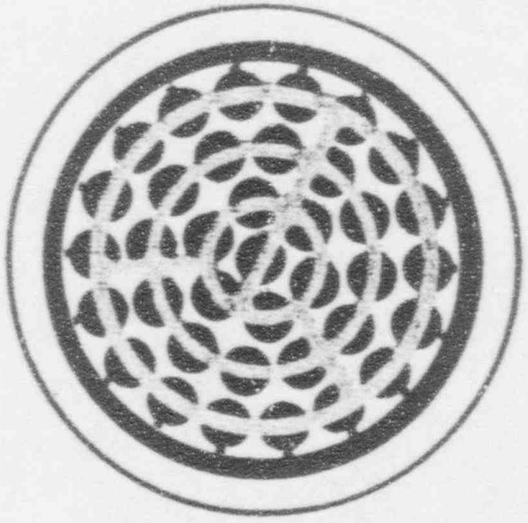
* Axial Steam flow in channel helps distribute heat circumferentially across the top of the pressure tube, reducing thermal gradients and thus reducing the likelyhood of pressure-tube failure.

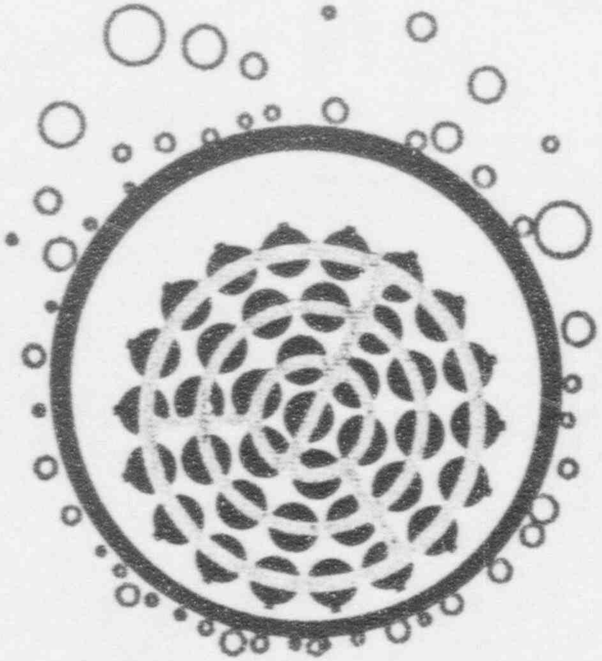
Bearing-Pad to Pressure-Tube Heat Transfer Experiments (WPIRs 0495 & 0550)



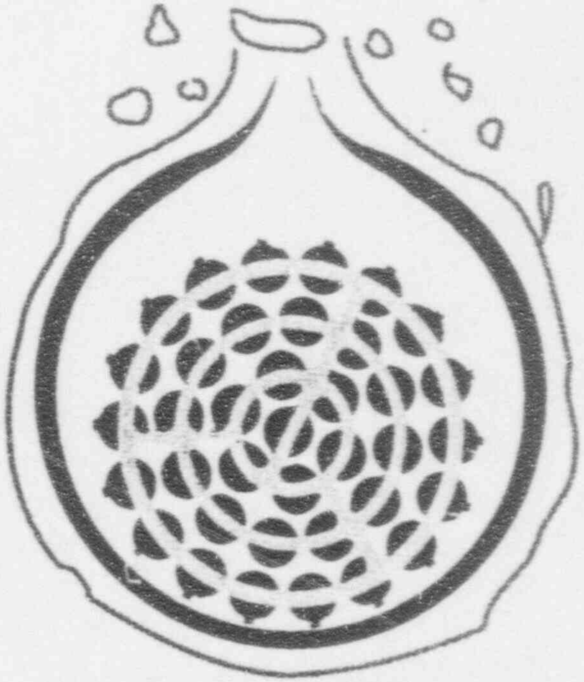
Scenario of Bearing-Pad Induced Rupture of Pressure Tube

Contact Boiling Experiments





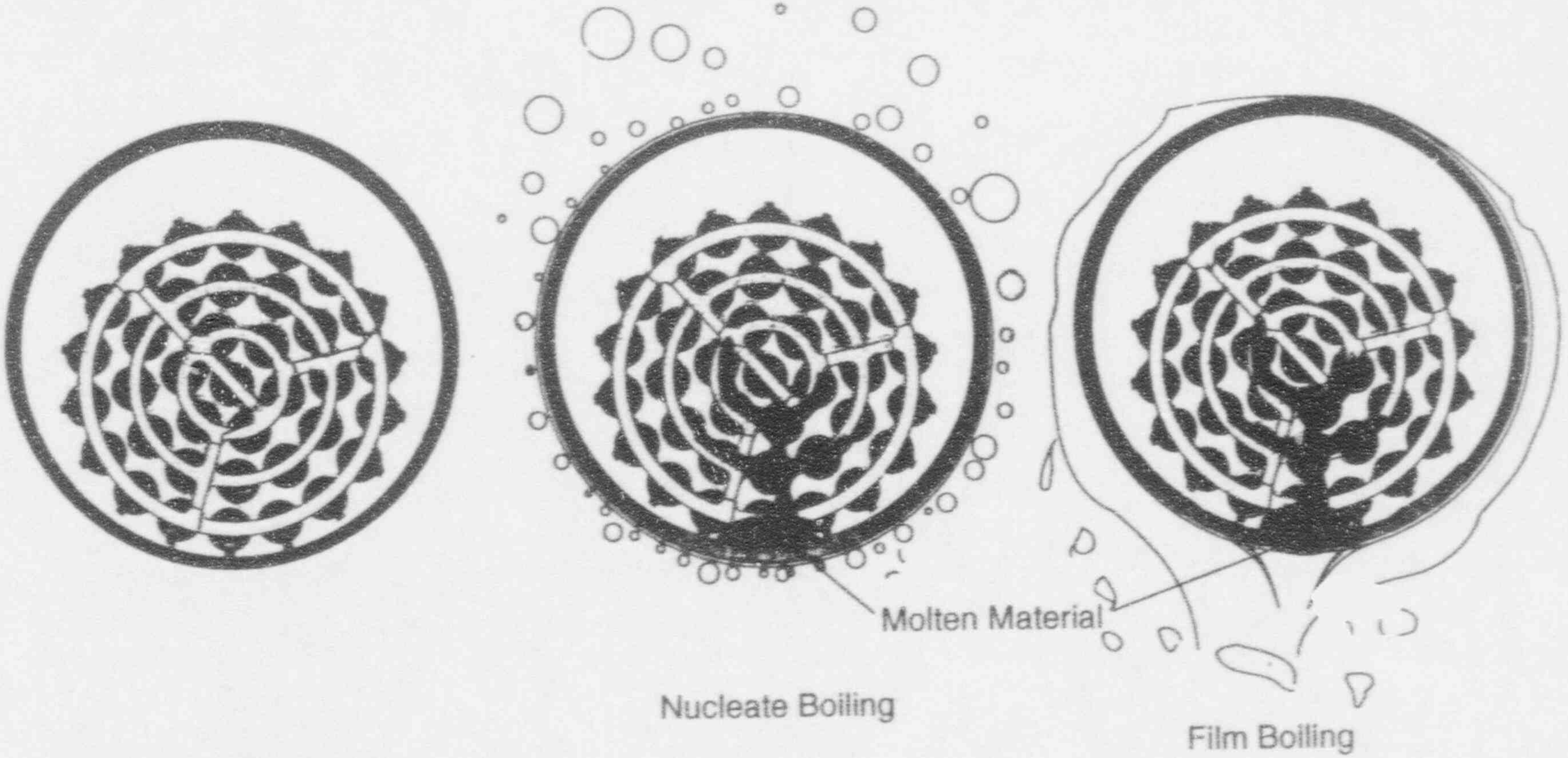
Nucleate Boiling
(Excellent Heat Transfer)



Film Boiling
(Poor Heat Transfer)

Experiments are used to further the understanding of the effectiveness of the moderator as a heat sink

Molten Zirconium / Pressure-Tube Interaction Experiments (WPIR 0418)



- Molten Zirconium did not cause fuel channels to fail as long as the calandria tube was NOT in film boiling prior to melting.
- Test performed with pressures up to 8 MPa.
- Emphasis presently on modelling experiments.

FUEL CHANNEL BEHAVIOUR PROGRAM

Understand Basic Phenomena/Processes (separate effect tests & model development)

Basic Heat Transfer

Fuel Channel Deformation

Thermal-Chemical Reactions

Hydrogen Embrittlement

Understand Interaction Between Various Processes (integrated effect tests & code development/verification)

Full-scale Thermal-Mechanical Fuel Channel Experiments

Full-scale Thermal-Chemical Fuel Channel Experiments

Fuel Channel Integrity

Safety

Understand and Predict Fuel Channel Behaviour Under LOCA/LOECC Accident Conditions

Mitigate Consequences of Upset Conditions

BENEFITS:

- RESOLUTION OF SAFETY ISSUES
- IMPROVED AND VERIFIED FUEL CHANNEL ACCIDENT MODELS
- IMPROVED LOCA/LOECC ANALYSIS OF FUEL CHANNELS (applicable for present and advanced fuel channel designs)
- MITIGATE EFFECTS OF AN ACCIDENT

②

EFFECTIVE USE OF THE MODERATOR AS A SECONDARY HEAT SINK FOR POSTULATED LOSS-OF-COOLANT ACCIDENT SCENARIOS

Presented by
Brock Sanderson

AECL RESEARCH
WHITESHELL LABORATORIES

Scope of Presentation

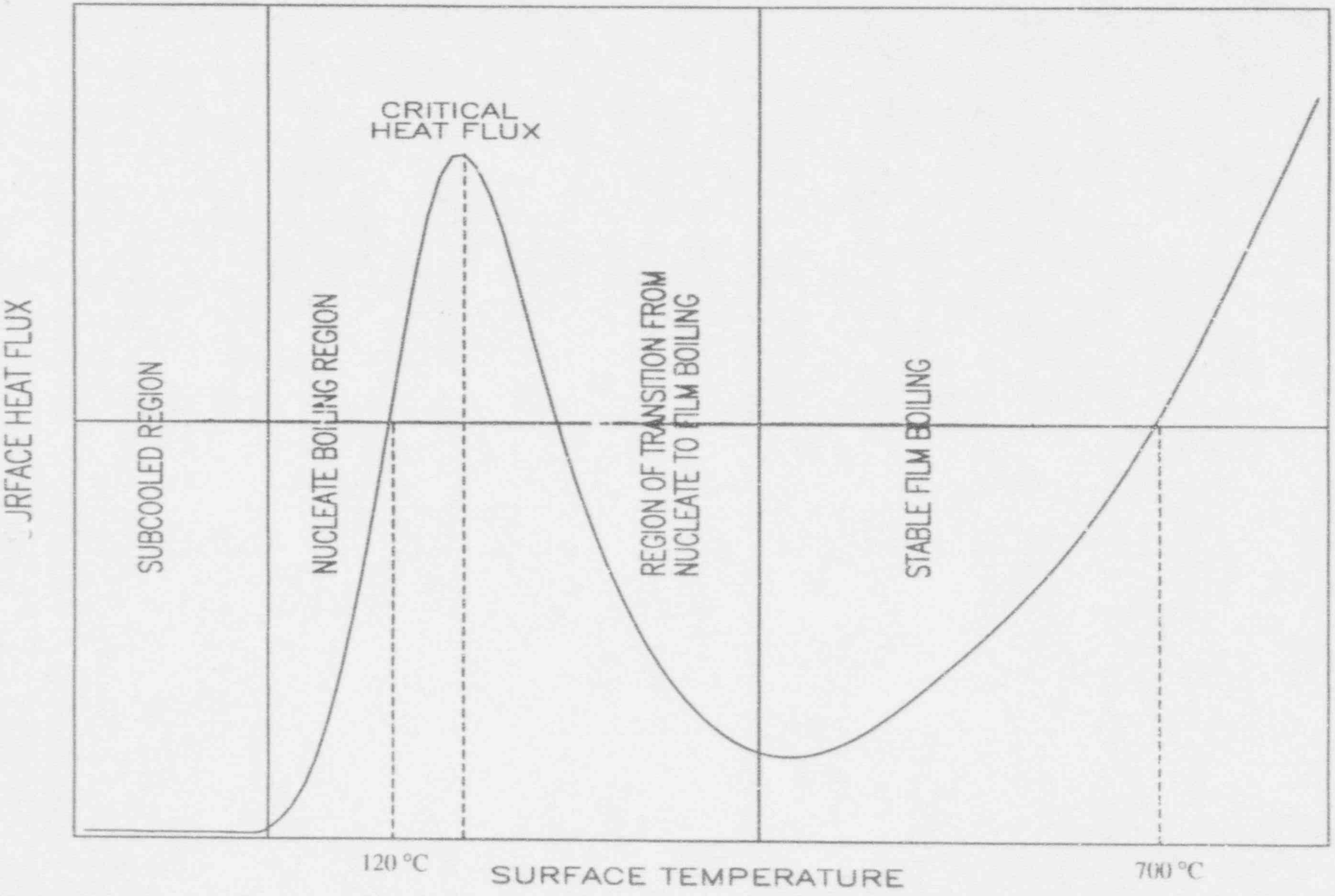
Demonstrate the effectiveness of the moderator as a secondary heat sink during postulated Loss-of-Coolant Accidents

- Experiments
- Theoretical Analysis

When a pressure tube makes contact with the moderator-cooled calandria tube, can get

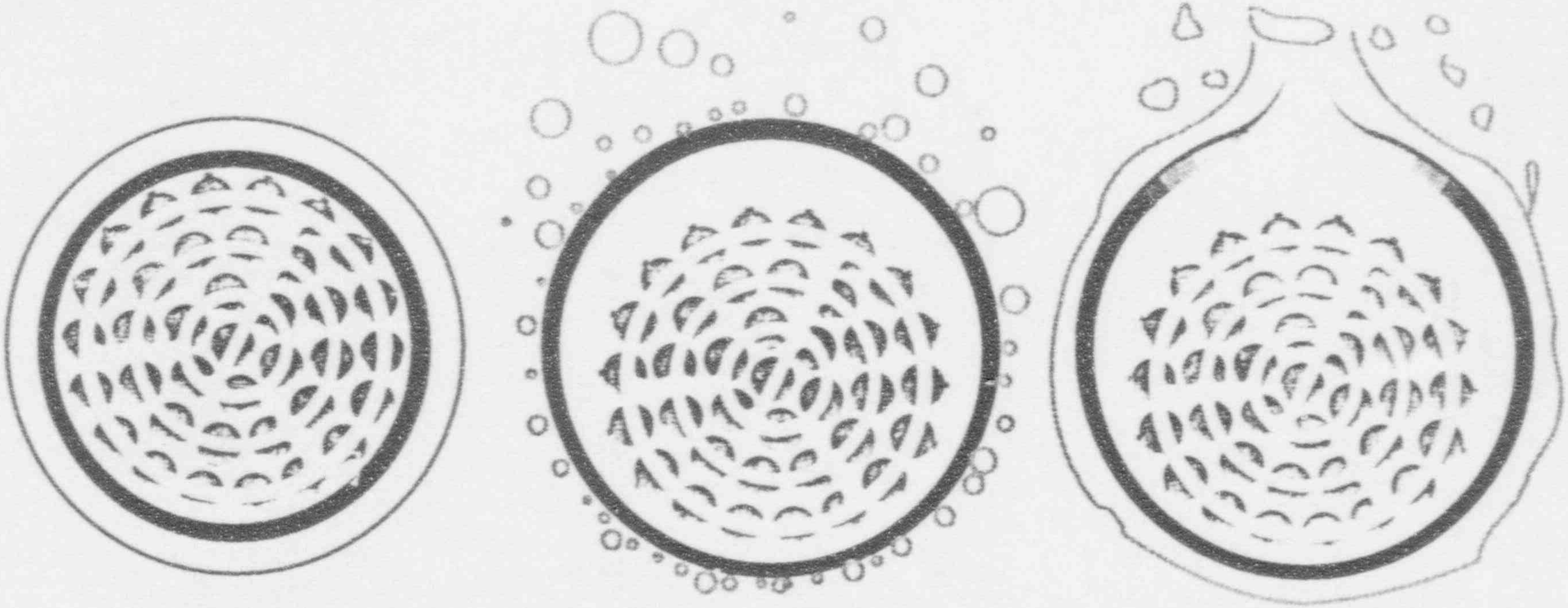
- * NUCLEATE BOILING
  - good heat transfer from pressure tube (fuel) to moderator
  - calandria tube ≤ 120°C
- * FILM BOILING
  - "dryout"
  - poor heat transfer from pressure tube (fuel) to moderator
  - calandria tube ≥ 400°C
  - calandria tube integrity in question

TYPICAL BOILING CURVE



- * WHETHER OR NOT A CALANDRIA TUBE GOES INTO DRYOUT DEPENDS ON:
  - Moderator subcooling
  - Decay power
  - Heat spike from PT/CT contact
- * MAGNITUDE OF HEAT SPIKE FROM PT/CT CONTACT DEPENDS ON:
  - Pressure-tube temperature
  - Internal pressure
  - Pressure-tube to calandria-tube contact conductance

Contact Boiling Experiments



Nucleate Boiling
(Excellent Heat Transfer)

Film Boiling
(Poor Heat Transfer)

Experiments are used to further the understanding
of the effectiveness of the moderator as a heat sink

CONTACT BOILING EXPERIMENTS

A SERIES OF 30 EXPERIMENTS WERE PERFORMED TO DETERMINE THE RELATIONSHIP BETWEEN PRESSURE-TUBE TEMPERATURES AND MODERATOR SUBCOOLING ON THE THERMAL RESPONSE OF A CALANDRIA TUBE UPON PRESSURE-TUBE/CALANDRIA-TUBE CONTACT

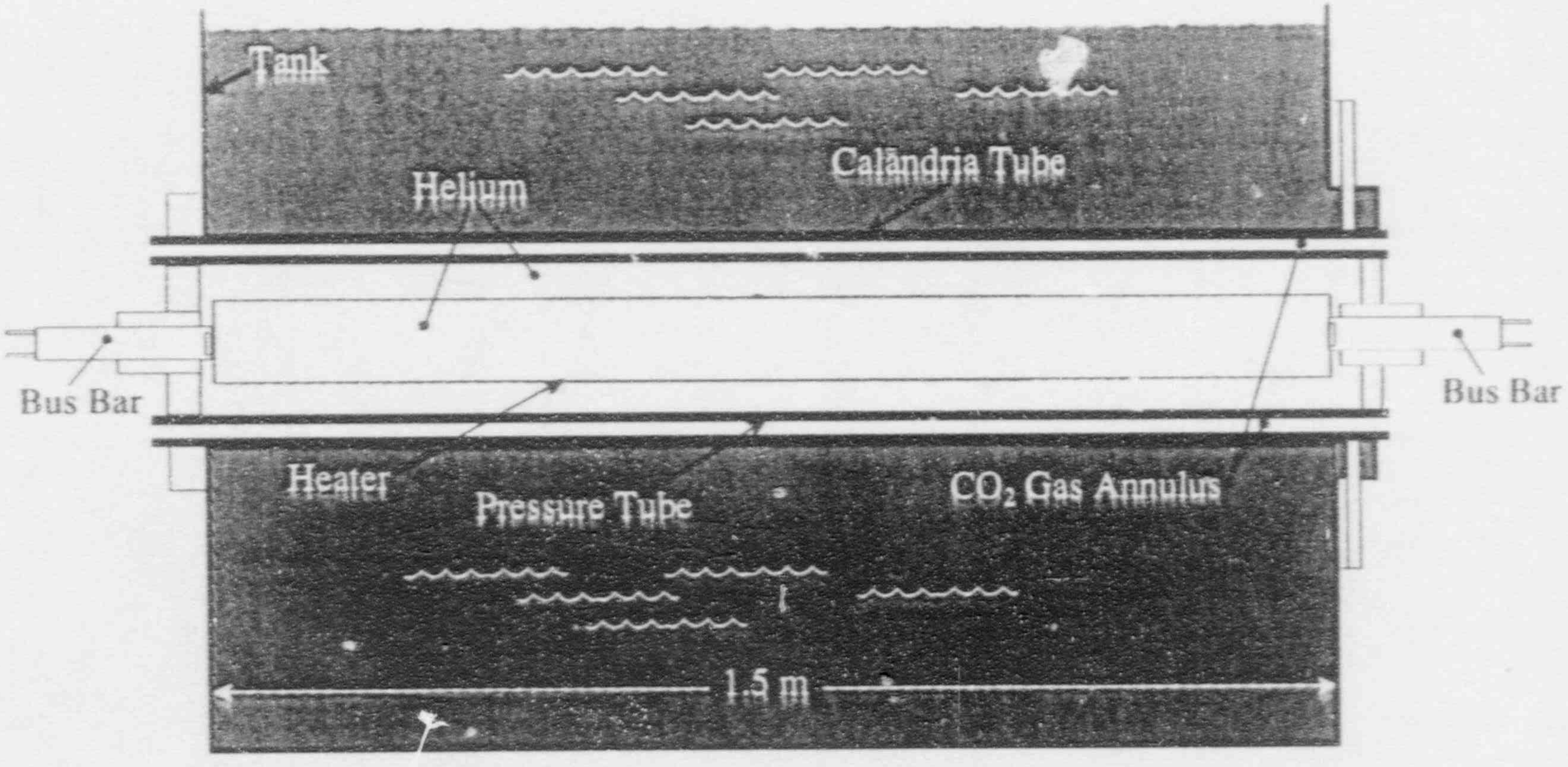
CONTACT BOILING EXPERIMENTS: Procedure

- Design and Build Apparatus
    - Tank with viewing port
    - Reactor grade pressure and calandria tubes
    - Internal heat source

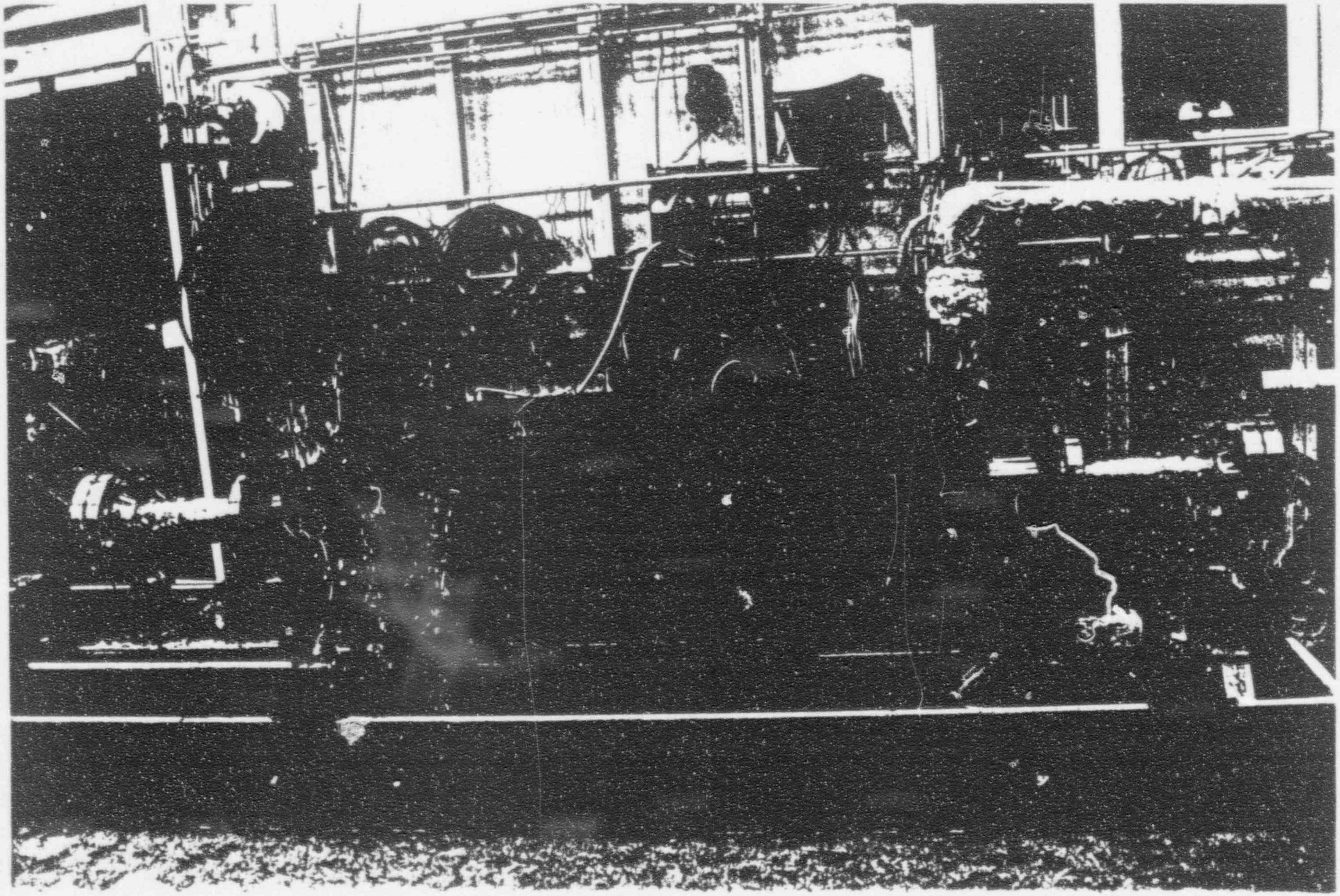
- Instrument Test Section
    - Pressure
    - Temperature
    - Radial creep of pressure tube
    - Video

CONTACT BOILING EXPERIMENTS: Procedure

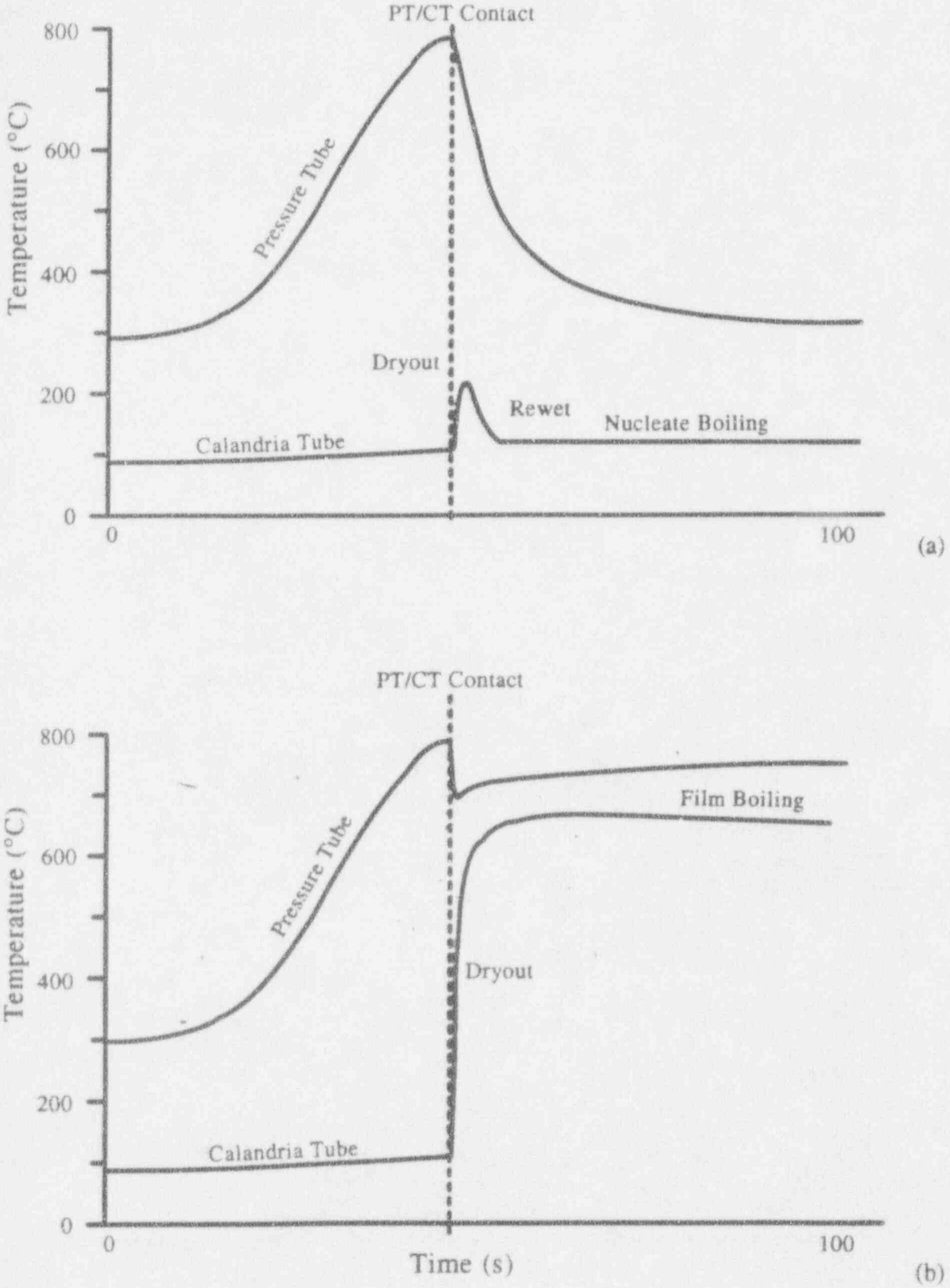
- Determine Test Conditions
  - Subcooling (0 to 40 °C)
  - PT Heatup Rate (0.5 to 20 °C/s)
  - PT Pressure (0.5 to 6 MPa)
- Perform Experiment & Analyze Results
- Document Findings



Contact Boiling Test Rig



TYPICAL PT/CT RESPONSE TO BALLOONING CONTACT

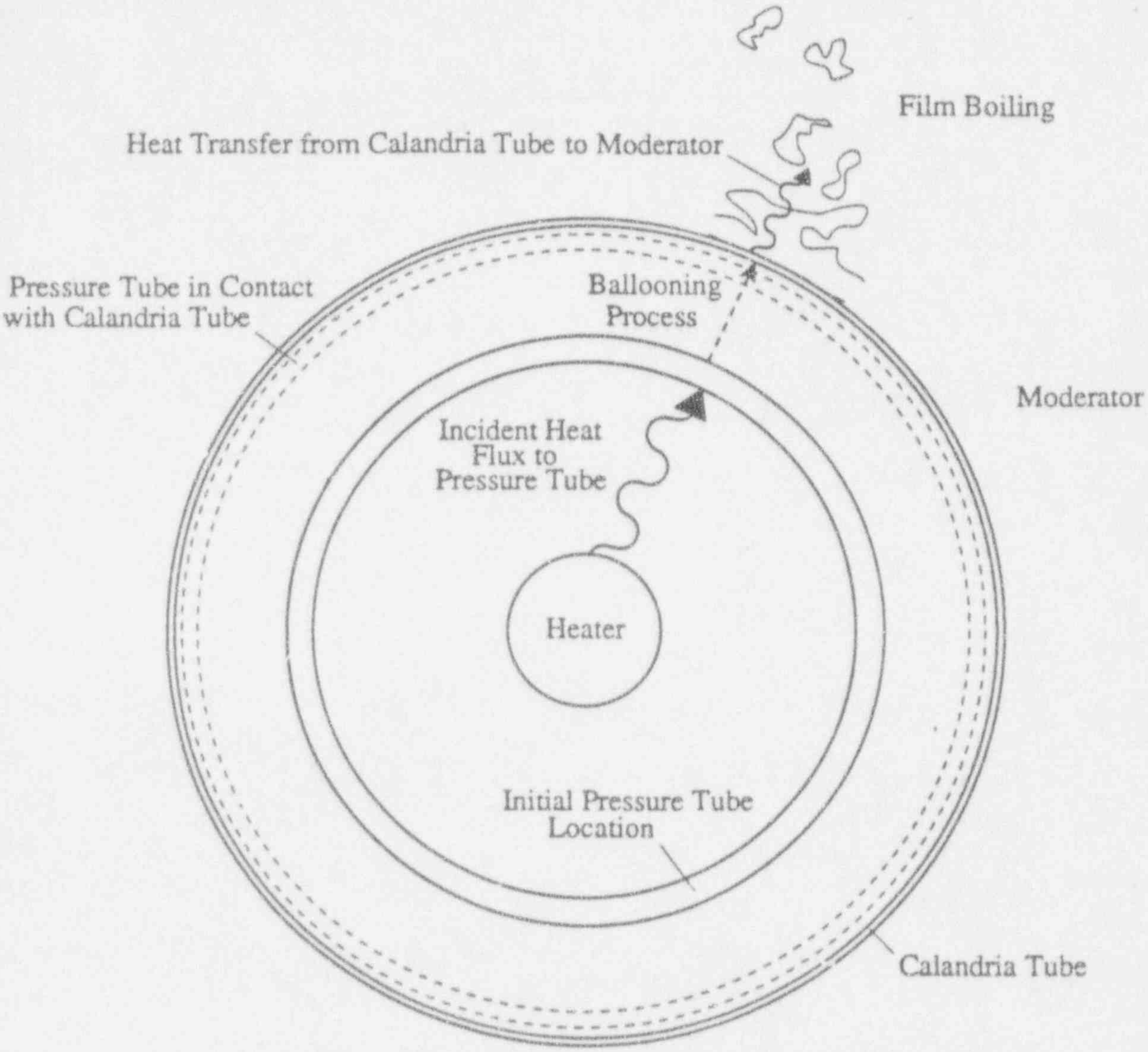


POST-TEST ANALYSIS USING CONTACT-1

- CONTACT-1 is a 1-D Thermal-Mechanical Code Developed at AECL-CANDU

- The code was used to model the transient response of the fuel channel during ballooning
  - Pressure-tube contact temperature
  - Pressure-tube to calandria-tube contact conductance
  - Heat transfer from calandria tube to the moderator

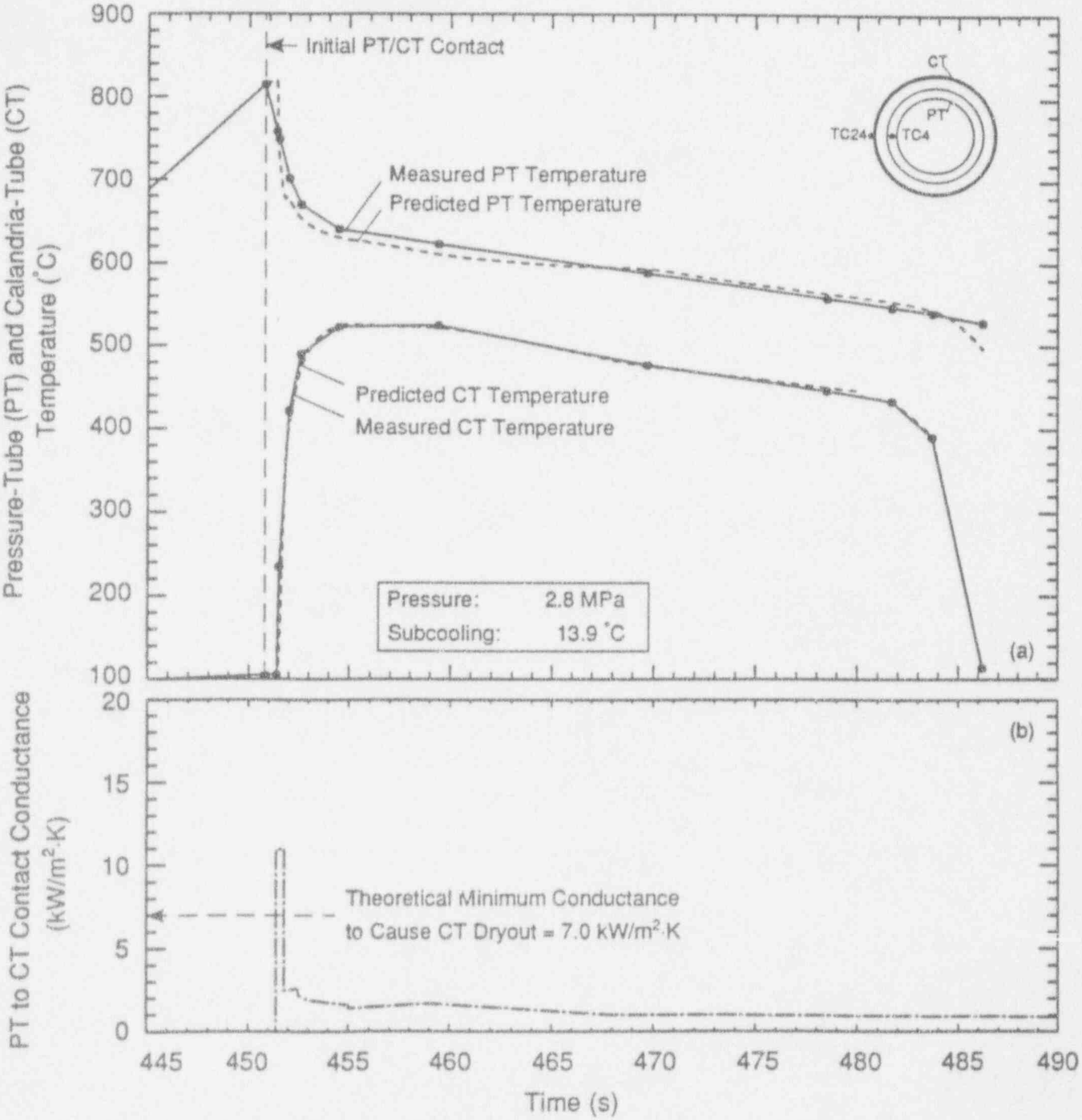
Diagram of CONTACT-1 Key Input Parameters:



Important Local Conditions used as Input Parameters:

- incident heat flux to the inner surface of the pressure tube
- moderator subcooling (and the resulting film boiling heat transfer coefficient)
- transient pressure-tube to calandria-tube contact conductance

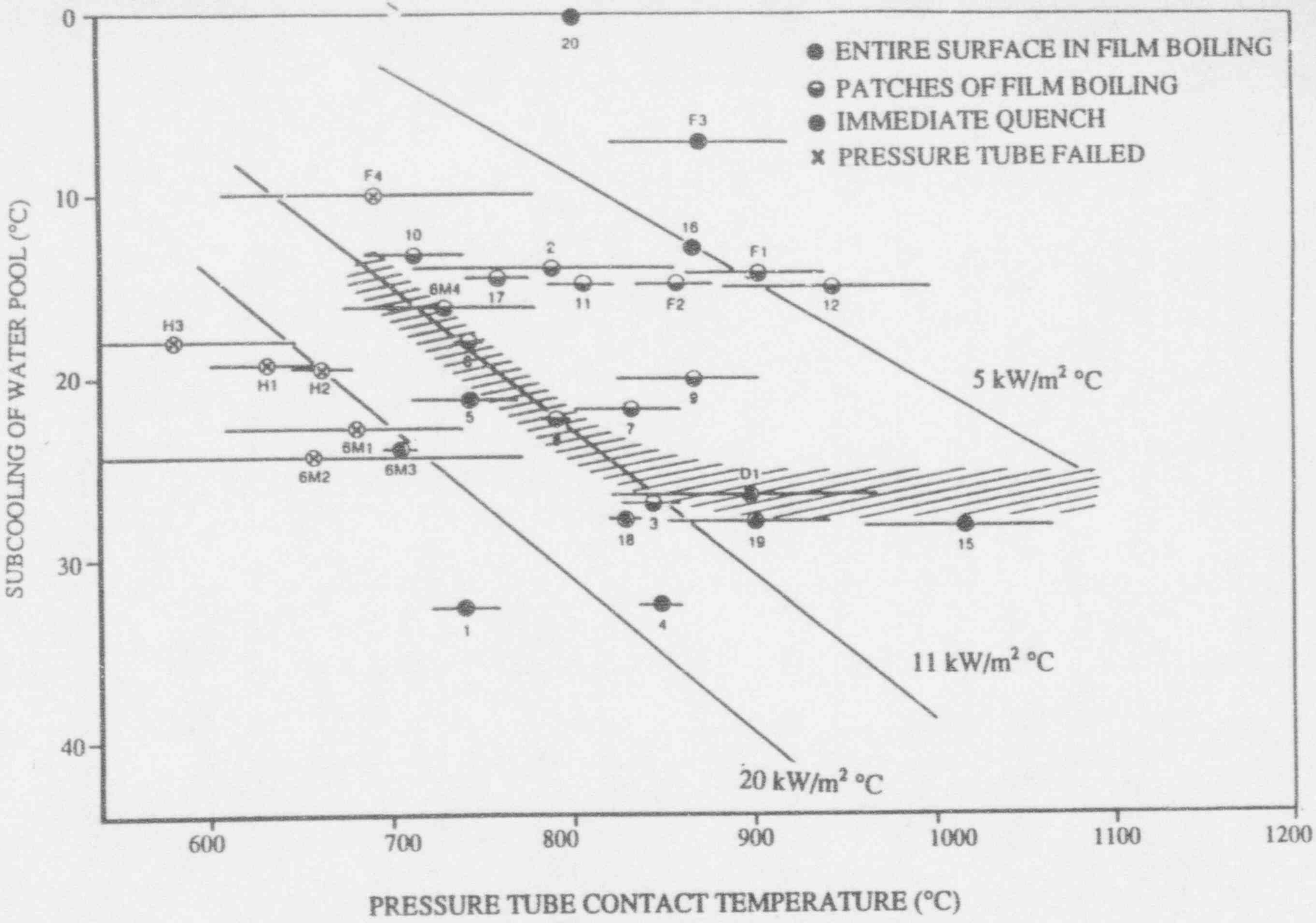
Results of Modelling Contact Heat Transfer Test 11 Experimental Data



(a) Comparison of CONTACT-1 predicted PT/CT temperatures with the measured values of Contact Heat Transfer Test 11.

(b) The PT to CT contact conductance used in CONTACT-1 to force the temperature agreement shown (rewet force at time = 480.0 s).

RESULTS FROM THE CONTACT BOILING EXPERIMENTS AND SUBSEQUENT ANALYSIS USING CONTACT-1 WERE USED TO DETERMINE MODERATOR SUBCOOLING REQUIREMENTS TO LIMIT THE EXTENT OF FILM BOILING UPON PT/CT CONTACT.



CONTACT BOILING EXPERIMENTS

SUMMARY

- The moderator is an effective secondary heat sink for cooling CANDU fuel channels under Loss-of-Coolant Accident Scenarios. Heat is transferred radially from the fuel pins to the pressure tube, the calandria tube and then to the moderator.

- Concept has been proven effective through:
    - Contact Boiling experiments
    - Pressure-tube sag experiments
    - Theoretical calculations (CATHENA, CHAN-II and HOTSPOT)

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COLD-WATER INJECTION TEST (CWIT) PROGRAM

By

J.E. Kowalski

AECL Research

Whiteshell Laboratories

1994 March 9

OVERALL OBJECTIVES

- To study two-phase phenomena that may occur in CANDU reactor feeders and channels under upset scenarios; such as
  - emergency coolant injection (ECI) during Loss-of-Coolant Accident (LOCA)
  - fuel cooling in the absence of forced flow
- To provide a data base for the development and verification of the channel ECI models in LOCA codes

FACILITY DESCRIPTION

- LOCATED AT STERN LABORATORIES INC. (FORMERLY WESTINGHOUSE CANADA INC.) IN HAMILTON, ONTARIO
- FULL GEOMETRICAL SCALE CANDU REACTOR CHANNEL-FEEDER SYSTEM
- CONSISTS OF :
  - Inlet and outlet headers
  - Inlet and outlet feeders
    - maximum vertical drop 9.75 m
    - minimum vertical drop 4.75 m
  - Inlet and outlet end fittings
    - side-to-side end fitting simulators
    - Pickering NGS end fittings
    - CANDU 6 end fittings

FACILITY DESCRIPTION

- Simulated fuel channels
  - fuel channel simulator
  - Pickering NGS channel assembly
  - CANDU 6 channel assembly
- Two break simulation devices
- Blowdown tank
- Cold-water injection system
- Various measurement and control systems

FACILITY DESCRIPTION
SIMULATED FUEL CHANNEL

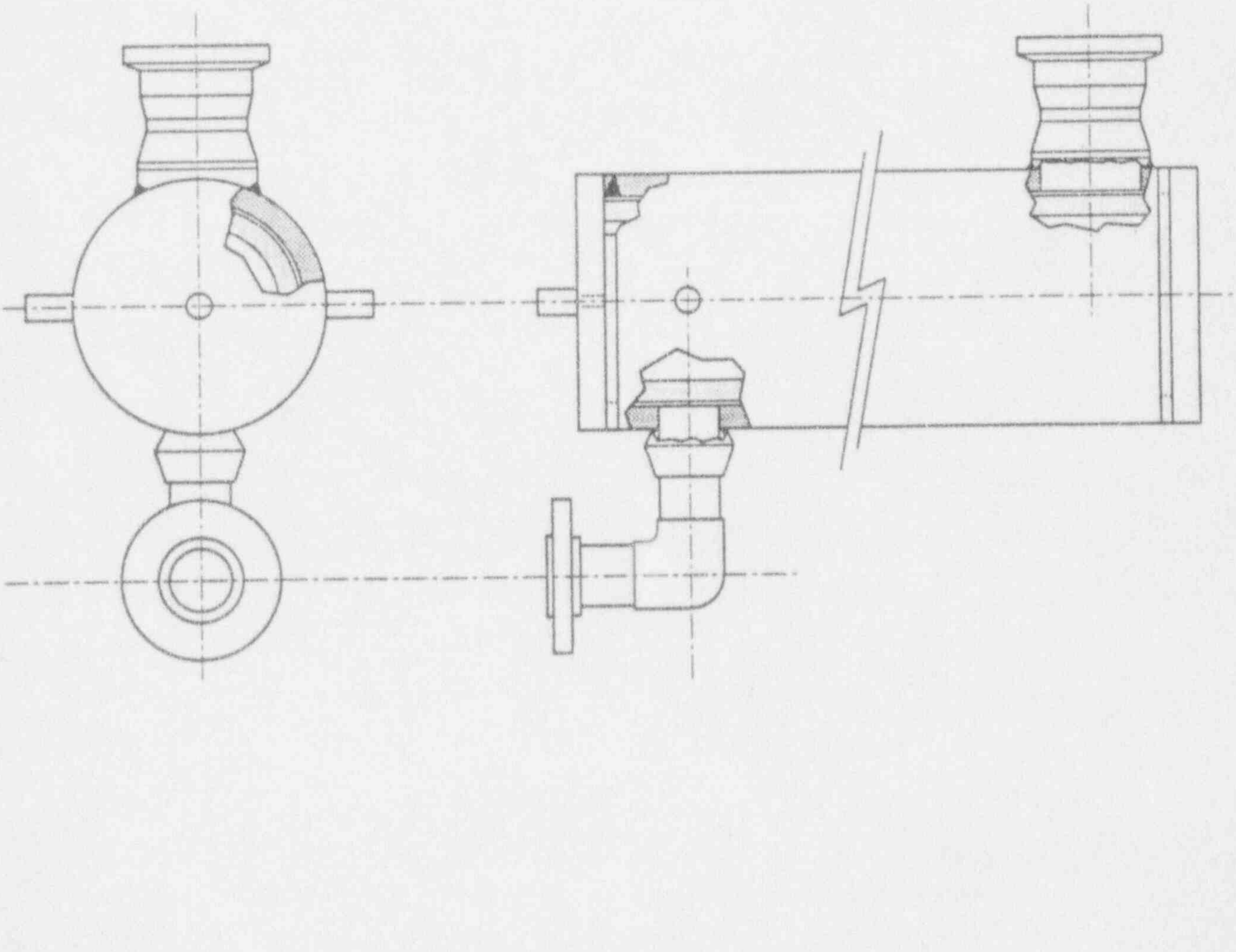
- FUEL CHANNEL SIMULATOR
  - 6-m electrically heated 37-element heater bundle
    - uniform axial power distribution
    - design heat flux of 5 W/cm^2
  - 100-mm Zircaloy pressure tube
- PICKERING NGS CHANNEL ASSEMBLY
  - 6-m electrically heated 28-element heater bundle
    - cosine axial power power distribution with axial power factor 1.367
    - radial outer to centre element power distribution 1.0/0.82/0.74
  - 100-mm Zircaloy pressure tube
  - calandria tube
  - simulated moderator tank

FACILITY DESCRIPTION
SIMULATED FUEL CHANNEL

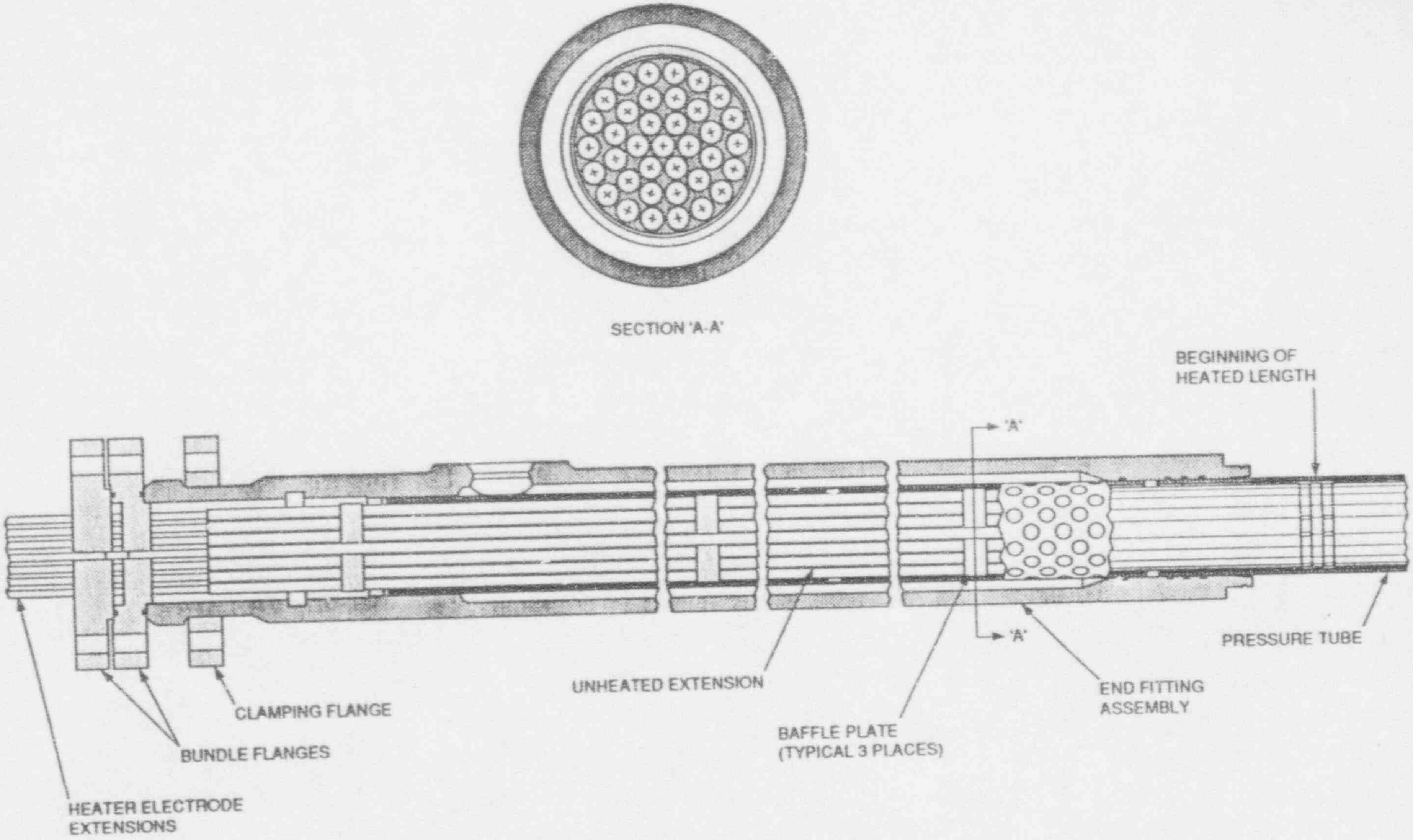
- **CANDU 6 CHANNEL ASSEMBLY** includes (Area 3
  - 6-m electrically heated 37-element heater bundle
    - cosine axial power power distribution with axial power factor 1.485
    - maximum power 300 kW
    - radial outer to centre element power distribution 1.0/0.81/0.72/0.68
  - Zircaloy pressure tube housed in a square channel enclosure

FACILITY DESCRIPTION
END FITTINGS

- **END FITTING SIMULATOR**
  - Two concentric pipes with air-filled inner pipe
  - Length 0.66 m
  - Horizontal feeder/end fitting connection
  - Mounted in parallel with the channel via a short pipe
- **PICKERING END FITTING**
  - Full length
  - Shield plug/latch assembly replaced by the unheated parts of the heaters
  - Unheated parts placed in the inner tube and are supported by baffle plates
  - Water cooling jacket to simulated end shield cooling
  - Inclined (32°) feeder/end fitting connection



SIMULATED END FITTING



CANDU 600 END FITTING

FACILITY DESCRIPTION
END FITTINGS

- CANDU 6 END FITTING
  - Full length
  - Unheated sections of heaters supported by baffle plates to simulate the shield plug assembly
  - Mass of unheated rods and water volume identical to real CANDU 6 end fittings
  - End fitting has no calandria tube and bellows
  - Inclined (32°) feeder/end fitting connection

FACILITY DESCRIPTION
HEADERS

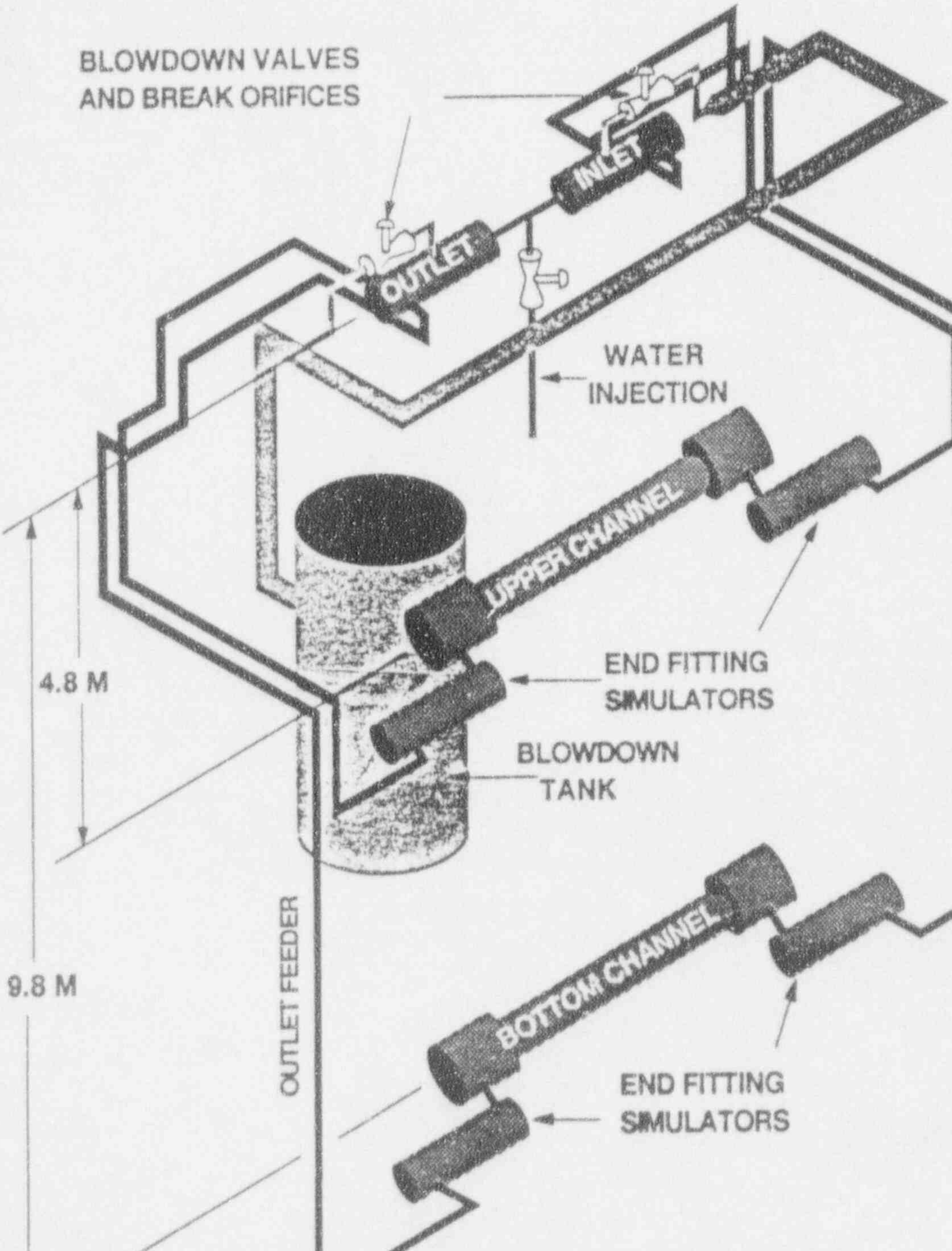
- LOCATED 10 M ABOVE THE BOTTOM CHANNEL
- OVERALL LENGTH 1.23 M
- MADE FROM 250-MM DIAMETER CARBON STEEL PIPE WITH SEVERAL 50-MM FLANGED CONNECTIONS
- FEEDER CONNECTIONS AT AN ANGLE OF 45° BELOW HORIZONTAL CENTRE LINE OF HEADER
- BREAK LINES FROM HEADERS CONNECT TO THE TOP EXIT NOZZLES

FACILITY DESCRIPTION
BREAK SIMULATION DEVICES

- CONSISTS OF :
  - Two pneumatic quick-acting valves
  - Orifice flanges fitted with various sizes of break orifices
    - located downstream of quick-acting valves
  - 50-mm diameter break lines enlarge to 200-mm blowdown lines
  - 100-mm diameter break lines installed in parallel with 50-mm break lines
  - Either 50-mm or 100-mm diameter break lines can be used while other lines are blanked off

FACILITY DESCRIPTION HIGH PRESSURE WATER INJECTION SYSTEM

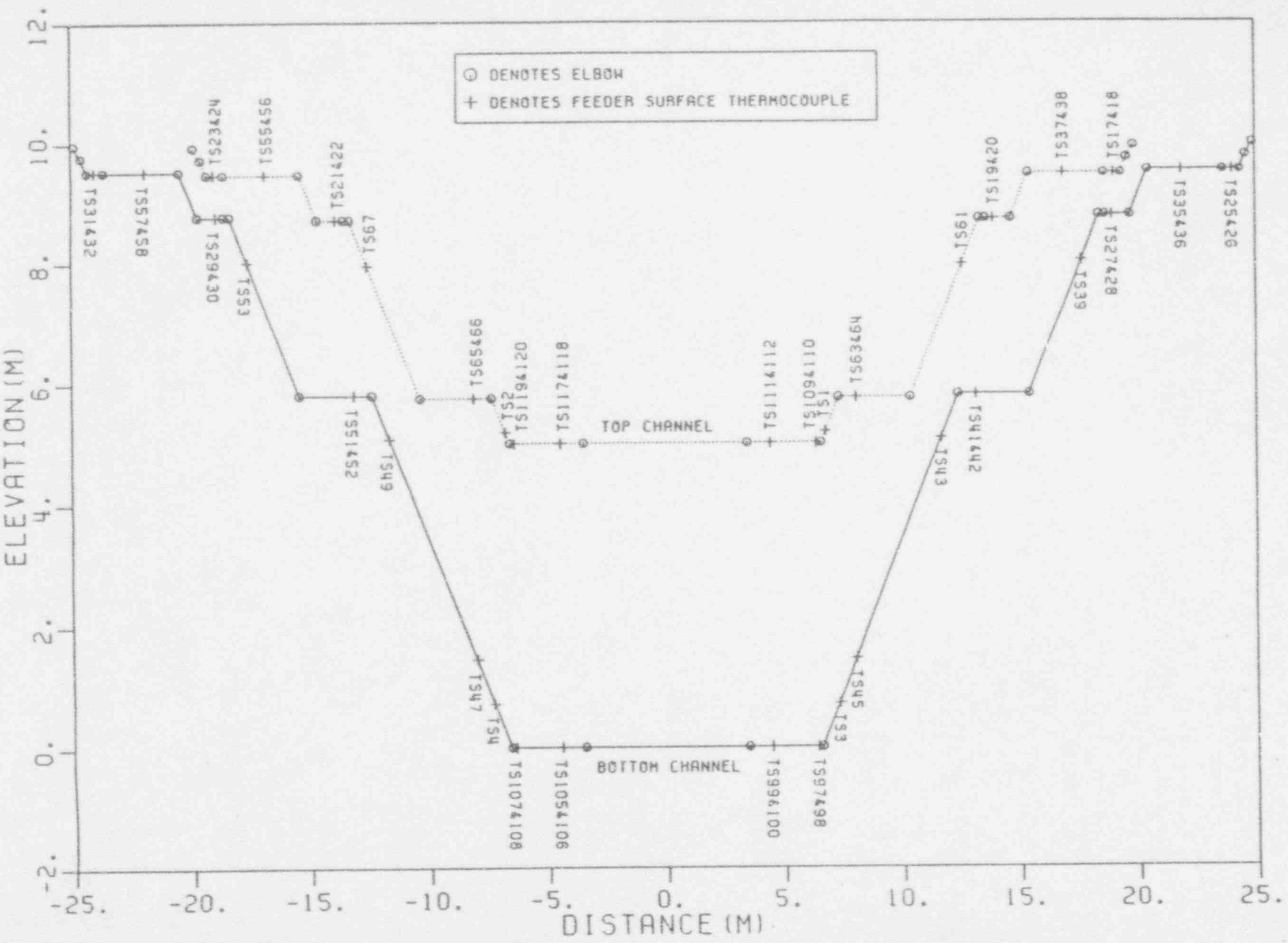
- CONSISTS OF
  - A pump (maximum flow rate of 6 l/s, head of 580 m)
  - Tank filled with water and nitrogen gas
  - Pressure control valve
  - 50-mm check valve
  - Venturi meter
  - Orifice plates
  - Isolation valve
  - Temperature control system



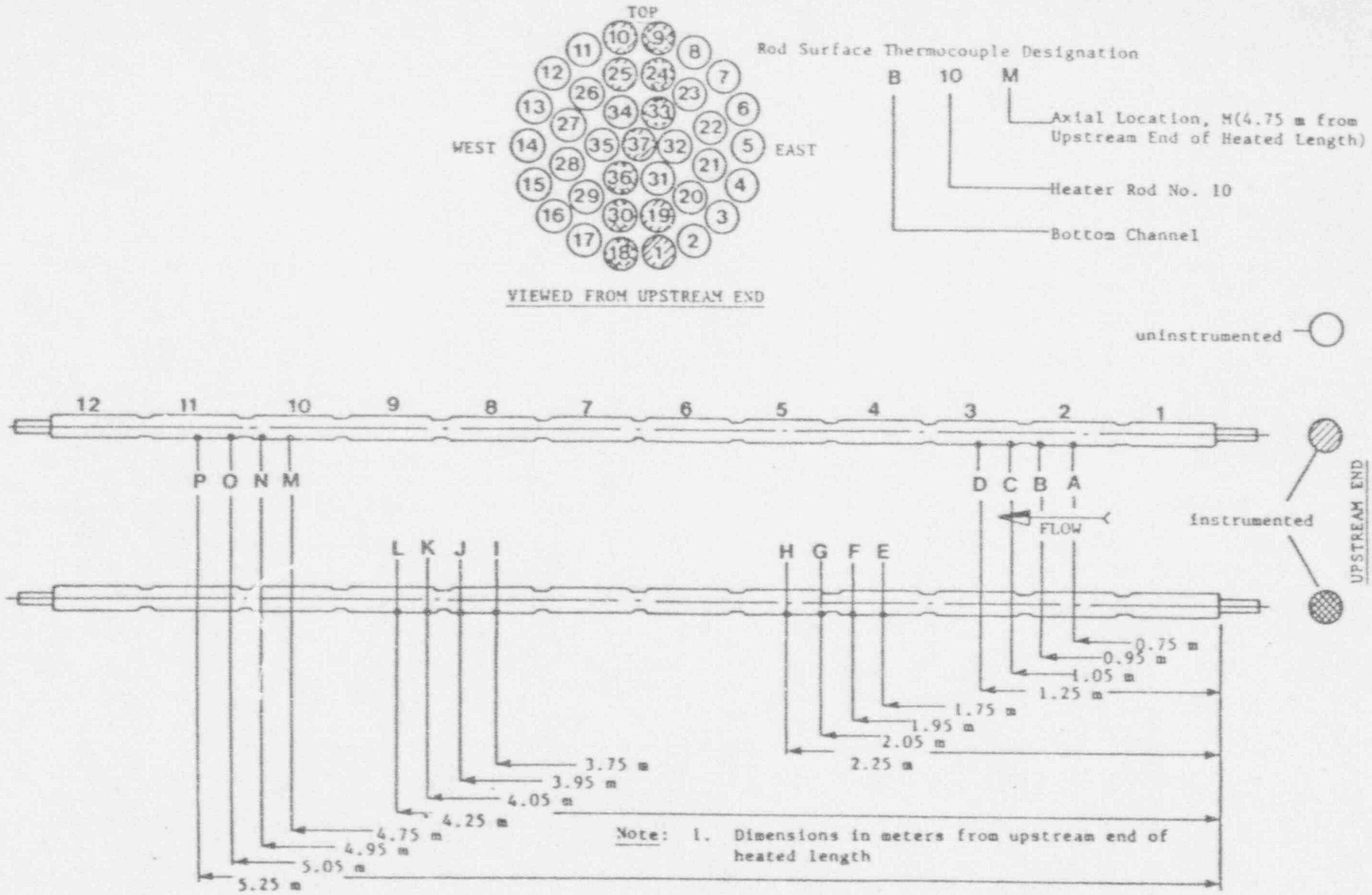
CWIT Test Facility

INSTRUMENTATION

- OVER 250 CHANNELS OF INSTRUMENTATION CONSISTING OF :
  - Thermocouples
    - ungrounded, 0.5-mm diameter, ANSI type K
    - connected to reference junctions
    - used to measure
      - header, feeder, end fitting, pressure tube and heater surface temperatures
      - fluid temperatures at various locations of the loop
  - Differential and absolute pressure transducers
    - strain gauge transducers
    - capacitance transducers
    - calibrated using dead-weight tester and mercury manometer
    - vertical sense lines for DP tranducers cooled with water jackets
    - water cooled stand-offs at pressure taps

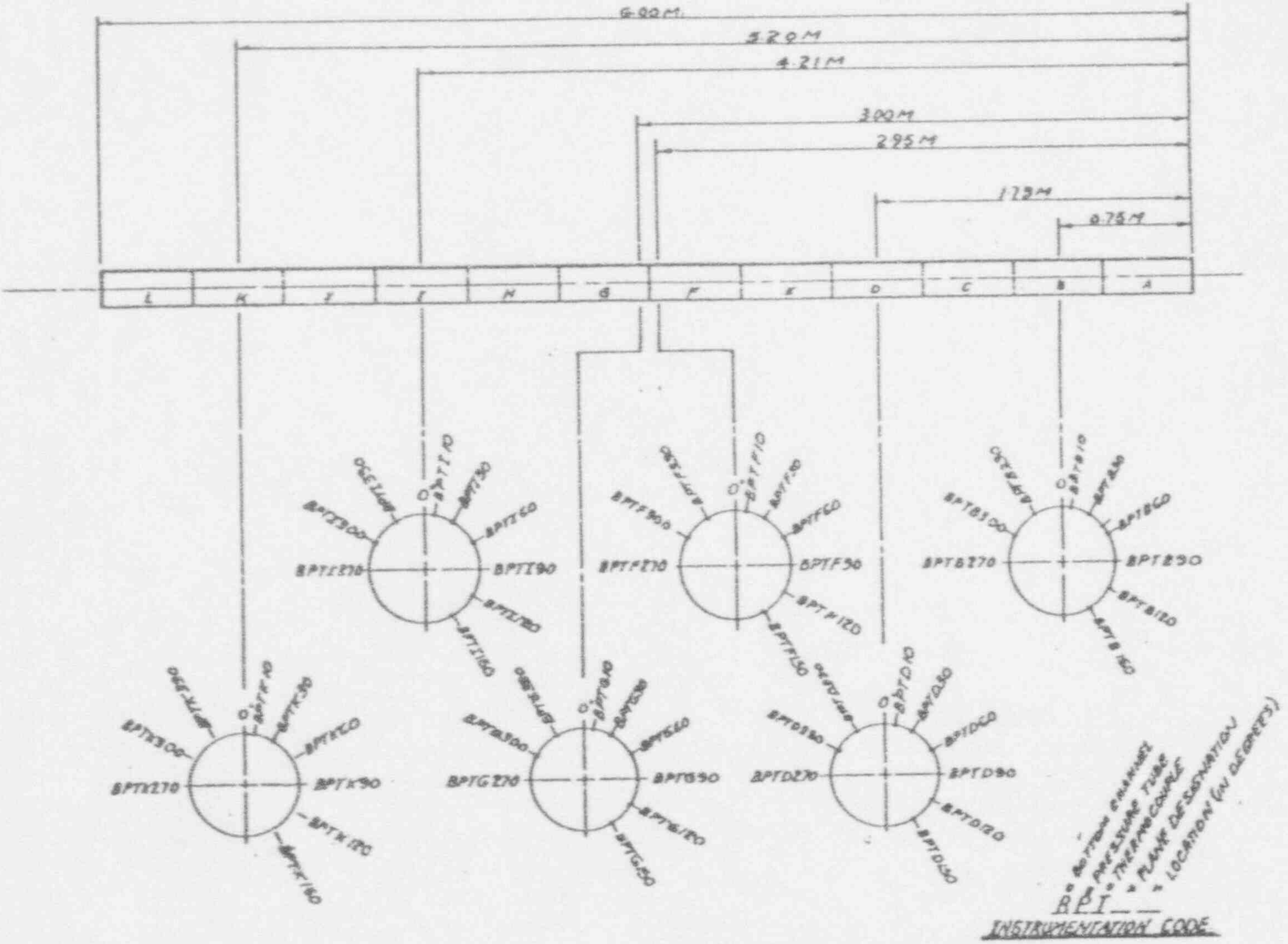


FEEDER ELEVATION vs. HORIZONTAL DISTANCE



Note: 1. Dimensions in meters from upstream end of heated length

FES THERMOCOUPLE LOCATIONS



PRESSURE TUBE THERMOCOUPLE LOCATIONS

INSTRUMENTATION

- **FLOWMETERS**
  - Venturi meters for measuring header water injection flow rates
  - Ultrasonic flowmeter installed on the inlet feeder (stratified flow tests only)
- **THREE-BEAM GAMMA DENSITOMETER**
  - Cesium gamma source, 25 Ci
  - Located at inlet and outlet of the channel
  - Used to detect the arrival of refill front and to determine the venting time during standing start experiments

TESTS PERFORMED

- CHANNEL/FEEDER REFILL EXPERIMENTS
- STANDING START EXPERIMENTS
- FLOW STRATIFICATION TESTS
- SINGLE-CHANNEL FLOW STABILITY TESTS

CHANNEL/FEEDER REFILL EXPERIMENTS
HEADER/FEEDER SPRAY TESTS (NO. 759 TO 786)

Initial [illegible] done 12-15 [illegible]

- **OBJECTIVE :**
  - To investigate the effects of the initial loop temperature, heater power, channel configuration, and the header/feeder spray cooling on channel refill
- **DATA REPORT : CWAPD-458**
- **LOOP SETUP**
  - Single and double break configuration
  - Water injection into inlet header or both headers
  - Bottom channel only
- **EXPERIMENTAL PROCEDURE**
  - Similar to standard procedure, but
  - For some tests, external water spray (30°C) into the header and feeder spray compartments with also cold-water injection into the headers

CHANNEL/FEEDER REFILL EXPERIMENTS STANDARD TEST PROCEDURE

- LOOP PREHEATED TO THE DESIRED TEMPERATURE BY CIRCULATING SUPERHEATED STEAM
- WHEN STEADY-STATE TEMPERATURES WERE OBTAINED, THE PREHEAT AND EFFLUENT ISOLATION VALVES WERE CLOSED
- DATA LOGGING STARTED
- BLOWDOWN INITIATED BY OPENING QUICK ACTING VALVE(S)
- COLD-WATER INJECTION BEGAN WHEN THE PRESSURE DROPPED BELOW 1.5 OR 2 MPa
- STOP TEST WHEN EITHER THE LOOP REFILLED OR THE HEATER SURFACE TEMPERATURE EXCEEDED 780°C

CHANNEL/FEEDER REFILL EXPERIMENTS
HEADER/FEEDER SPRAY TESTS (NO. 759 TO 786)

- **INSTRUMENTATION**
  - Fuel string instrumented with thermocouples at 16 axial planes and 7 cross sections
- **TEST CONDITIONS**
  - Initial preheat temperature 300°C
  - Initial header pressure : 4.5 to 5.5 MPa
  - Blowdown tank pressure : 0.1 to 0.2 MPa
  - Cold-water injection pressure : 1.5 to 3 MPa
  - Channel power : 50 to 300 kW
- **TESTS 774 USED FOR CATHENA VALIDATION**

CHANNEL/FEEDER REFILL EXPERIMENTS
CHANNEL SPRAY TESTS (NO. 801 TO 856)

OBJECTIVE :

- To investigate the effects of the initial loop temperature, heater power, channel configuration, and pressure-tube cooling on channel refill

DATA REPORT : CWAPD-412

LOOP SETUP

- Single or double break configuration
- Cold-water injected into both headers
- Water spray system consisted of :
    - two 38-mm spray headers
    - 34 spray nozzles
    - flow control valve
    - flow orifice
    - spray box (around the bottom channel) with drain and overflow lines
- 50-mm diameter break line

CHANNEL/FEEDER REFILL EXPERIMENTS
CHANNEL SPRAY TESTS (NO. 801 TO 856)

■ EXPERIMENTAL PROCEDURE

- Similar to standard test procedure
- For channel spray tests, external spray started at the same time as the opening of the quick-acting valves

■ TEST CONDITIONS

- Initial heater temperature : 350 to 700 °C
- Initial header pressure : 5 MPa
- Blowdown tank pressure : 0.1 and 0.2 MPa
- Cold-water injection pressure : 1.5 and 2 MPa
- Break size : 6.4% to 100%
- Channel power : 50 to 300 kW

■ TESTS PERFORMED

- 24 tests with external channel spray
- 23 tests without external spray

■ TEST 848 USED FOR CATHENA VALIDATION

CHANNEL/FEEDER REFILL EXPERIMENTS FEEDER REFILL TIME DELAY TESTS (NO. 1081 TO 1129)

■ OBJECTIVE :

- To investigate the feeder refill phase
- To study the effects of initial feeder temperature, system pressure during refill, channel power, and cold-water injection pressure on the feeder refill delay time

■ DATA REPORT : WNRE-613

■ LOOP SETUP

- Bottom and upper channel used
- Double-break, double-injection mode

■ EXPERIMENTAL PROCEDURE

- Similar to standard test procedure

CHANNEL/FEEDER REFILL EXPERIMENTS FEEDER REFILL TIME DELAY TESTS (NO. 1081 TO 1129)

- **TEST CONDITIONS**
  - Initial feeder temperature : 150 to 300 °C
  - Initial header pressure : 0.4 to 1.5 MPa
  - Cold-water injection pressure : 1.5 MPa
  - Break size : 6.4% to 100%
  - Channel power : 0 and 50 kW
- **TEST USED FOR CATHENA VALIDATION : 1086, 1092, and 1097**

CHANNEL/FEEDER REFILL EXPERIMENTS

- NON-CONDENSIBLE GAS INJECTION TESTS (NO. 1258-1265 AND 1284-1286)
  - DATA REPORTS : CWAPD-433 AND CWAPD-480
  - OBJECTIVE :
    - To investigate the effect of non-condensible gas injection on channel refill (Hydrogen may be generated in the channel during some LOCAs due to Zircaloy-steam reaction)
- FEEDER REFILL TESTS (NO. 1267-1293 AND 1294-1314)
  - DATA REPORTS : CWAPD-480 AND CWAPD-481
  - OBJECTIVE :
    - To investigate the effect of break asymmetry and feeder orifice size on feeder refill

CHANNEL/FEEDER REFILL EXPERIMENTS

- ■ INCLINED FEEDER REFILL TESTS (NO. 1401-1422)
  - – DATA REPORTS : SL-010
  - – OBJECTIVE :
    - To investigate the effect of inclining the horizontal feeder sections on quench and refill times
- ■ CHANNEL/FEEDER REFILL TESTS CONDUCTED IN MODIFIED FACILITY (NO. 1465-1473)
  - – DATA REPORTS : SL-041
  - – OBJECTIVE :
    - To investigate the effect of a cosine axial power distribution and Gentilly-II end fittings on quench and refill behaviour

STANDING START EXPERIMENTS
(TESTS NO. 913 TO 1000)

- OBJECTIVE :
  - To study the behaviour of the channel/feeder system under standing start conditions; loss of forced circulation due to a small or large-break LOCAs
  - Investigate the effects of channel power, liquid subcooling, pressure, and channel configuration on the channel heat-up and venting time
  - Provide a data base for model development and validation
- DATA REPORT : CWAPD-405
- LOOP SETUP
  - Double-break, double-injection configuration
  - 100% break size
  - Pipes connecting channel with end fittings enlarge from 50 mm to 100 mm

STANDING START EXPERIMENTS (TESTS NO. 913 TO 1000)

- Tests 913 to 919 and 953 to 958 conducted without insulation on the pressure tube of the bottom channel
- Bottom and both channels used

■ INSTRUMENTATION

- Thermocouples for surface and fluid temperature measurements
- Absolute and diiferential pressure transducers
- Two gamma densitometers located at the bottom of the feeders
- Flow orifices installed in the inlet and outlet feeders near the headers (except for tests 913 to 919, 930 to 933, 947 to 958, and 963 to 965)

STANDING START EXPERIMENTS (TESTS NO. 913 TO 1000)

■ EXPERIMENTAL PROCEDURE

- Subcooled water circulated from the injection system through the outlet header break location to heat up the loop to the desired temperature
- When steady-state temperatures were achieved, the inlet header break valve was opened and the desired injection and blowdown tank pressures were established
- Data logging started
- The heater power was rapidly increased to the desired value
- Experiment terminated when
  - the heater surface temperature cooled down, or
  - maximum heater or pressure-tube temperature exceeded 780°C, or
  - no heater rewetting was apparent

STANDING START EXPERIMENTS (TESTS NO. 913 TO 1000)

- **TEST CONDITIONS**
  - Cold-water injection pressure : 1.6 to 1.9 MPa
  - Blowdown tank pressure : 0.1 to 1.0 MPa
  - Initial water temperature : 30°C
  - Channel power : 50 to 200 kW
- **TEST USED FOR CATHENA VALIDATION : 937, 939, 959, 974, AND 975**

STANDING START EXPERIMENTS

- TESTS : 759-786, 1001-1013, AND 1198-1257
- DATA REPORTS : CWAPD-459, WNRE-558, CWAPD-447
- OBJECTIVES :
  - To investigate the thermalhydraulic behaviour of the channel containing a 37-element bundle with uniform axial power distribution under standing start conditions
  - To provide a data base for code validation
- TESTS : 1315-1377 AND 1378-1400
- DATA REPORTS : SL-002 AND SL-005
- OBJECTIVE :
  - To investigate the effects of channel and end-fitting (Pickering NGS) configurations on channel venting, sheath temperature transient and rewet process under standing start conditions

STANDING START EXPERIMENTS

- **TESTS : 1424-1463**
- **DATA REPORT : SL-032**
- **OBJECTIVE :**
  - To investigate the effect of cosine axial power distribution and Gentilly-II end-fitting geometry on channel venting, sheath temperature transient and duration of flow stratification under standing start conditions

FLOW STRATIFICATION TESTS
(NO. 1154 TO 1181)

- OBJECTIVE :
  - To investigate the flow stratification threshold in a full-scale CANDU channel
  - To provide data for the assessement of the flow stratification criteria used in CATHENA
- DATA REPORT : CWAPD-433
- LOOP SETUP
  - Bottom channel used
  - Single-break, single-injection configuration
  - Inlet header break line blanked off
- INSTRUMENTATION
  - Thermocouples installed on the pressure tube and heater bundle
  - Ultrasonic flowmeter and two venturi meters installed on the inlet feeder

FLOW STRATIFICATION TESTS
(NO. 1154 TO 1181)

EXPERIMENTAL PROCEDURE

- Subcooled water circulated to preheat loop
- When steady-state temperatures were achieved, the desired injection and blowdown tank pressures were established
- Channel power increased until the channel outlet temperature was slightly below the saturation temperature
- When steady-state conditions were achieved, data logging was started
- As power increased, boiling occurred leading to flow stratification (detected by thermocouples at the top of the heater)
- Test stopped if the maximum heater or pressure tube temperature exceeded 780°C

FLOW STRATIFICATION TESTS
(NO. 1154 TO 1181)

- TEST CONDITIONS
  - Water injection pressure : 0.9 to 5.5 MPa
  - Initial water temperature : 100 to 200°C
  - Blowdown tank pressure : 0.5 to 5.0 MPa
- TESTS USED FOR CATHENA VALIDATION : 1164, 1172, AND 1178

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LARGE-SCALE HEADER (LASH) PROGRAM

By

J.R. Buell

AECL Research

Whiteshell Laboratories

1994 March 9

LASH OBJECTIVES

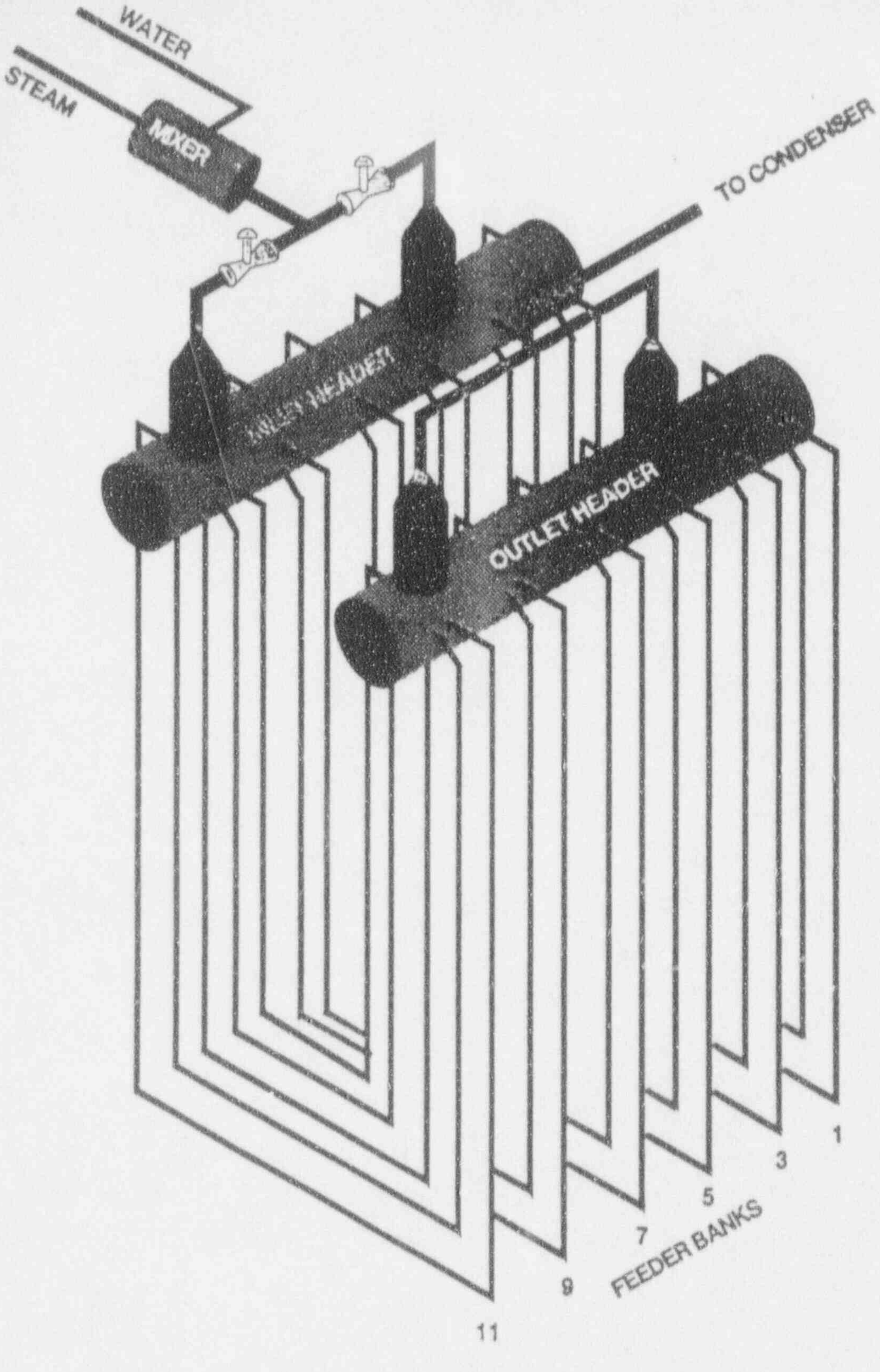
- SPECIFIC OBJECTIVE:
  - Study the behaviour that may occur in a CANDU header/feeder system under two-phase flow conditions and blowdown/refill conditions
- TO PROVIDE
  - An improved understanding of the flow behaviour of a CANDU header/feeder system under postulated accident conditions
  - Identify phenomena that occur during postulated accident conditions
  - Use this information in deriving header models
  - Provide a database for code validation

FACILITY DESCRIPTION

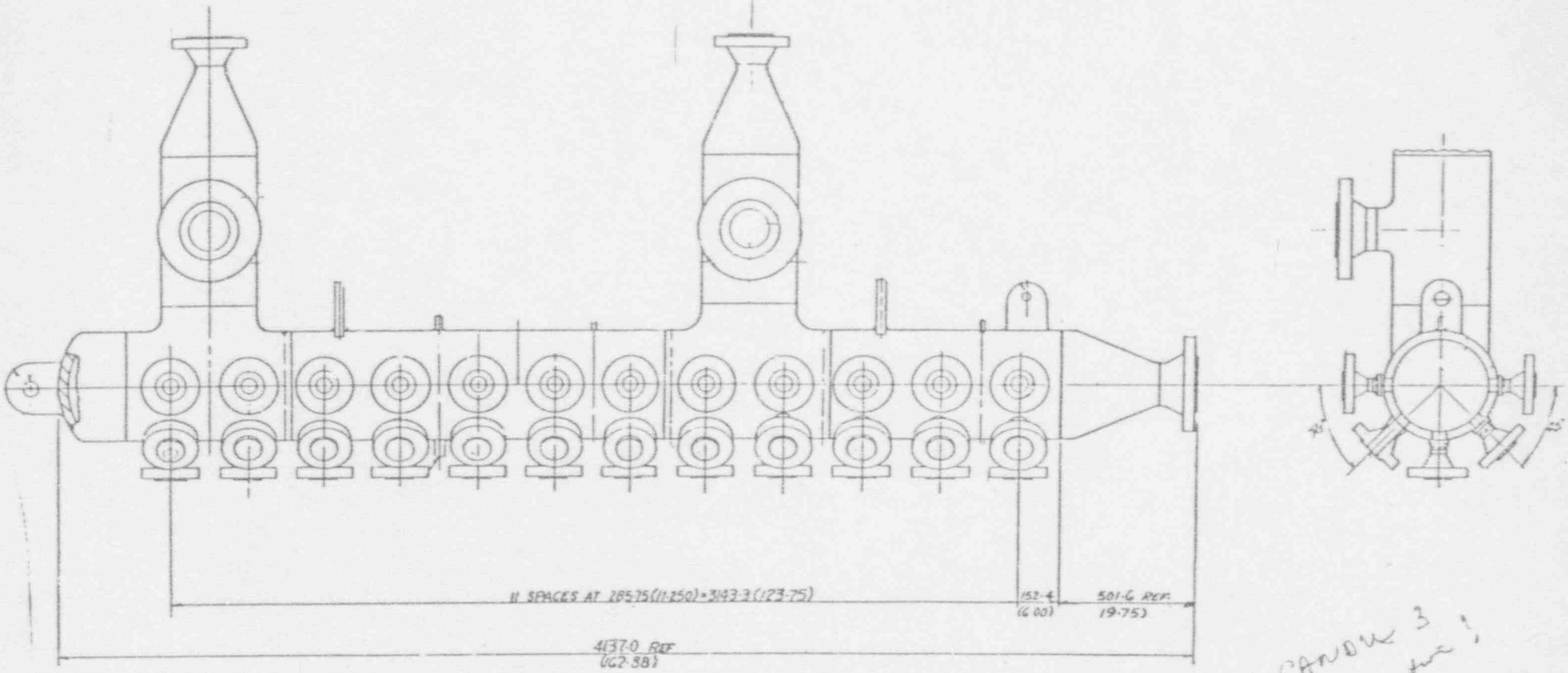
- LOCATED AT STERN LABORATORIES INC. (FORMERLY WESTINGHOUSE CANADA INC.) IN HAMILTON, ONTARIO
- SIMULATION OF A HEADER/FEEDER SYSTEM
- CONSISTS OF :
  - Inlet and outlet headers
    - representative of Pickering NGS headers
      - full-scale diameter (0.325 m)
      - half-length (4.2 m)
      - two turrets per header (3 turrets in CANDU header)

FACILITY DESCRIPTION

- 30 feeder pipes
  - 50-mm diameter
  - "U" shaped
  - vertical inlet and outlet feeders
  - unheated horizontal sections
  - maximum vertical drop 10 m
  - minimum vertical drop 8.6 m
  - layout differs from CANDU feeder geometry



LASH (TWO-PHASE INJECTION TESTS)



CANDU 3
Configuration !

LASH INLET HEADER

INSTRUMENTATION

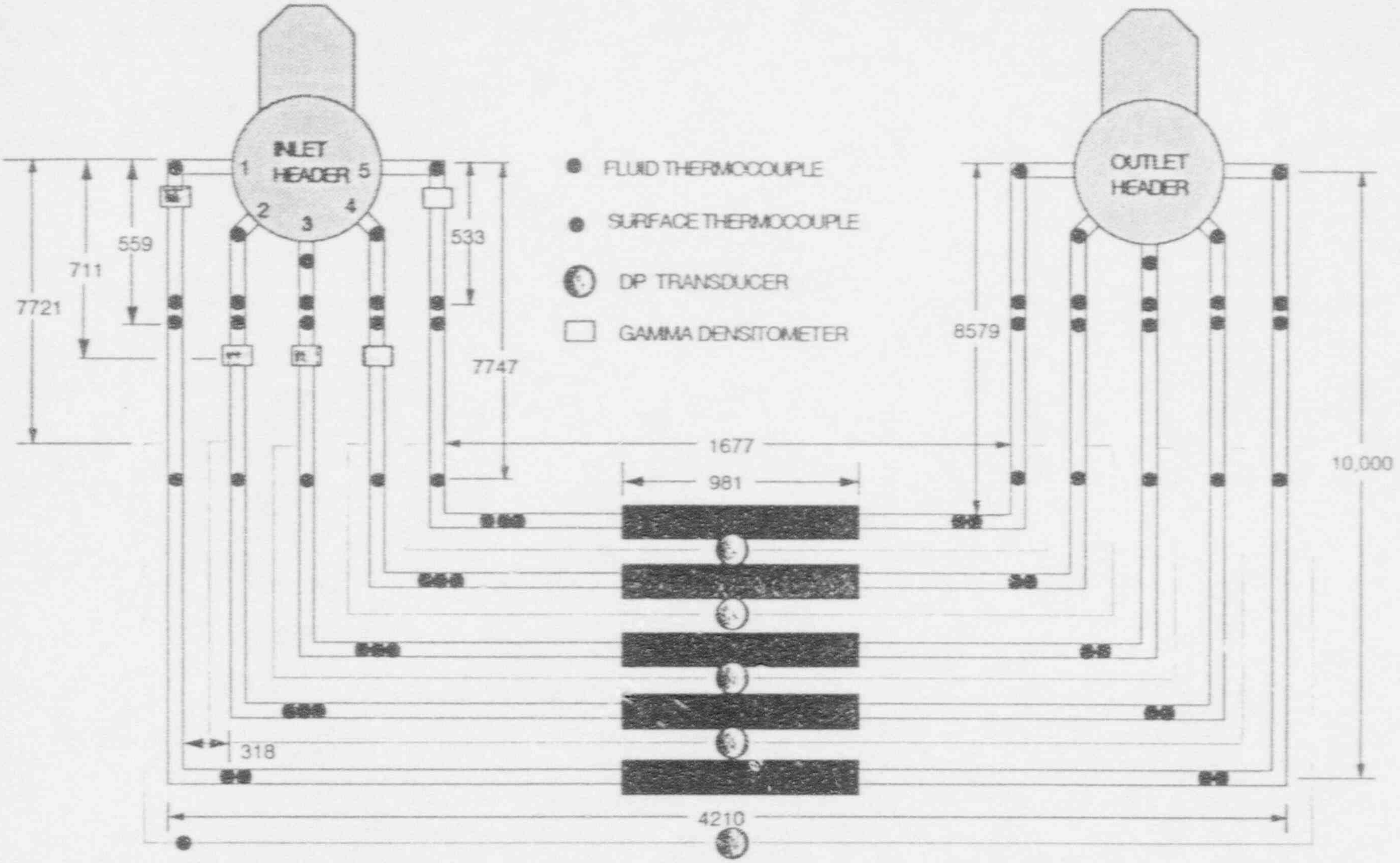
- OVER 300 CHANNELS OF INSTRUMENTATION CONSISTING OF
  - FLOWMETERS
    - turbine flowmeters in horizontal feeder sections
      - calibrated under single-phase liquid conditions
    - orifice meters for measuring steam and liquid flows
      - designed and constructed in accordance with ASME Fluid Meters

INSTRUMENTATION

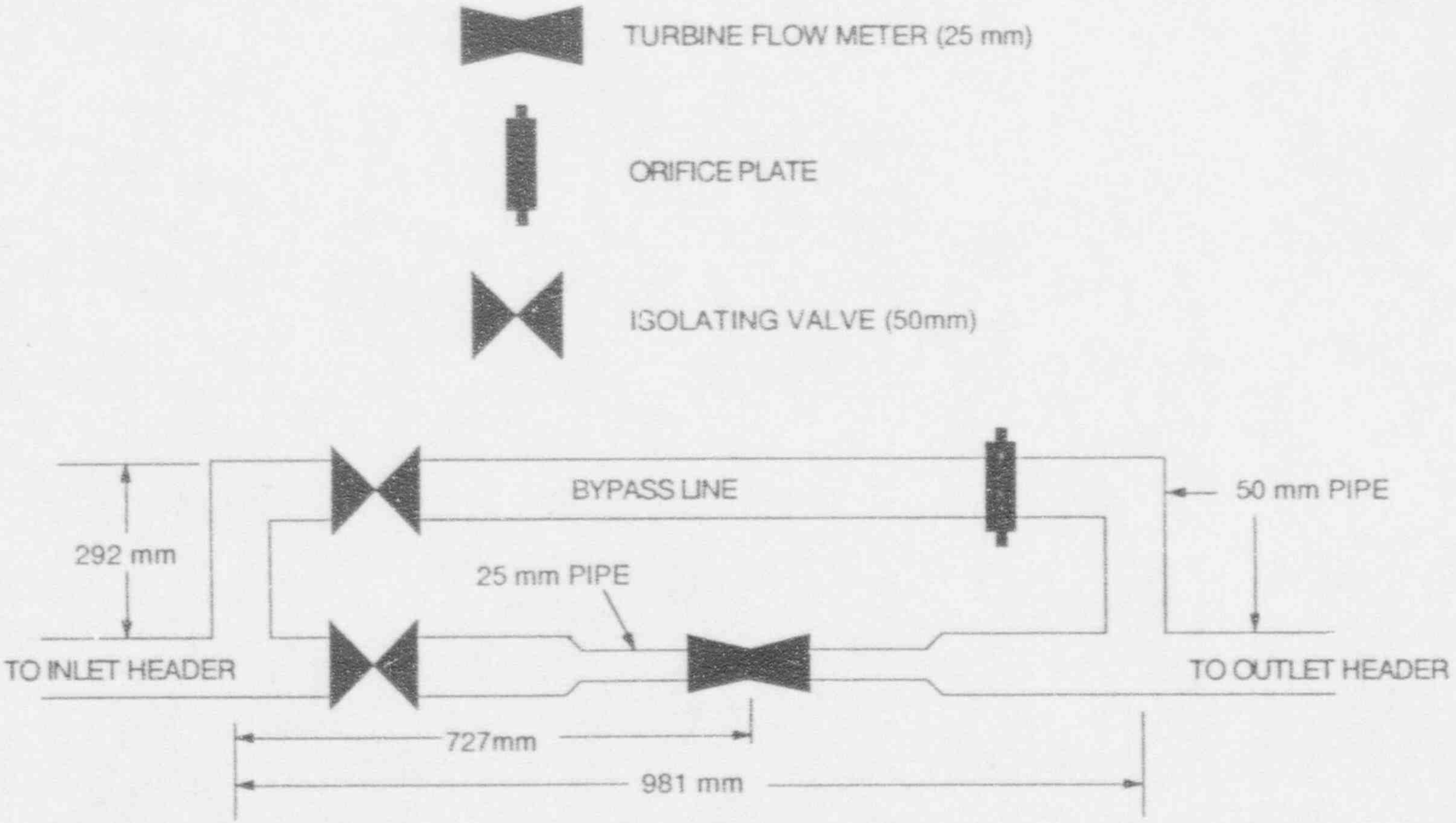
- CONDUCTIVITY/DP/THERMOCOUPLE PROBE
  - used to measure liquid level and phase distributions in inlet and outlet headers
    - DP level measurements
    - conductivity elements to detect liquid or vapour phase
    - thermocouples to measure fluid temperature distribution (refill tests)
- THERMOCOUPLES
  - ungrounded, 1.0 mm diameter, ANSI type K
  - connected to reference junctions
  - standard grade 2.2°C accuracy
  - 45 fluid and 160 surface temperatures

INSTRUMENTATION

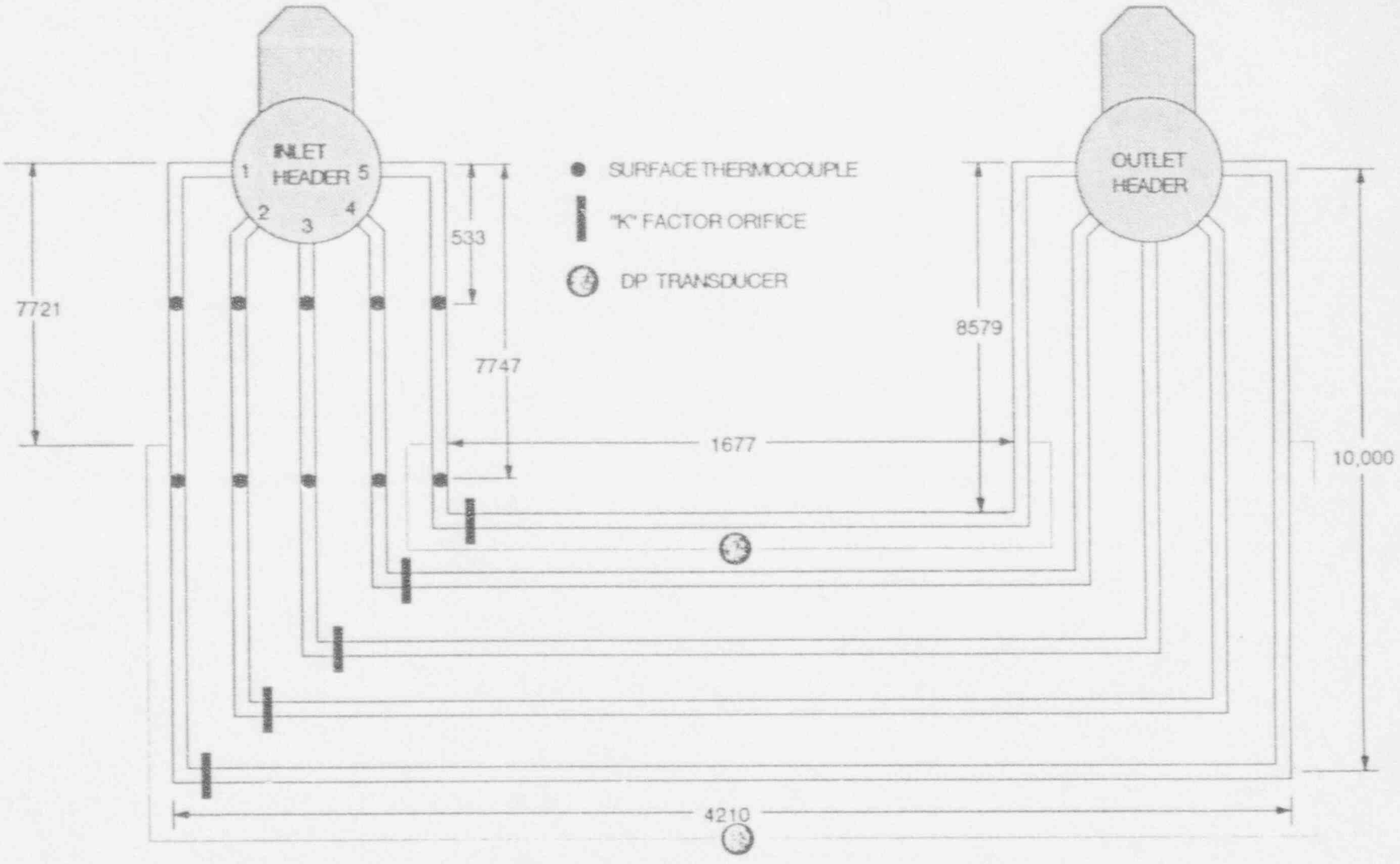
- SINGLE-BEAM GAMMA DENSITOMETERS
  - feeder void fractions
  - Cesium 137, 3 mCi
  - full and empty readings before performing test
- DIFFERENTIAL AND ABSOLUTE PRESSURES
  - strain gauge transducers
  - capacitance transducers
  - calibrated using dead-weight tester and/or mercury manometer
  - vertical sense lines for DP tranducers cooled with water jackets
  - water cooled stand-offs at pressure taps



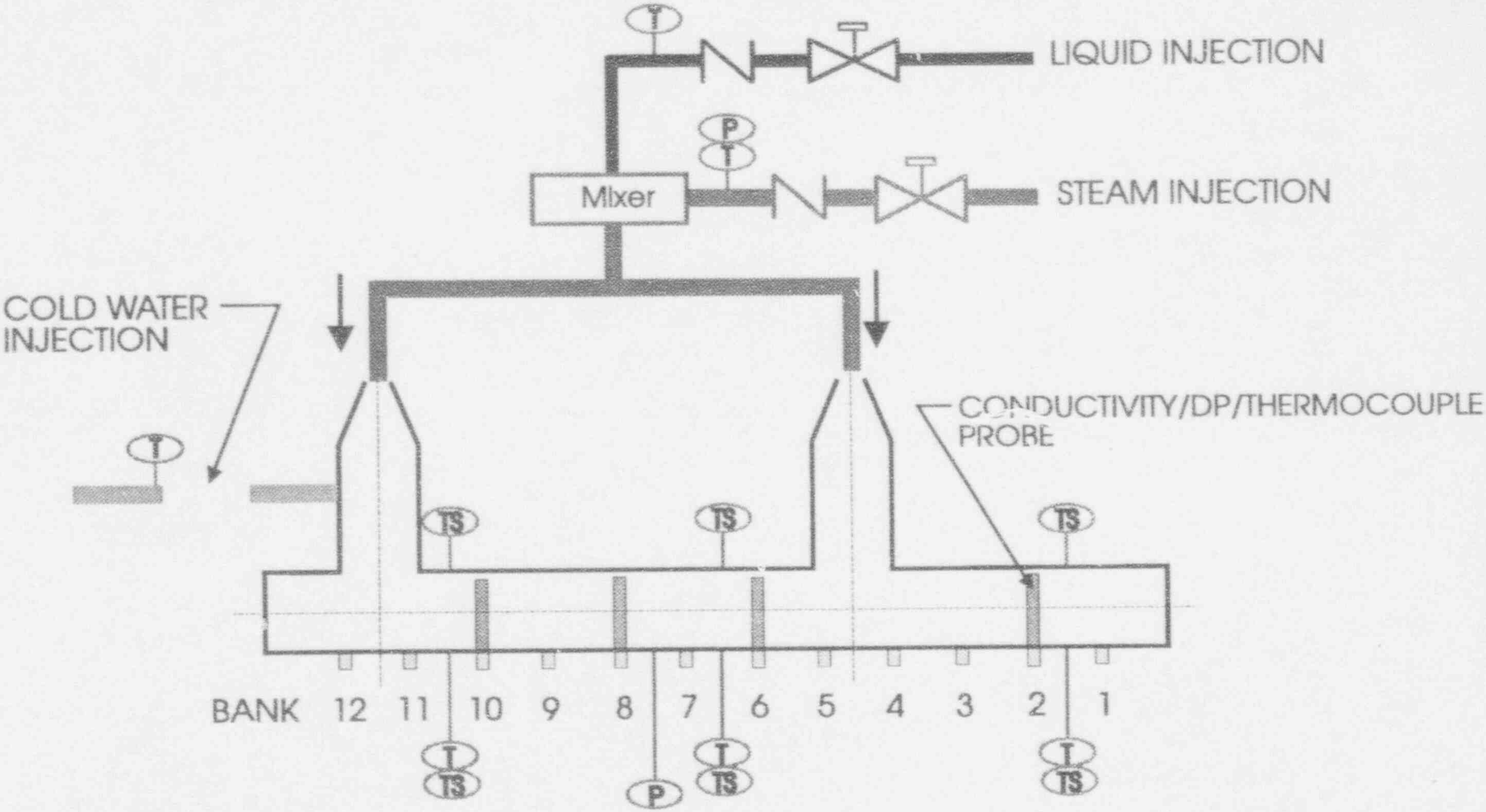
INSTRUMENTATION LOCATIONS FOR FEEDER BANKS 1, 3, 5, 9,
FOR TEST SERIES 686-748



SIMULATED FUEL CHANNEL FOR FEEDER BANKS 1, 3, 5, 9
FOR TEST SERIES 686-748



INSTRUMENTATION LOCATIONS FOR FEEDER BANKS 7, 11
FOR TEST SERIES 686-748



INSTRUMENTATION OF INLET HEADER

TWO-PHASE INJECTION TESTS

- **PURPOSE :**
  - Study the flow behaviour with "steady-state" or near steady-state two-phase injection into the inlet header
  - Obtain data for the onset of vapour pull-through and liquid entrainment in an inlet feeder

TWO-PHASE INJECTION TESTS

- THREE DIFFERENT TEST PROCEDURES
  - Steady two-phase injection : increasing inlet-header injection quality
    - preheat loop with slightly subcooled water at desired pressure, temperature, and flow rate
    - Achieve steady-state temperatures throughout loop
    - inject superheated steam into mixer to achieve desired inlet-header injection quality
    - record data (average of 20 or 30 scans)
    - increase inlet-header injection quality in steps of approximately 0.2 to 0.5% until turbine flowmeter reaches maximum flow rate

TWO-PHASE INJECTION TESTS

– Steady two-phase injection : decreasing inlet-header injection quality

  - preheat loop as before
  - start from high steam injection flow rate
  - decrease inlet-header injection quality
  - performed with fixed liquid injection flow rate and pressure

TWO-PHASE INJECTION TESTS

- Time dependent two-phase injection
  - preheat loop as before
  - performed with fixed liquid injection flow rate and pressure
  - record data at approximately 1 sample per second
  - slowly increase steam injection flow rate until
    - steam flow reaches maximum of 0.9 kg/s
    - turbine flowmeter reaches maximum flow rate

STEADY TWO-PHASE INJECTION TESTS 238 TO 374

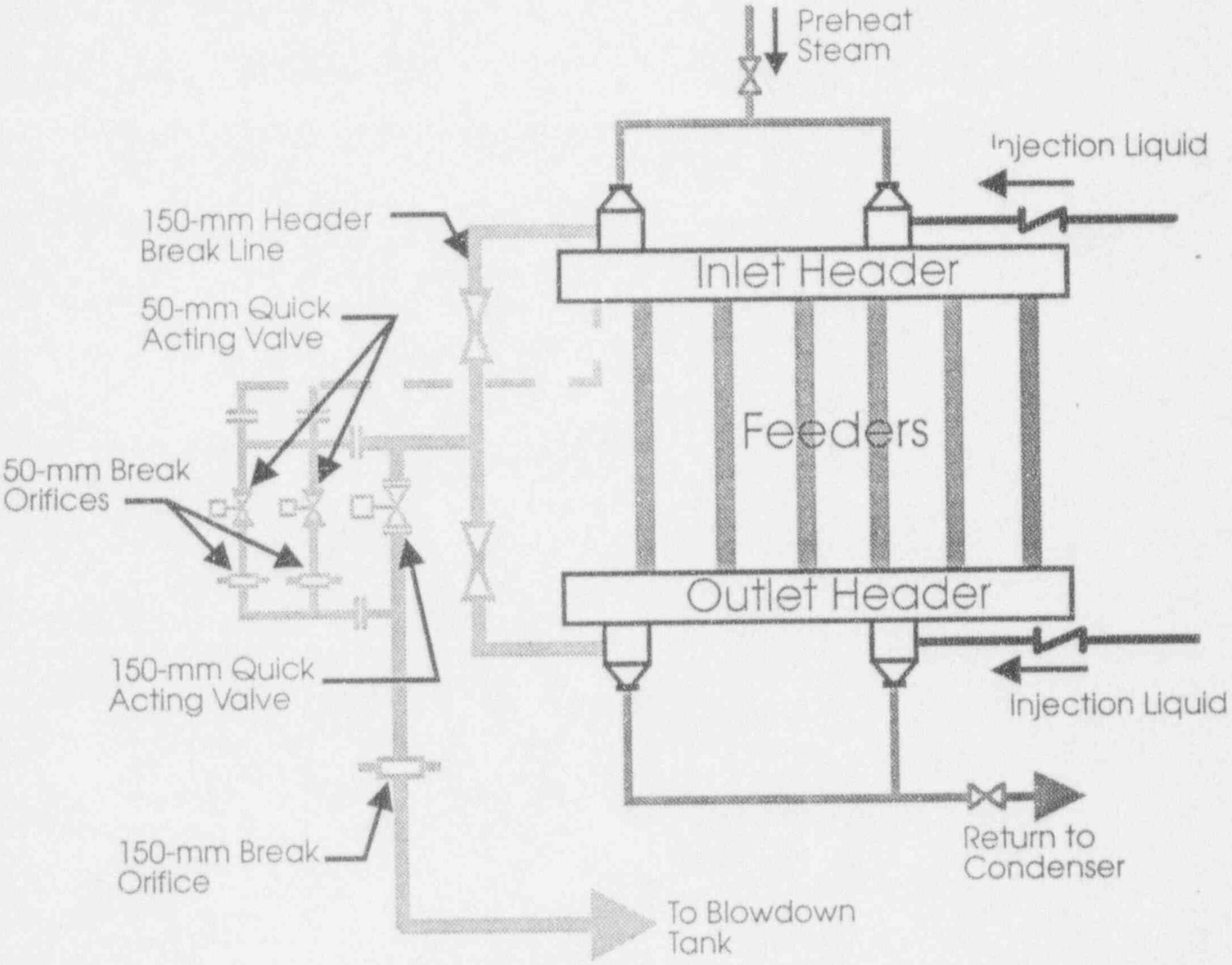
- DATA REPORT : CWAPD-478
- INSTRUMENTATION
  - 15 gamma densitometers on all inlet feeders of banks 1, 5, and 9
  - Turbine flowmeters on all feeders banks 1, 5, 9, and 11
- TEST CONDITIONS
  - Increasing and decreasing injection quality mode

TEST MATRIX
TESTS 238 TO 374

Test Number	Pressure (MPa)	Number Turrets	Liquid Inj. Flow Rate (kg/s)	Injection Quality (%)		
				Initial	Maximum	Final
238 - 247	2	2	30	-1.2	1.9	-0.2
248 - 264	2	2	60	-0.4	1.8	-1
265 - 281	1	2	60	-0.8	2.3	-0.3
282 - 296	2	2	30	-1.1	2.3	-0.5
297 - 312	5	2	30	-2.2	3.6	-1.3
313 - 327	1	1	30	-1.1	0.2	-0.2
328 - 343	2	1	30	-0.9	1.8	-0.4
347 - 364	5	1	30	-2.2	3.1	-1.4
365 - 374	2	1	60	-0.4	0.9	-1.2

BLOWDOWN/REFILL TESTS

- PURPOSE :
  - Simulate conditions that may occur in a CANDU header/feeder system during certain accident scenarios
  - Study the refill behaviour during cold-water injection with various break sizes and locations
- PROCEDURE
  - Preheat loop to desired temperature using superheated steam
  - Pressurize loop at desired pressure
  - Initiate blowdown by opening quick acting valve(s)
  - Inject cold water into both headers



LASH BLOWDOWN CONFIGURATION

BLOWDOWN/REFILL WITH INLET AND/OR OUTLET HEADER BREAK : TESTS 500 TO 522

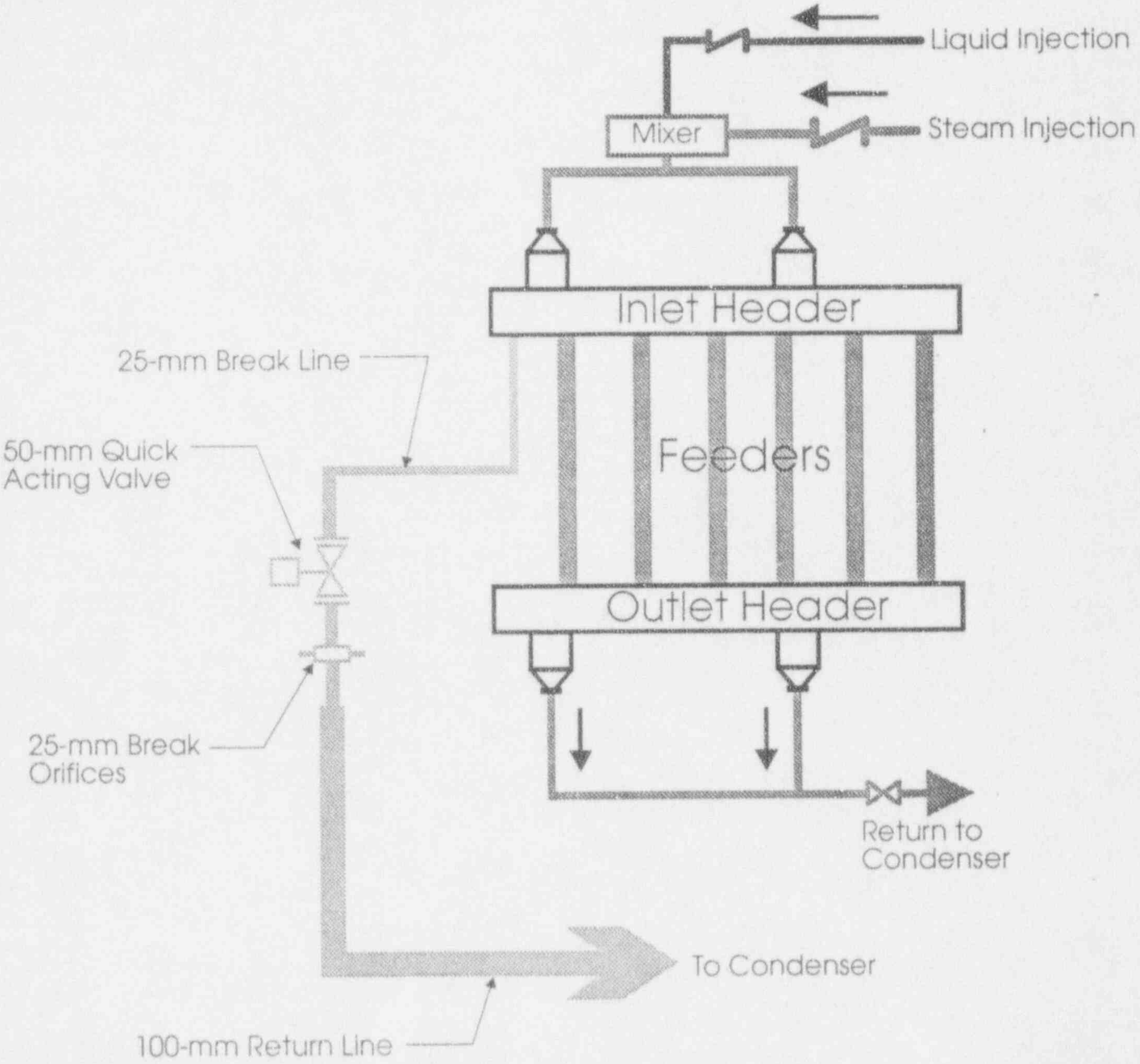
- PURPOSE:
  - Study the refill behavior and obtain quench and refill times for tests with inlet and/or outlet header breaks
- DATA REPORT : SLI-004
- INSTRUMENTATION
  - Turbine flowmeters banks 1, 5, 9, and 11
  - 20 single-beam gamma densitometers
    - inlet and outlet feeders banks 1 and 9
    - located near top of feeder

BLOWDOWN/REFILL WITH INLET AND/OR OUTLET HEADER BREAK : TESTS 500 TO 522

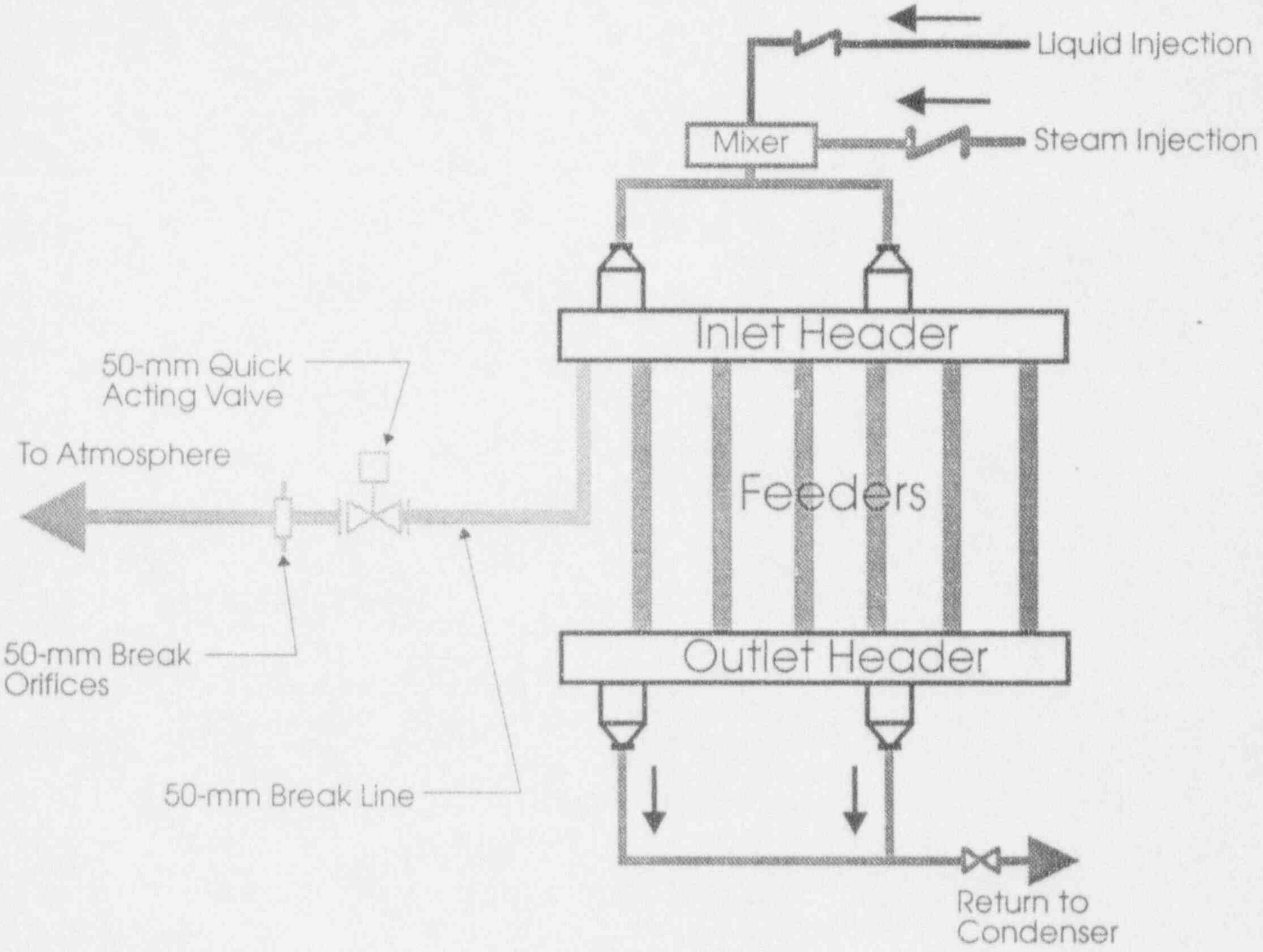
- TEST CONDITIONS
  - Cold-water injection flow rate : 30 and 60 kg/s at 30°C
  - Initial pressure : 1.7 to 5.0 MPa
  - Break sizes : 50, 100, 150 mm
  - Break locations
    - inlet header
    - outlet header
    - both headers
  - Preheat temperature : 200°C to 380°C

BLOWDOWN TESTS : TESTS 686 TO 748

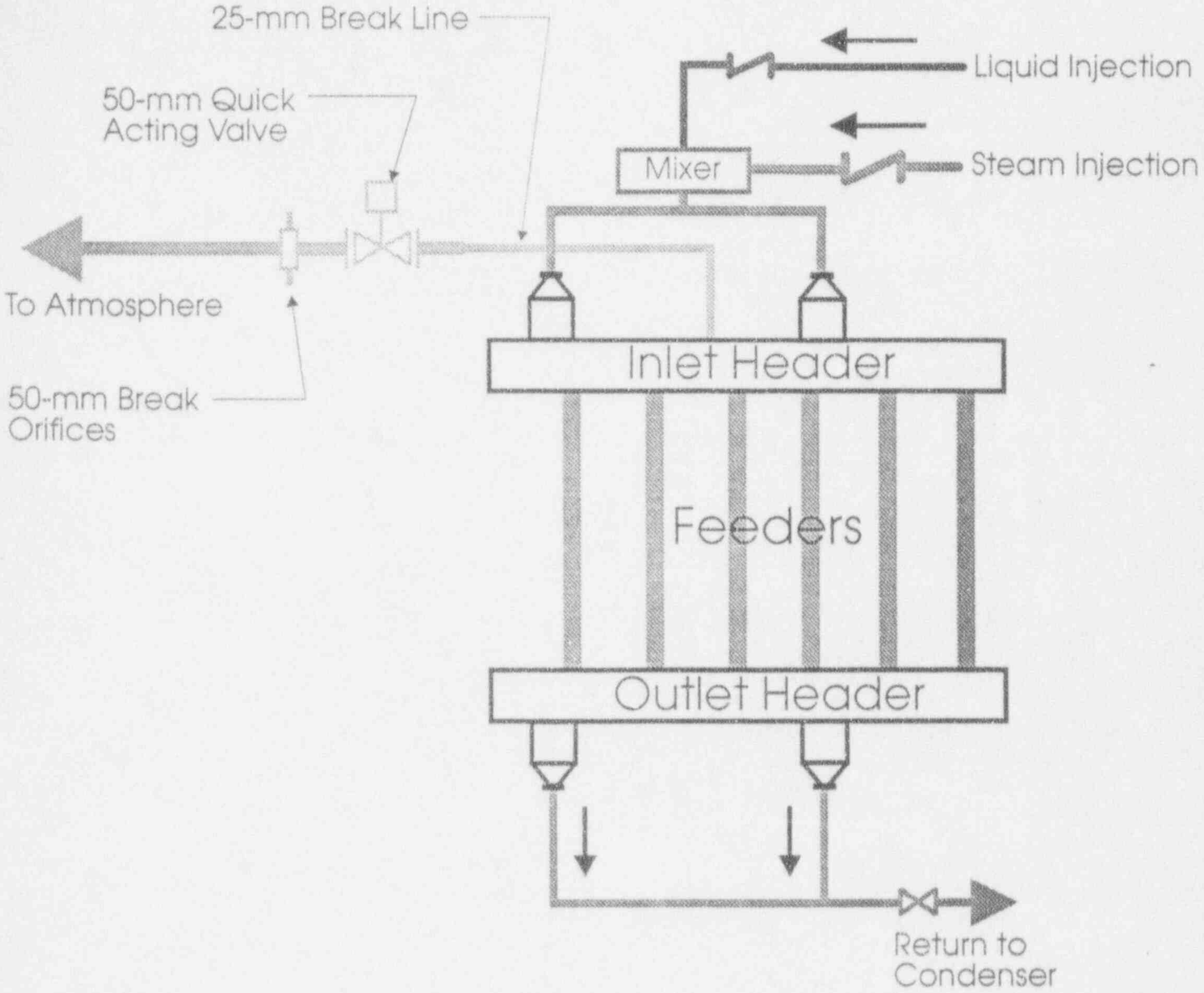
- PURPOSE :
  - Study the blowdown behaviour with liquid injection or two-phase injection into the inlet header
- DATA REPORT : SL-018
- PROCEDURE
  - Preheat loop to desired temperature using subcooled water
  - Inject fixed liquid and steam flow into inlet header
    - single and two-turret injection
  - Continuously scan data
  - Initiate blowdown by opening quick acting valve



LASH BLOWDOWN CONFIGURATION 1



LASH BLOWDOWN CONFIGURATION 2



LASH BLOWDOWN CONFIGURATION 3

BLOWDOWN TESTS : TESTS 686 TO 748

- TEST CONDITIONS
  - One and two-turret injection
  - Liquid injection flow rate : 0 to 60 kg/s
  - Initial injection quality : single-phase liquid and 0.5% to 2.8%
  - Initial pressure 5 MPa

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END-FITTING CHARACTERIZATION PROGRAM

By

J.E. Kowalski and E.L. Bibeau

AECL Research

Whiteshell Laboratories

1994 March 9

OBJECTIVES

- SPECIFIC OBJECTIVES
  - Flow resistance characterization of a CANDU end-fitting under single- and two-phase flow conditions at low flow rates and for different flow paths
  - Determine transient blowdown behavior for different blowdown paths
  - Heat transfer characterization for various regions of the end-fitting under single- and two-phase flow conditions
- TO PROVIDE
  - An improved understanding of the thermalhydraulic behaviour of a CANDU end-fitting under postulated accident conditions
  - Determine if the water in the dead space can be accounted for cooling of the fuel during some postulated accidents
  - A database for code validation

FACILITY DESCRIPTION

- LOCATED AT STERN LABORATORIES INC. (FORMERLY WESTINGHOUSE CANADA INC.) IN HAMILTON, ONTARIO
- TEST FACILITY CONSISTS OF :
  - Darlington end-fitting (Phase I) and CANDU-6 end-fitting (Phase II)
  - Fuel channel containing five simulated fuel bundles
- Three different loop configurations:
  1. Flow resistance tests: two-phase loop which can be configured to obtain six flow paths:
     - Feeder to channel
     - Dead space to channel
     - Dead space to feeder/channel
     - Channel to feeder
     - Dead space to feeder
     - Channel/feeder to dead space
  2. Blowdown tests: added two break orifices, two quick acting valves, a 6" blowdown line, and a blowdown tank
  3. Heat transfer tests: modifications are scheduled later this year

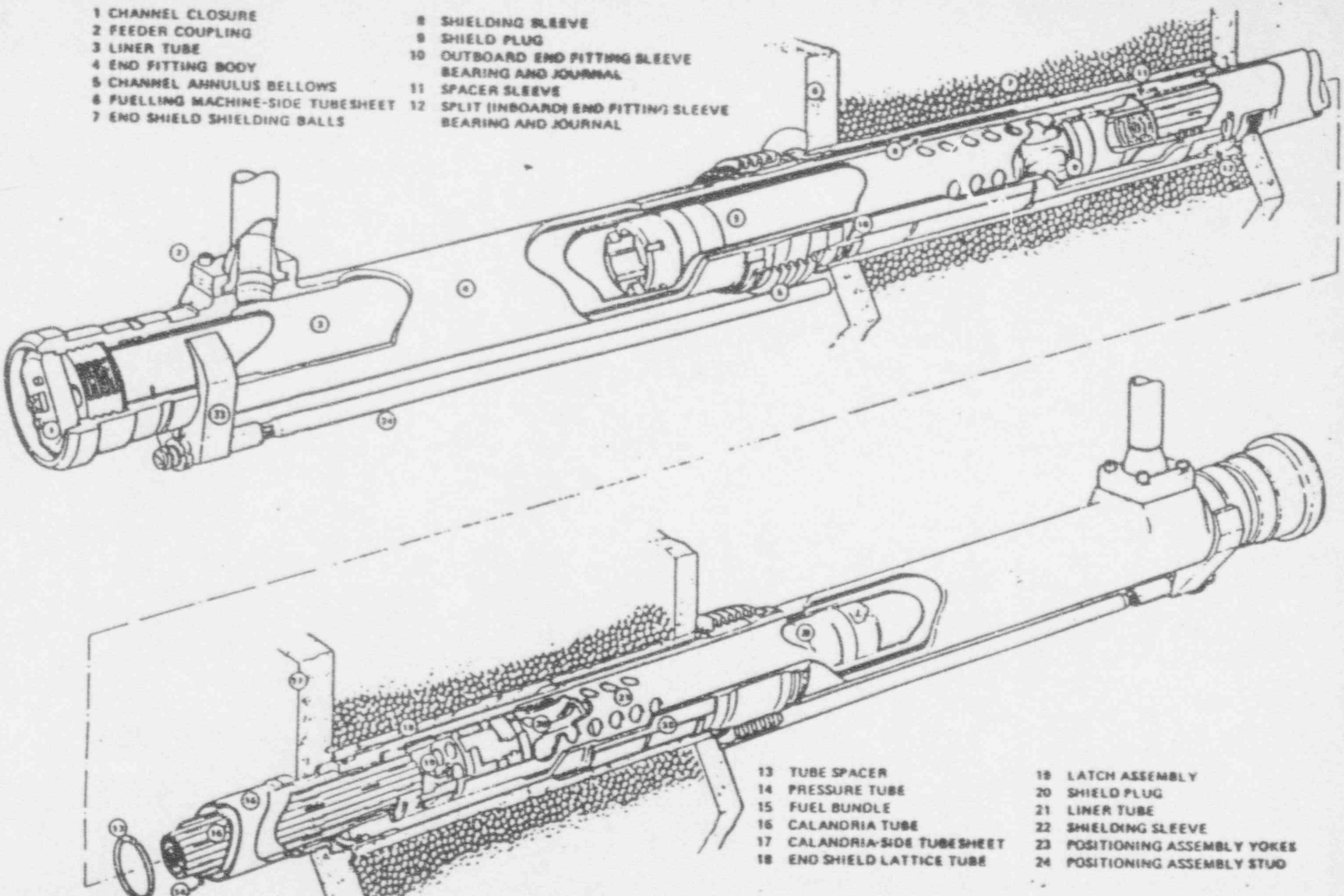
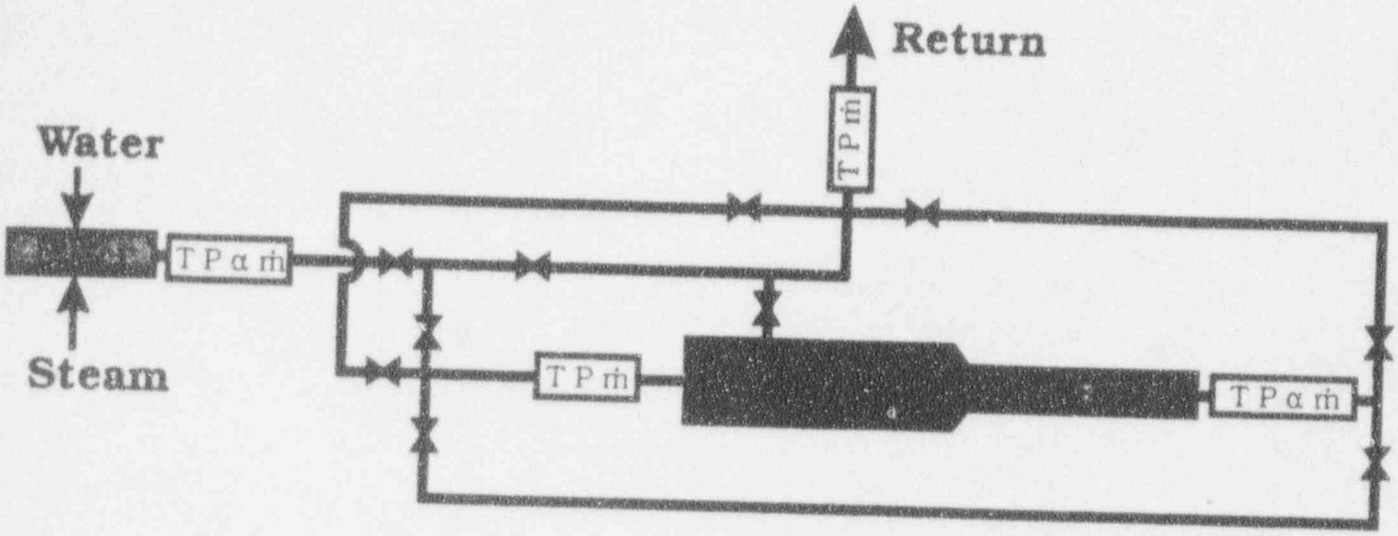
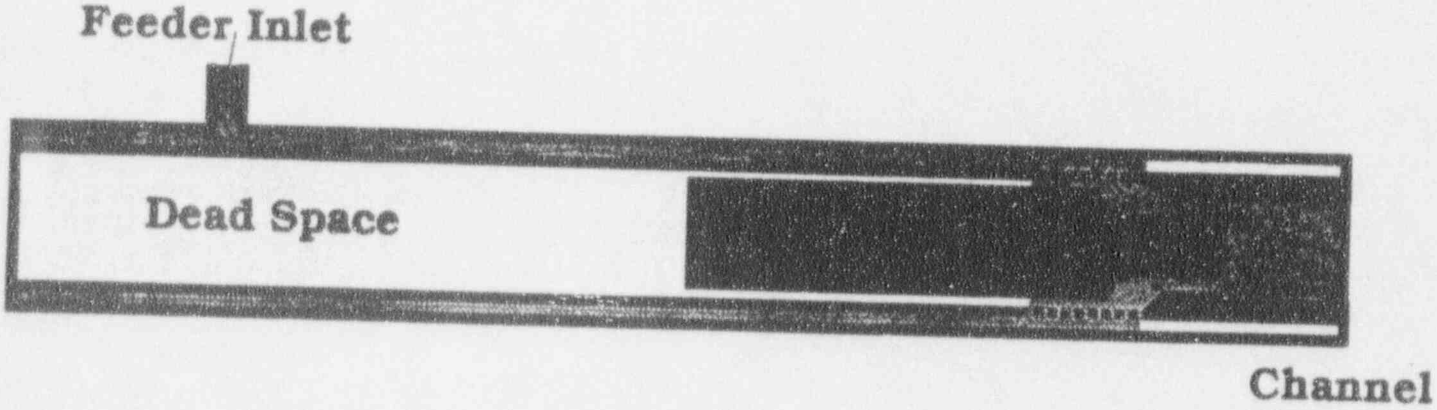


FIGURE 1 DARLINGTON 'A' FUEL CHANNEL ASSEMBLY

Test Facility



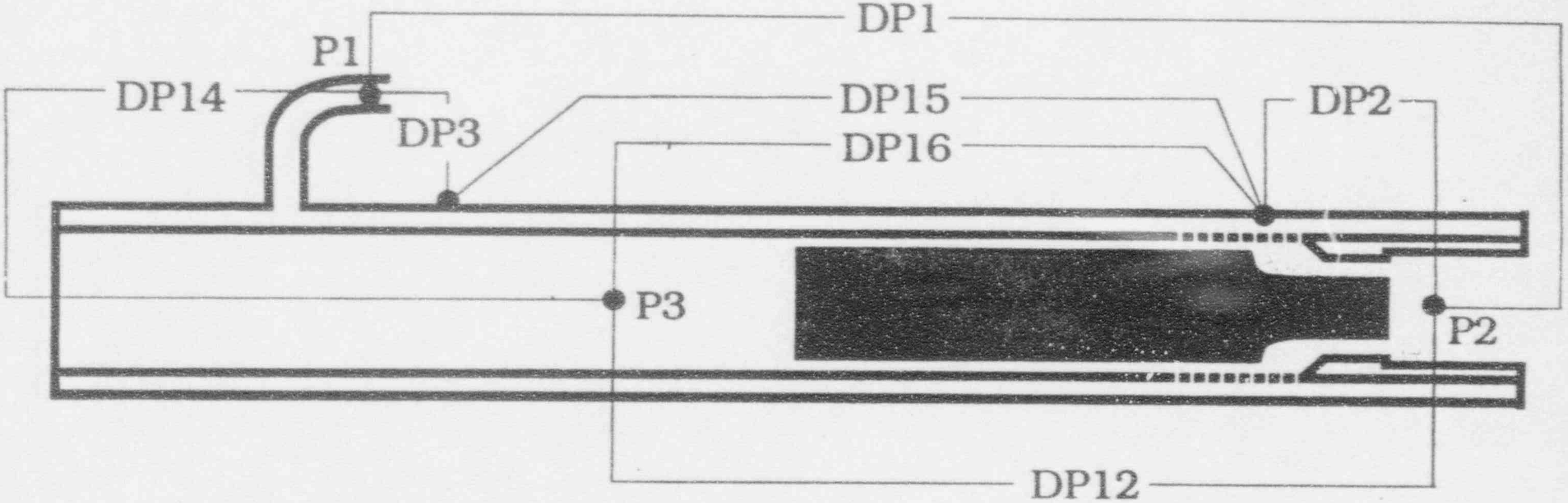
End-Fitting Component



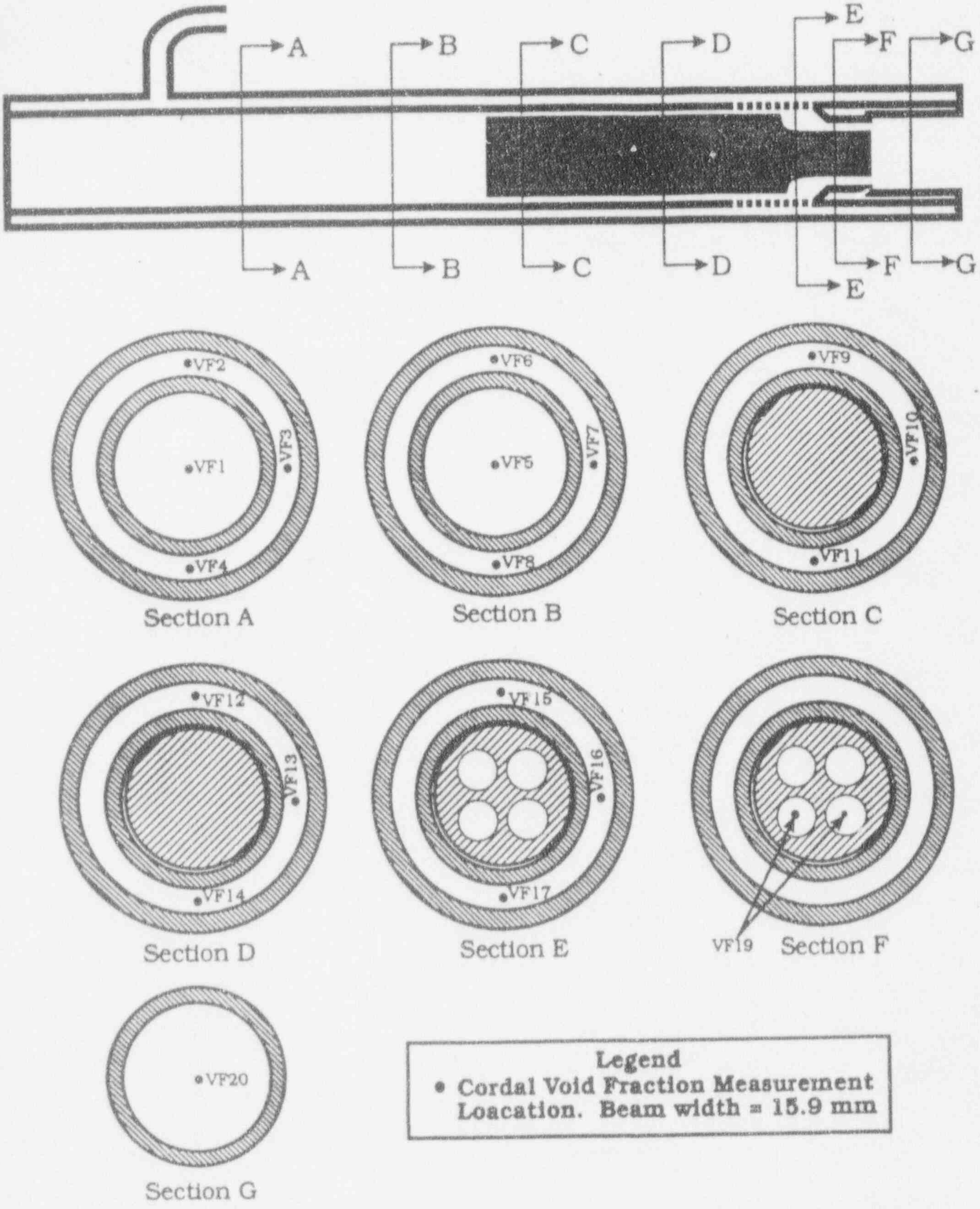
End-Fitting Characterization

INSTRUMENTATION

- END-FITTING
  - 19 gamma densitometers in the annulus, dead space, shield plug holes, and channel
  - 80 thermocouples to measure fluid and wall temperatures
  - 11 turbine flowmeters in the annulus, dead space, channel, and shield plug holes
  - 5 Pitot tubes in the annulus and in the channel
  - 8 DP water level measurements in the annulus, the dead space, and the channel
  - 17 differential pressure transducers measuring 7 pressure drops
  - 3 absolute pressure transducers
- TWO-PHASE LOOP
  - 2 gamma densitometers, 11 thermocouples, 4 absolute pressure transducers, 4 turbine flow meters, 2 Venturi flow meters, and 2 orifice flow meters

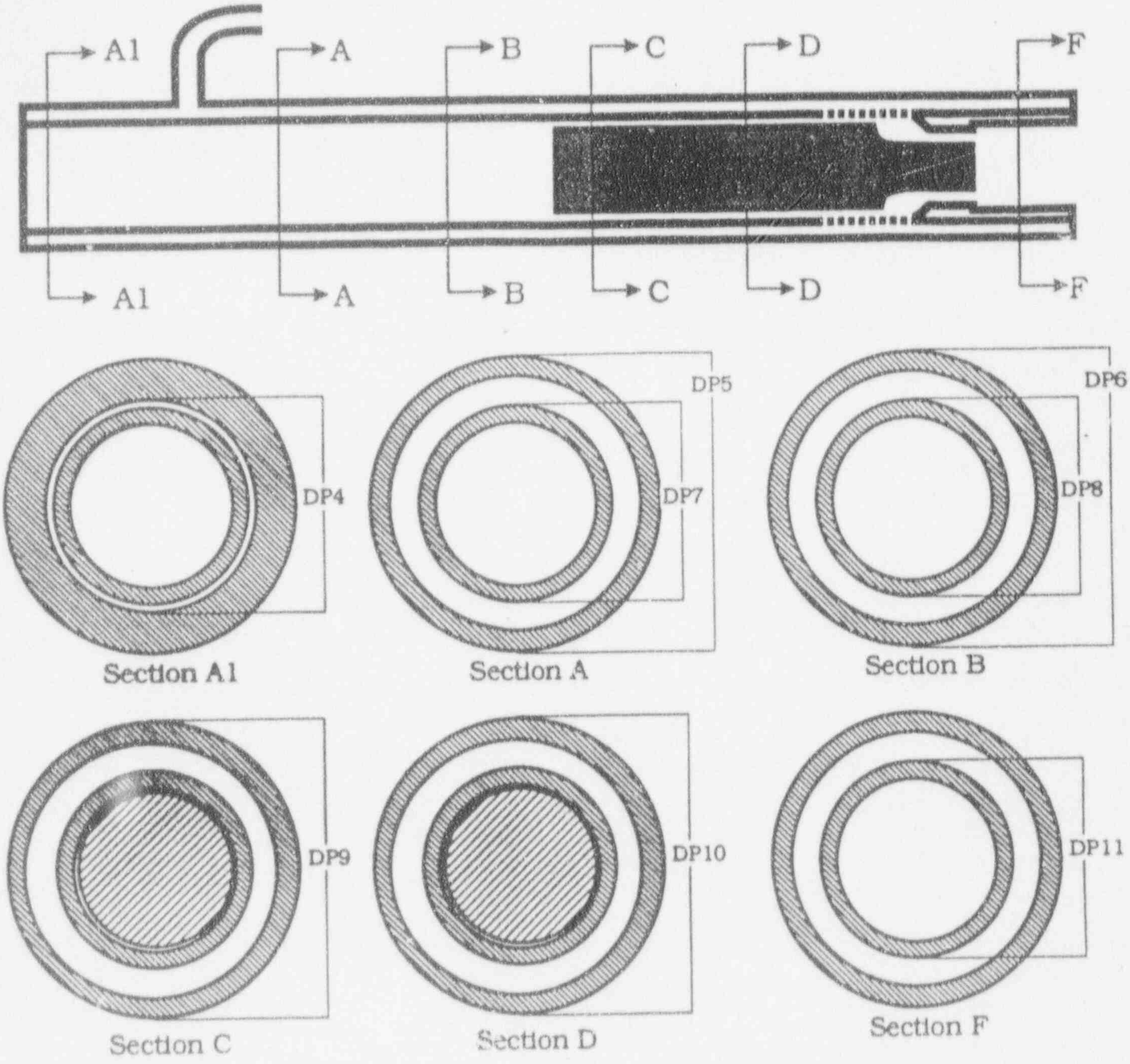


Absolute and Differential Pressure Measurements



Legend

● Cordal Void Fraction Measurement Loacation. Beam width = 15.9 mm



Section A1

Section A

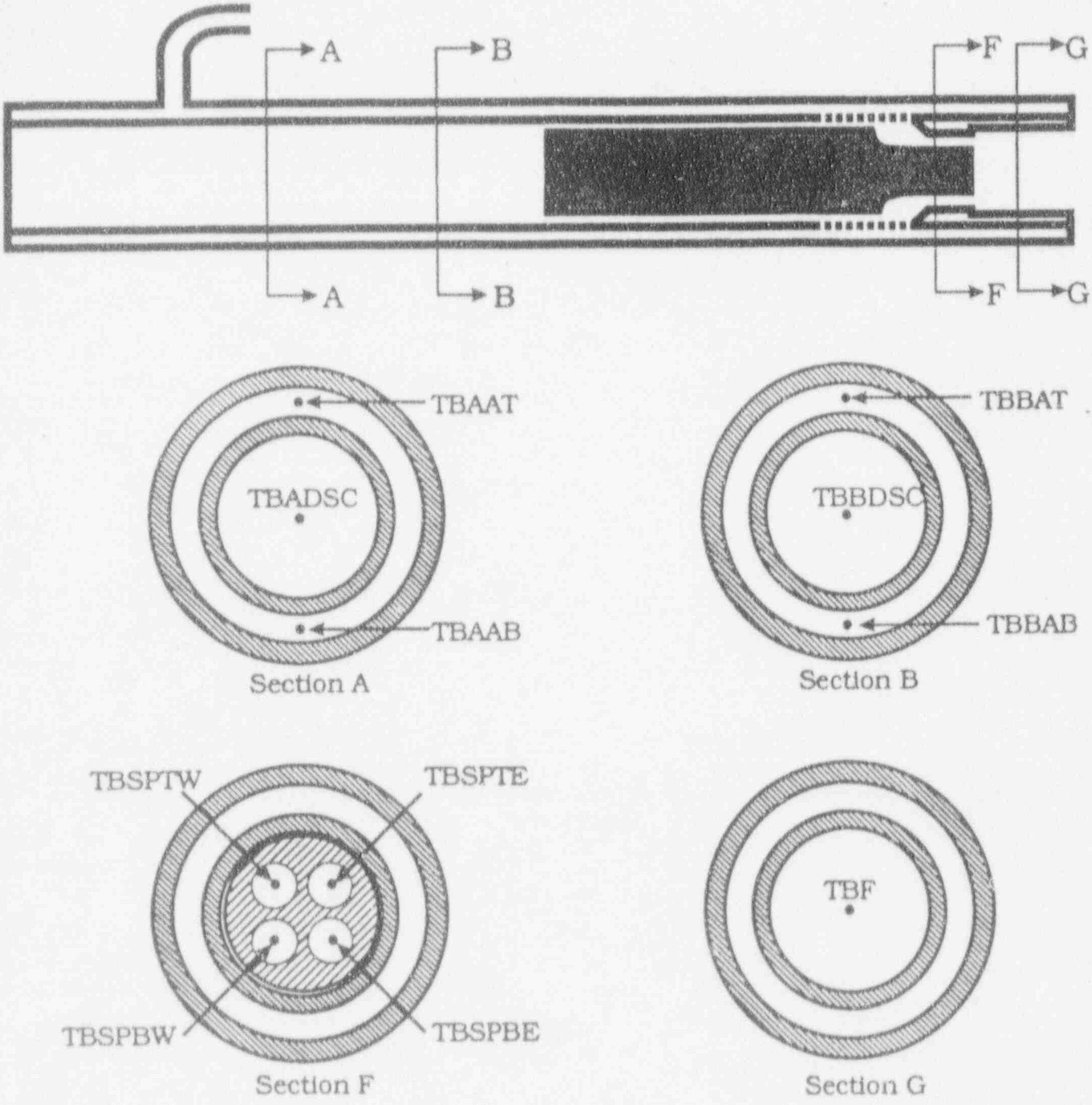
Section B

Section C

Section D

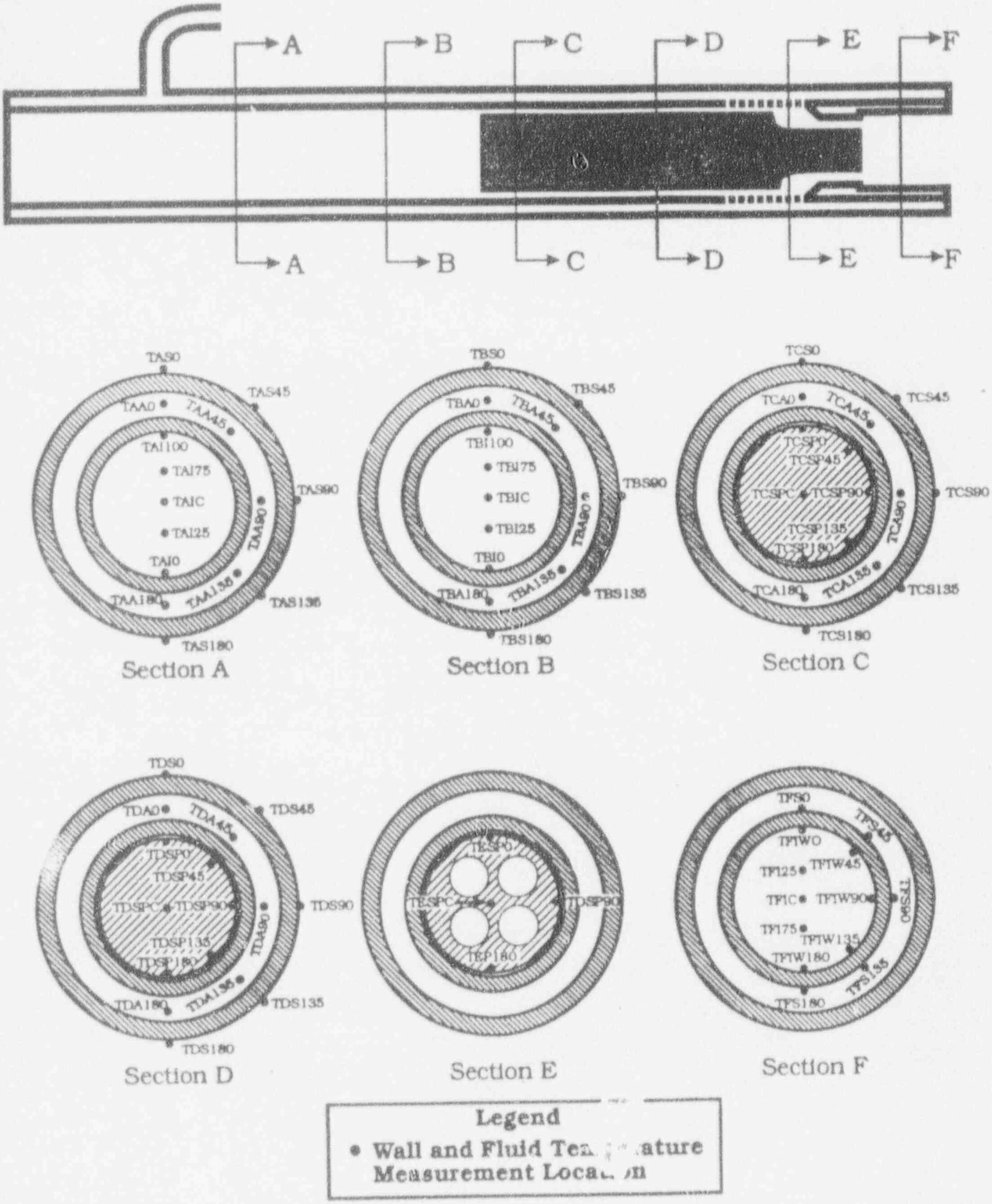
Section F

Legend
● Fluid level Measurement Location



Legend

- ● 13 and 35 mm Turbine Flow Meter Location


A
B
C
D
E
F
TAS0
TAS45
TAA0
TAA45
TAI100
TAI75
TAIC
TAI25
TAS90
TAA90
TAI0
TAA180
TAA135
TAS135
TAS180
Section A
TBS0
TBS45
TBA0
TBA45
TBI100
TBI75
TBIC
TBI25
TBS90
TBA90
TBI0
TBA180
TBA135
TBS135
TBS180
Section B
TCS0
TCS45
TCA0
TCA45
TCSP0
TCSP45
TCSPC
TCSP90
TCS90
TCA90
TCSP135
TCSP180
TCA180
TCA135
TCS135
TCS180
Section C
TDS0
TDS45
TDA0
TDA45
TDSP0
TDSP45
TDSPC
TDSP90
TDS90
TDA90
TDSP135
TDSP180
TDA180
TDA135
TDS135
TDS180
Section D
TESP0
TESPC
TDSP90
TEP180
Section E
TFS0
TFS45
TFIW0
TFI25
TFIW45
TFIC
TFIW90
TFS90
TFI75
TFIW135
TFIW180
TFS135
TFS180
Section F
Legend
● Wall and Fluid Temperature Measurement Location

TESTS SERIES (PHASE I)

- **FLOW RESISTANCE TESTS**
  - SPW-001 to SPS-056: Commissioning Tests (Dec 1992)
  - SPW-057 to SPS-140: Commissioning Tests (Feb 1994)
  - SPW-141 to SPS-465: Flow Resistance Tests (Feb 1994)
- BLOWDOWN AND HEAT TRANSFER TESTS ARE SCHEDULED IN APRIL 1994 AND DECEMBER 1994, RESPECTIVELY

TEST MATRIX FOR FLOW RESISTANCE TESTS

- WATER FLOW
  - Pressure: 0.5, 1.0, 4.5 MPa
  - Flow rate: 0.3 to 5.0 kg/s
  - Temperature: 30 and 230 °C
  - Flow paths: 6
- STEAM FLOW
  - Pressure: 1.0, 4.5 MPa
  - Flow rate: 0.05 to 0.7 kg/s
  - Temperature: 30 to 50 °C superheat
  - Flow paths: 6
- STEAM/WATER TWO-PHASE FLOW
  - Pressure: 0.5, 1.0, 4.5 MPa
  - Flow rate water: 0.5 to 3.0 kg/s
  - Flow rate steam: as required (0.02 to 0.4 kg/s)
  - Temperature: saturated
  - Void Fraction: 20 to 80 % void
  - Flow paths: 6

TEST PROCEDURE FOR FLOW RESISTANCE TESTS

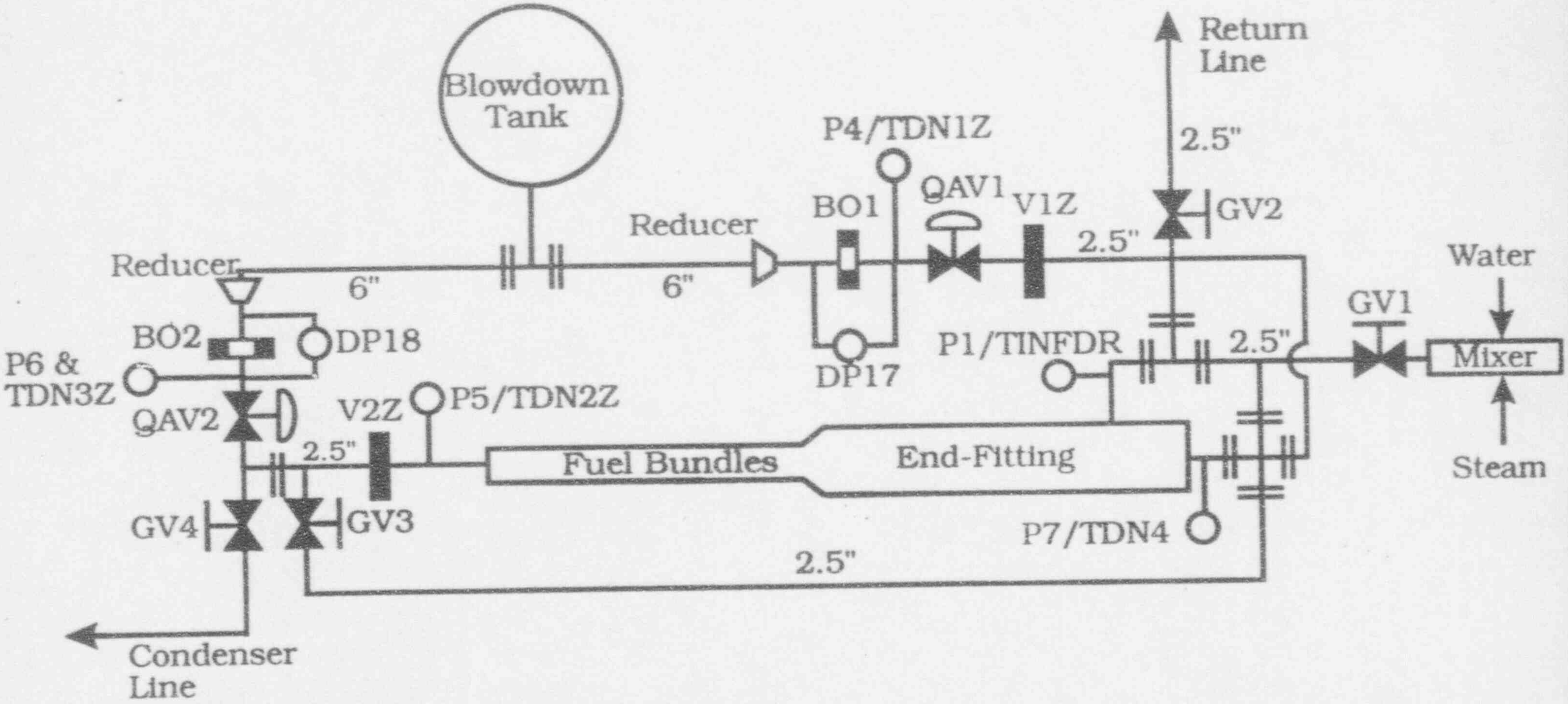
STEAM FLOW

- For each flow path, the loop is preheated to the desired temperature by circulating steam
- The desired pressure and temperature (30 °C superheat) is established through the loop
- The end-fitting surface temperatures are verified to be above saturation to prevent condensation
- All pressure transducers are purged and equalized; DP transducers "zero flow" measurements are obtained
- Steam flow is adjusted to desired value
- Data is recorded at a 10 Hz sampling rate for 60 s
- Zero flow DP measurements are checked

TEST PROCEDURE FOR FLOW RESISTANCE TESTS

WATER AND TWO-PHASE FLOW

- For each flow path, the loop is preheated to the desired temperature by circulating subcooled water
- All pressure transducers are purged and equalized; DP transducers "zero flow" measurements are obtained
- A small amount of superheated steam is injected into the mixer until the desired void fraction is achieved for two-phase flow tests
- Data is recorded at a 10 Hz sampling rate for 60 s
- Zero flow DP measurements are checked



Experimental Facility for Blowdown Experiments

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CRITICAL HEAT FLUX (CHF) TEST FACILITY

JANUSZ KOWALSKI

AECL Research

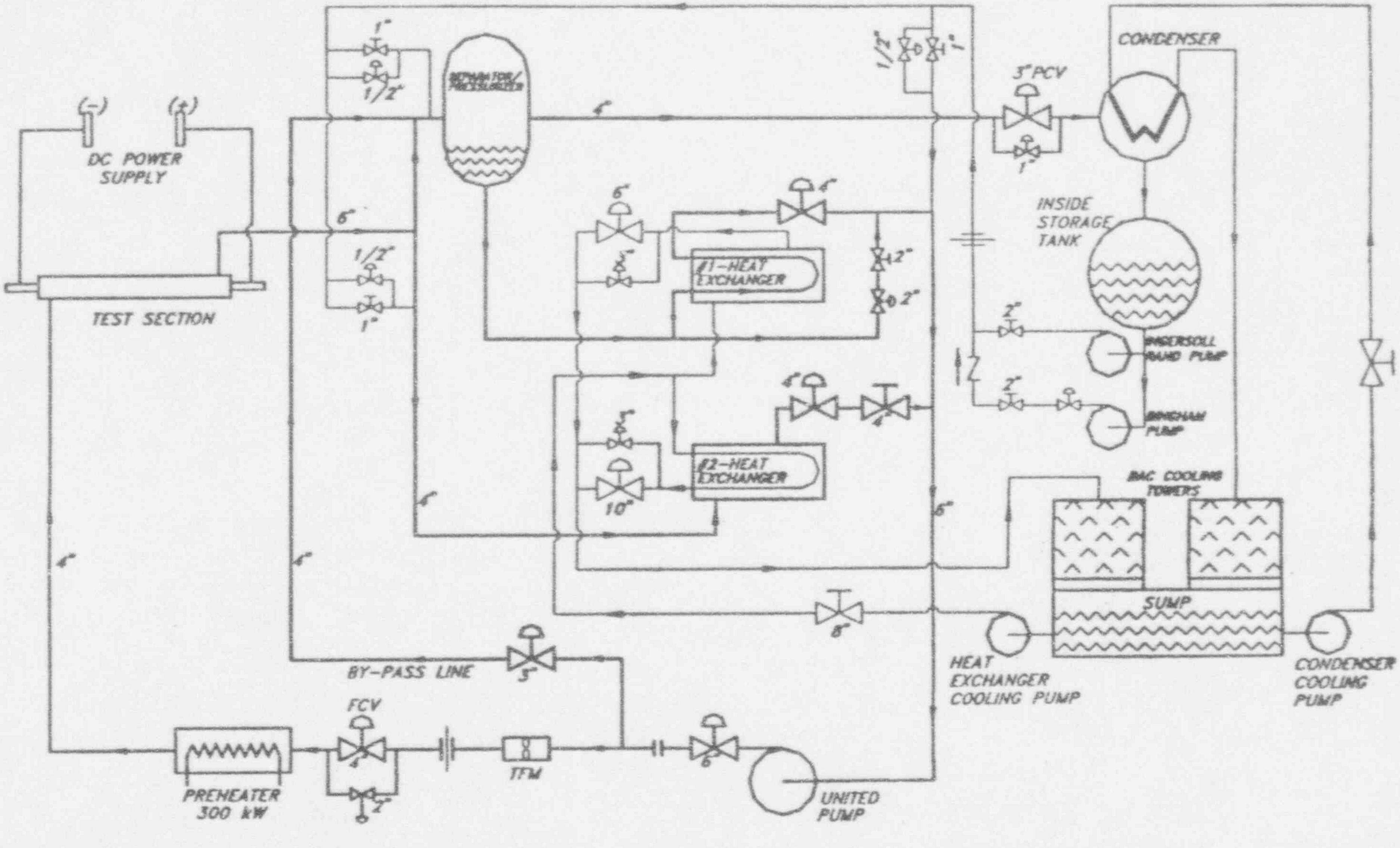
1994 March 9

OBJECTIVES

- SPECIFIC OBJECTIVES
  - Determine dryout (CHF) in simulated CANDU reactor fuel assemblies under steady and transient conditions
- TO PROVIDE
  - A database of dryout (CHF) values under various flow conditions for code validation

FACILITY DESCRIPTION

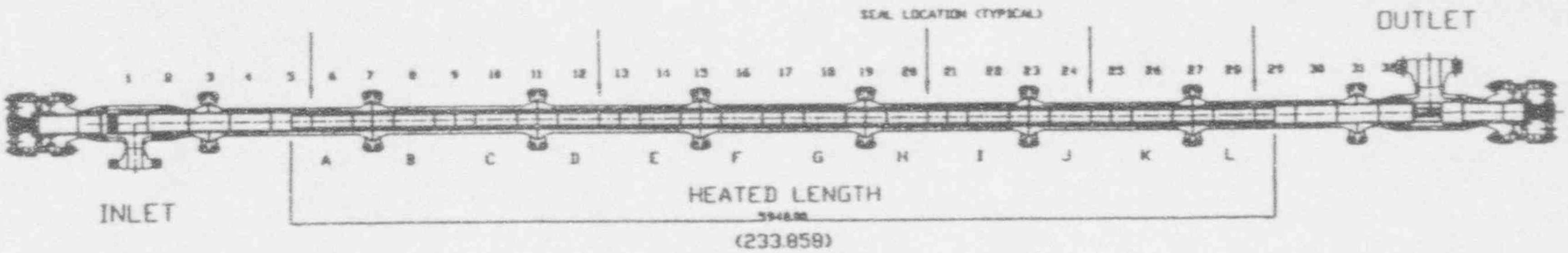
- LOCATED AT STERN LABORATORIES INC. (FORMERLY WESTINGHOUSE CANADA INC.) IN HAMILTON, ONTARIO
- PRIMARY 12.5 MPa TEST LOOP
  - Pump: rated at 55 l/s at 380 m head
  - preheater
  - separator/pressurizer
  - two heat exchangers
  - PH water control
- 15 MW DC CONTROLLED POWER SUPPLY
  - incremental and ramping



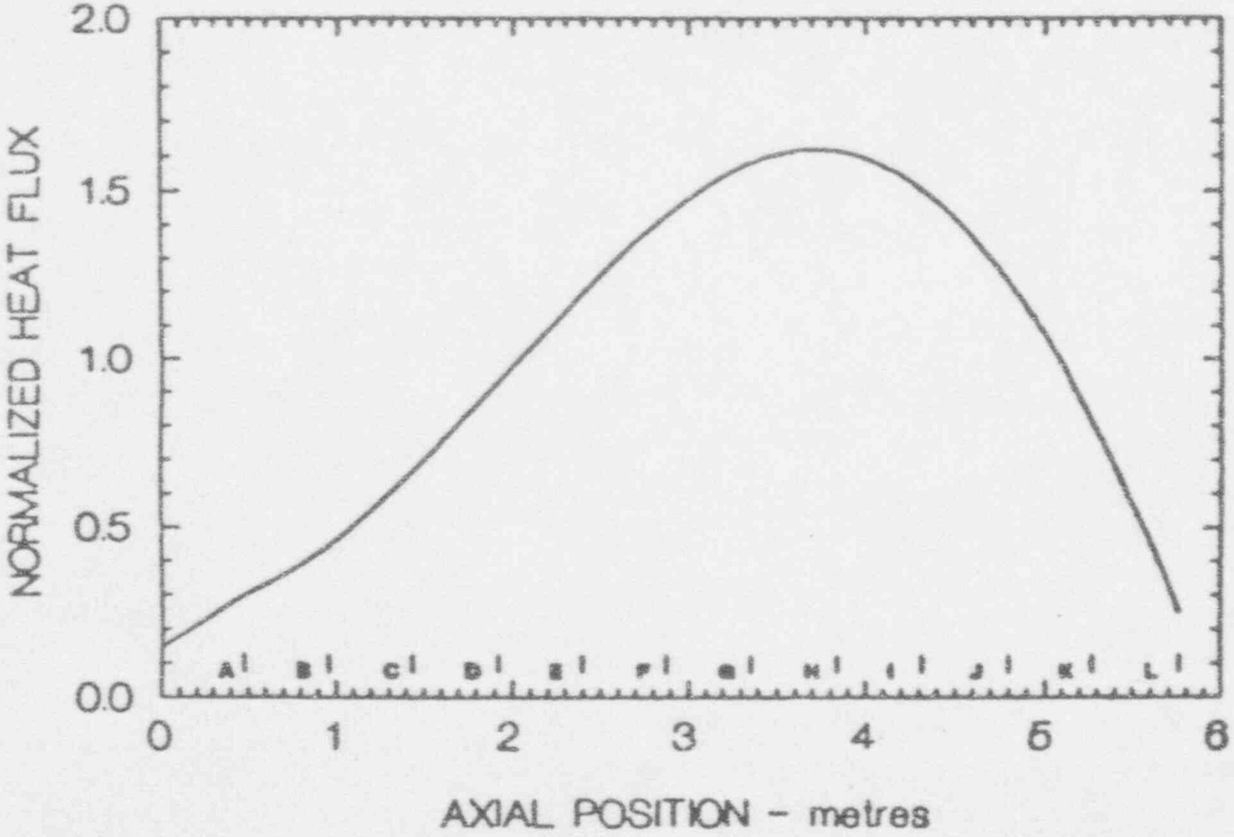
SCHEMATIC OF CHF TEST FACILITY

FACILITY DESCRIPTION

- **TEST SECTION:**
  - pressure boundary
  - fuel string
  - ceramic liner to electrically isolate the pressure boundary and the fuel string
- **FUEL STRING SIMULATION:**
  - 6 m electrically heated 37-element fuel string
  - Non-uniform, skewed cosine axial heat flux distribution
  - Radial flux distribution (outer ring to center): 1.102/0.932/0.859/0.826
  - Axial and radial flux profiles obtained by varying the tube wall thickness
  - End-plates and appendage simulation to represent 12 aligned fuel bundles
  - 12.5 MW at 220 volts DC



CHF TEST SECTION



HEAT FLUX PROFILE

DATA ACQUISITION SYSTEM

- DEC VAX 4000-100 computer clustered with a MicroVAX 2000 and two VAXStation 3100
- Four CPI scanners each 120 A/D channels
- HP A600 computer with 80 A/D channels
- Terminal video displays
- On-line monitoring of fuel string thermocouples

INSTRUMENTATION

- Test facility is extensively instrumented with power, temperature, flow, and pressure transducers
- Dryout (CHF) detector:
  - Monitors the fuel element simulators wall temperature
  - Uses 222 internal thermocouples mounted in alumina carriers
  - Axially and circumferentially movable carriers controlled via Programmable Logic Controllers

TEST CONDITIONS FOR CHF TESTS

■ System Pressure	7-11 MPa
■ Water subcooling	30-50 °C
■ Flow rate	7-21 kg/s
■ Channel power	5-12.5 MW

TEST PROCEDURE FOR STEADY CHF TESTS

- Instrumentation is checked
- Loop is preheated to desired conditions
- Loop conditions are maintained
- Low power: the power is increased stepwise and the heat balance is checked
- High power: power is increased gradually until CHF is confirmed from the wall thermocouple measurements (T > 425 °C) at the assumed location
- Data is recorded for 30 s with a 10 Hz scanning rate
- The bundle thermocouples are rotated and traversed axially to ensure CHF is not occurring elsewhere
- If CHF is found elsewhere the power is reduced and the test is repeated for the new CHF location

TEST PROCEDURE FOR TRANSIENT CHF TESTS

- Instrumentation is checked
- Loop is preheated to desired conditions
- Steady state CHF is obtained
- Flow rate is rapidly reduced by 15 % from reference conditions
- Data acquisition continuously scans and stores data at a 10 Hz scanning rate

THE RD-14M PROGRAM: INTEGRATED EXPERIMENTS AND ANALYSIS

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NRC Licensing
March, 1994

PRESENTATION OUTLINE

Program Objectives

Program History

RD-14M, What is it?

Scaling

- approach
- compromises

PRESENTATION OUTLINE *(Continued)*

Complimentary Facilities (CCF & FCF)

New Facilities

Test Matrix & Rationale

Instrumentation

Heat Losses

Reproducibility

Facility Documentation

RD-14M PROGRAM

Objectives

To provide integrated experimental data on thermalhydraulic behaviour in a multiple-channel test facility.

To improve the understanding of the underlying physical phenomena governing behaviour.

Facilitate verification of computer codes.

To enhance the ability to predict behaviour in reactor specific geometries.

History of Integral Test Facilities

RD-4 (1974) - small scale

RD-12 (1976 - 83) - half scale

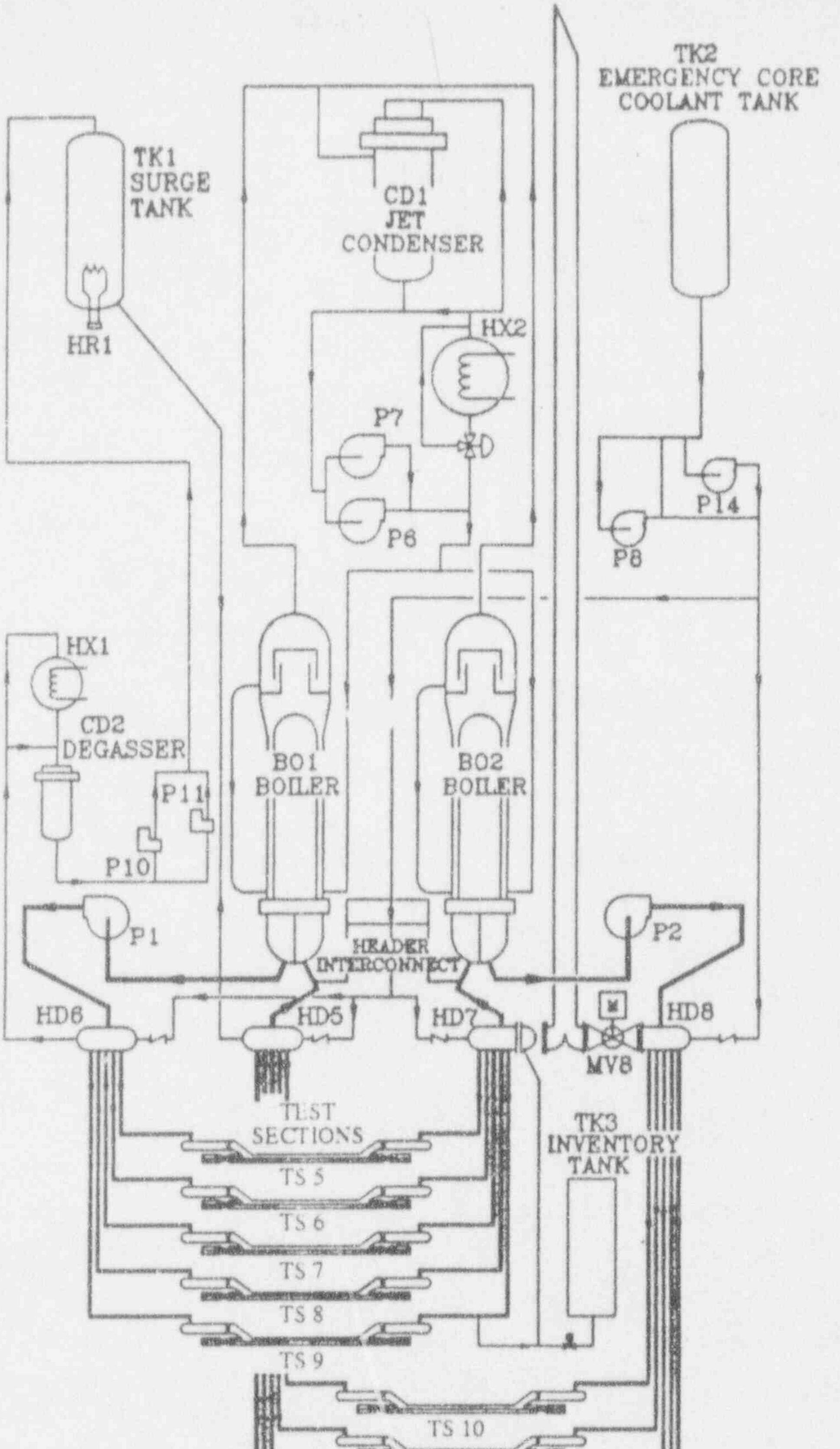
RD-14 (1983 - 87) - full elevation,
one channel per pass

RD-14M (1987 -) - full elevation,
multiple channel

FACILITY DESCRIPTION

What is RD-14M?

RD-14M is a figure of eight loop possessing many of the physical and geometrical characteristics of a CANDU reactor heat transport system.



A SCHEMATIC OF THE RD-14M FACILITY

Design Features of RD-14M

- Full elevation changes between major components.
- Ten full length electrically heated channels.
- Simulated end fittings.
- Full length feeder pipes.
- Full height steam generators.
- Blowdown / ECI and natural circulation simulation.
- Extensively instrumented.
- Dedicated Data Acquisition System.

RD-14M SPECIFICATIONS

Legend	Description	Elevation* m	Volume m^3	Specifications
BO1	Steam generator	Top - 24.7 Top of U-tubes - 22.8 Bottom - 12.6	0.18	U-tube, 44 tubes, 15.9 mm diameter Heat transfer area 41 m^2 External downcomer, spiral arm steam separator
BO2 - Pump 1	Above header piping		0.03	
P1	Primary pump	12.4 inlet 12.7 outlet	0.06	Single stage vertical Impeller diameter .381 m Rated flow 24 kg/s Rated head 224 m
P1 - HD6	Above header piping		0.01	
HD6	Inlet header	10.2	0.03	Length 1 m, 8 inch schedule 80
HD6 - TS5	Inlet feeder		0.004	
HD6 - TS6	Inlet feeder		0.006	
HD6 - TS7	Inlet feeder		0.03	
HD6 - TS8	Inlet feeder		0.01	
HD6 - TS9	Inlet feeder		0.01	
TS5	Test section 5	6.0	0.01	Each test section contains 7 electrically heated FES, length 6 m, FES diameter 0.0131 m Flowtube area 0.448 m^2, volume includes 2 end fittings. End fitting volume 0.0058 m^3
TS6	Test section 6	3.43		
TS7	Test section 7	3.15		
TS8	Test section 8	2.57		
TS9	Test section 9	0.0		
TS5 - HD7	Outlet feeder		0.01	
TS6 - HD7	Outlet feeder		0.01	
TS7 - HD7	Outlet feeder		0.04	
TS8 - HD7	Outlet feeder		0.02	
TS9 - HD7	Outlet feeder		0.02	
HD7	Outlet header	10.2	0.03	Length 1 m, 8 inch schedule 80
HD7 - BO1	Above header piping		0.03	

* Reference is TS9 at 0 m.

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SCALING LAWS FOR SIMULATING THE CANDU HEAT TRANSPORT SYSTEM

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March, 1994

94-028

PRESENTATION OUTLINE

SCALING OF INTEGRAL FACILITIES

1. Scaling Philosophy
2. RD-14 - Design
   - Compromises in Implementation
3. RD-14M - Design
   - Compromises in Implementation

SCALING PHILOSOPHY

- Test facilities were designed to preserve DYNAMIC SIMILARITY with CANDU PHTS based on a developed set of scaling criteria.

- Where scaling criteria could not be applied, past experience and engineering judgement were used to provide a conservative component design.

DEVELOPMENT OF SCALING CRITERIA TO PRESERVE DYNAMIC SIMILARITY

- Approach of Ishii and Kataoka used to develop scaling criteria to obtain dynamic similarity.

- Write the governing thermalhydraulic equations in dimensionless form (Mass, energy and momentum balances) using drift flux or homogeneous flow models as required.

- Achieve dynamic similarity by adjusting facility design variables (pipe length, diameter, etc.) to match value of dimensionless groups for facility and reactor.

DEVELOPMENT OF SCALING CRITERIA TO PRESERVE DYNAMIC SIMILARITY

(Continued)

- Key dimensionless groups include:

Phase Change Number

Density Ratio

Friction Number

Subcooling Number

Time Ratio Group

Drift Flux Number

Froude Number

Orifice Number

Critical Heat Flux Number

Heat-Source Number

SCALING

Phase change number

$$N_{pch} \equiv \left(\frac{4\ \delta\ q'''_o\ \ell_o}{d\ u_o\ \Delta H_{fg}\ \rho}\right)\ \left(\frac{\Delta\rho}{\rho_g}\right)$$

Drift Flux number

$$N_d \equiv \frac{V_{gj}}{u_o}$$

Froude number

$$N_{Fr} \equiv \frac{u_o^2}{g\ \ell_o\ \langle a\rangle_o}\ \frac{\Delta\rho}{\rho}$$

Density ratio group

$$N_\rho \equiv \frac{\rho_g}{\rho}$$

Friction number

$$N_f \equiv \left(\frac{f\ell}{d}\right)\ \left(\frac{1 + x\ (\Delta\rho/\rho_g)}{[1 + x\ (\Delta\mu/\mu_g)\ ]^{0.25}}\right)\ \left(\frac{a_o}{a_i}\right)^2$$

SCALING (Continued)

Orifice number

$$N_o \equiv K\,[1 + x^{3/2}\,(\Delta\rho/\rho_g)\,]\,\left(\frac{a_o}{a_i}\right)^2$$

Subcooling number

$$N_{sub} \equiv \left(\frac{\Delta H_{sub}}{\Delta H_{fg}}\right)\left(\frac{\Delta\rho}{\rho_g}\right)$$

Critical Heat Flux number

$$N_q \equiv \frac{q_c'''}{\delta q_{so}'''}$$

Heat-source number

$$Q_{si} \equiv \frac{q_{si}'''\ \ell_o\ C_p}{\rho_{si}\ Cp_{si}\ u_o\ \Delta H_{sub}}$$

Time Ratio group

$$T_i^* \equiv \left(\frac{\alpha_s}{\delta^2}\ \frac{\ell_o}{u_o}\right)_i$$

LIMITATIONS OF SCALING LAWS

Scaling laws only apply if flow is 1-D, well mixed and void / quality relationship for homogeneous flow can be applied.

If horizontal stratified, or horizontal / vertical annular flow occurs departures from similarity between reactor and loop behaviour will occur.

RD-14 DESIGN

Reference Design Basis:
single 5.5 MW, 37-element channel
per pass figure-of-eight loop
with 1:1 vertical scaling.

- Conducting experiments at reactor typical conditions (pressure, temperature, power and flow) and use of full-size channels and feeders ensure all scaling criteria below headers are met (except for end-fitting simulators).

- Steam generators designed maintain 1:1 matching of scaling criteria.

- Compromises in design of above header piping, headers and end-fittings.

SCALING COMPROMISES IN THE DESIGN OF RD-14

1) Thermal mass relative to fluid volume of above header piping is up to 5 times greater in RD-14M. This may distort time scale for system heat-up rates and refill.

2) End-fittings sized to maintain thermal masses and moving-fluid volume. CWIT tests identified these as the most important parameters in channel refill and IBIF. Internal surface areas and flow paths are undersized.

3) Headers scaled to retain reactor typical fluid volumes and metal thermal mass. Most important parameters in determining header cool-down and refill-time delays. Flow patterns and degree of stratification may not be representative.

COMPONENT SCALING RATIOS[1]

Component	l_R	u_R	$(N_{pch})_R$	$(N_{Fr})_R$[2]	$(N_f)_R$
Channel	1	1	1	1	1
End Fitting	0.2	0.2	N/A	~0.2	
Feeders	~1	~1	N/A	~1	~1
Headers	N/A	0.5-1	N/A	N/A	N/A
SG Inlet Piping	~1	0.3	N/A	~0.1	~0.4
Steam Generator	~1	1	~1	~1	~1
SG Outlet Piping	~1	0.3	N/A	~0.1	0.1-0.2
Pump	N/A	0.3-0.8	N/A	N/A	N/A
Pump Outlet Piping	~1	0.6-0.8	N/A	0.4-0.6	1.0-1.8

[1] - using average reactor values (Darlington, Bruce, Pt. Lepreau)

[2] - assuming homogeneous flow

COMPONENT SCALING RATIOS[1] (Continued)

Component	$(N_o)_R$	$(T^*)_R$	$(Q_{sl})_R$	$(\Delta H_{sub})_R$	$(N_d)_R$[2]	$(N_q)_R$
Channel	1	1	1	1	1	1
End Fitting	N/A	N/A	N/A	1	-1	N/A
Feeders	-1	N/A	N/A	1	-1	N/A
Headers	N/A	N/A	N/A	1	-1	N/A
SG Inlet Piping	N/A	N/A	N/A	1	-1	N/A
Steam Generator	-1	-1	-1	1	-1	N/A
SG Outlet Piping	N/A	N/A	N/A	1	-1	N/A
Pump	N/A	N/A	N/A	1	N/A	N/A
Pump Outlet Piping	N/A	N/A	N/A	1	-1	N/A

[1] - using average reactor values (Darlington, Bruce, Pt. Lepreau)

[2] - assuming homogeneous flow

COMPARISON OF D_2O AND H_2O

Property Ratio $\left(\frac{H_2O}{D_2O}\right)$	Pressure		
	0.1 MPa	4.0 MPa	10 MPa
T_{SAT}	0.982	1.001	1.003
ΔH_{fg}	1.090	1.107	1.112
ρ_f	0.902	0.904	0.904
ρ_g / ρ_f	1.001	0.990	0.995

RD-14M DESIGN

To study the interaction between parallel channels in thermosiphoning and LOCA transients, the RD-14 test facility was modified to a multiple channel geometry.

For economic reasons, the steam generators and total power and flow per pass from RD-14 were retained.

Scaling Criteria

The same scaling approach and criteria used in designing RD-14, based on preserving dynamic similarity, was applied to designing RD-14M.

RD-14M DESIGN

No significant change from RD-14 above header pipework and steam generators.

Scaling compromises for above header components are the same in both facilities.

New design required for:

- Channels
- End-fittings
- Feeders
- Headers

RD-14M CHANNEL DESIGN

Requirements:

- It is desirable to have as many channels as possible to simulate CANDU behaviour.
- The heaters should have a ring geometry as in CANDU fuel bundles.

Constraints:

- The number of heated sections is limited by existing loop specifications
  - steam generators, pumps and flow areas scaled for a single pass of a 37 element 5.5 MW channel
- For economic reasons, the existing heater design was used - to maintain the same element heat flux at a given power, the number of elements in a single pass should be 37.

RD-14M CHANNEL DESIGN

Three channel geometries satisfy the design requirements and economic and design constraints:

- two 18 element channels
- three 12 element channels
- five 7 element channels

The five channel geometry was chosen since it has weaker channel to channel interactions than the other configurations and seven element channels were used in earlier RD-12 experiments.

RD-14M CHANNEL DESIGN

IMPLICATIONS OF COMPROMISES

1) - 7-pin, full-length design permitted excellent agreement for all dimensionless scaling groups except for the Friction number.

   - Friction number for RD-14M is 29% higher than the reactor value.

2) - Correlations for the transition to stratified flow for both 7 and 37 pin CANDU channel geometries indicate stratified flow is expected to occur at a loop mass flux which is 30% lower than in a full size channel.

   - this difference is within the uncertainties of flow regime transitions.

RD-14M END-FITTING DESIGN

Flow cannot be considered one dimensional (during thermosiphoning will stratify, 3D).

During blowdown and refill transient, delay of ECI into a channel is related to fluid volume and heat storage capacity of the end-fitting.

Thermal mass determines the timing of natural circulation following a flow stagnation.

RD-14M END-FITTING DESIGN

(Continued)

Both fluid volumes and thermal masses should be scaled. (stagnant volumes, also scaled, can act as a thermal mass during end-fitting heat up, and a potential source of channel coolant during blowdown and refill)

Under intermittent bouyancy induced flow, recirculation flow patterns may be established near the end-fittings during end-fitting heat up periods, i.e. steam produced in the channel and condensed in the end-fitting can flow back into the channel, driven by the gravity head within the end-fitting.

To simulate the flow phenomena, L/D_H ratios should be preserved.

RD-14M END-FITTING DESIGN

(Continued)

- Pressure, heat losses and heat capacity requirements for the end-fittings were developed by writing integral momentum and energy balances.

- This led to approximate scaling rules for the end-fitting geometry.

- Scaling criteria satisfied in the final design.

SCALING RATIOS FOR END-FITTING

$(K_{EF})_R$	$(V_f/A_o\ell_o)_R$	$(M_wC_w/A_o\ell_o)_R$	$(Q_{LS}/A_o)_R$
1	1	1	0.9

- It should also be noted that L/D_h ratios were preserved in the end fitting design.

RD-14M FEEDER DESIGN

Five CANDU reactor channel/feeder geometries will be simulated in each pass

- one top channel (B10)
- three middle channels (L2, M11,O5)
- one bottom channel (X12)

- These geometries cover the full range of elevation differences, pipe diameters, horizontal lengths and flow restricting orifices present in a reactor.

- They have five channel average flows and powers equal to the core average power and flow.

- The nozzle angles, at header connections, cover the range found in a typical reactor.

RD-14M FEEDER DESIGN IMPLICATION OF COMPROMISES

Major compromise in feeder design was in cross-sectional area terms.

Flooding in RD-14M expected to occur at 70% of the steam mass flux required for a typical reactor feeder.

This is expected to delay feeder refill times.

RD-14M HEADER DESIGN

- Scaling laws are not applicable, flow is three dimensional.

- The flow will stratify during thermosiphoning, blowdown and refill. This will affect the quality of fluid supplied from the headers to the feeders.

- To simulate quality distribution, headers have the same feeder to header diameter ratio as in a typical reactor.

- Volumes are scaled.

- Header feeder angles are also reactor typical.

- Fluid flow length cannot be accurate because of the geometry requirements outlined above.

RD-14M HEADER DESIGN

Similarities:

- Volumes scaled
- Covers feeder nozzle geometries
- Can investigate channel interactions
- Can investigate the affect of nozzle location during stratified flow

Differences:

- Header mass is too high
- Short fluid flow paths
- Only five channels

SUMMARY

Consideration was given to thermosiphoning, blowdown and ECI transients.

Scaling laws, consistant with those derived by Ishii & Kataoka, were developed and applied to the design of a multiple channel loop.

Full linear dimensions and elevation changes present in a typical CANDU™ reactor were maintained. If this requirement is not met, simulation of the reactor void distribution, caused by elevation induced flashing,would not be possible in the multiple channel loop.

Other Facilities

- Component Characterization Facility (CCF)

- Flow Calibration Facility (FCF)

COMPONENT CHARACTERIZATION FACILITY (CCF)

Brief Description:

- pressurized loop
- test section can receive a wide range of two-phase steam-water mixtures
- connected to RD-14M secondary side

COMPONENT CHARACTERIZATION FACILITY (CCF)

Loop Parameters:

- Design pressure: 7.4 MPa(g)
- Design temperature: 343°C

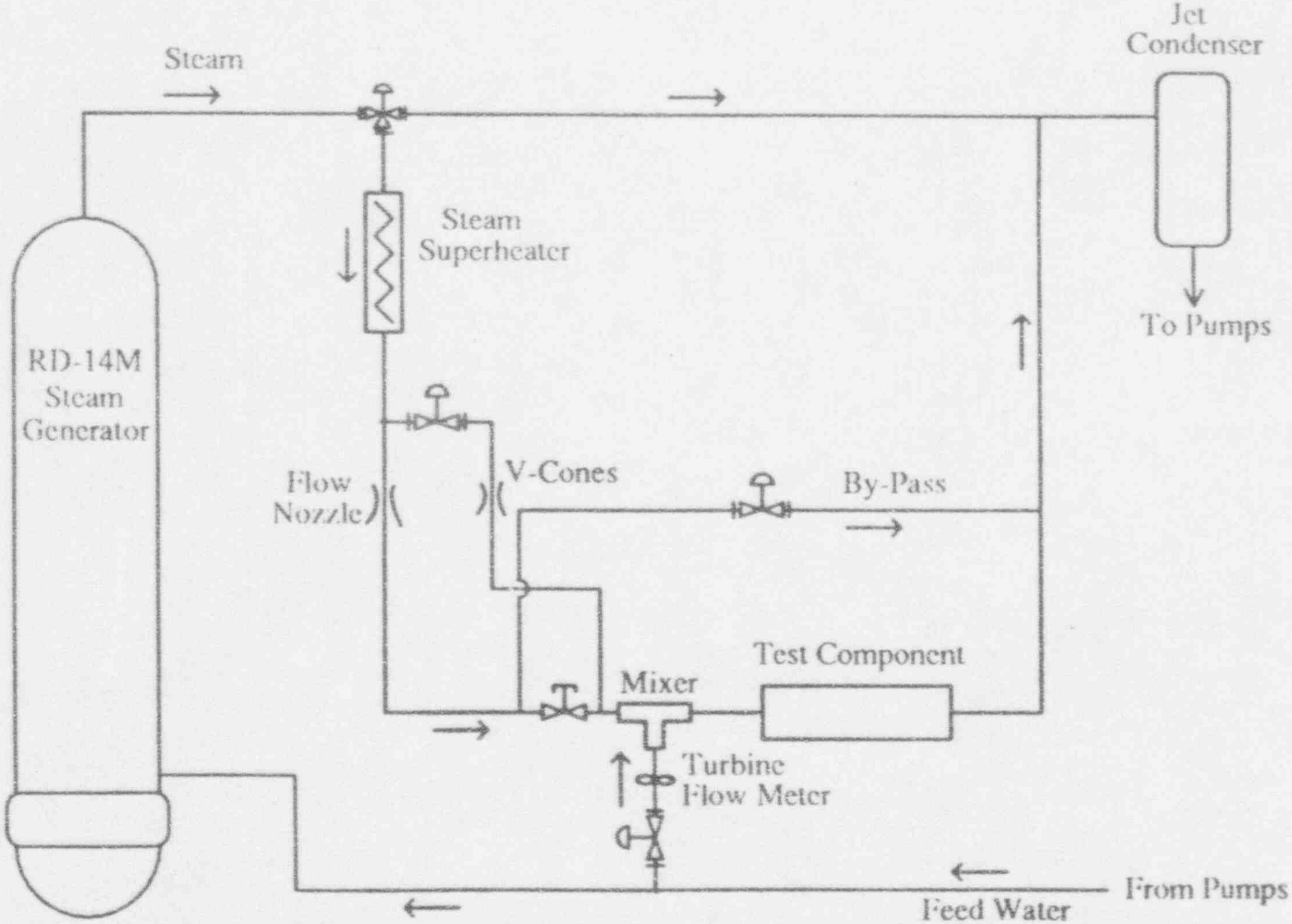
- Operating pressure: 5.5 MPa(g)
- Operating temperature: 260°C

- Maximum flow rates: steam 5.5 kg/s
  water 5.4 kg/s

COMPONENT CHARACTERIZATION FACILITY (CCF)

Features:

- water supply: 0.06 to 5.4 kg/s
- steam supply: 0.008 to 5.5 kg/s @5.5 MPa(g)
  0.002 to 0.25 kg/s @0.1 MPa(g)
- steam superheater: 125 kW
- steam-water mixer: desuperheater-type
- automatic or manual control of flow rates
- steam by-pass line
- blowdown line



COMPONENT CHARACTERIZATION FACILITY (CCF)

New Facilities Planned

Moving towards separate effect type testing (SG's)

Text Matrix & Rationale

- Feedback from other experiments, feedback from customers / utilities on range of applications

RD-14M TEST MATRIX

Natural Circulation

1. Partial Inventory
2. Transition to thermosiphoning

LOCA

1. Small Break
2. Critical Break
3. Large Break

Flow Stability

RD-14M TEST MATRIX

NUMBER OF TESTS CONDUCTED

Type of Test	RD-14M	RD-14
Natural Circulation		
Partial Inventory	49	30
Transition	17	--
LOCA		
Small Break	9	11
Critical Break	14	13
Large Break	15	7
Flow Stability	9	11

NATURAL CIRCULATION TESTS PROCEDURE

PARTIAL INVENTORY TESTS:

1. Establish steady-state, single phase natural circulation flow at desired operating conditions.

2. Drain a fixed quantity of fluid intermittently from outlet header and monitor resulting thermalhydraulic behaviour.

3. Repeat intermittent draining until test terminated due to high Fuel Element Simulator temperature (600°C).

NATURAL CIRCULATION TESTS PROCEDURE

TRANSITION TO THERMOSIPHONING TESTS:

1. Establish steady-state, forced convective flow at desired operating conditions.

2. Drain a fixed quantity of fluid from outlet header.

3. Trip primary pumps.

4. Monitor resulting natural circulation behaviour until steady-state is achieved or test terminated due to high Fuel Element simulator temperature (600°C).

NATURAL CIRCULATION TESTS - VARIABLES

Power Level	60, 100, 160 kW/pass
Secondary-side Pressure	0.2, 1.1, 4.6 MPa and ramped
Drain rate	0.025 to 0.2 L/s
Header Interconnect	none, geometric and dynamic scaled
Surge Tank	on-line, off-line
Emergency Coolant Injection	yes, no
Secondary-side System	high power, low power
Feeder Trace Heating	on / off

FLOW STABILITY TESTS

Objective:

Investigate effect of header interconnects on flow stability.

Experimental Procedure:

Induce quality in outlet feeders by:

1. reducing primary pump speed, or
2. reducing primary pressure.

TEST MATRIX & RATIONALE

Simulating Plant Transients
- we don't.

Instrumentation

Calibrated to traceable standards (T, P, Q)

Available in electronic data base.

RD-14M INSTRUMENTATION

Void Fraction Measurements

- 4 two-beam gamma densitometers measuring boiler inlet and outlet void fraction.

- 2 three-beam gamma densitometers measuring void at pump discharge.

- 20 single-beam densitometers measuring void at inlet and outlet to each channel.

- recently developed conductivity probes and fibre optic probe for local measurements.

RD-14M INSTRUMENTATION

Pressure Drop Measurements

- 60 pressure drop measurements around primary circuit.
- pressure drop across all potential flow paths measured.
- duplicate, multi-range instruments on key components (i.e. heated sections, pumps, etc.) to measure both high and low pressure drops.
- pressure drop balance performed before each test.
- majority of instruments are Rosemount 1151 DP cells calibrated to traceable standards.

RD-14M INSTRUMENTATION

Pressure Measurements

- 24 primary-side pressure measurements made at each header and at the inlet and outlet to each channel
- 1 surge tank / pressurizer pressure measurement
- 3 secondary-side pressure measurements made in each boiler and in jet condenser.
- majority of instruments are Rosemount 1151 P cells calibrated to traceable standards

RD-14M INSTRUMENTATION

Flow Rate Measurements

- 22 primary-side flow measurements using Turbine Flow Meters located at entrance and exit of each channel and at pump discharge.
- mass flow rate of steam leaving each boiler (orifice plate with mass flow computer)
- boiler feedwater flow rate to each boiler (turbine flow meter)

RD-14M INSTRUMENTATION

Flow Rate Measurements *(continued)*

- boiler downcomer flow rate in each boiler (orifice plate)
- flow to inventory tank in natural circulation tests (turbine flow meter)
- mass balance check prior to each experiment
- Turbine Flow Meters calibrated to traceable standards using gravimetric technique

RD-14M INSTRUMENTATION

Temperature

- over 90 temperature measurements of the primary-side temperature including inside select boiler tubes (k-type thermocouples and RTD's)
- 280 temperature measurements of Fuel Element Simulators (k-type thermocouple)
- about 30 temperature measurements in the secondary-side including shell side measurements at various locations (k-type thermocouple and RTD's)

RD-14M INSTRUMENTATION

Temperature *(continued)*

- Energy balance before each test
- RTD's calibrated to traceable standards
- thermocouple transmitters calibrated to traceable standards.
- thermocouples have been verified to be within NBS standards

RD-14M INSTRUMENTATION

Power

- individual voltage and current measurements to each channel using thermal RMS voltmeters with an automated measuring device
- voltage and power from each of the four power supplies
- meters calibrated to traceable standards

RD-14M INSTRUMENTATION

Miscellaneous

- individual power measurements to trace heating of feeders

- level measurements in surge tank, inventory tank, jet condenser

- collapsed liquid level measurements in each boiler and boiler drum

- speed and current for each primary pump

RD-14M INSTRUMENTATION

Data Acquisition System

- Computer Product A/D system

- 7 chassis, 12 bit A/D's with 120 differential inputs for a total of 840 input channels

- maximum sampling speed of 20,000 samples/sec./channel

Heat Losses

Extensively characterized for natural circulation conditions
(THB-92-188)

Mass Inventory

Monitored for natural circulation experiments

Not available for LOCA's

REPRODUCABILITY

LOCA Tests

- generally, only one test condition repeated in each test series.

- comparison of data from 8 Critical Break tests performed showed good agreement during initial critical blowdown phase.

- performed bench-mark tests to relate different test series and facilities.

MAXIMUM FES SHEATH TEMPERATURE DURING CRITICAL BREAK LOCA

	HS10	HS11	HS12	HS13	HS14
Highest Tmax (°C)	469	483	489	509	509
Lowest Tmax (°C)	461	470	477	500	478
Average Tmax (°C)	464	474	484	505	490
Range Tmax (°C)	8	13	12	9	31

Note: Overall maximum for each test varied by: 2°C.

REPRODUCABILITY

Natural Circulation Tests

- examined reproducability in terms of global behaviour (inventory at dryout, etc.) and individual parameter time-series behaviour.

- reproducability is very good to excellent for some tests (i.e. 160 kW / pass and 4.6 MPa secondary-side pressure).

REPRODUCABILITY

Natural Circulation Tests *(continued)*

- reproducability in other tests is very good up to a "critical point" where thermalhydraulic behavicur can be significantly effected by small differences (i.e. 100 kW / pass and 1.1 MPa secondary-side pressure).

- despite differences in behaviour following a "critical point", reproducability of final global behaviour at dryout is good for most tests.

- performed bench-mark tests to relate different test series and facilities.

Reproducability

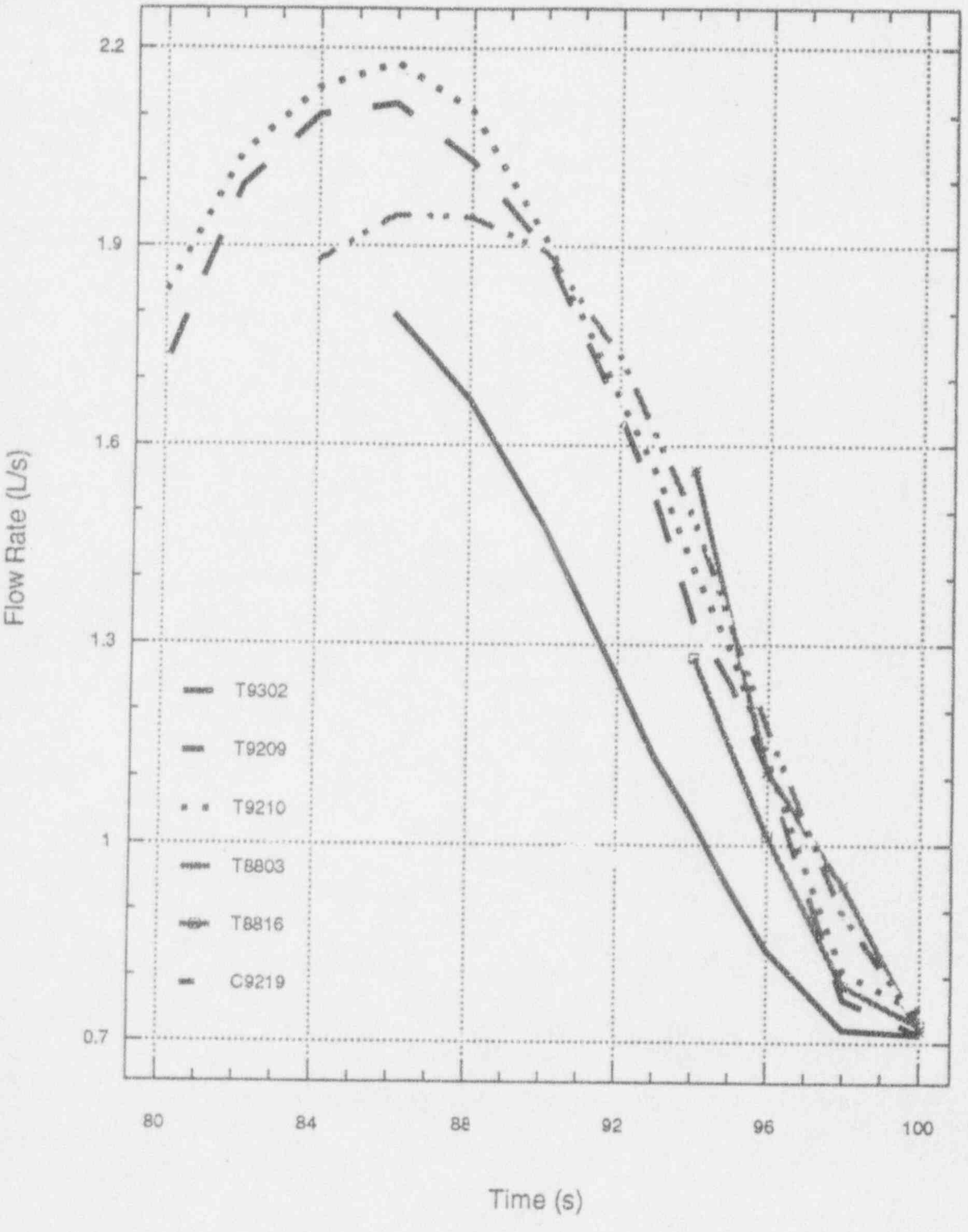
Standard statistical tests, such as T-tests for averages and F-tests for variances, are applied to assess reproducability of:

- flows
- periods of oscillation
- temperature
- pressure

A statistical test which satisfies a 95% confidence range will be indicative of reproducability.

Comparison of Loop Flow Rates

(1.1 MPa and 100 kW/pass)



Facility Documentation

RD-14M Facility Description (COG-88-42)

a) Modified Secondary System (THB-93-219)

b) ECI Systems (THB-91-475)

c) Primary System (pending)

d) Heat Losses (THB-92-188)

a, b, c - Living documents

AECL EACL
AECL Research EACL Recherche

CATHENA VALIDATION

J.P. Mallory

March 10/93

OUTLINE

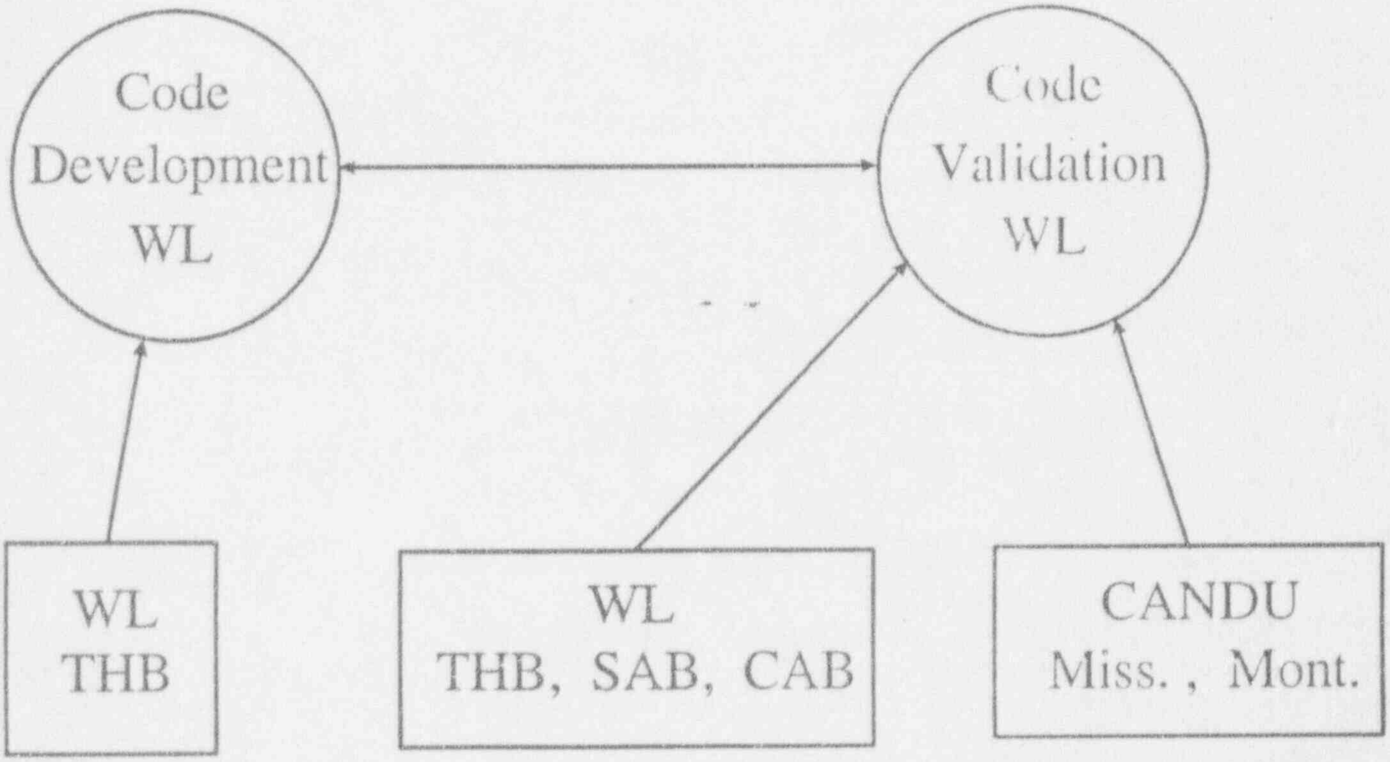
VALIDATION APPROACH

VALIDATION TESTS

RESULTS (RD-14 & RD-14M)

FUTURE VALIDATION

VALIDATION APPROACH



Code Development WL

Code Validation WL

WL
THB

WL
THB, SAB, CAB

CANDU
Miss., Mont.

VALIDATION APPROACH

Validation Conducted According to Validation Plan

- **ALL** validation reported in Compendium of CATHENA Validation Cases
- Validation work reported in COG reports and results archived
- Integral tests simulated using standardized and documented idealization
- Validation conducted using Reference version of CATHENA code only

VALIDATION APPROACH

- CATHENA Validation Matrix Composed of:

Separate Effects Tests

- Simple tests designed to assess modelling of specific phenomena
- Wide variety of sources from the international literature

Component Tests

- More complex tests designed to assess reactor-typical component modelling capabilities
- Typical data come from CWIT or LASH

Integral Tests

- Most complex tests involving several different phenomena and components
- Typical data come from RD-14/RD-14M

VALIDATION TESTS

Separate Effects Tests

- Pipe Refill
    - Empty unheated tube
    - Empty heated tube
    - Unheated tube containing a 7-element bundle
- Marviken Blowdown Tests
- Countercurrent Flooding
    - In a vertical tube
    - In a tube with an 90° upward facing elbow
- Flow Stratification

VALIDATION TESTS

Separate Effects Tests (Cont'd)

- THETIS vertical level swell
- Fuel channel deformation tests
- Forward flow through orifices and area changes
- High-Temperature Zirconium-Steam reaction rates
- Vapour and liquid entrainment at junctions

VALIDATION TESTS

Component Tests

- Feeder-Channel Refill
    - CWIT 774, 848, 1086, 1092 and 1097
- RD-12 Steam Generator Blowdowns
    - B8510 and B8522
- RD-14M Steam Generator Characterization (Steady-State and Transient)
    - C8613, C8626 and C8627
- Pressure-Tube Circumferential Temperature Distribution
    - Tests # 1, 2, 3 and 4

VALIDATION TESTS

Component Tests (Cont'd)

- Full-Scale Header ECC Injection
    - LASH Test # 505, 506 and 520
- Standing-Start Tests
    - CWIT-937, 939, 959, 974 and 975
- High-Temperature Channel Tests
    - CHAN CS11, 13, 76, 78 and 28-1
- Small Break in a Full-Scale Header
    - LASH Test # 730, 736 and 748

VALIDATION TESTS

Integral Tests

- ISP-18, LOBI-MOD2, Test A2-81
- WOLSONG Spill Incident of Nov. 25/84
- Pt. Lepreau Reactor Trip of Dec. 20/83
- RD-14 Natural Circulation Tests
  - T8513, T8515, T8517 and T8602
- RD-14 Blowdown Tests
  - B8601, B8603, B8604, B8711, B8713 and B8715
- RD-14 Flow Stability Tests
  - L8605 and L8705

VALIDATION TESTS

Integral Tests (Cont'd)

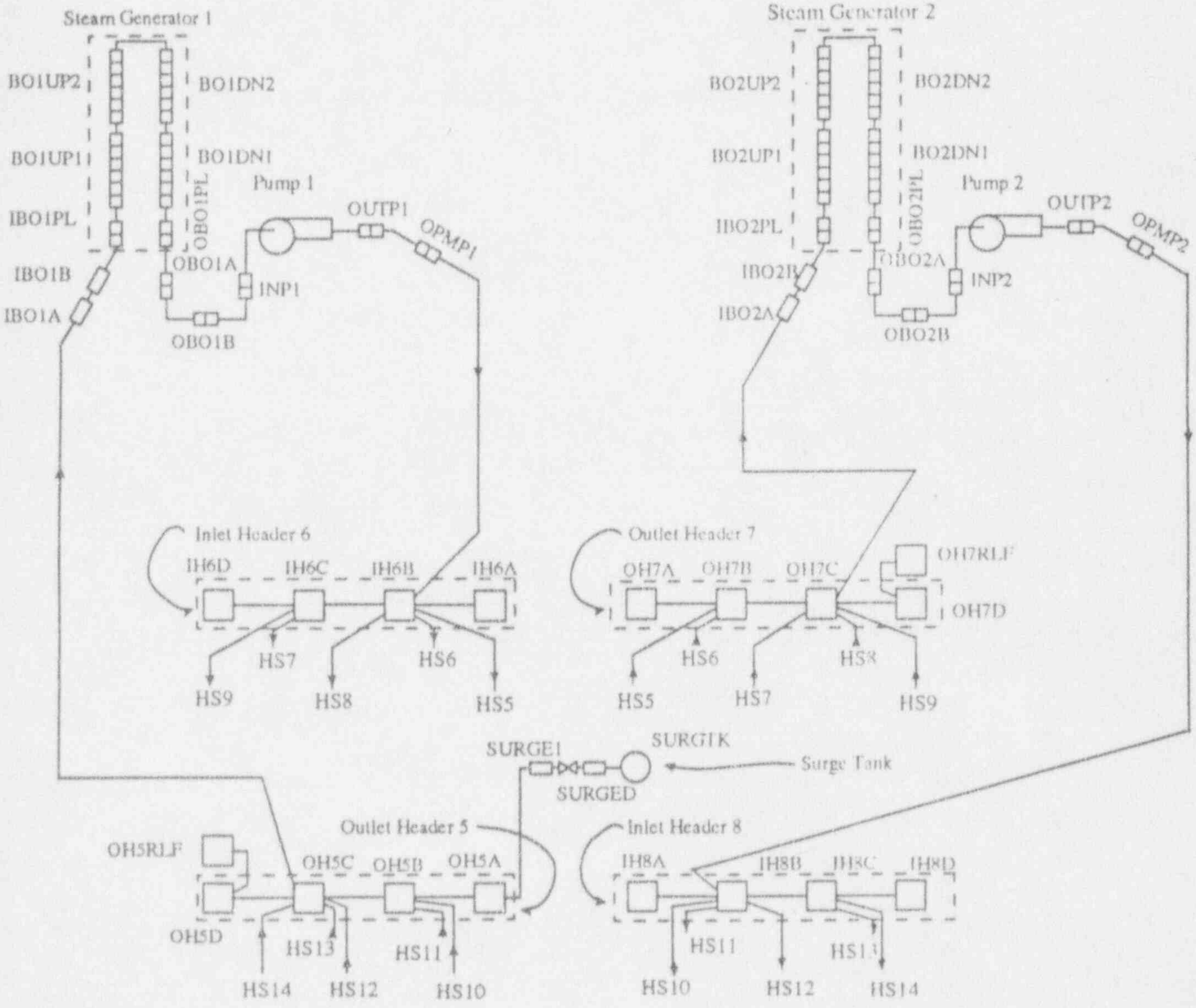
- RD-14M Natural Circulation Tests
  - T8802, T8808, T8809, T8903, T8907, R8907 and R8909
- RD-14M Blowdown Tests
  - B9001, B9006 and B9121

RESULTS

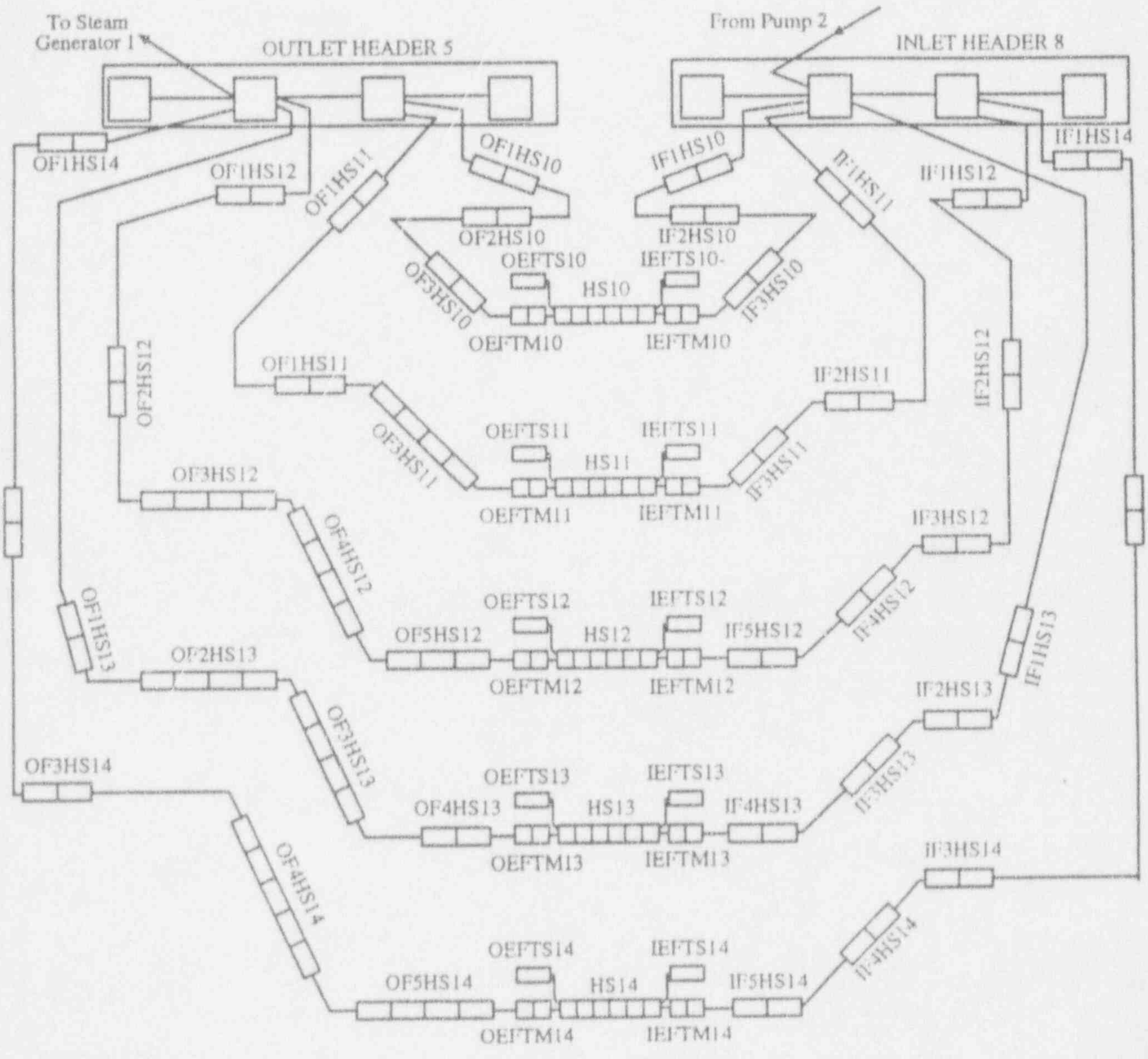
Test Type	RD-14M		RD-14	
	EXP.	SIM.	EXP.	SIM.
Natural Circulation				
Partial Inventory	49	5	30	4
Transition	17	2	--	--
LOCA				
Small	9	2	11	4
Critical	14	1	13	2
Large	15	--	7	1
Flow Stability	9	--	11	2

AECL EACL

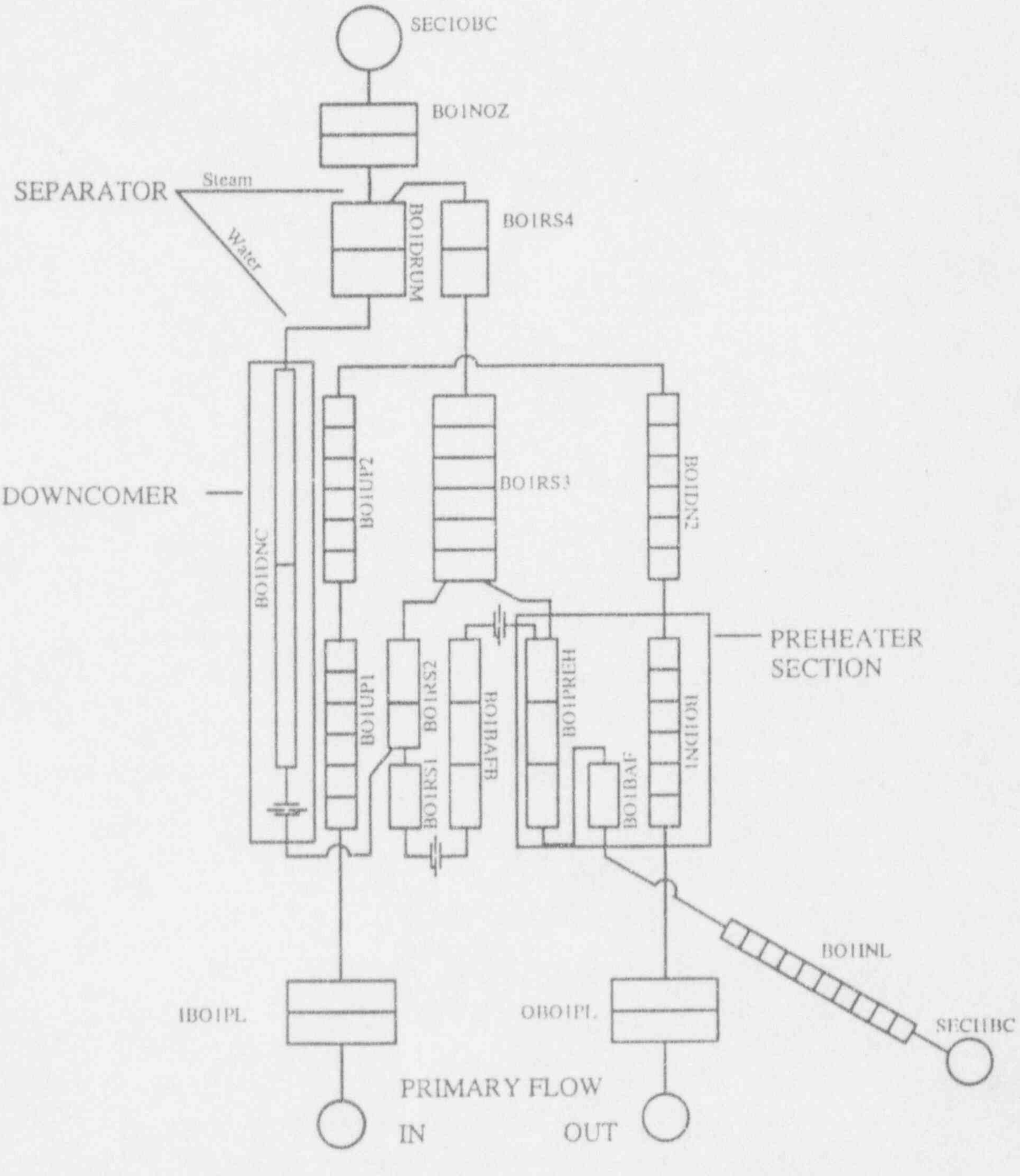
AECL Research EACL Recherche



Thermalhydraulic Representation of RD-14M Above-Header Piping



Thermalhydraulic Representation of RD-14M Below-Header Piping



Thermalhydraulic Representation of RD-14M Steam Generators

RESULTS

LOCA - Small, Critical, Large

Objective:

- Investigate the thermalhydraulic consequences of small, critical and large header breaks

Sequence of Events:

- Establish steady, single-phase forced circulation at full power, full flow conditions
- Pressurizer isolated
- Break initiated
- Power reduced to 200 kW/pass when primary pressure reaches set point (8.8 MPa) or 2 s after break
- Controlled pump rundown, ECI and secondary side depressurization initiated if used
- Test terminated when Fuel Element Simulator (FES) temperature reached 600°C or steady-state achieved

RESULTS

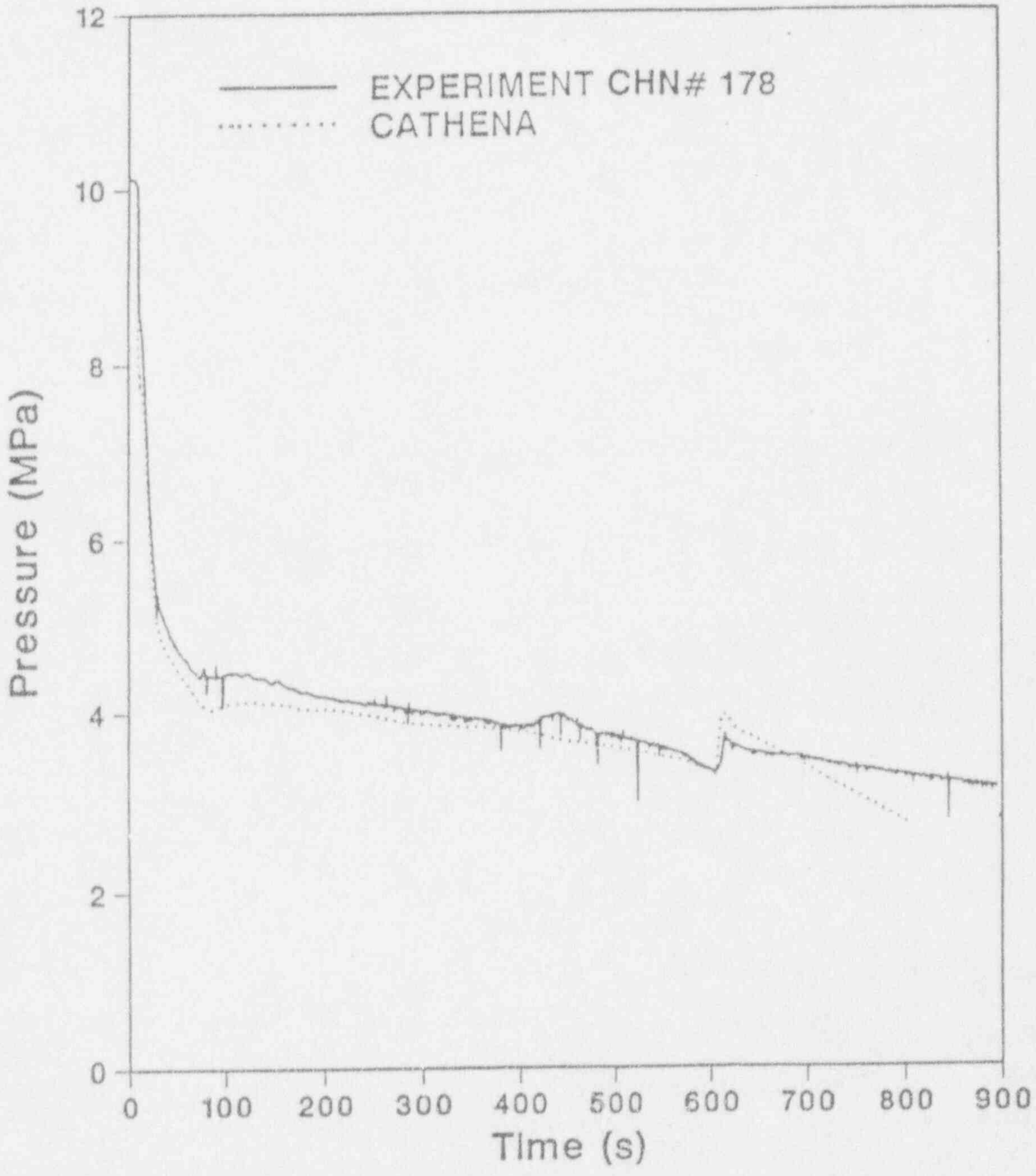
LOCA - Small, Critical, Large

Parameters Varied:

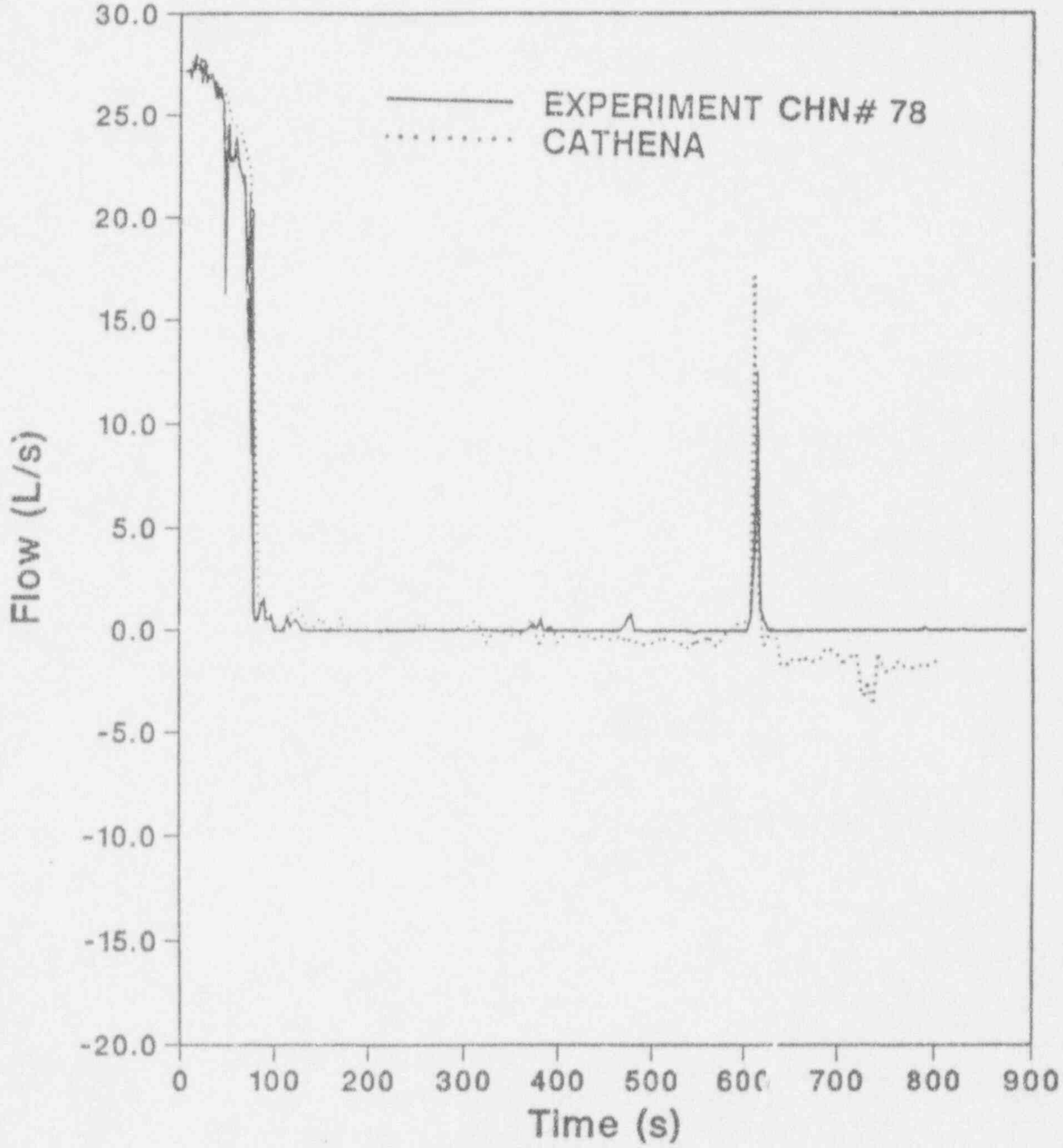
Secondary Pressure	ramped or constant
Primary Pump	rundown Yes, No Tripped Yes, No
Use of ECI	Yes, No
Header Interconnect	On-line, Off-line
Break Size	7-mm to 50-mm
Break Location	IH or OH
Pressurizer Iso.	Prior to Break when ECI starts

Test Conditions (Small Break):

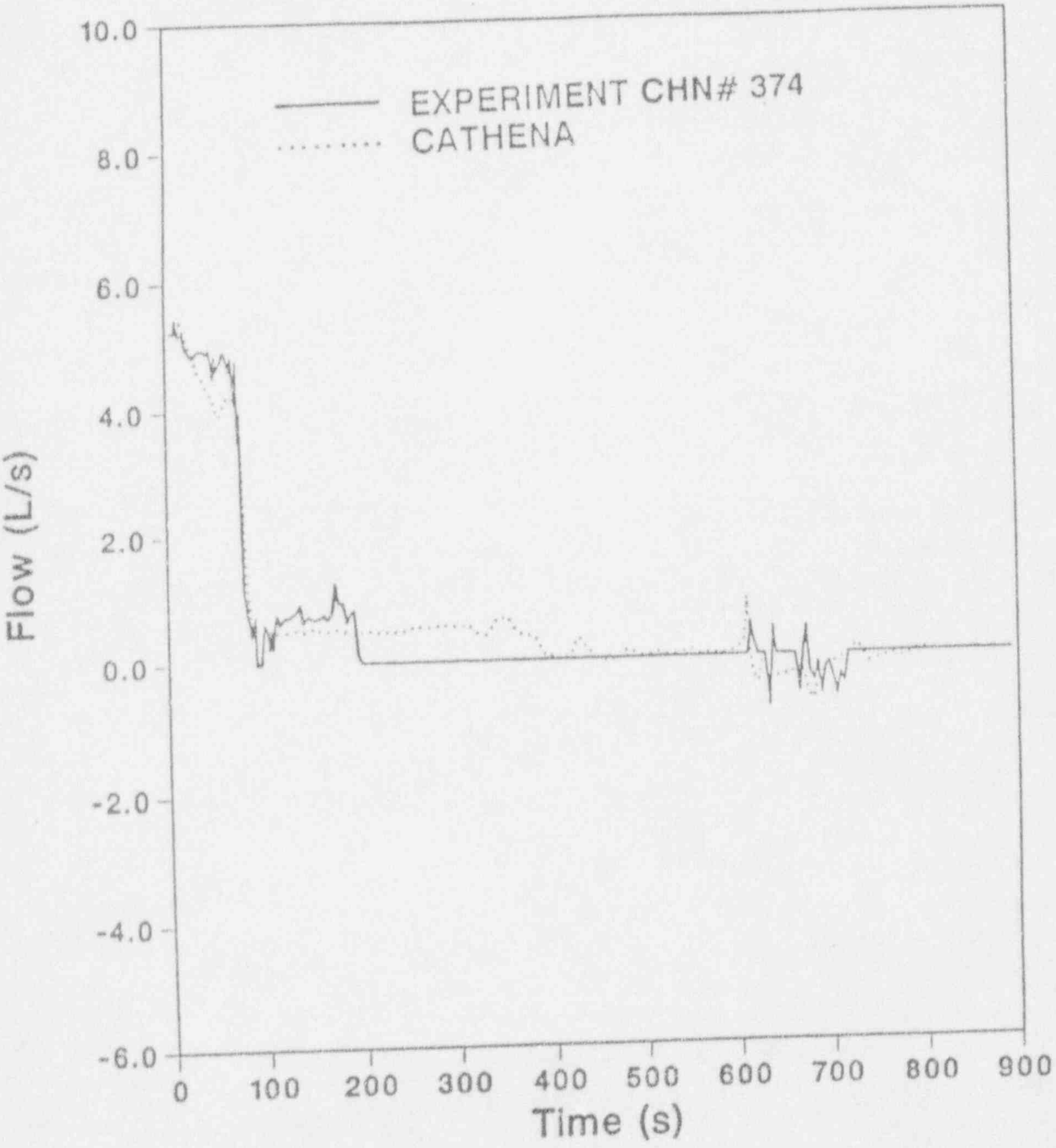
- Constant Secondary Side Pressure
- Primary Pump Tripped
- No ECI
- No Header Interconnect
- 7-mm Inlet Header Break
- Pressurizer Isolated prior to break



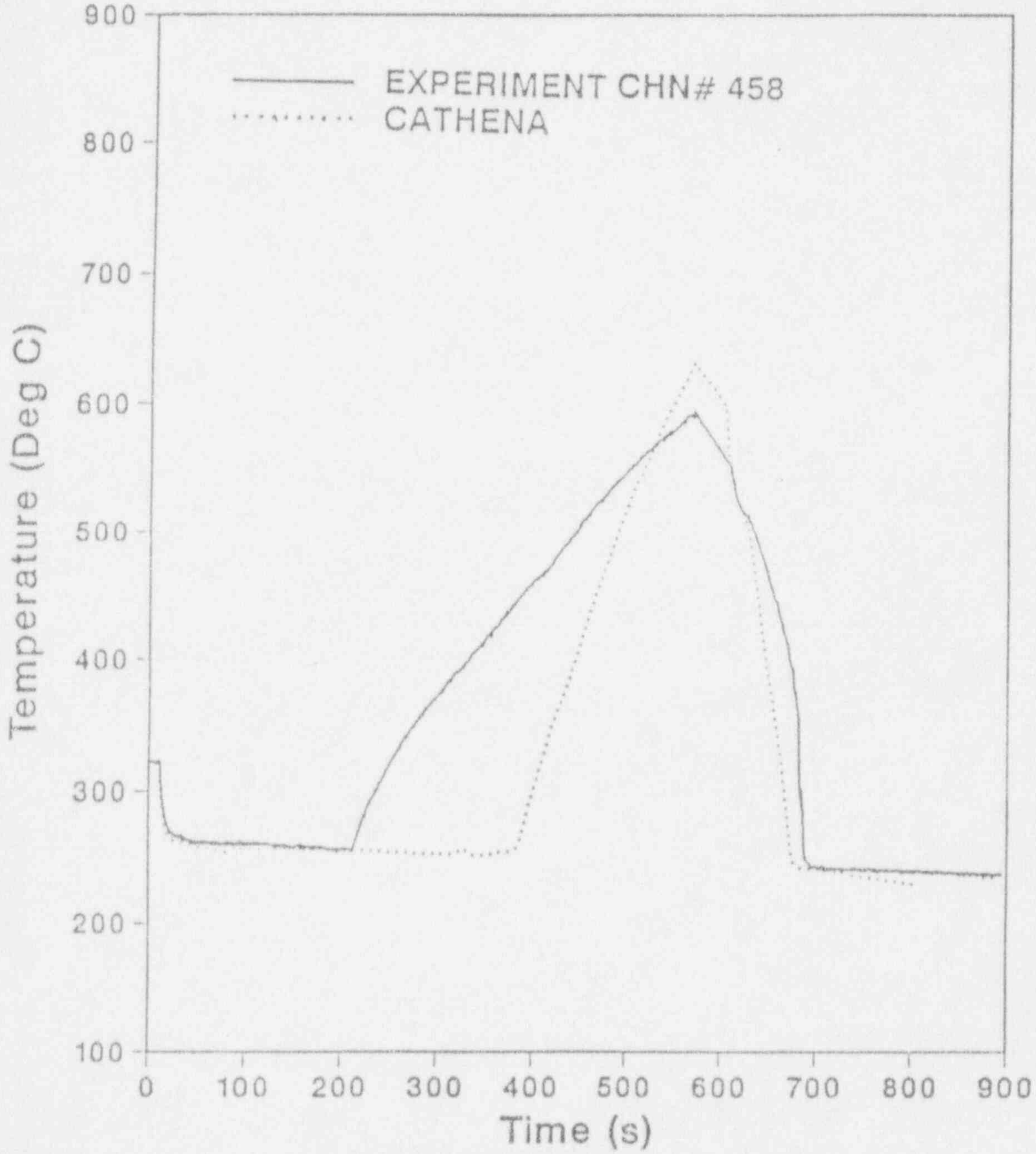
Outlet Header 7 Pressure



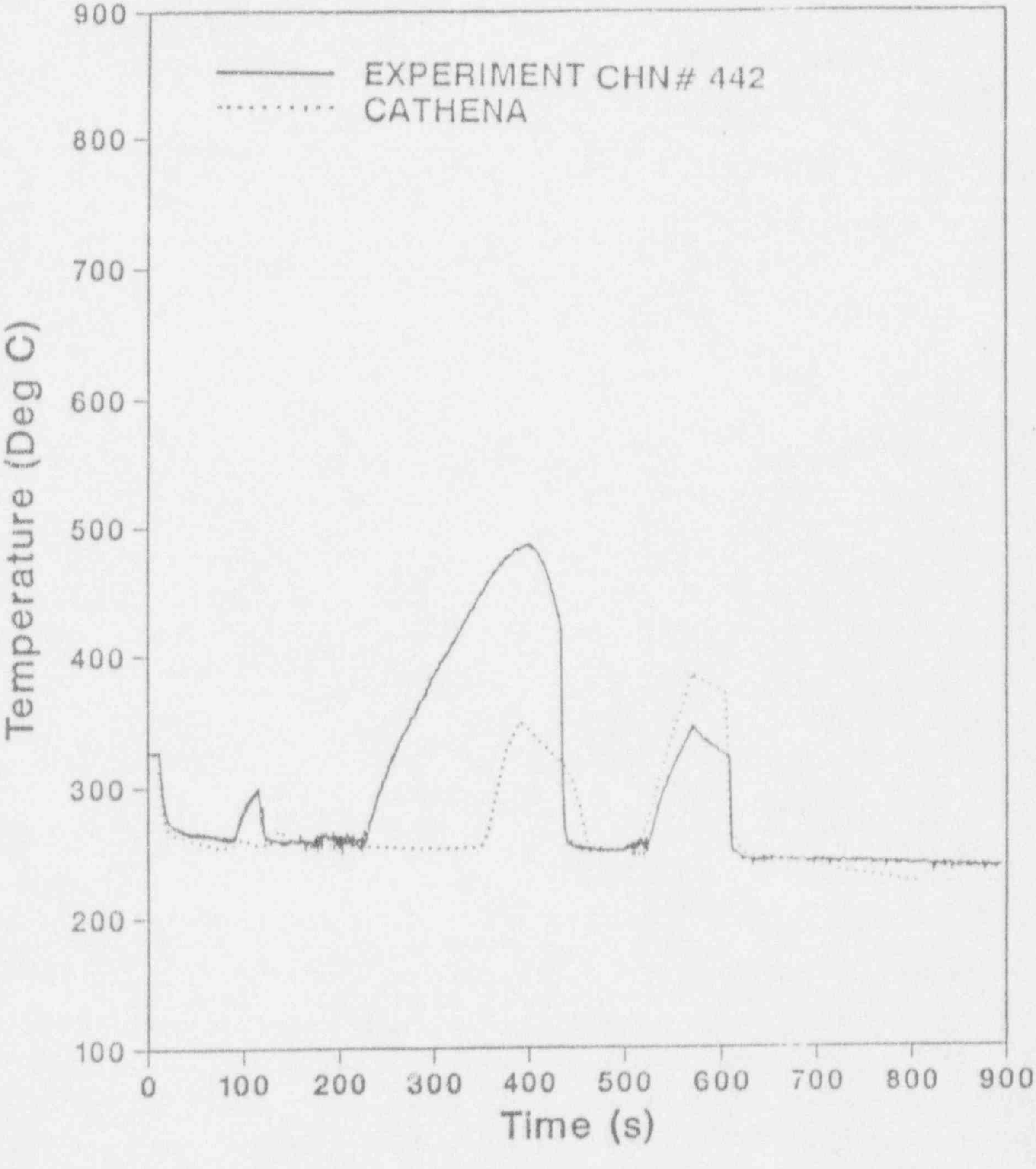
Pump 1 Outlet Flowrate



Channel 9 Outlet Flowrate



Channel 9 Sheath Temperature



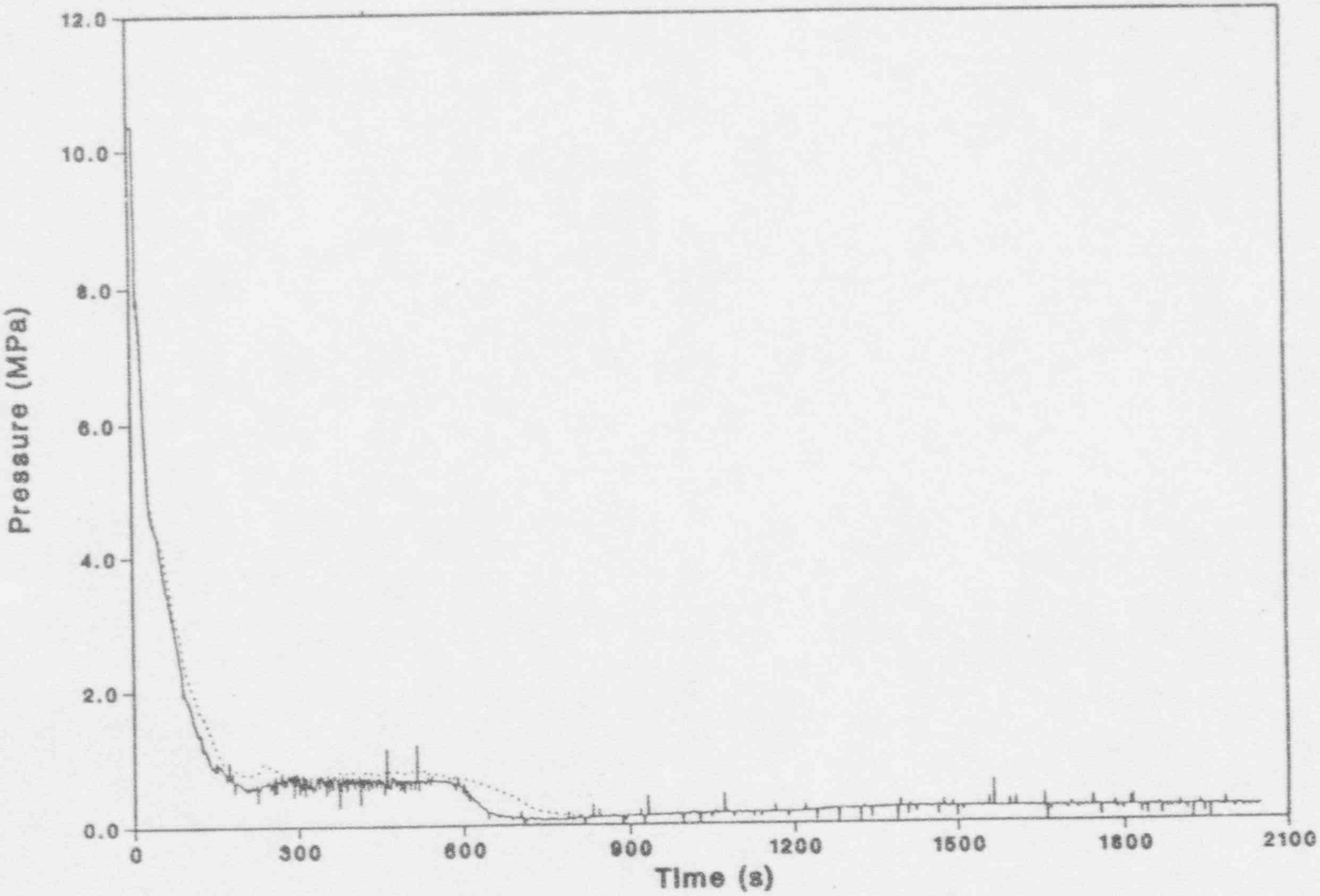
Channel 9 Sheath Temperature

RESULTS

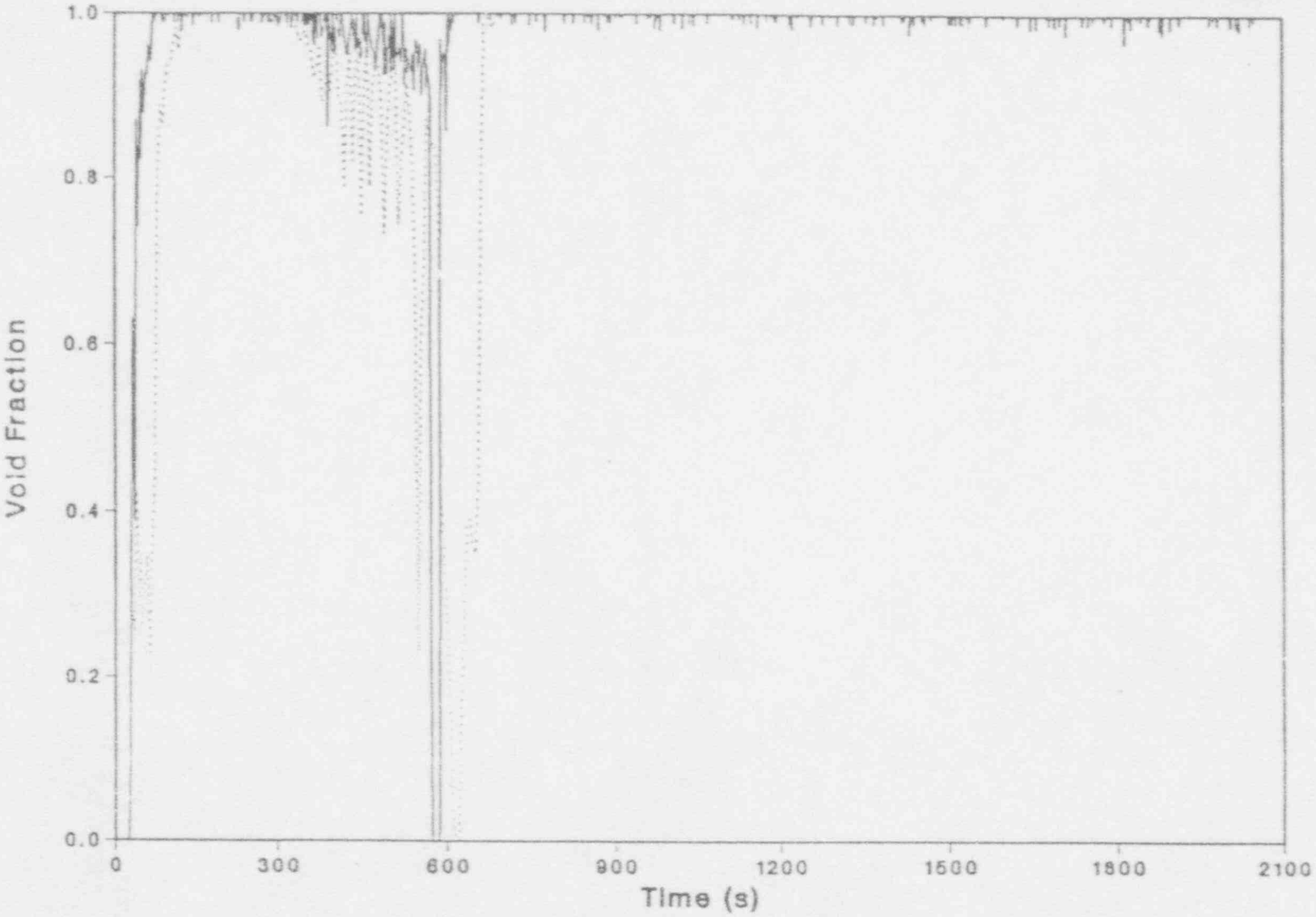
LOCA - Critical Break

Test Conditions:

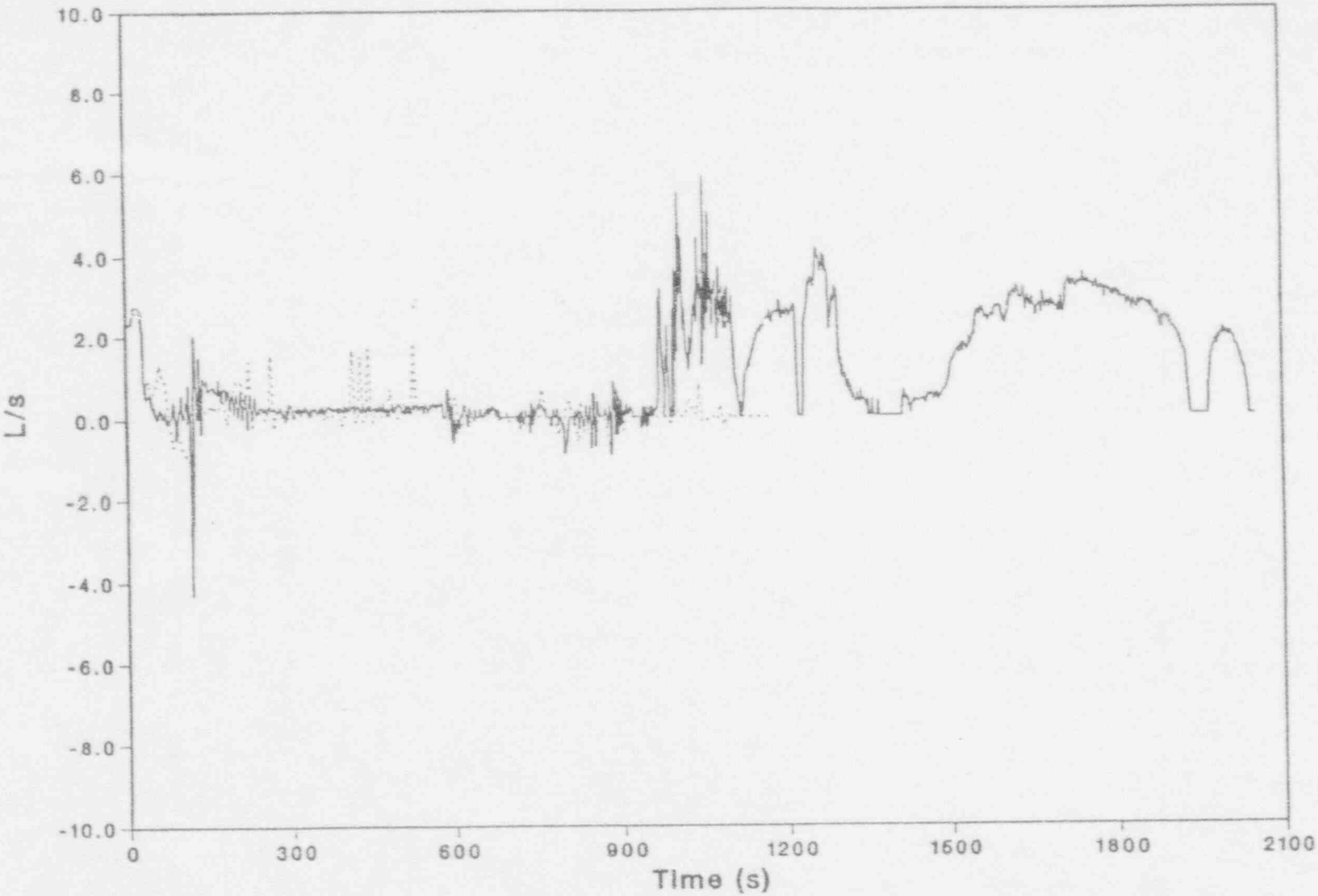
- Secondary Side Depressurization
- Pump continued at 50% rated speed
- ECI, high pressure & pumped injection
- No Header Interconnect
- 18-mm Inlet Header Break
- Pressurizer Isolated prior to break
- Only case where pump continued to run



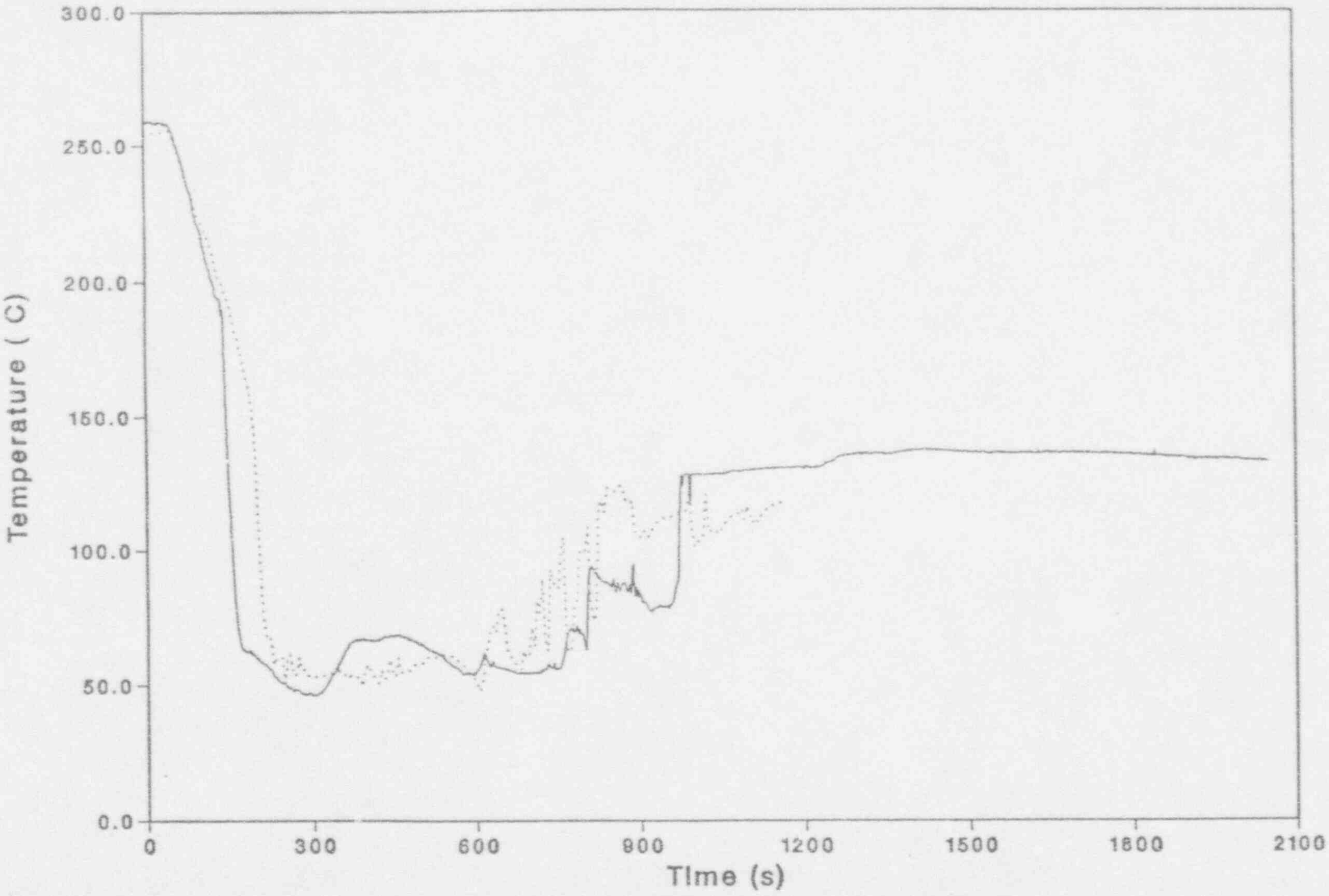
Header 8 Pressure



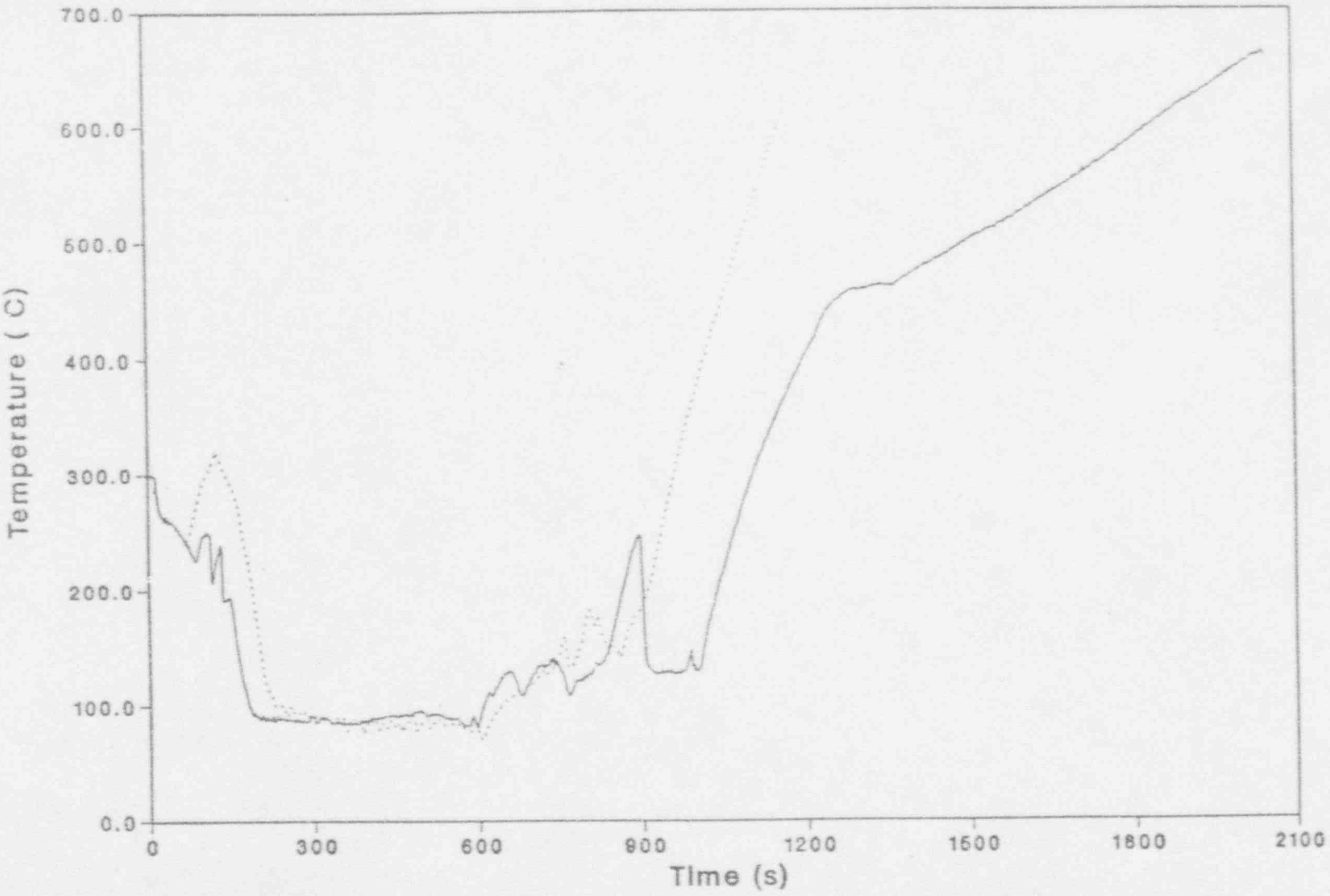
Boiler 2 Outlet Void Fraction



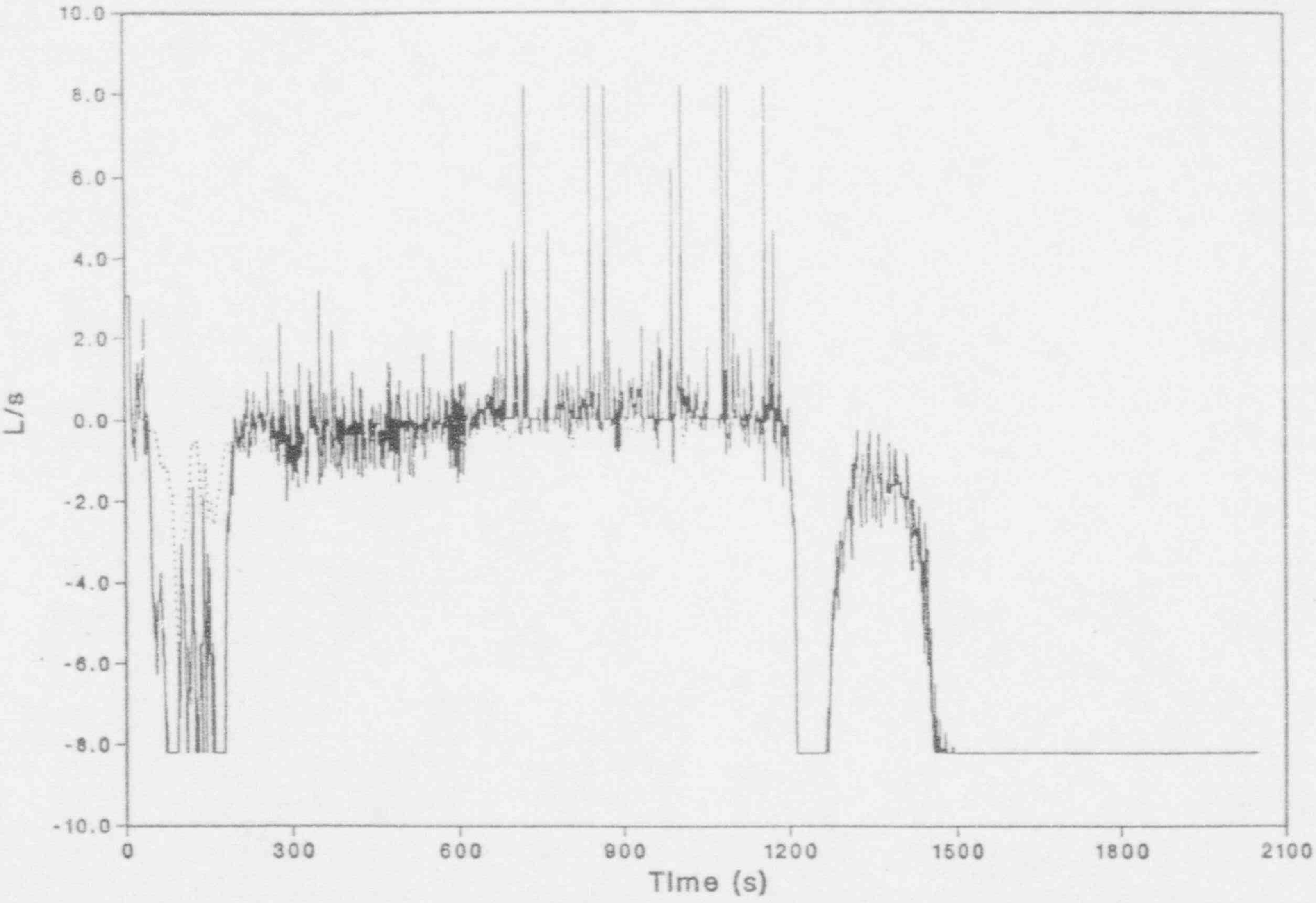
Channel 9 Inlet Flowrate



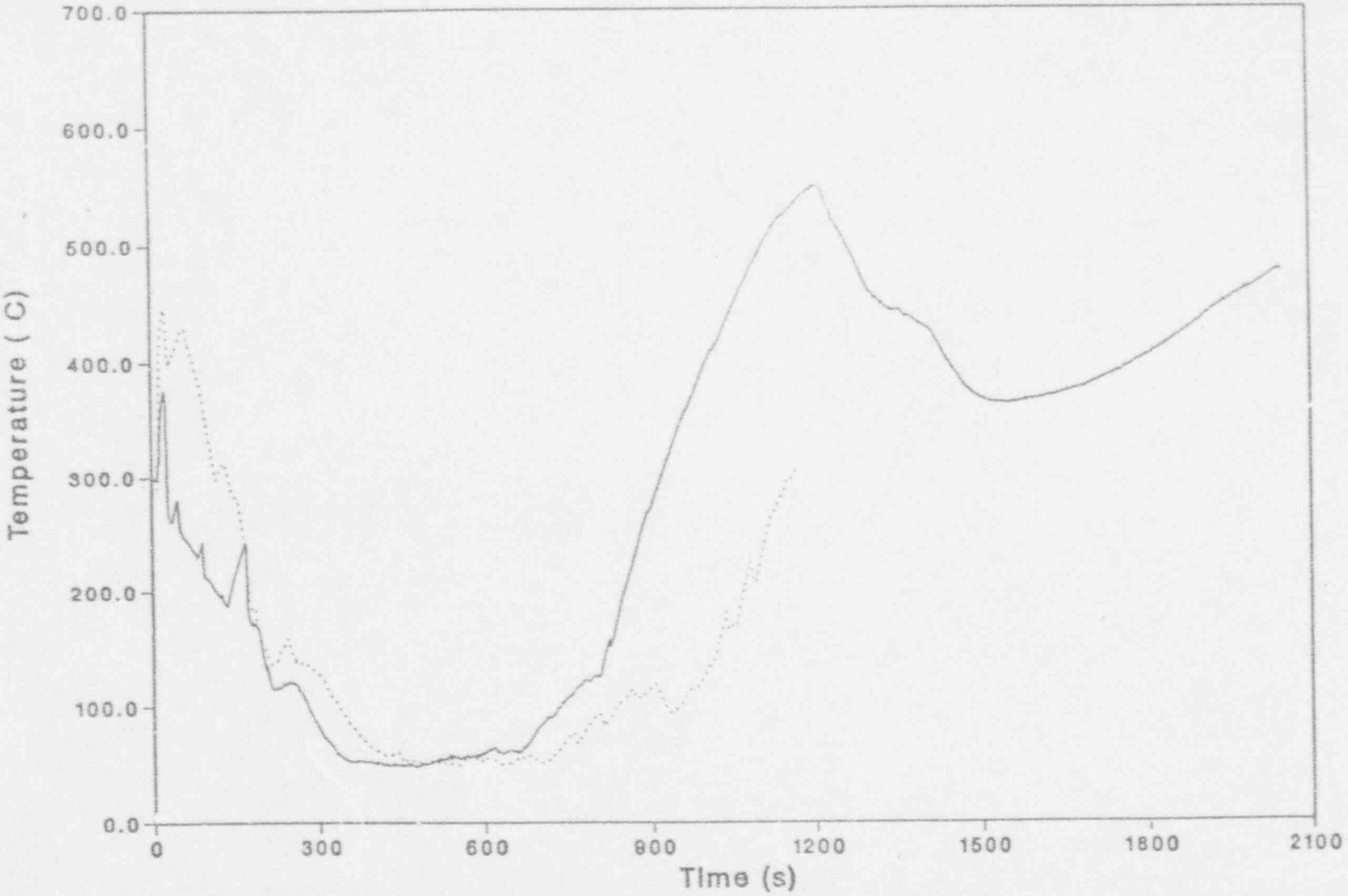
Channel 9 Inlet Fluid Temperature



Channel 9 Sheath Temperature



Channel 12 Inlet Flowrate



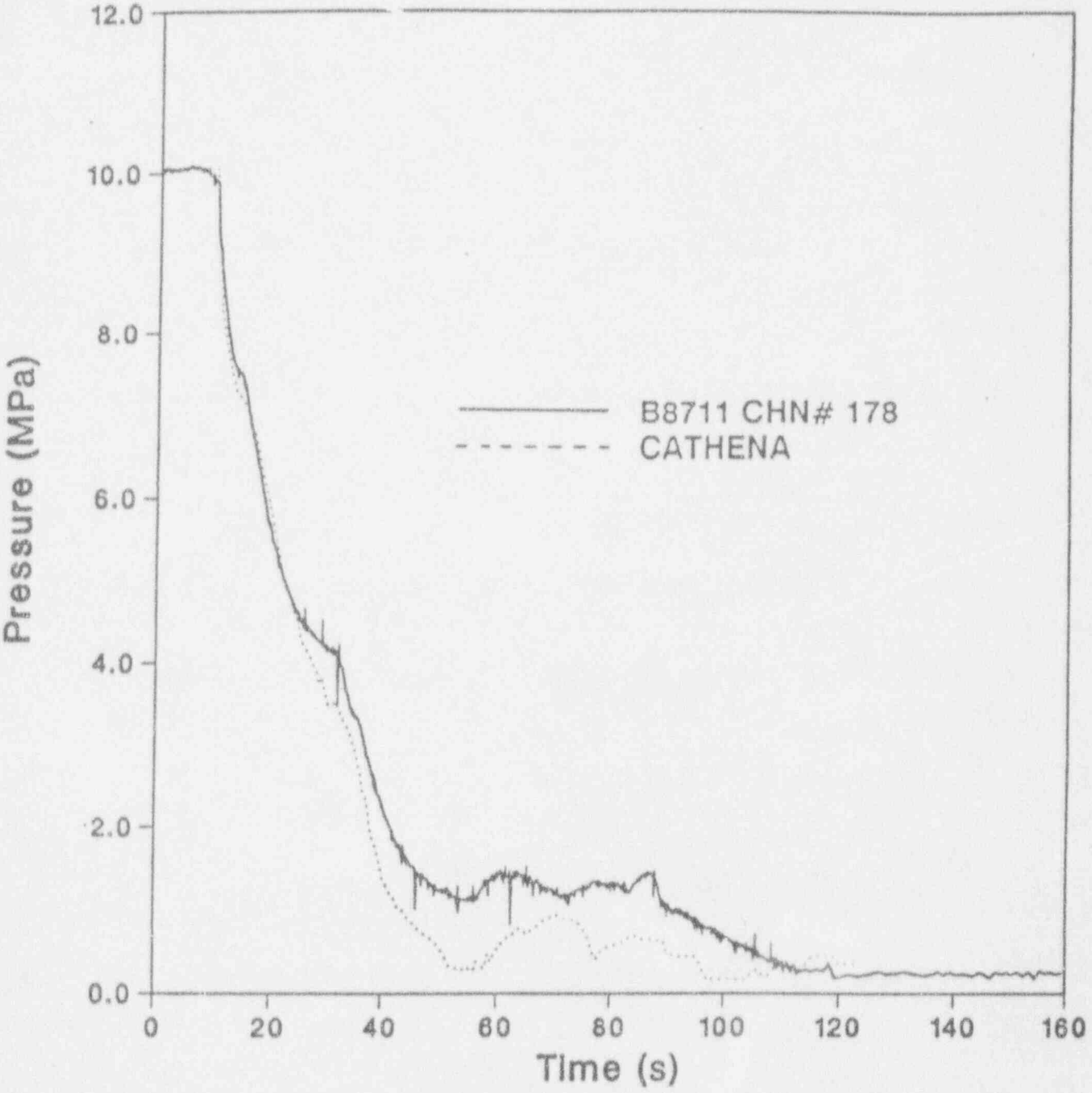
Channel 12 Sheath Temperature

RESULTS

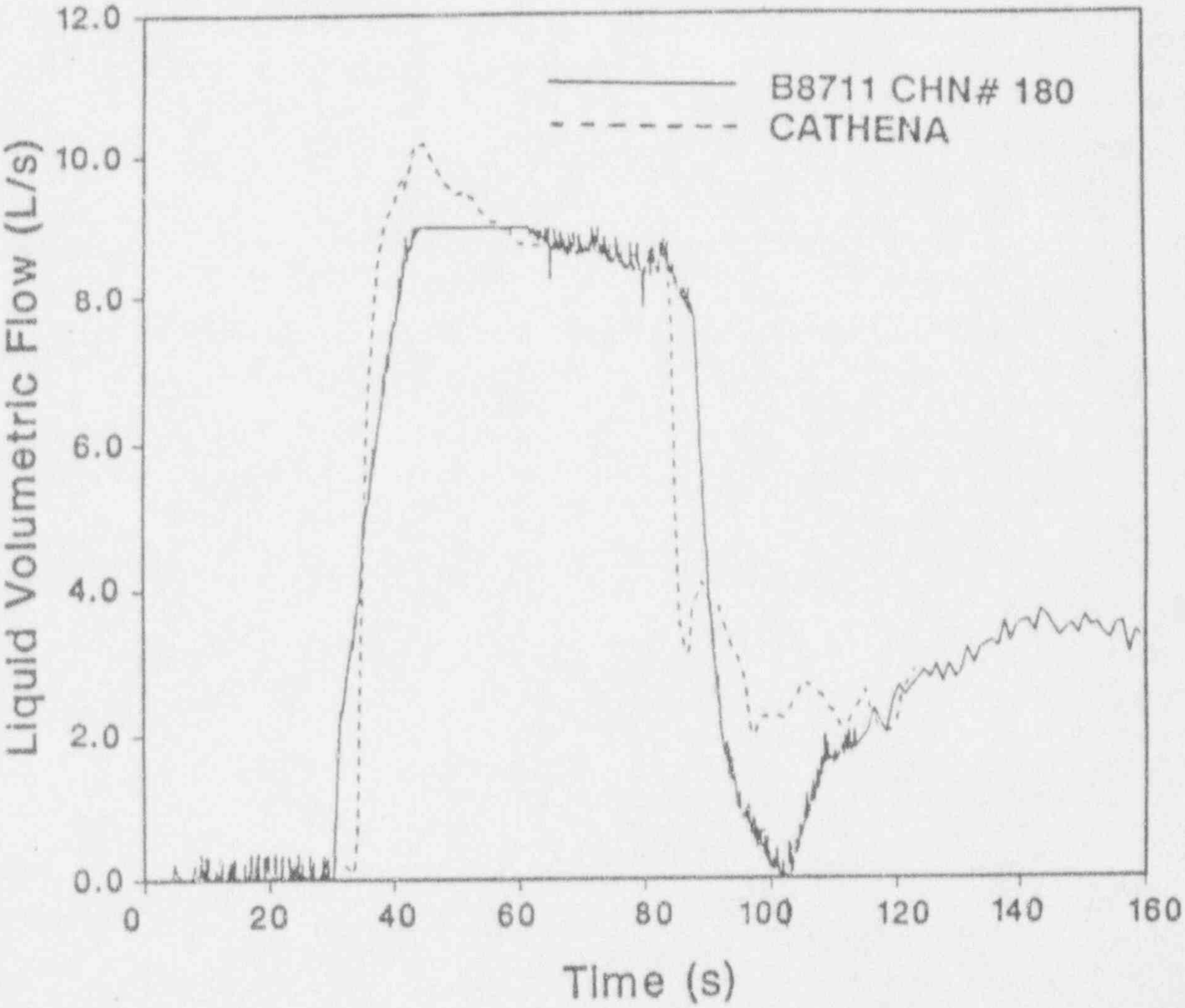
LOCA - Large Break

Test Conditions:

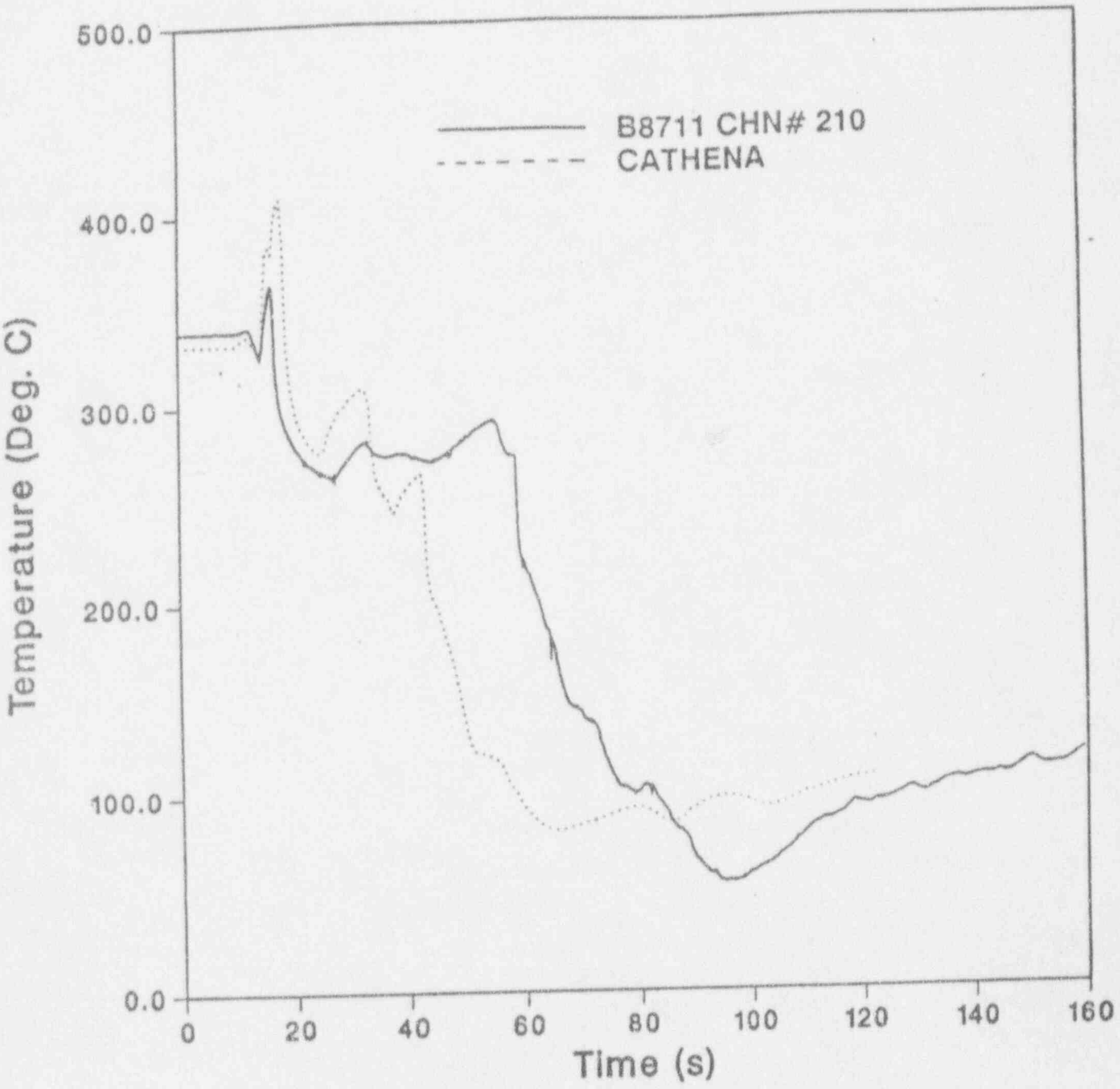
- Constant Secondary Side Pressure
- Pump tripped 2 s after break
- ECI, high pressure injection
- No Header Interconnect
- 35-mm Inlet Header Break
- Pressurizer Isolated prior to break



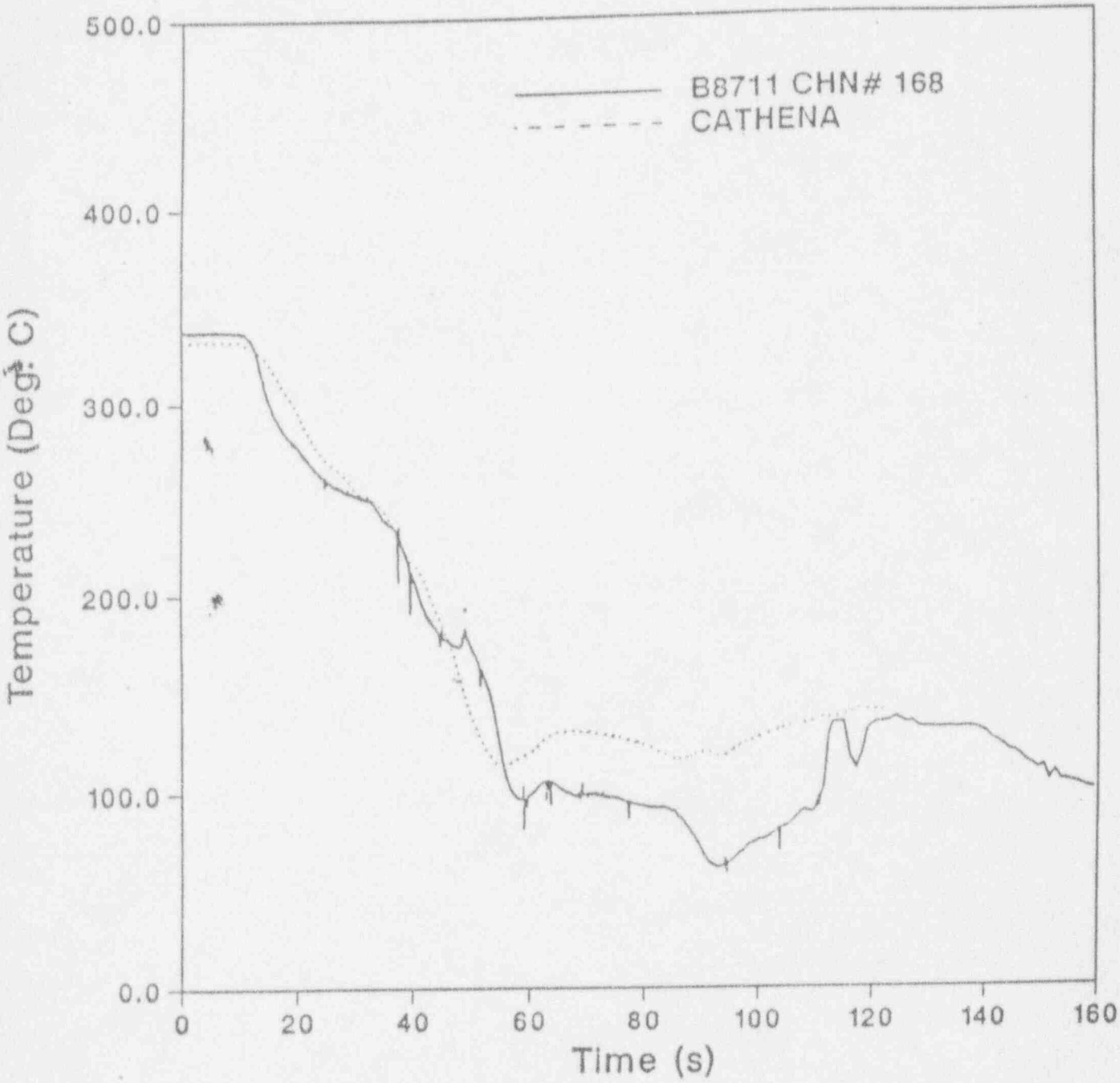
Outlet Header 3 Pressure



Header 2 ECI Flowrate



Channel 1 Sheath Temperature



Channel 2 Sheath Temperature

FUTURE VALIDATION

(Integral Tests)

- Fill in gaps in validation base

- Revisit previous simulations as new models become available
  - Generalized Tank Model
  - Level Swell (Stratified Flow)
  - Generalized Discharge Model
  - 2-D Header Model

- Assess end-fitting modelling

NATURAL CIRCULATION TESTS PROCEDURE

PARTIAL INVENTORY TESTS:

1. Establish steady-state, single phase natural circulation flow at desired operating conditions.

2. Drain a fixed quantity of fluid intermittently from outlet header and monitor resulting thermalhydraulic behaviour.

3. Repeat intermittent draining until test terminated due to high Fuel Element Simulator temperature (600°C).

NATURAL CIRCULATION TESTS PROCEDURE

TRANSITION TO THERMOSIPHONING TESTS:

1. Establish steady-state, forced convective flow at desired operating conditions.
2. Drain a fixed quantity of fluid from outlet header.
3. Trip primary pumps.
4. Monitor resulting natural circulation behaviour until steady-state is achieved or test terminated due to high Fuel Element simulator temperature (600°C).

NATURAL CIRCULATION TESTS - VARIABLES

Power Level	60, 100, 160 kW/pass
Secondary-side Pressure	0.2, 1.1, 4.6 MPa and ramped
Drain rate	0.025 to 0.2 L/s
Header Interconnect	none, geometric and dynamic scaled
Surge Tank	on-line, off-line
Emergency Coolant Injection	yes, no
Secondary-side System	high power, low power
Feeder Trace Heating	on / off

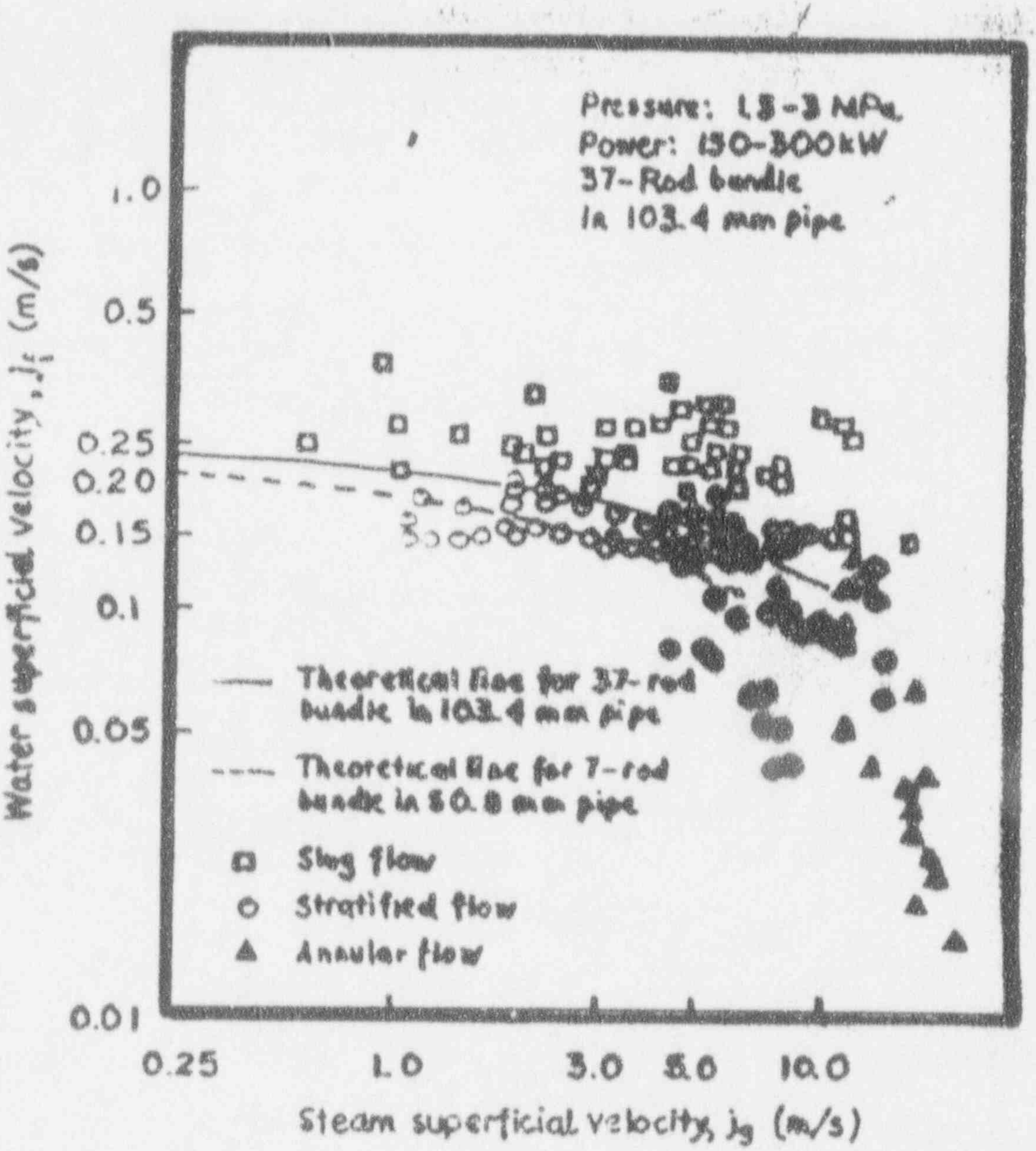
FLOW STABILITY TESTS

Objective:

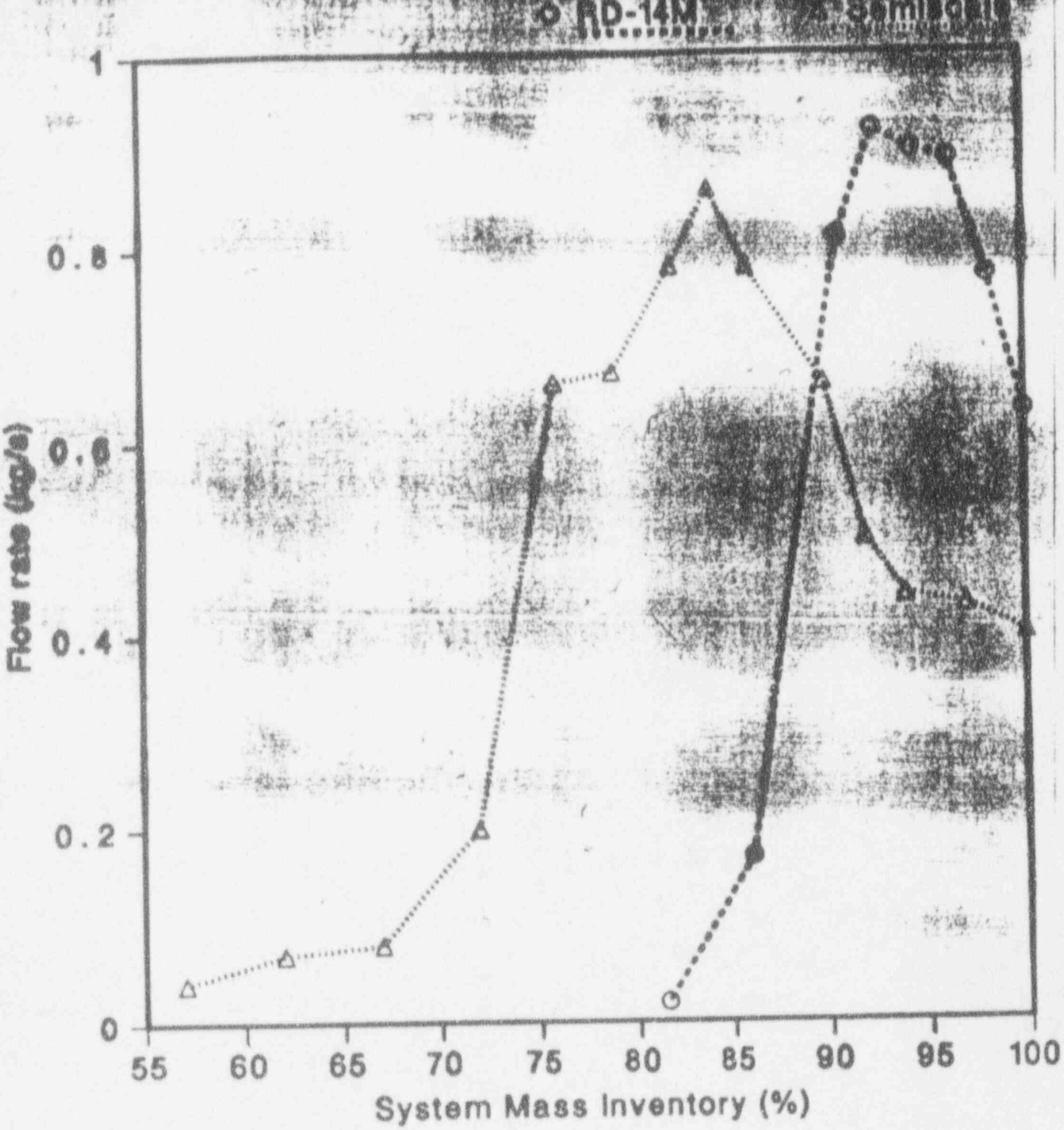
Investigate effect of header interconnects on flow stability.

Experimental Procedure:

Induce quality in outlet feeders by:
1. reducing primary pump speed, or
2. reducing primary pressure.


Pressure: 1.8-3 MPa
Power: 150-300kW
37-Rod bundle
in 103.4 mm pipe
Water superficial velocity, j_f (m/s)
1.0
0.5
0.25
0.20
0.15
0.1
0.05
0.01
Theoretical line for 37-rod bundle in 103.4 mm pipe
Theoretical line for 7-rod bundle in 50.8 mm pipe
Slug flow
Stratified flow
Annular flow
0.25
1.0
3.0
5.0
10.0
Steam superficial velocity, j_g (m/s)

System Flow Rate vs Mass Inventory



SMALL BREAK LOCA ASSESSMENT IN RD-14M

Objective:

To provide information on the blowdown and refill phenomena that occur following a feeder sized break at an inlet header

BREAK SIZE SCALING RATIONALE

7-mm diameter orifice used to simulate feeder line break based on:

$$\frac{\text{Area of RD-14M orifice}}{\text{Volume of RD-14M loop}} = \frac{\text{Area of broken reactor feeder}}{\text{Volume of reactor}}$$

INITIAL EXPERIMENTAL CONDITIONS FOR RD-14M SMALL BREAK TESTS

Primary System	Outlet Header Pressure - 10 MPa(g) Input Power - 4.0 MW/pass Flow - 27 $L \cdot s^{-1}$
Secondary System	Steam drum pressure - 4.5 MPa(g) Feedwater temperature - 187° C

TIME/EVENT SEQUENCE FOR SMALL BREAK TESTS

Time/Event	Action
t = 0 s	- Start gathering data
t = 6 s	- Isolate surge tank
t =10 s	- Open break valve
P = 8.8 MPa	- Step input power to decay levels (200 kW/pass, 5% of 4.0 MW/pass) - Start pump ramp [illegible] if necessary
P = 6.0 MPa	- Open ECI isolation valves at headers
P = 4.2 or 5.5 MPa	- Start high-pressure ECI (depending on system) - Start secondary pressure ramp
ECI tank empty	- Stop high-pressure ECI - Start low-pressure ECI
Conditions Stabilized	- Stop gathering data

Small Break LOCA Experimental Test Matrix

ECI	Pump Ramp	Secondary Pressure Ramp
No	No	No
Yes	Yes	Yes
Yes	No	No
Yes*	No*	Yes*

* done with header interconnect.

9 tests in total, with high pressure pumped ECI and high pressure ECI from an accumulator tank.

TEST MATRIX FOR RD-14M SMALL BREAK EXPERIMENTS

Test Number	ECI SYSTEM	Pump Ramp	Secondary Pressure Ramp	Header Interconnect
B9001	None	No	No	No
B9002	Pumped	No	No	No
B9003	Pumped	No	Yes	No
B9004	Pumped	Yes	Yes	No
B9005	Accumulator	No	Yes	No
B9006	Accumulator	Yes	Yes	No
B9007	Accumulator	No	Yes	No
B9008	Accumulator	No	No	No
B9009	Accumulator	No	Yes	Yes

Critical-Break LOCA Experiments

Objectives:

- To investigate the thermalhydraulic behaviour of RD-14M under critical-break conditions.
- To examine the effect of break size, primary-side flow rate, decay power level, isolation of surge tank and mode of ECI on blowdown and refill behaviour.

CRITICAL BREAK TESTS

Definition:

A critical break in RD-14M is a break that results in the flow split point remaining in the heated portion of the channels (3) for several seconds (2 or 3) in the first five or ten seconds of the transient.

CATHENA was used to aid in experimental design of these tests.

INITIAL EXPERIMENTAL CONDITIONS FOR RD-14M LOCA TESTS

Primary System	Outlet Header Pressure - 10 MPa(g) Input Power - 4.0 MW/pass Flow - 27 L/s
Secondary System	Steam drum pressure - 4.5 MPa(g) Feedwater temperature - 187°C

EXPERIMENTAL PROCEDURE FOR CRITICAL BREAK TESTS

Time / Event	Action
t = 0 s	Start gathering data
t = 6 s	Isolate surge tank (if required)
t =10 s	Open break valve
t =12 s	Step input to decay level (165 kW/pass) Start pump ramp if necessary
P = 4.2 or 5.5 MPa	Start high-pressure ECI Isolate Pressurizer (if required)
ECI tank empty	Stop high-pressure ECI Start low-pressure ECI
Conditions Stabilized	Stop gathering data

RD-14M CRITICAL BREAK TEST MATRIX

Test	High-Pressure ECI System	Break Location (Header)	Pump Ramp	Break Size (mm)	Pressurizer	Critical
B9010	Accumulator	Inlet	No	30	Off-line	Yes
B9011	Accumulator	Inlet	No	30	On-line until ECI	Yes
B9012•	Accumulator	Inlet	No	35	On-line until ECI	Yes
B9013	Accumulator	Inlet	Yes	30	On-line until ECI	Yes
B9014	Accumulator	Outlet	No	70	Off-line	?
B9016	Accumulator	Outlet	Yes	60	On-line until ECI	?
B9016•	Pumped	Inlet	No	30	Off-line	Yes
B9017·	Pumped	Inlet	Yes	30	On-line until ECI	Yes
B9101	Pumped	Inlet	Yes	30	On-line	Yes
B9102▫	Pumped	Inlet	Yes	30	On-line until ECI	Yes
B9103•	Pumped	Inlet	Yes	30	On-line until ECI	Yes
B9104•	Pumped	Inlet	No	30	On-line until ECI	No
B9105▪	Pumped	Inlet	No	18	On-line until ECI	Yes

Notes: ▫ - Repeat of test B9017

• - Decay power level set at 200 kW/pass

▪ - Conducted at one-half normal initial power (2 MW/pass) and flow rate (12.3 L/s⁻¹)

· - Water hammer

Critical Break LOCA Test Matrix

Break Location (Header)	Pump Ramp	Pressurizer
Inlet	No	Off-line
Inlet	No	On-line
Inlet	Yes	On-line
Outlet	No	Off-line
Outlet	Yes	On-line

A total of 14 tests with high pressure pumped ECI or high pressure ECI from an accumulator tank.

Flow Stability Experiments

Objectives:

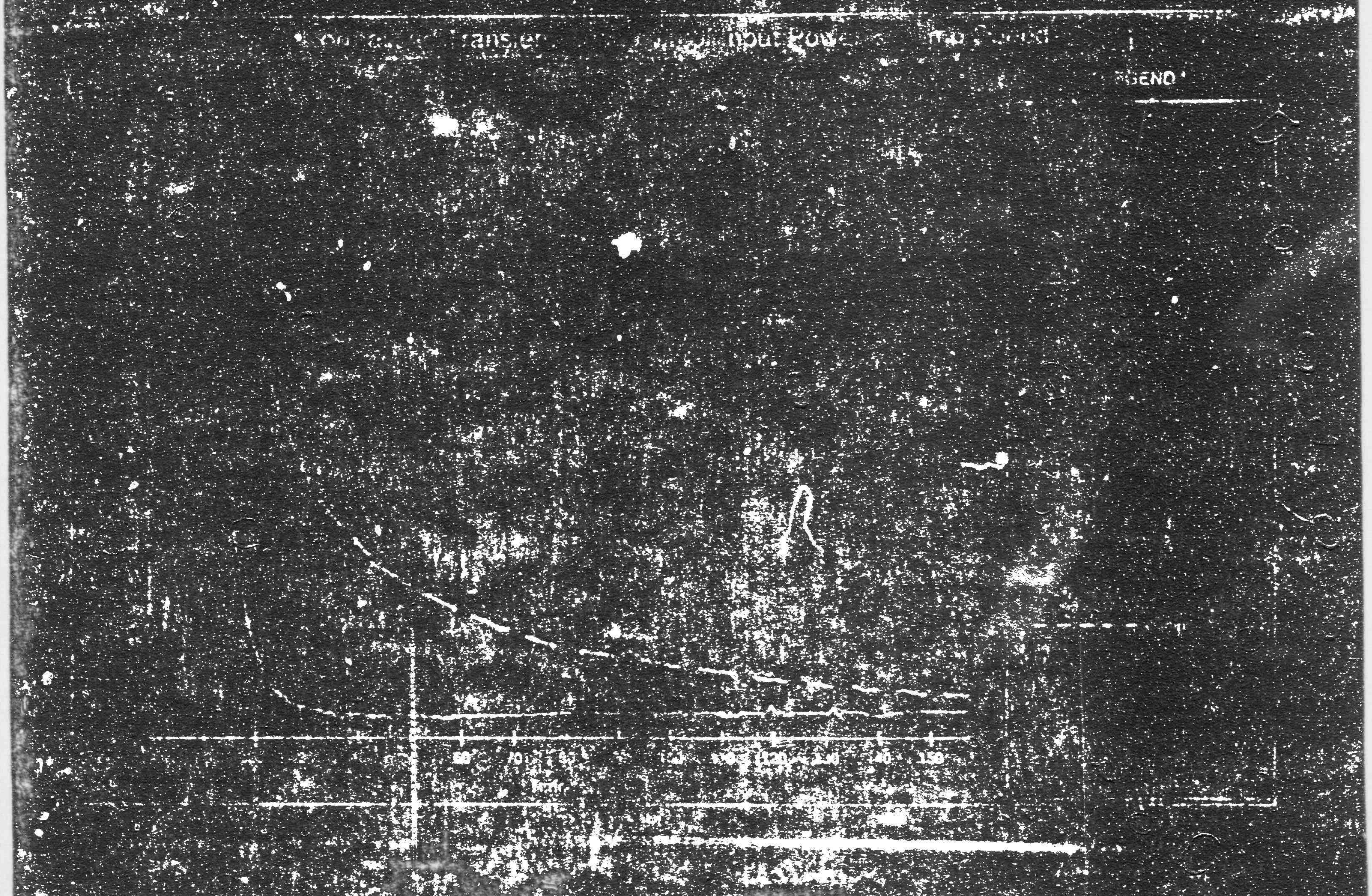
- To investigate the stabilizing influence of various header interconnect geometries on the primary heat transport system flow behaviour with net quality in the outlet headers.

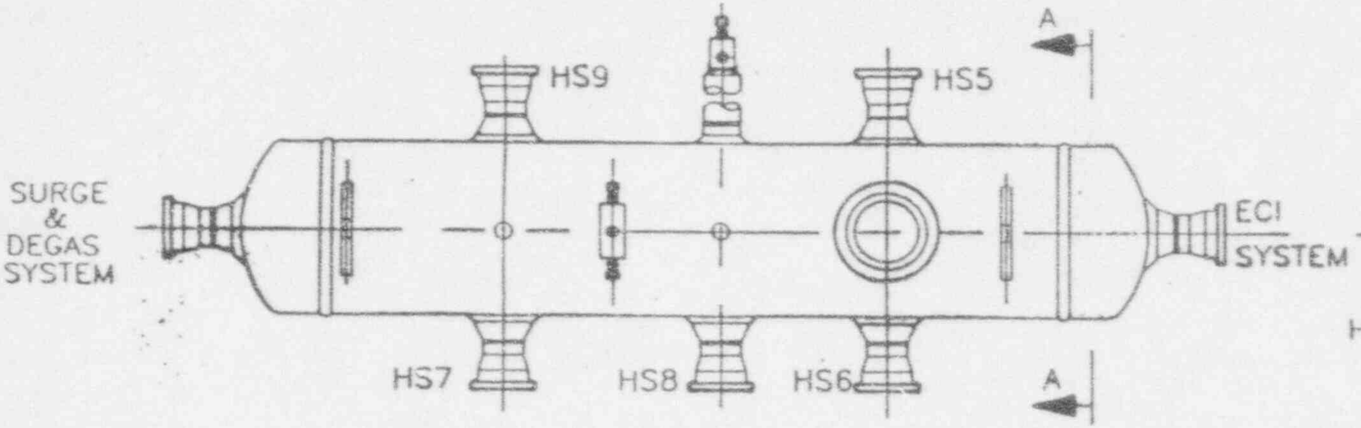
Experimental Procedure

- Bring to nominal full power conditions
- Induce quality in primary loop
- Start data collection
- Periodically isolate surge tank

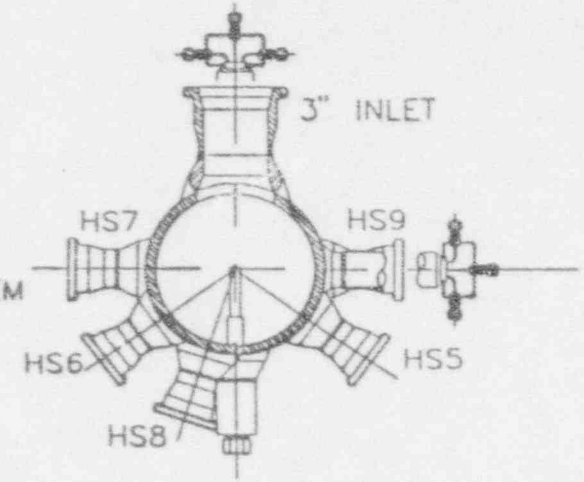
STEAM GENERATOR COMPARISON

Parameter	BRUCE B	CANDU-600	RD-14M
Tube OD (mm)	12.96	15.9	15.9
Tubing Wall Thickness (mm)	1.13	1.13	1.13
Primary Mass Flux ($\text{kg}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	3750	4215	3740
Heat Flux ($\text{kW}\cdot\text{m}^{-2}$)	120	165	130
Tube Bundle Height (m)	8.56	9.42	9.4
Overall Height (m)	15	18.7	12
Tube Material	Inconel 600	Incoloy 800	Incoloy 800
Recirculation Ratio (full power)	5:1	5.7:1	6:1


Transfer
Input Power
LEGEND
60
70
120
130
140
150

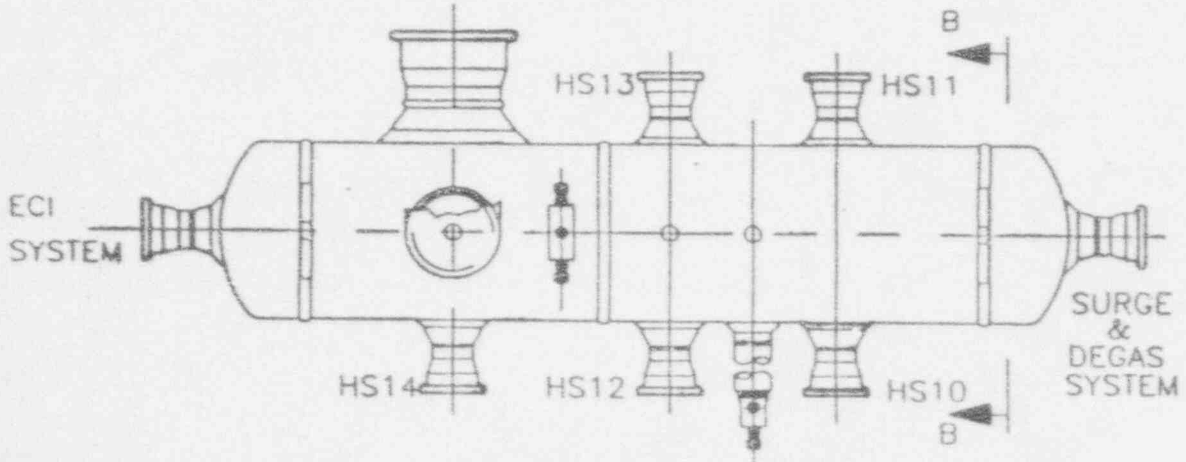


INLET HEADER RD14-HD6

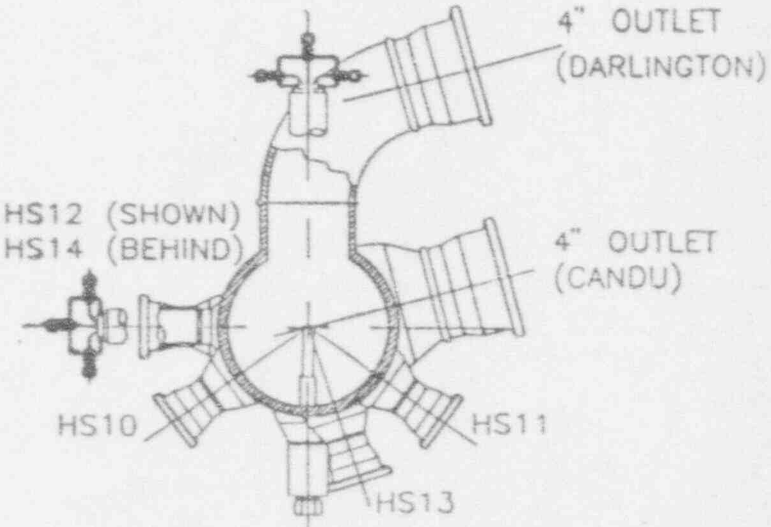


SECTION A-A

ROTATED 90'



OUTLET HEADER RD14-HD5



SECTION B-B

ROTATED 90'

HS= HEATER SECTION

Experimental Procedures

- Induce quality in the outlet headers by:
  - Reducing primary pump speed
  - Reducing primary pressure

- Investigate effect of header interconnect

Scaling Rationale

Two scaling rationales were used:

- preservation of geometric similarity
- preservation of flow dynamics

Geometric Similarity

Based on conservation of momentum equation

$$\Delta P = L\frac{dG}{dt} + \left[\frac{FL}{D} + K\right]\frac{G^2}{2\rho} + \Delta P_{grav}$$

where L = length (m)
G = mass flux ($Kg/(m \cdot s^2)$)
F = friction factor
D = pipe internal diameter (m)
K = geometrical loss coefficient
ΔP_{grav} = hydrostatic head (Pa)
ρ = fluid density (Kg/m^3)

Dynamic Similarity

Ratio of interconnect pipework resistance to heat transport pipe resistance.

Comparison of Header Interconnect Designs used in RD-14M

Parameter	Scaling Technique	
	Geometric Similarity	Dynamic Similarity
Length (m)	**32.**	**15.**
Flow Area (mm^2)	**176**	**452**
Internal Diameter (mm)	**15**	**24**
Height (m)	**5.5**	**1.79**
Orifice Diameter (mm)	**8.5**	**9.7**
A/L (mm)	0.006	0.03

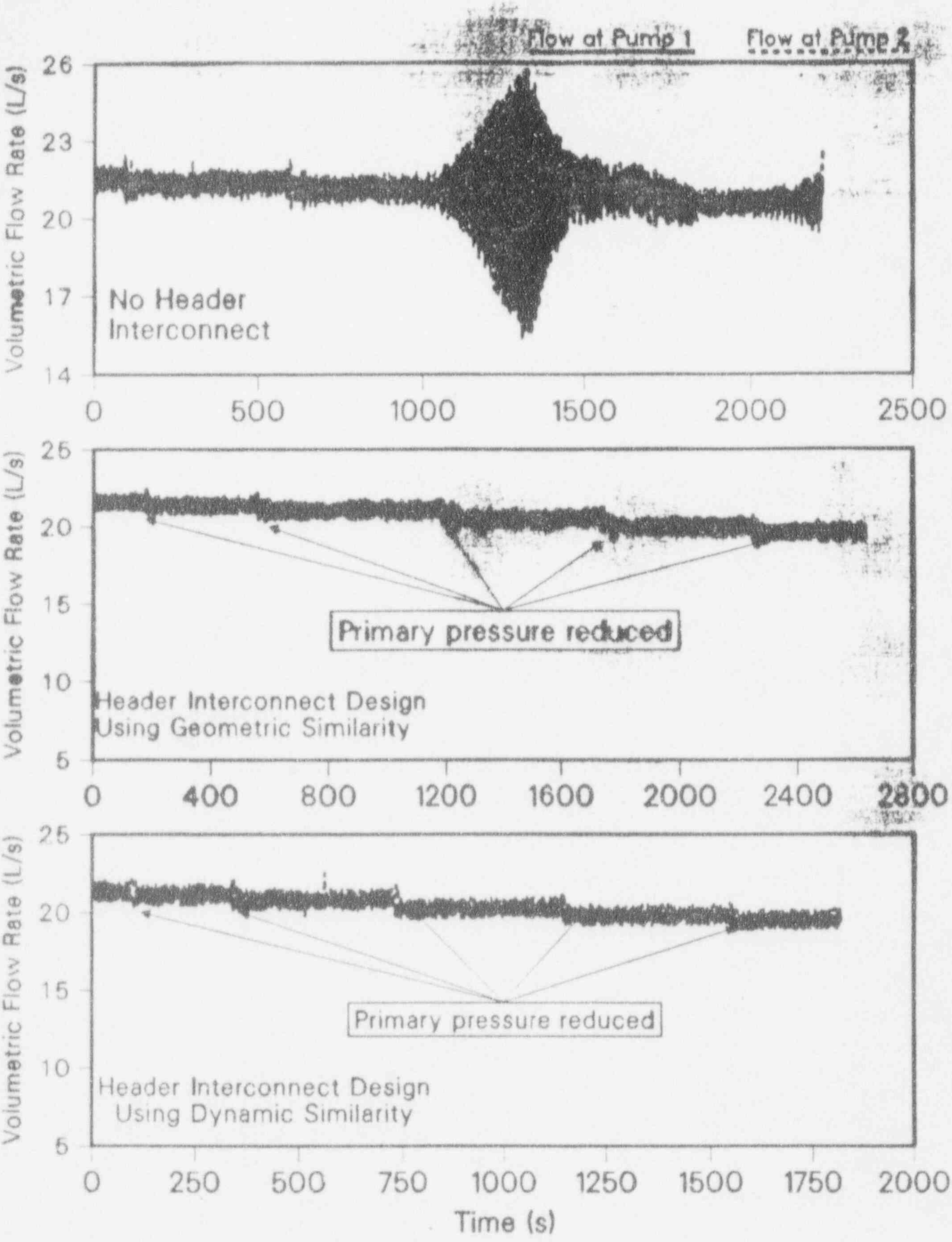
RD-14M Flow Stability Test Matrix

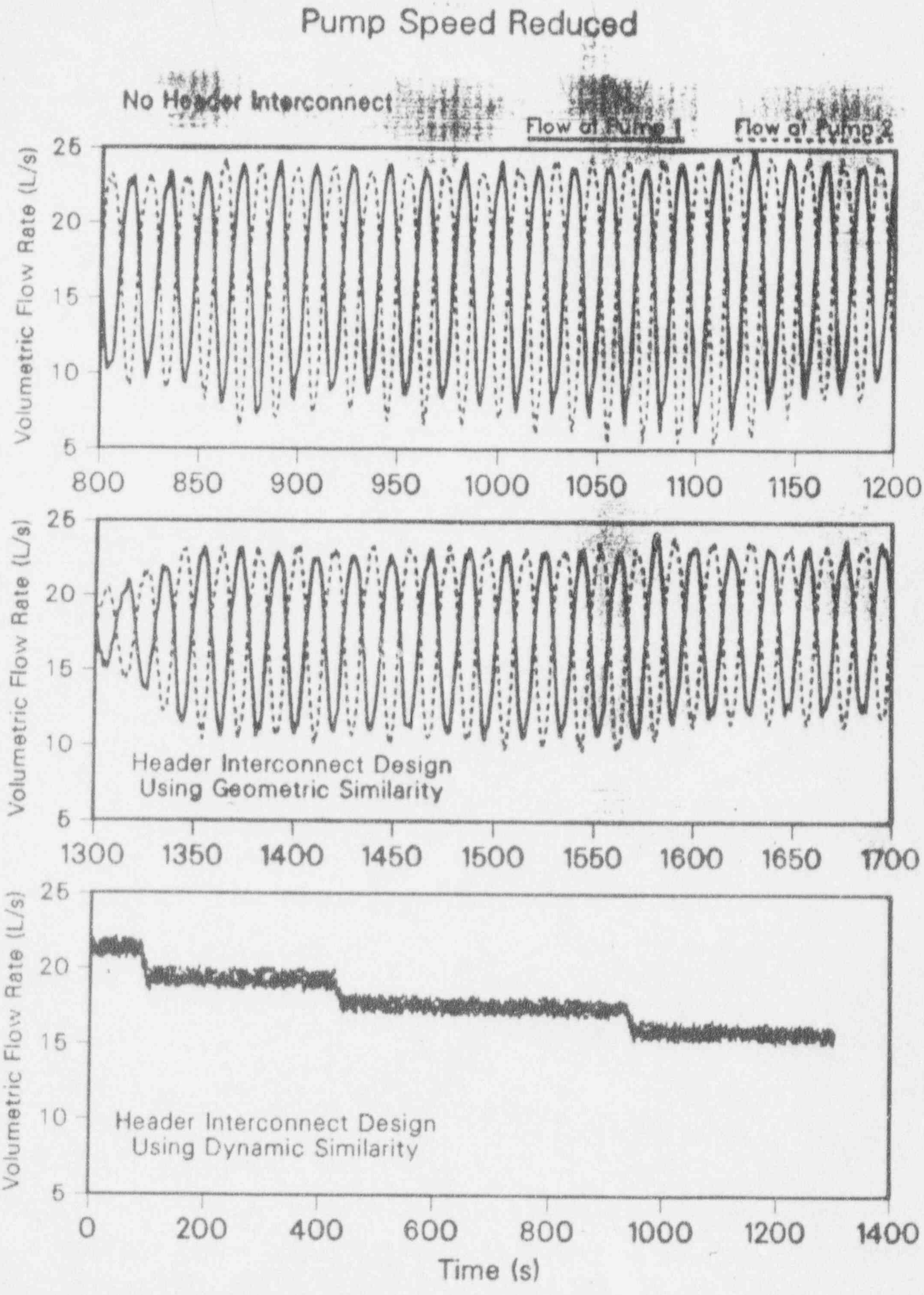
Test #	Experimental Method	Interconnect	
		Geometric Similarity	Dynamic Similarity
F8901	Pump speed reduced	No	No
F8902	Primary pressure decreased	No	No
F8903	Primary pressure decreased	No	No
F8904	Primary pressure decreased	Yes	No
F8905	Pump speed reduced	Yes	No
F8906	Primary pressure decreased	No	Yes
F8907	Pump speed reduced	No	Yes
F8908	Pump speed reduced	No	Yes
F8909	Pump speed reduced	Yes	No

RD-14M Nominal Full Power Conditions

Primary Pressure	10 MPa
Primary Power	4.1 MW/pass
Primary Flow	21 L/s (75% full pump RPM)
Primary Temperature at Outlet Header	310°C
Secondary Pressure	5.4 MPa

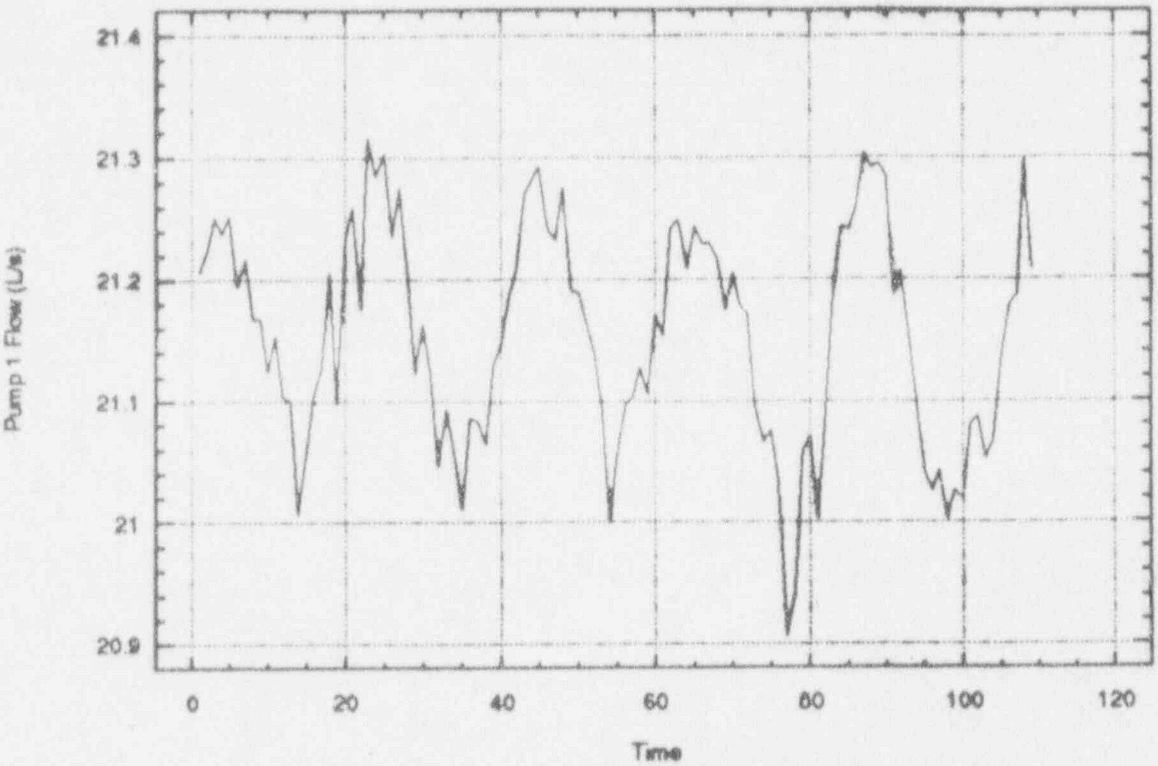
Primary Pressure Reduced




Pump Speed Reduced
No Header Interconnect
Flow of Pump 1
Flow of Pump 2
Volumetric Flow Rate (L/s)
25
20
15
10
5
800
850
900
950
1000
1050
1100
1150
1200
Volumetric Flow Rate (L/s)
25
20
15
10
5
Header Interconnect Design
Using Geometric Similarity
1300
1350
1400
1450
1500
1550
1600
1650
1700
Volumetric Flow Rate (L/s)
25
20
15
10
5
Header Interconnect Design
Using Dynamic Similarity
0
200
400
600
800
1000
1200
1400
Time (s)

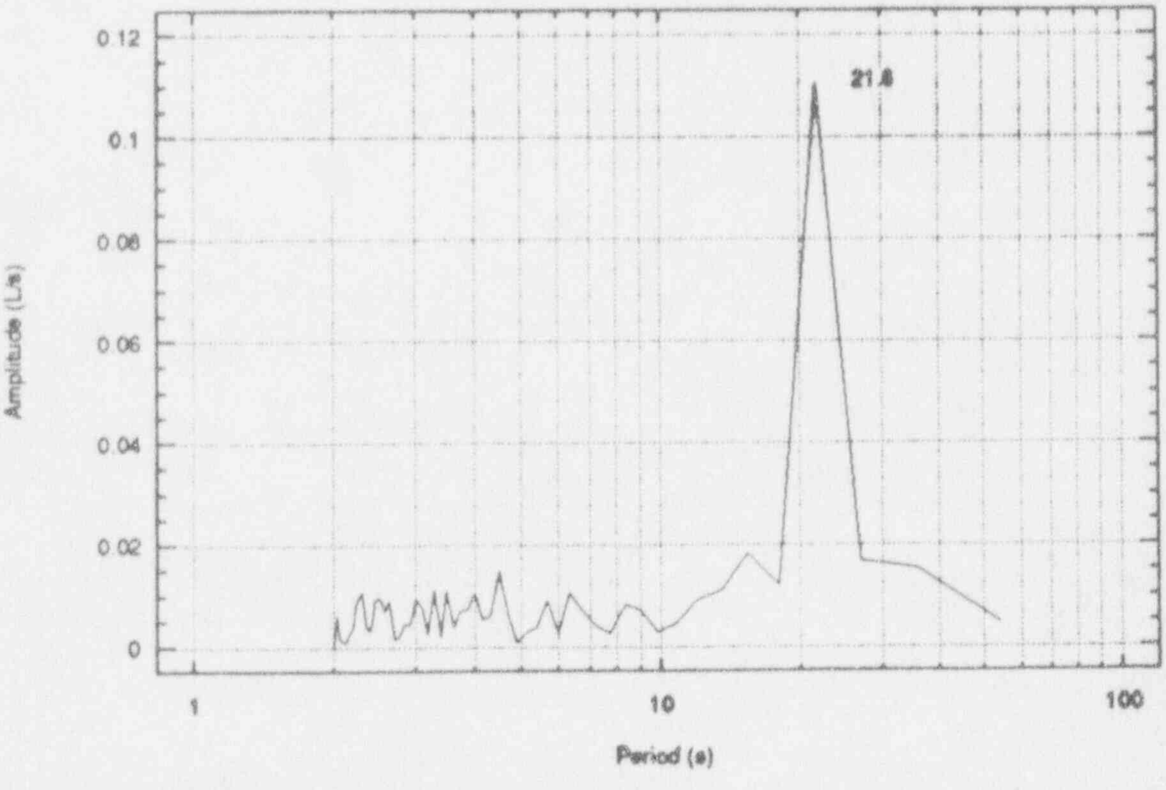
Test F8903

Pump 1 Flow vs Time



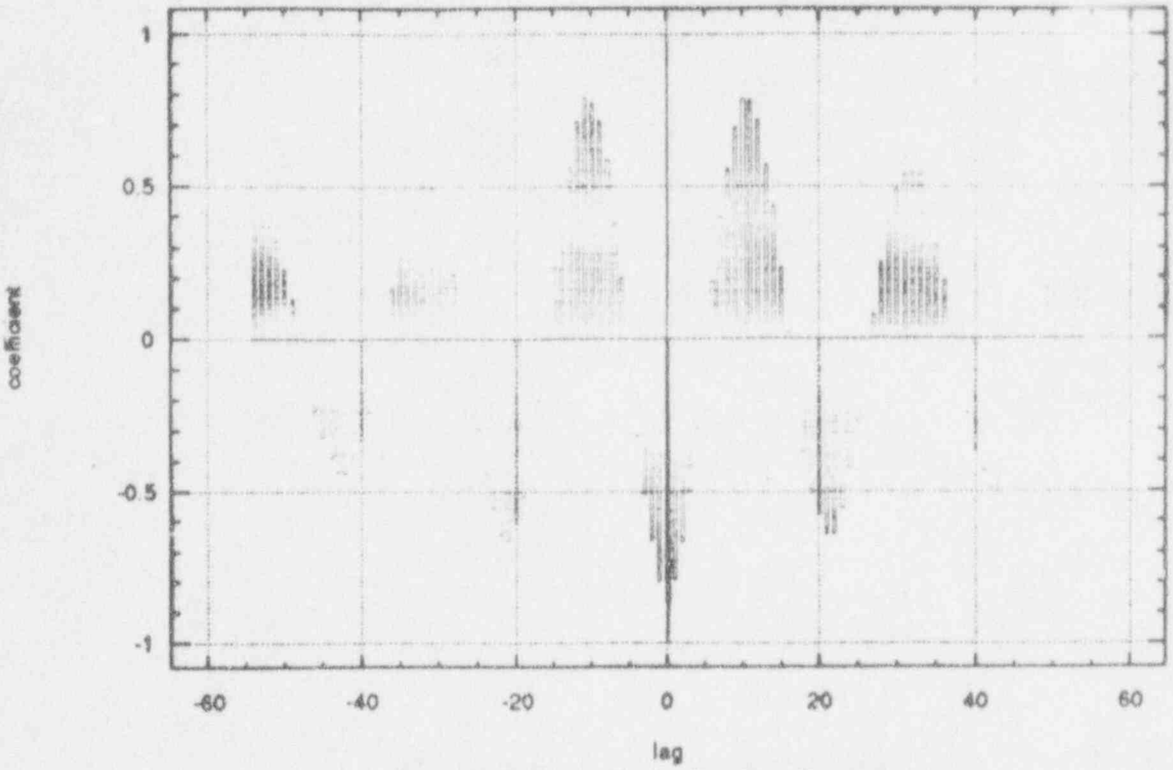
Test F8903

Periodogram of Pump 1 Flow Oscillations



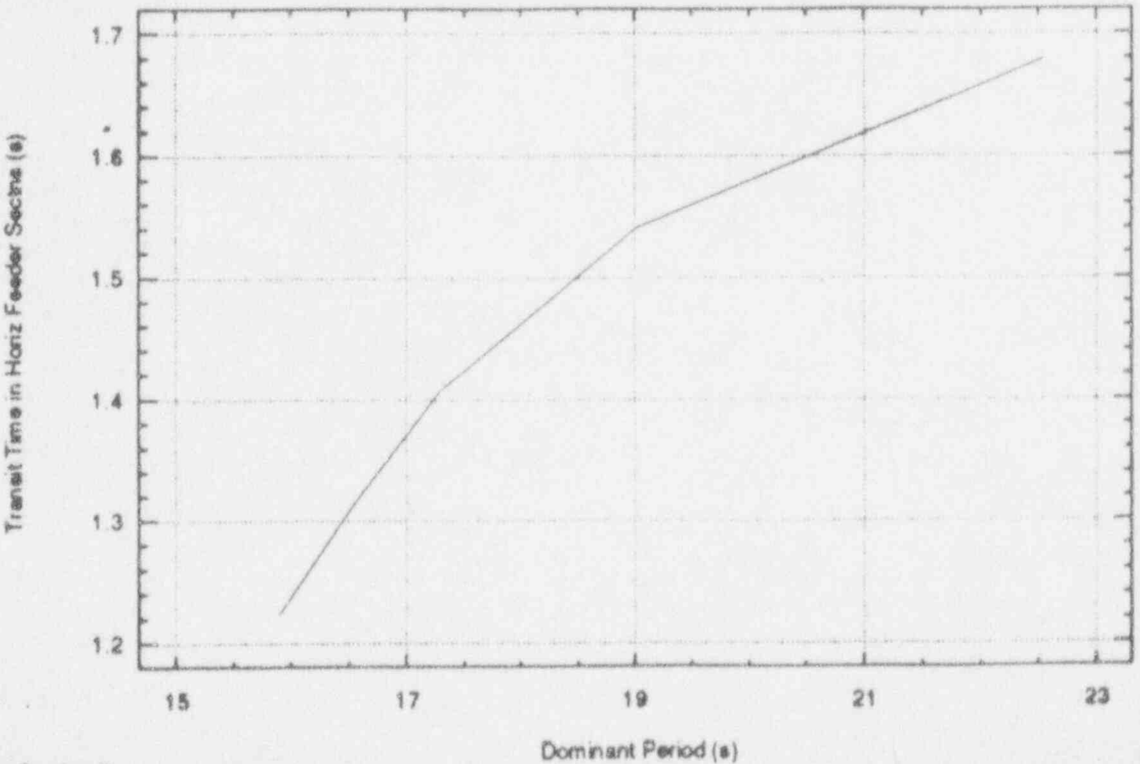
Test F8903 - Estimated Cross Correlation

Pump 1 Flow vs Pump 2 Flow



Transit Time in Horiz Feeder Sections vs

Dominant Period - Test F8903



No Header Interconnect

Experimental Method	Observations (Primary circuit)
Reduce pump speed	large out-of-phase oscillations
Reduce primary pressure	9.5 - 9.8 MPa, large out-of-phase oscillations, otherwise stable

Header Interconnect With Dynamic Similarity

Experimental Method	Observations (Primary circuit)
Reduce pump speed	stable
Reduce primary pressure	stable

Header Interconnect with Geometric Similarity

Experimental Method	Observations (Primary circuit)
Reduce pump speed	large out-of-phase oscillations
Reduce primary pressure	stable

LARGE BREAK LOCA

Objective

To provide information on the underlying physical processes governing blowdown and refill behaviour following a header end cap failure.

Scaling Rationale

$$\frac{\text{Reactor Header Area}}{\text{Reactor Loop Volume}} = \frac{\text{RD-14M Break Size Area}}{\text{RD-14M Loop Volume}}$$

LARGE BREAK INLET HEADER LOCA
TEST MATRIX

High Pressure ECI System	Break Size	Pump Ramp	Pressurizer	Secondary Pressure Ramp	Decay Power (kW/pass)
Pumped	44 mm	Yes	Isolated	No	165
Pumped	44 mm	Yes	Isolated	Yes	165
Pumped	44 mm	Yes	Isolated on ECI*	No	165
Pumped	44 mm	Yes	Online	No	165
Pumped	44 mm	Yes	Isolated	No	200
Pumped	44 mm	Pump at 50% Full Speed	Isolated	No	165
Accumulator	48 mm	Yes	Isolated	Yes	165
Accumulator	48 mm	Yes	Isolated on ECI*	Yes	200
Accumulator	48 mm	Yes	Isolated on ECI*	Yes	165
Accumulator	48 mm	Yes	Online	No	165
Accumulator	48 mm	Yes	Isolated	No	200
Accumulator	48 mm	Pump at 50% Full Speed	Isolated	No	165

* pressurizer to be valved out on initiation of high pressure ECI

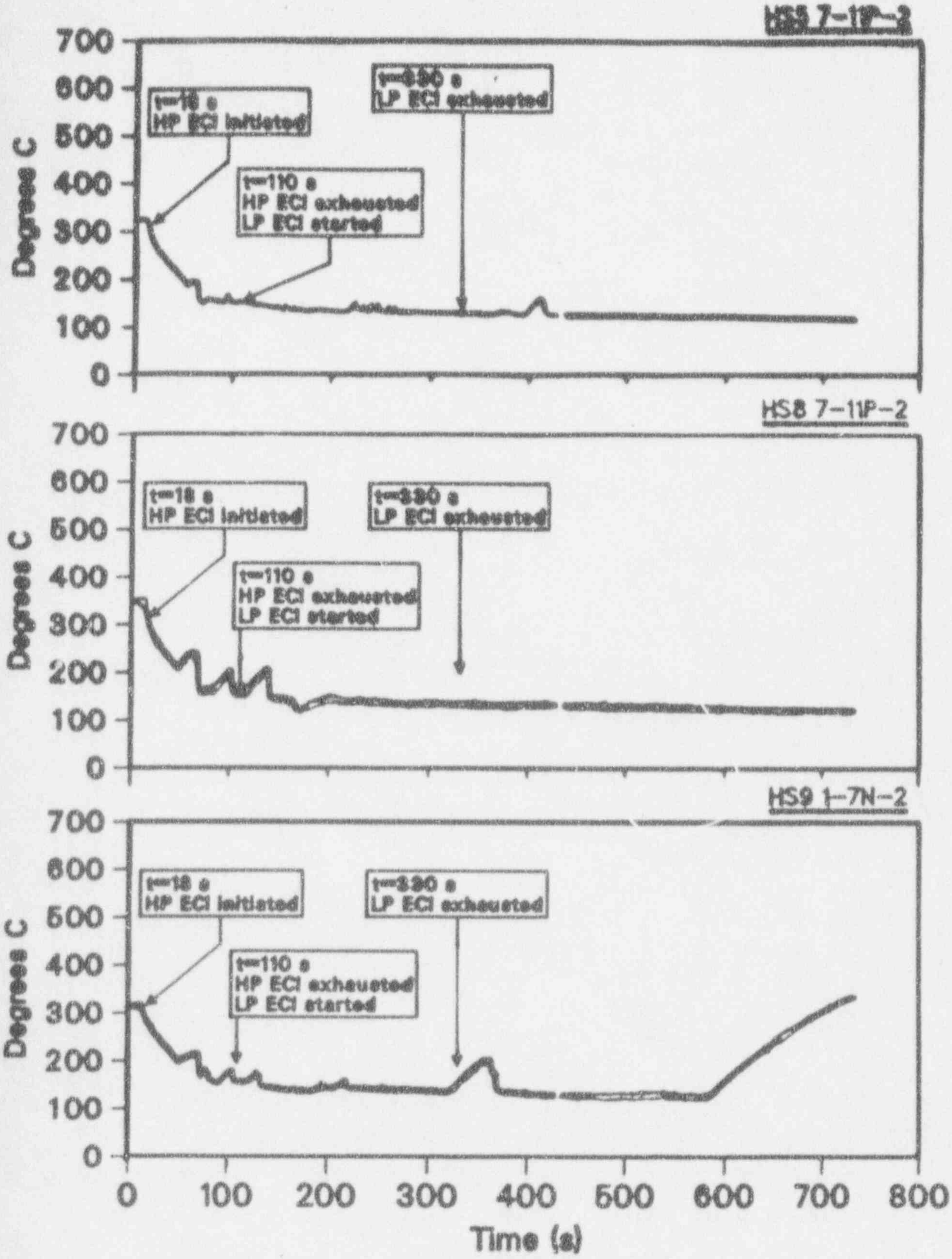
Large Break LOCA Tests

General Behaviour

- Strong flow reversal in channels downstream of break during blowdown transient
- Channels downstream of break remain well cooled while ECI is available
- Some channels upstream of the break experienced temperature excursions.

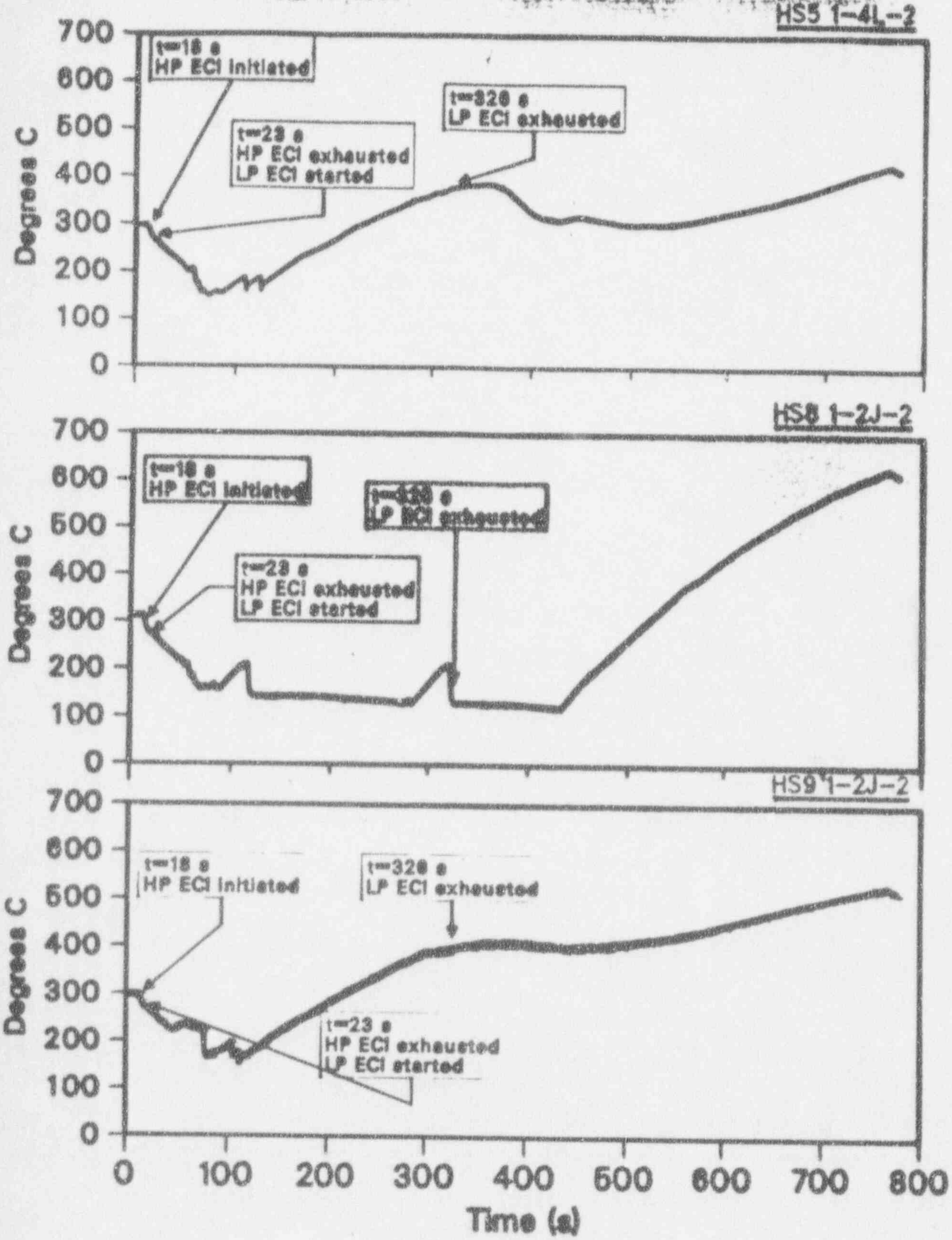
B9106 - 44 mm Inlet Header Break

Maximum Sheath Temperatures



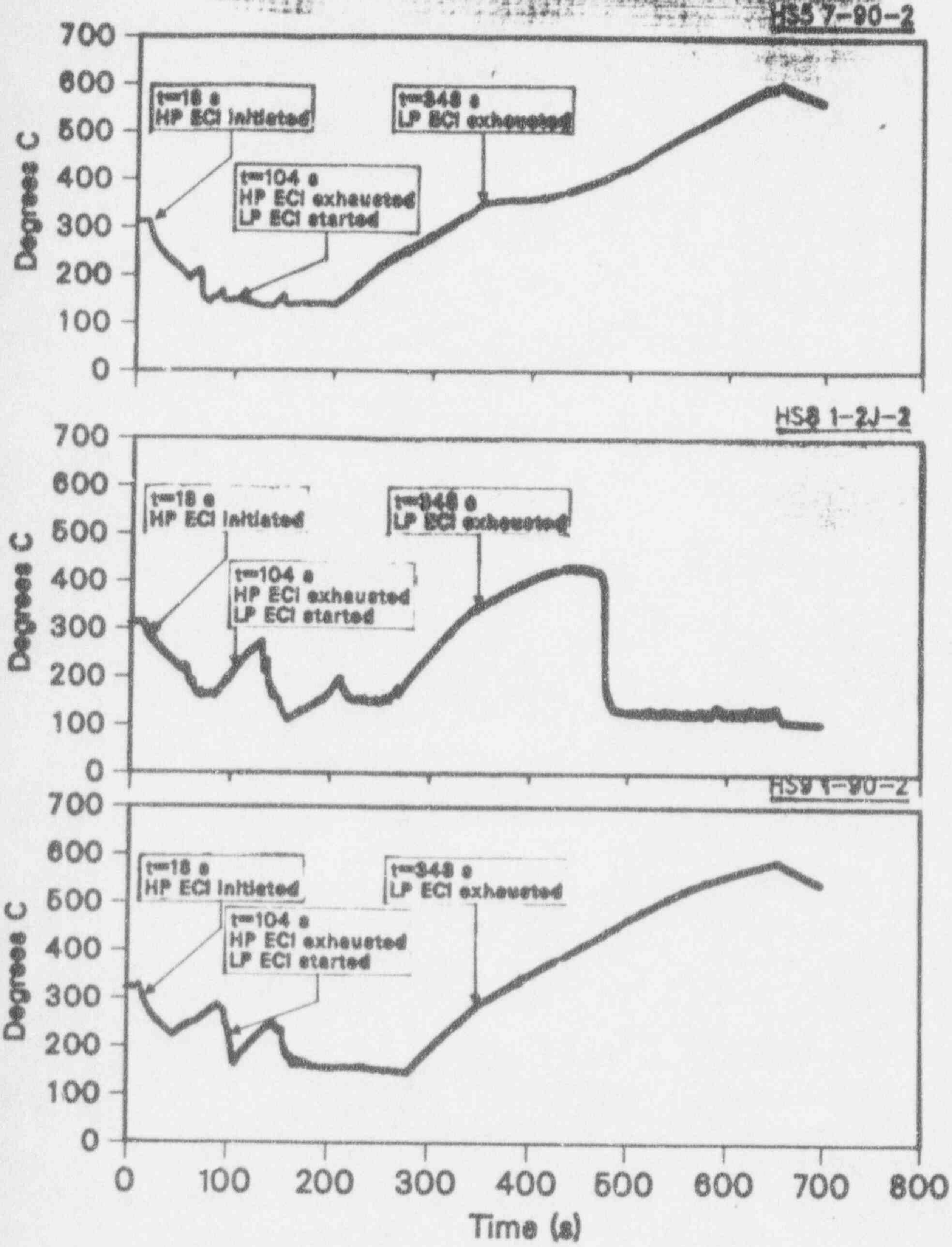
B9111 - 44 mm Inlet Header Break

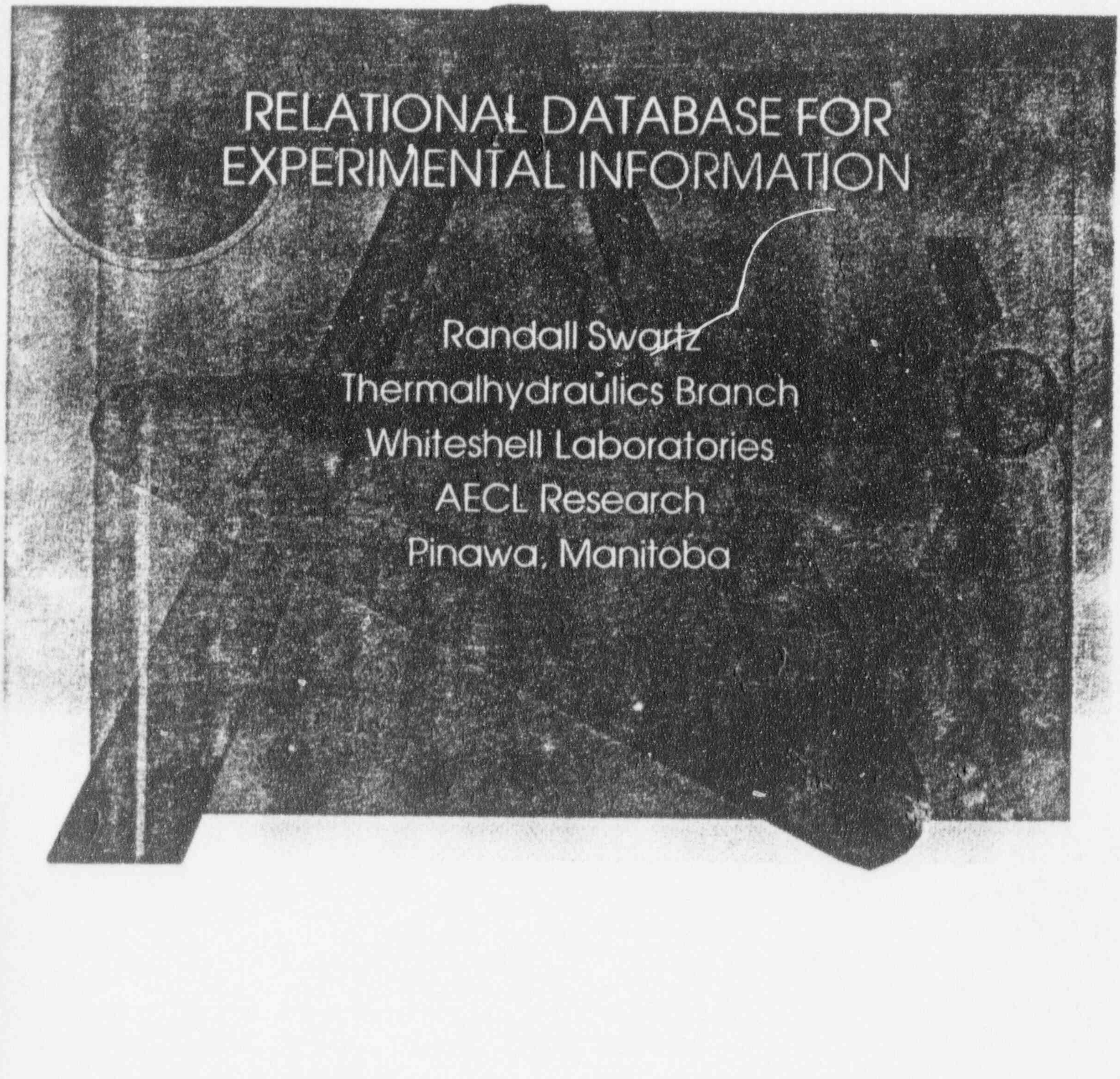
Maximum Sheath Temperatures



B9110 – 44 mm Inlet Header Break

Maximum Sheath Temperatures



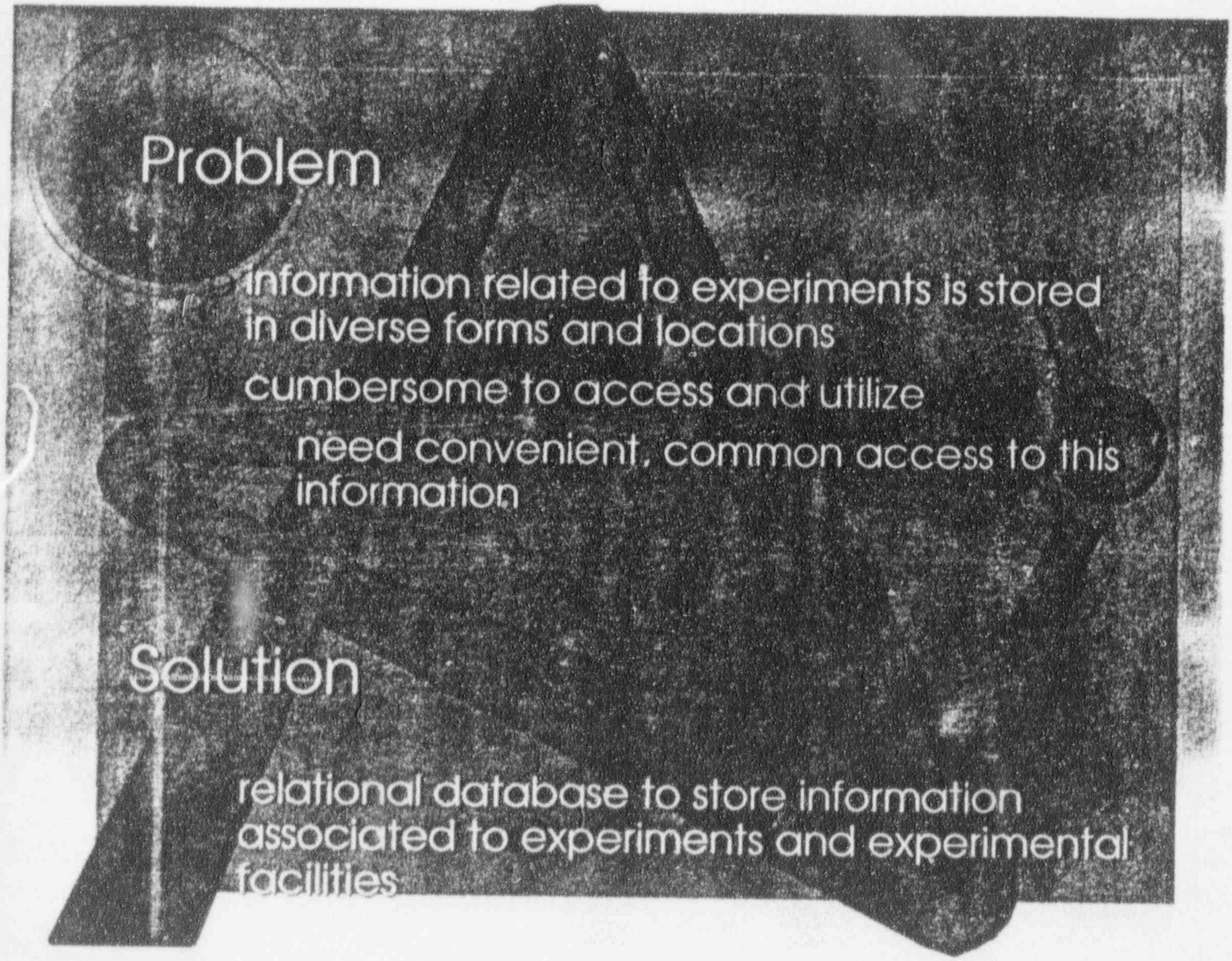


RELATIONAL DATABASE FOR EXPERIMENTAL INFORMATION

Randall Swartz
Thermalhydraulics Branch
Whiteshell Laboratories
AECL Research
Pinawa, Manitoba

Objective of Program

- build a database of experimental results and other archival information related to COG-funded Safety Thermalhydraulics experimental programs

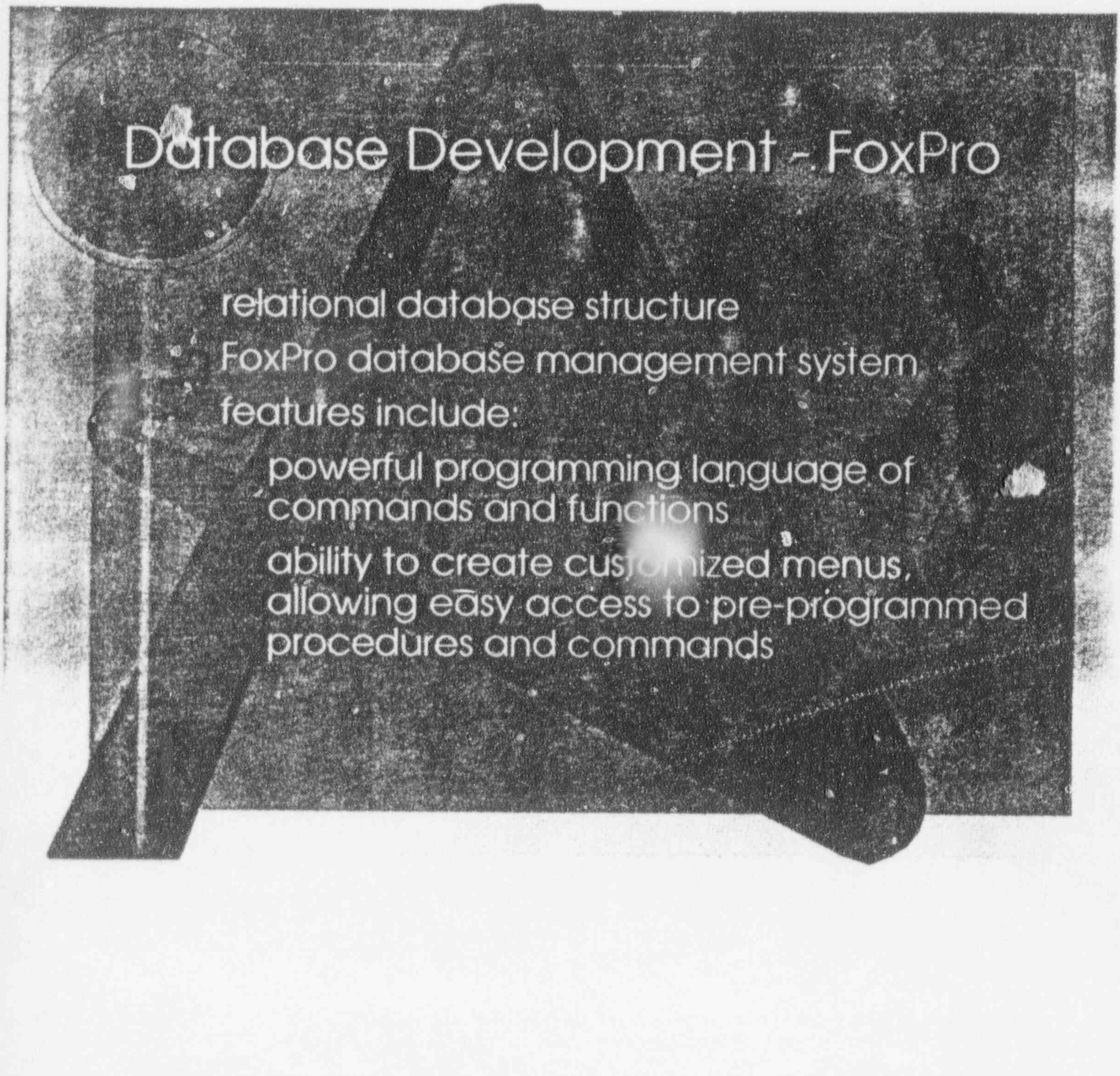


Problem

- information related to experiments is stored in diverse forms and locations
- cumbersome to access and utilize
  - need convenient, common access to this information

Solution

- relational database to store information associated to experiments and experimental facilities



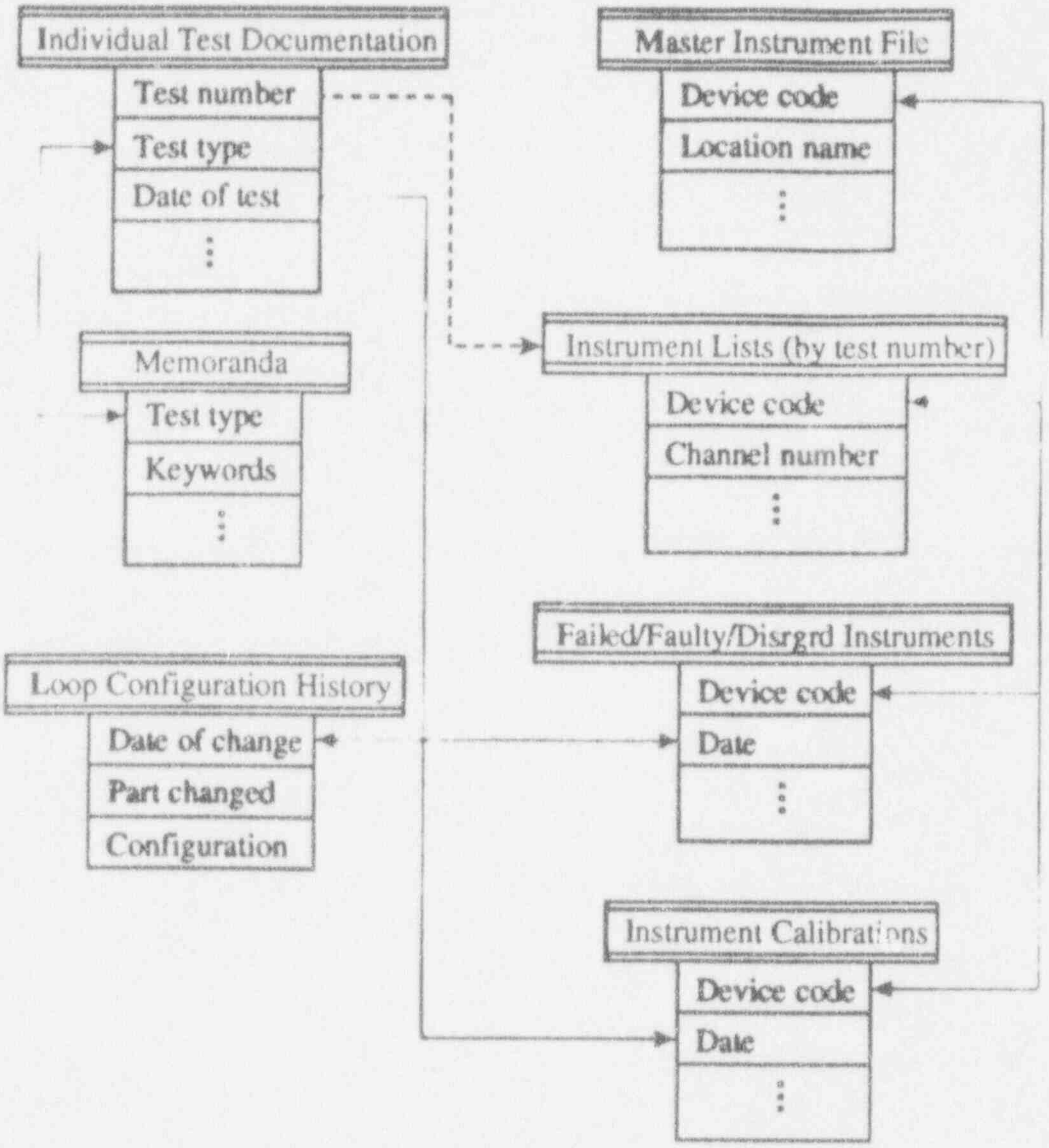
Database Development - FoxPro

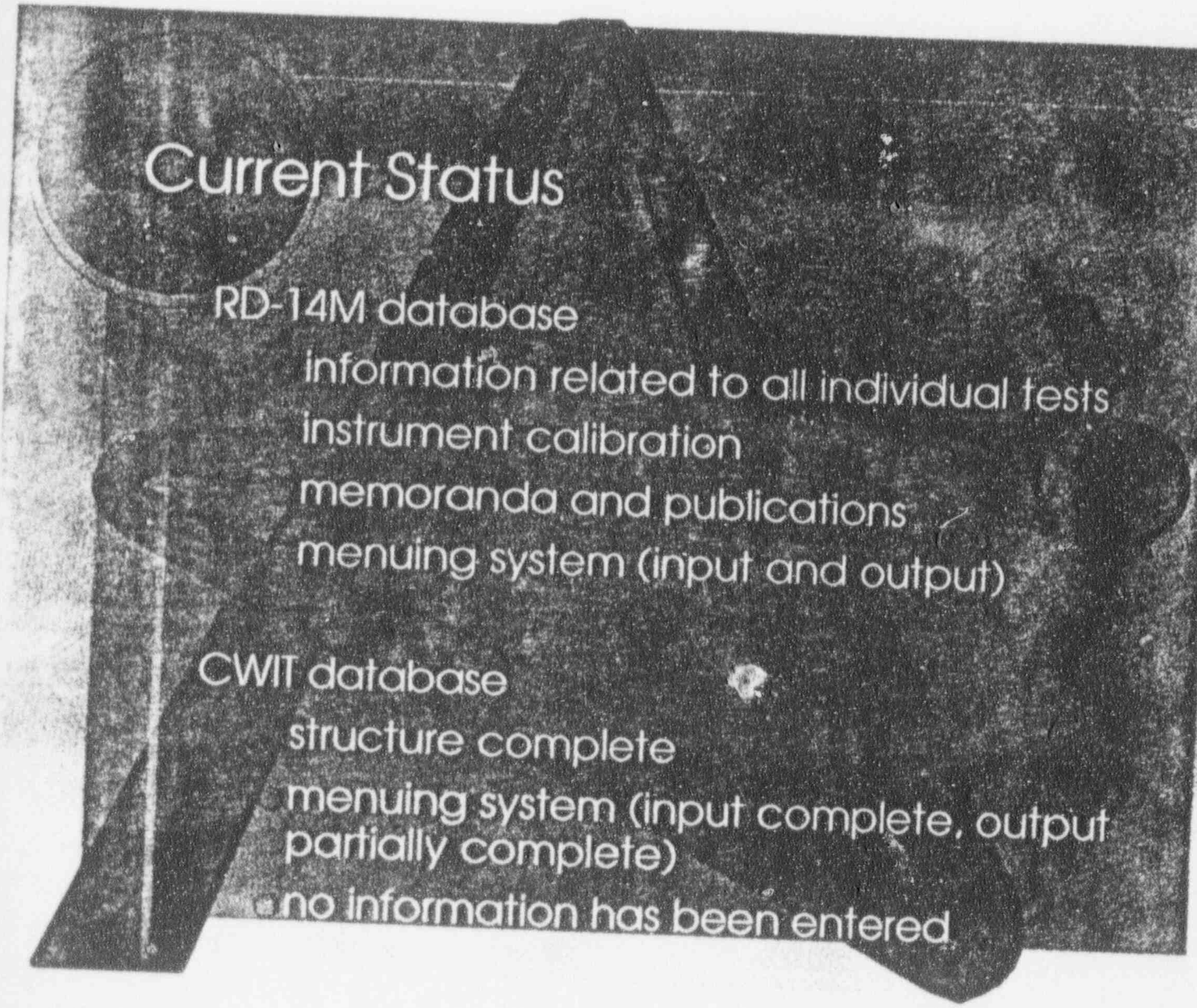
- relational database structure
- FoxPro database management system
- features include:
  - powerful programming language of commands and functions
  - ability to create customized menus, allowing easy access to pre-programmed procedures and commands

RD-14M Database

- database information includes:
  - test specific information
  - instrument lists
  - instrument calibrations
  - failed/faulty/disregarded instruments
  - loop configuration history
  - memoranda
  - publications
- database of information - does not include the experimental data

RD-14M Database





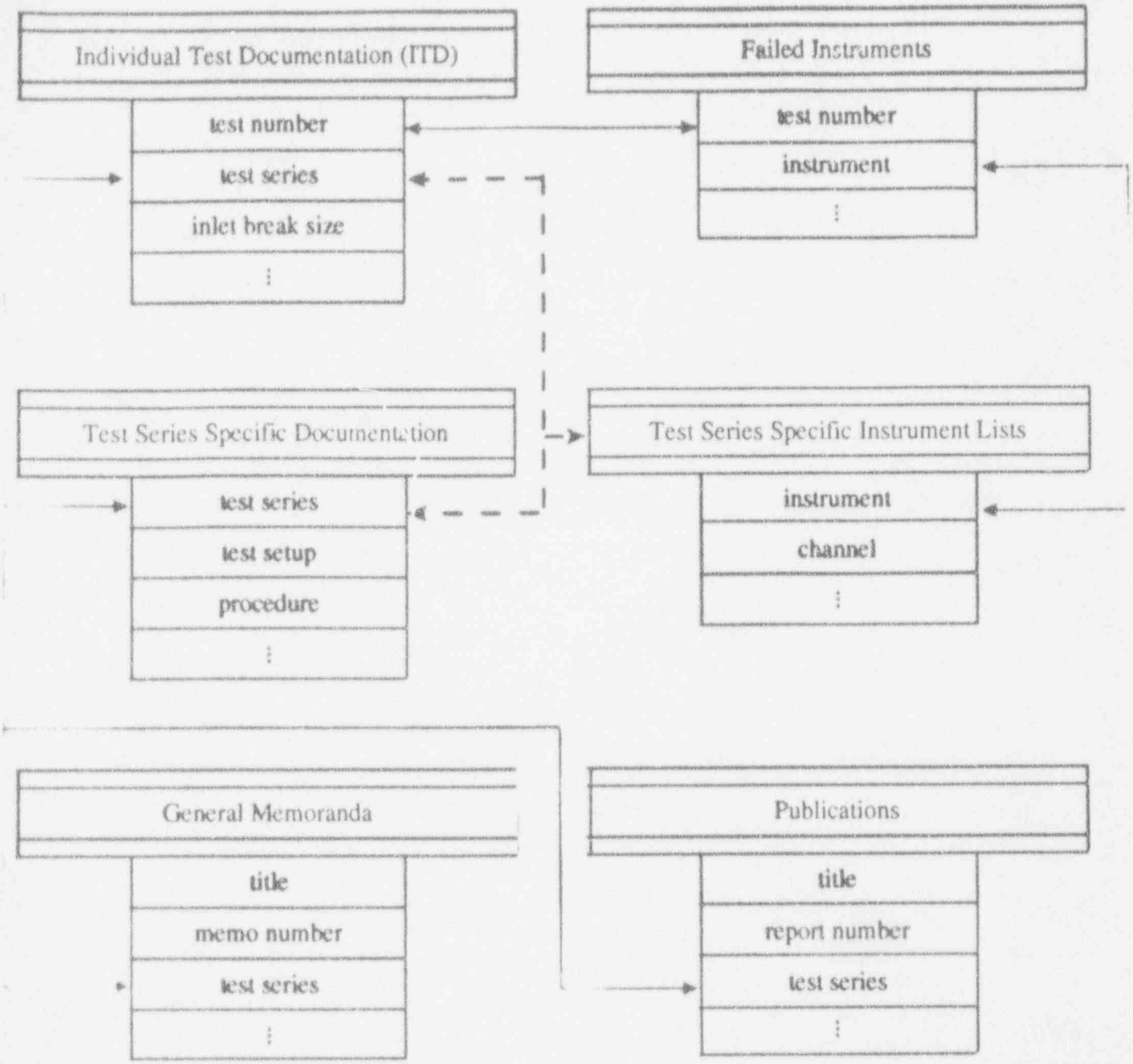
Current Status

- RD-14M database
  - information related to all individual tests
  - instrument calibration
  - memoranda and publications
  - menuing system (input and output)
- CWIT database
  - structure complete
  - menuing system (input complete, output partially complete)
  - no information has been entered

CWIT Database

- database information includes:
  - test specific information
  - test series specific information
  - instrument lists
  - failed instruments
  - memoranda
  - publications
- database of information - does not include the experimental data

CWIT Database



Future Work

entry of CWIT database information

databases for other experimental facilities (e.g., LASH, RD-14)

RD-14M LOCA Experiments

Definition:

Small Break LOCA -

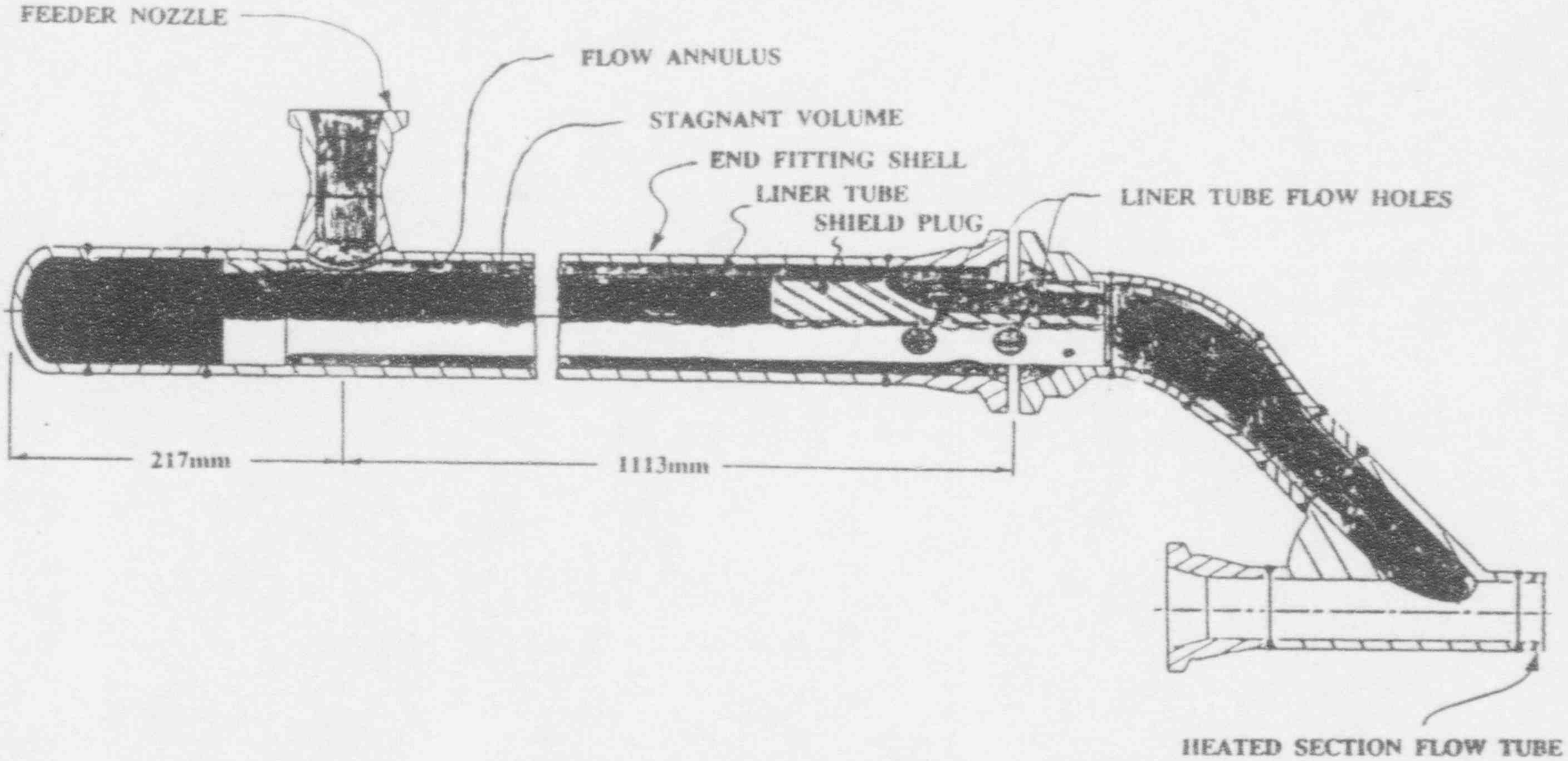
Simulates a feeder-sized break on an inlet or outlet header. (1990)

Critical Break LOCA -

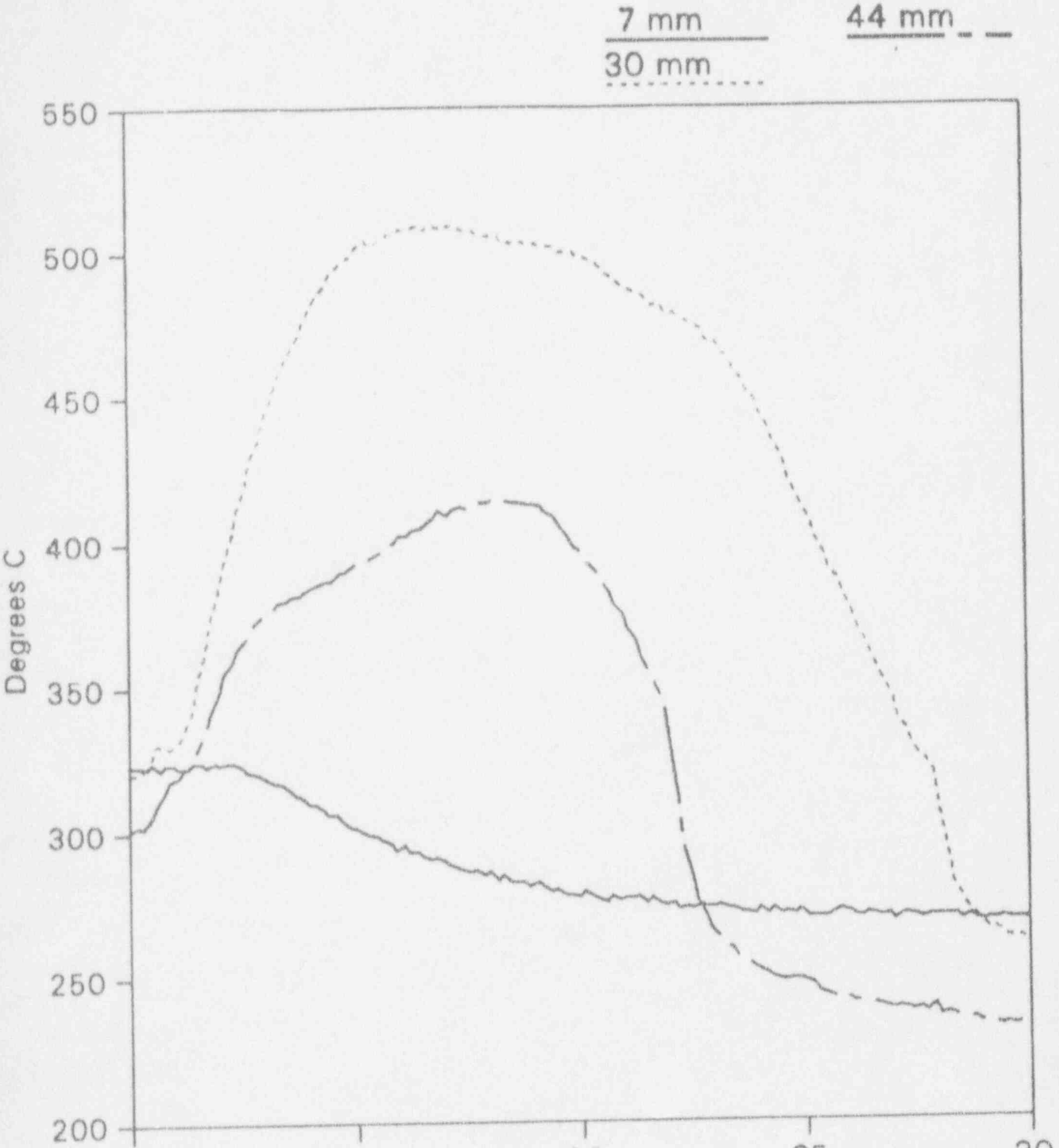
Results in the formation of flow split points in the heated portion of the channels for several seconds in the first 10 seconds of the blowdown transient. (1990-91)

Large Break LOCA -

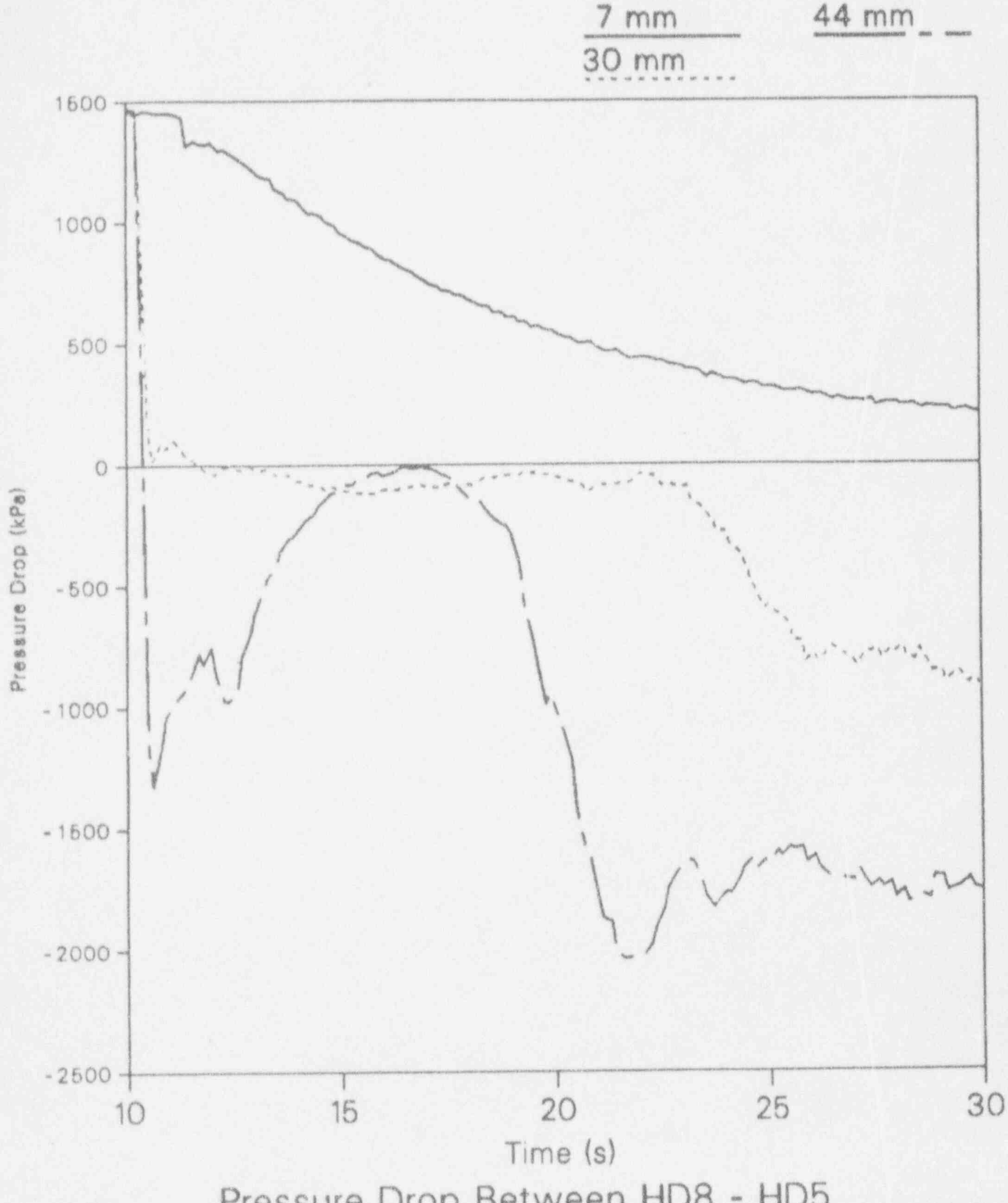
Simulates an end cap failure of an inlet or outlet header. (1991)



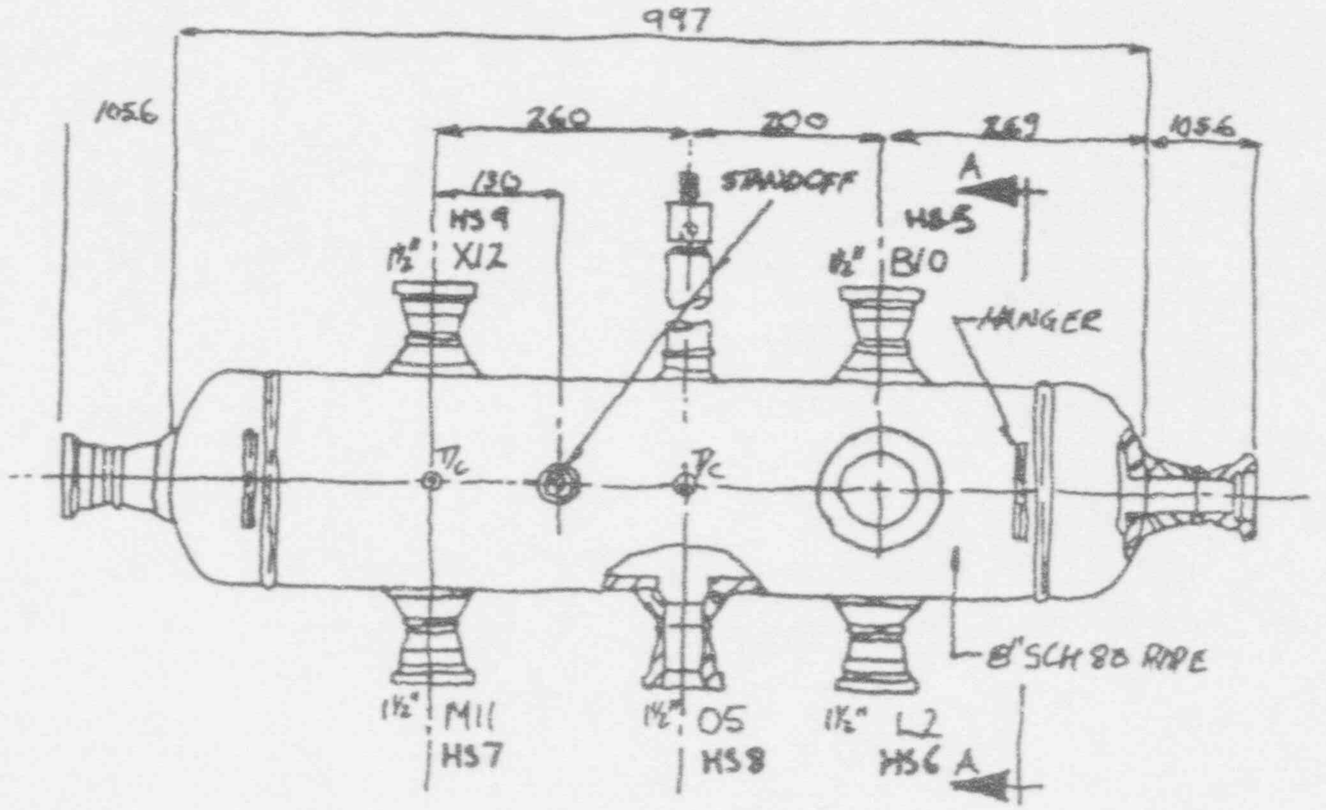
RD-14M END FITTING LONGITUDINAL CROSS SECTION



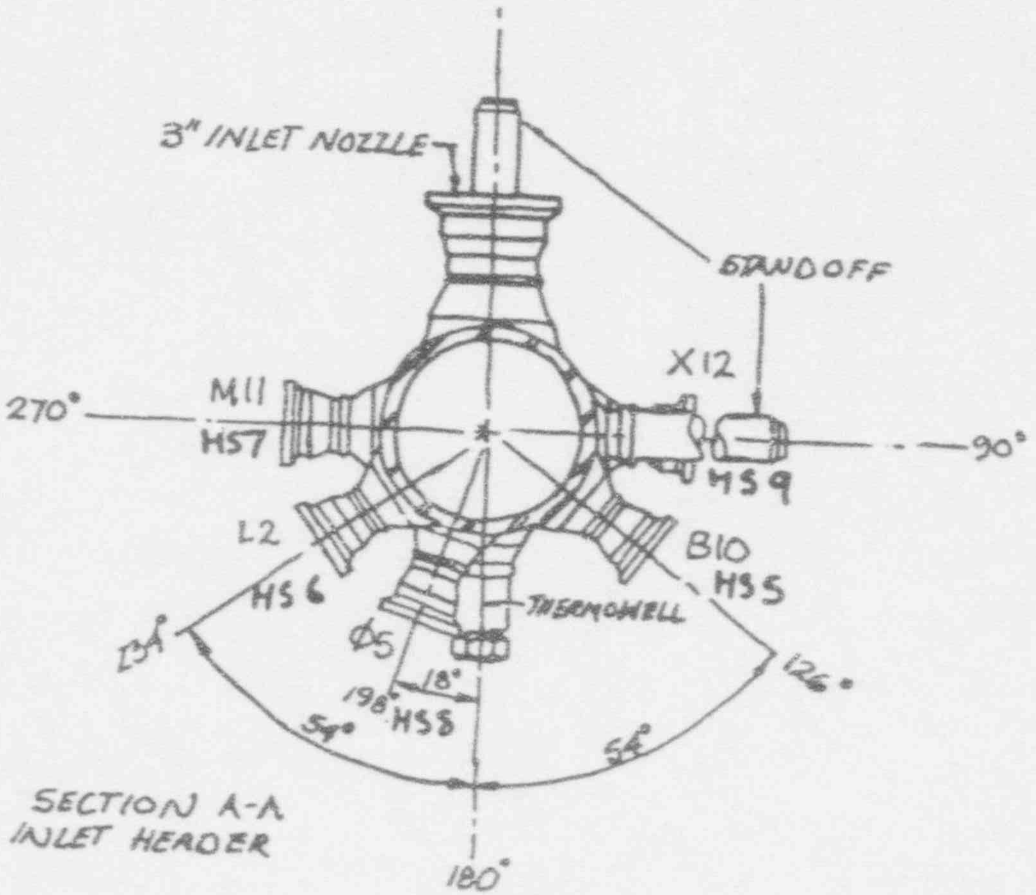
Maximum FES Sheath Temperature
for Small, Critical and Large Breaks



Pressure Drop Between HD8 - HD5
for Small, Critical and Large Breaks



INLET HEADER (PLAN)



SECTION A-A
INLET HEADER