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SEMISCALE MOD-3 TEST PROGRAM AND SYSTEM DESCRIPTION

MORRIS L. PATTON

July 1978

EG&G Idaho, Inc.

IDAHO NATIONAL ENGINEERING LABORATORY

DEPARTMENT OF ENERGY

IDAHO OPERATIONS OFFICE UNDER CONTRACT EY-76-C-07-1570

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SEMISCALE MOD-3 TEST PROGRAM AND SYSTEM DESCRIPTION

by

Morris L. Patton

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PREPARED FOR THE
U.S. NUCLEAR REGULATORY COMMISSION
AND THE
DEPARTMENT OF ENERGY
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UNDER CONTRACT NO. EY-76-C-07-1570

ABSTRACT

This document describes the Semiscale Mod-3 test program and experimental test system to provide a reference source of information in support of the data reports and topical analysis reports for the Semiscale Mod-3 experimental test series. The Semiscale Mod-3 experiments represent the current phase of the Semiscale Program as conducted by EG&G Idaho, Inc. Presented are descriptions of the Semiscale Mod-3 overall test objectives, design rationale, test hardware, and control systems and instrumentation.

SUMMARY

The Semiscale Mod-3 test program and experimental test system are described to provide a reference source of information for support of data and topical analysis reports which present and interpret results of Mod-3 system experiments. The overall objectives are described for the two test series (Test Series 7 and 8) planned for the Mod-3 system. Also described are the Mod-3 system design rationale, test hardware, control systems and instrumentation, including the data acquisition and processing system.

The Semiscale Mod-3 experiments represent the current phase of the Semiscale Program, as part of the Water Reactor Research Program sponsored by the Nuclear Regulatory Commission through the Department of Energy.

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SEMISCALE MOD-3 TEST PROGRAM AND SYSTEM DESCRIPTION

I. INTRODUCTION

The Semiscale Mod-3 experiments represent the current phase of the Semiscale Program conducted by EG&G Idaho, Inc., for the United States Government. The Semiscale Program[1], as part of the Water Reactor Research Program, is sponsored by the Nuclear Regulatory Commission (NRC) through the Department of Energy (DOE) and is designed to investigate the thermal-hydraulic phenomena accompanying a hypothesized loss-of-coolant accident (LOCA), in a water-cooled nuclear reactor system.

The Semiscale Mod-3 test system is a small-scale representation of a typical pressurized water reactor (PWR) system and is provided with the necessary apparatus to simulate a LOCA. The Mod-3 test program and experimental configuration are designed to investigate the effects of upper head injection (UHI) emergency core cooling on the thermal-hydraulic response of the Mod-3 system configuration. Two experimental test series (Test Series 7 and 8) are planned for the Mod-3 program.

The purpose of this report is to provide a reference source of information for support of data and topical analysis reports relating to the specific tests to be conducted in the two Mod-3 test series. Presented are descriptions and objectives of the overall Semiscale Mod-3 test program, the baseline test series (Test Series 7), and the upper head injection sensitivity test series (Test Series 8); descriptions of the Mod-3 system hardware configuration, and descriptions of the Mod-3 control systems and instrumentation, including the data acquisition and processing system.

II. PROGRAM DESCRIPTION

The Semiscale Program consists of a continuing series of thermal-hydraulic experiments having as their primary purpose the generation of experimental data that can be applied to the development and verification of analytical models that describe phenomena in water-cooled nuclear power plants. Emphasis is placed on acquiring integral system effects data that characterize the most significant thermal-hydraulic phenomena likely to occur in the primary coolant system of a nuclear plant during the depressurization (blowdown) and emergency core cooling (ECC) phases of a LOCA. The experiments are performed with a test system that simulates the principal physical features of a nuclear plant but which is smaller in volume. Nuclear heating is simulated in the experiments by a core composed of an array of electrically heated rods, each of which has dimensional heat flux characteristics similar to those of a nuclear fuel rod.

1. SEMISCALE MOD-3 TEST PROGRAM

The Semiscale Mod-3 test program is being conducted to investigate the thermal and hydraulic phenomena accompanying a hypothesized LOCA in a water-cooled nuclear reactor system. The Semiscale Mod-3 tests are conducted in a two-loop system with both intact and broken loops containing active components representative of nuclear system components. In addition, the Mod-3 vessel is designed to be representative of a PWR utilizing a UHI emergency core cooling system.

The Mod-3 test program objectives are to:

(1) Produce separate and integral effects, and experimental and thermal-hydraulic response data to provide an experimental basis for analytical model development and assessment.

(2) Produce experimental data to aid other DOE-NRC-sponsored experimental programs, such as Loss-of-Fluid-Test (LOFT), in optimizing test series, selecting test parameters, and evaluating test results.

(3) Provide data for assessing the requirements and reliability of selected LOFT instrumentation.

Separate effects tests provide detailed information for specific areas of interest. This information is used to determine the applicability of previously developed correlations and models to the Mod-3 system and to provide an initial basis for modification of these correlations and models if necessary. The resulting analytical description of the Mod-3 system that is supported by the separate effects test data provides insight into the interacting effects that may occur during integral-type tests.

2. SEMISCALE MOD-3 TEST SERIES OBJECTIVES

Two test series are planned for the Semiscale Mod-3 system, the baseline test series (Test Series 7) and the upper head injection sensitivity test series (Test Series 8). The overall objectives of these series are described in the following subsections.

2.1 Baseline Test Series (Test Series 7)

Test Series 7 is the first test series to be conducted with the Mod-3 system and has been designated as the baseline test series. Two main objectives for the test series are:

(1) To assess the influence of changes in the specific physical characteristics of the Mod-3 system on the thermal-hydraulic behavior of the system during the various phases of a loss-of-coolant experiment (LOCE). The changes to be evaluated are:

   (a) The use of a 3.66-m versus a 1.66-m core

   (b) The use of an active versus a passive broken loop

   (c) The use of an external versus an internal downcomer.

(2) To establish the operational capabilities and baseline performance of the Mod-3 system during integral blowdown and reflood experiments with cold leg ECC injection.

Series 7 consists of test groups that emphasize the evaluation of the Mod-3 system performance during different phases of the LOCE transient. The first test group, which investigates the system performance during blowdown, consists of three blowdown tests with cold leg ECC injection. The principal objectives of the initial blowdown test group are to determine the influence of system modifications on blowdown behavior and to gain some insight into the effect of this blowdown behavior on subsequent reflood behavior. Therefore, particular attention is given (a) to the core heat transfer and departure from nucleate boiling (DNB) characteristics of the core heater rods and (b) to the end of blowdown conditions which establish the initial conditions for reflood. Since the first group of tests emphasizes the Mod-3 system operation during blowdown, each of the initial experiments is terminated after refilling the lower plenum but prior to the initiation of core reflood.

The second experimental grouping consists of two tests. These tests investigate the behavior of the Mod-3 system during core reflood. The principal objective of this test group is to determine the influence of core length on reflood heat transfer. A second objective is to evaluate the influence of active broken loop components on core reflood behavior. The combined results of the initial blowdown test and the reflood behavior from these tests are intended to provide insight into expected behavior of the Mod-3 system during integral blowdown and reflood experiments.

Four integral blowdown and reflood experiments constitute the final test grouping. The objective of these tests is to establish baseline integral blowdown and reflood response characteristics for the Mod-3 system with cold leg ECC injection. The first test evaluates the performance characteristics for the Mod-3 system under conditions approximating those of Semiscale Mod-1 Test S-04-6[2]. For this test, cold leg ECC injection is used, and the post rupture power decay is specified to approximate the core power decay characteristics in Test S-04-6. The second integral blowdown and reflood test, also using cold leg ECC injection, differs from the first in that the on-line power control system is utilized, and initial conditions and operating parameters representative of a UHI plant are used. This second test provides the reference baseline performance data for future Mod-3 test series. The third and fourth tests are conducted to investigate the effectiveness of lower plenum ECC injection in the Mod-3 system.

2.2 Upper Head Injection Sensitivity Test Series (Test Series 8)

Test Series 8 has been designated the upper head injection sensitivity test series. The series objectives are as follows:

(1) To provide an independent experimental data base from which to evaluate upper head injection capabilities.

(2) To determine the sensitivity of the Mod-3 system response to variations in the following UHI parameters:

(a) injection rate,

(b) temperature,

(c) injection time,

(d) fluid mixing.

Eight tests are currently planned for the upper head injection sensitivity test series; however, final test series specifications have not been completed.

III. DESIGN RATIONALE

The Semiscale Mod-3 system is a two-loop representation of a four-loop PWR system and utilizes a 25-rod, 3.66-m heated core. The system utilizes an intact loop, a broken loop, and a simulated reactor vessel which are representative of a PWR with upper head injection design. The scaling rationale is based on applying the core thermal power ratio to the primary system volume. This rationale produces the same power-to-volume ratio in the Mod-3 system as exists in a PWR system.

The primary system volume, excluding the vessel, is distributed on a three-to-one basis with 75% in the intact loop and 25% in the broken loop. The intact loop is thus representative of three operating loops of a four-loop PWR system, and the broken loop is representative of a single operating loop. The primary system flow resistance is maintained and distributed on a one-to-one basis with the PWR, producing full-scale pressure drops throughout the system. The Mod-3 coolant injection system parameters are volume-scaled to be representative of those found in a PWR plant.

Additional design and scaling requirements for Mod-3 are to preserve as closely as possible the full-scale elevations and volume distributions of the primary system flow circuit, and to maintain flow velocities sufficiently high to preserve representative flow regime behavior. Table I compares the Mod-3 system volumes and volume distributions with corresponding reference system values.

Table II lists estimated hydraulic resistances and elevation changes between locations for the Mod-3 system. The system components and locations discussed in Table II are described in Section IV (Test Hardware). Hydraulic resistances are calculated in terms of the parameter R' which is defined as

$$R' = \frac{\sum (K_L + fL/D)}{2\ g\ (A_f)^2 (10\ 000)}$$

where

K_L = loss coefficient

f = friction factor

L = length of pipe (m)

D = diameter (m)

g = gravitational constant (m/s^2)

A_f = flow area (m^2).

Table III lists the component elevations for the Semiscale Mod-3 system.

TABLE I

VOLUME AND VOLUME DISTRIBUTIONS FOR SEMISCALE MOD-3 SYSTEM VERSUS REFERENCE SYSTEM (COLD LEG BREAK)

	Reference System		Semiscale Mod-3 System		
	m^3	Percentage Total Liquid Volume	Desired Volume Scaled From Reference System m^3	Design m^3	Percentage Total Liquid Volume
Vessel					
Downcomer region	--	--	--	--	--
Distribution annulus	12.091 3	3.76	0.007 1	0.007 7	3.91
Downcomer pipe	12.629 3	3.93	0.007 4	0.014 5	7.38
Core bypass	6.626 1	2.06	0.003 9	--	--
TOTAL DOWNCOMER VOLUME	31.346 7	9.75	0.018 4	0.022 2	11.29
Upper head region	--	--	--	--	--
Above top of guide tube	7.588 9	2.36	0.004 4	0.004 6	2.37
Below top of guide tube	14.923 0	4.64	0.008 7	0.009 4	4.78
TOTAL UPPER HEAD VOLUME	22.511 9	7	0.013 1	0.014 0	7.15
Upper plenum	17.471 5	5.44	0.010 3	0.011 2	5.71
Core region	18.292 7	5.69	0.010 7	0.010 5	5.39
Lower plenum	27.495 7	8.56	0.016 1	0.015 1	7.99
Control rod guide tube	8.438 4	2.63	0.005 0	0.001 5	0.78
Core support tubes	1.189 3	0.37	0.007 0	0.000 4	0.20
TOTAL VESSEL VOLUME	126.746 2	39.45	0.074 3	0.074 9	38.51

TABLE I (continued)

	Reference System		Semiscale Mod-3 System		
	m^3	Percentage Total Liquid Volume	Desired Volume Scaled From Reference System m^3	Design m^3	Percentage Total Liquid Volume
Intact Loop					
Hot leg	6.711 1	2.09	0.003 9	0.010 3	5.23
Pressurizer (liquid volume)	30.582 2	9.52	0.017 9	0.013 7	6.99
Surge line	--	--	--	0.000 4	0.19
Steam generator	91.491 7	28.48	0.053 5	0.042 1	21.46
Pump suction leg	10.703 8	3.33	0.006 3	0.011 1	5.65
Pump	6.796 0	2.12	0.004 0	0.004 1	2.08
Cold leg	7.220 3	2.25	0.004 2	0.008 8	4.51
TOTAL OPERATING LOOP VOLUME	153.505 6	47.79	0.089 9	0.090 4	46.11
Broken loop					
Hot leg	2.237 0	0.70	0.001 3	0.002 1	1.07
Steam generator	30.497 2	9.50	0.017 9	0.017 5	8.96
Pump suction leg	3.567 9	1.11	0.002 1	0.005 4	2.76
Pump	2.265 3	0.70	0.001 3	0.001 3	0.68
Pipe	--	--	--	0.002 3	1.16
Cold leg	2.406 9	0.75	0.001 4	0.001 5	0.75
TOTAL BROKEN LOOP VOLUME	40.974 5	12.76	0.024 0	0.030 1	15.38
TOTAL SYSTEM LIQUID VOLUME	321.226 3	100	0.183 2	0.195 4	100

TABLE II

SEMISCALE MOD-3 SYSTEM RESISTANCES AND ELEVATION CHANGES

Between Instrumentation Sections	Resistance ($s^2/cm^2 \cdot m^3$)	Elevation Change (m)
Intact Loop		
Vessel upper plenum to Spool 3	0.38	0.35
Spool 3 to 6	0.15	0
Spool 6 to 7	6.22	-0.46
Steam generator inlet and steam generator outlet orifice	14.0	0
Spool 7 to 13	0.86	0
Spool 13 to 15	0.11	0.25
Spool 15 to 17	0.21	0
Spool 17 to downcomer inlet annulus	0.34	0.29
Broken Loop		
Cold Leg		
Downcomer inlet annulus to Spool 45	8.99	0.29
Spool 45 to 43	50.40	0
Hot Leg		
Vessel to Spool 20	5.99	0.35
Spool 20 to 21	5.19	0
Spool 21 to steam generator outlet	6.19	0.02
Steam generator inlet to steam generator outlet	207.46	-0.08
Steam generator outlet to 27	4.08	-0.93

TABLE II (continued)

Between Instrumentation Sections	Resistance ($s^2/cm^2 \cdot m^3$)	Elevation Change (m)
Spool 27 to 37	22.11	-0.86
Spool 37 to 40	3.01	0.65
Spool 40 to 43	27.75	0
Vessel		
Downcomer inlet annulus to bottom of vessel lower plenum	6.95	-6.07
Bottom of lower plenum to bottom of core	1.59	-0.77
Bottom of core to top of core	8.08	3.96
Top of core to vessel hot leg nozzle	1.70	0.92

TABLE III

SEMISCALE MOD-3 NOMINAL COMPONENT ELEVATIONS

Component	Reference Plant and Mod-3 Design Point (nominal location from cold leg centerline in cm)
Vessel	
Upper head assembly	
Bottom of top head	423.2
Top of core support plate	156.0
Top of guide tube	335.5
Bottom of UHI injection tube	322.8
Top of core	-170.4
Upper plenum	
Bottom of core support plate	135.6
Hot leg nozzle centerline	21.6
Top of core measurement station	-8.9
Core area	
To top of heated length	-129.8
Lower plenum	
Bottom of lower plenum	-576.8
Downcomer	
Centerline of downcomer inlet	-498.9
Bottom of downcomer distribution annulus	-534.4
Intact and Broken Loops	
Centerline of pump suction	-292.1
Bottom of steam generator tube sheet	126.4
Centerline of pump outlet nozzle	0

IV. TEST HARDWARE

The Semiscale Mod-3 system consists of a pressure vessel with simulated reactor internals and external downcomer assembly; an intact loop with numbered piping sections, steam generator, pump, and pressurizer; a broken loop with numbered piping sections, steam generator, pump, and pipe rupture assembly; a pressure suppression system with header, suppression tank, and steam supply system; and a coolant injection system with injection pumps, accumulators, and delivery piping. The system is designed to operate at typical PWR pressure and temperature (15 510 kPa and 594 K). The intact loop simulates three parallel operating loops of a commercial PWR plant. The broken loop simulates a single operating loop of a typical PWR plant in which a postulated LOCA occurs. The simulated reactor and pressure vessel are designed to be representative of a PWR utilizing an UHI emergency core cooling system. The entire system exterior is thermally insulated. The intact loop, broken loop, and pressure suppression system components (excluding the steam supply system) for cold leg, hot leg, and pump suction break configurations in both noncommunicative and communicative break modes (Section IV-3.4) are shown in Figures 1 through 6.

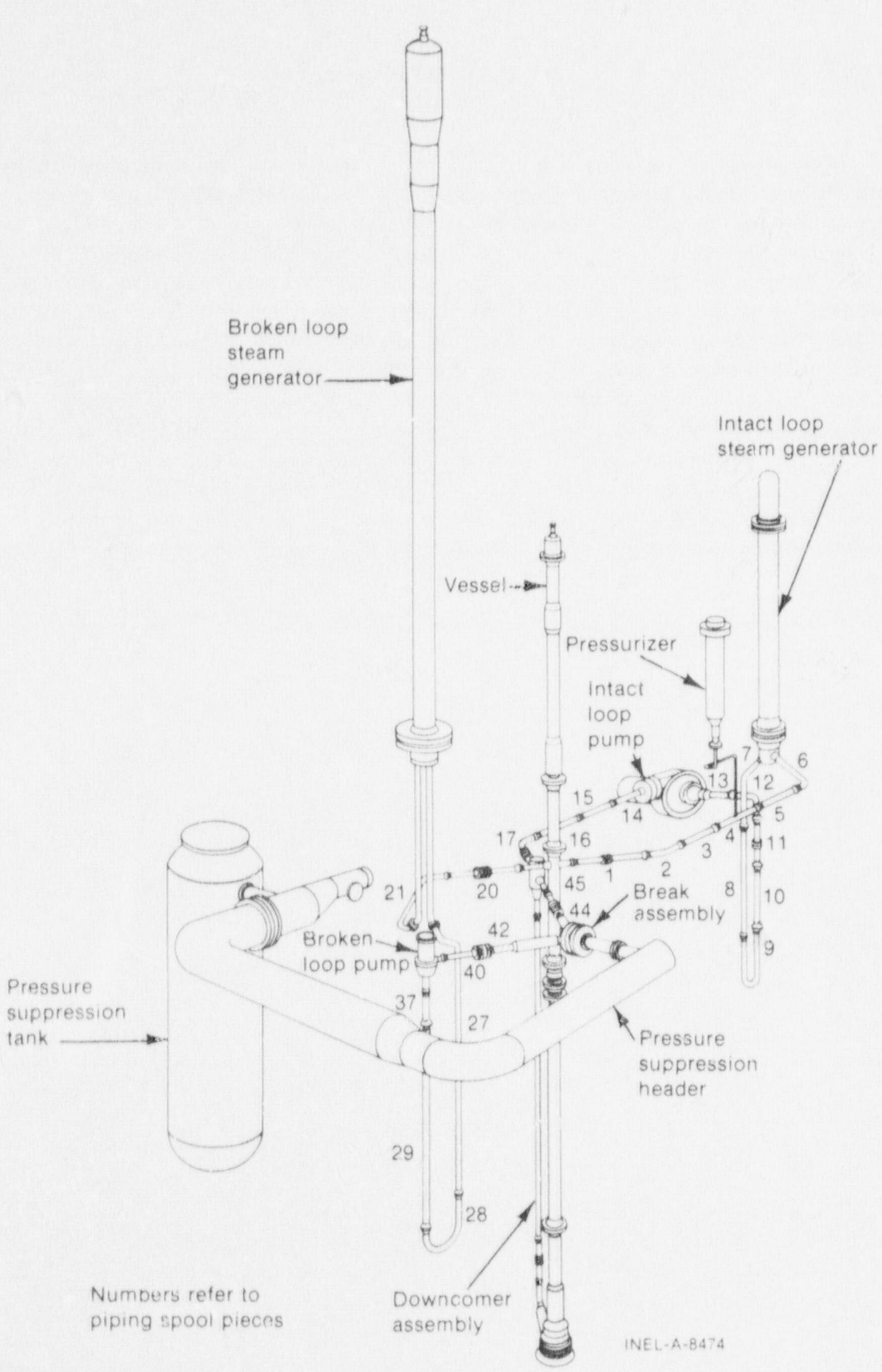


Fig. 1 Semiscale Mod-3 cold leg break configuration – noncommunicative.

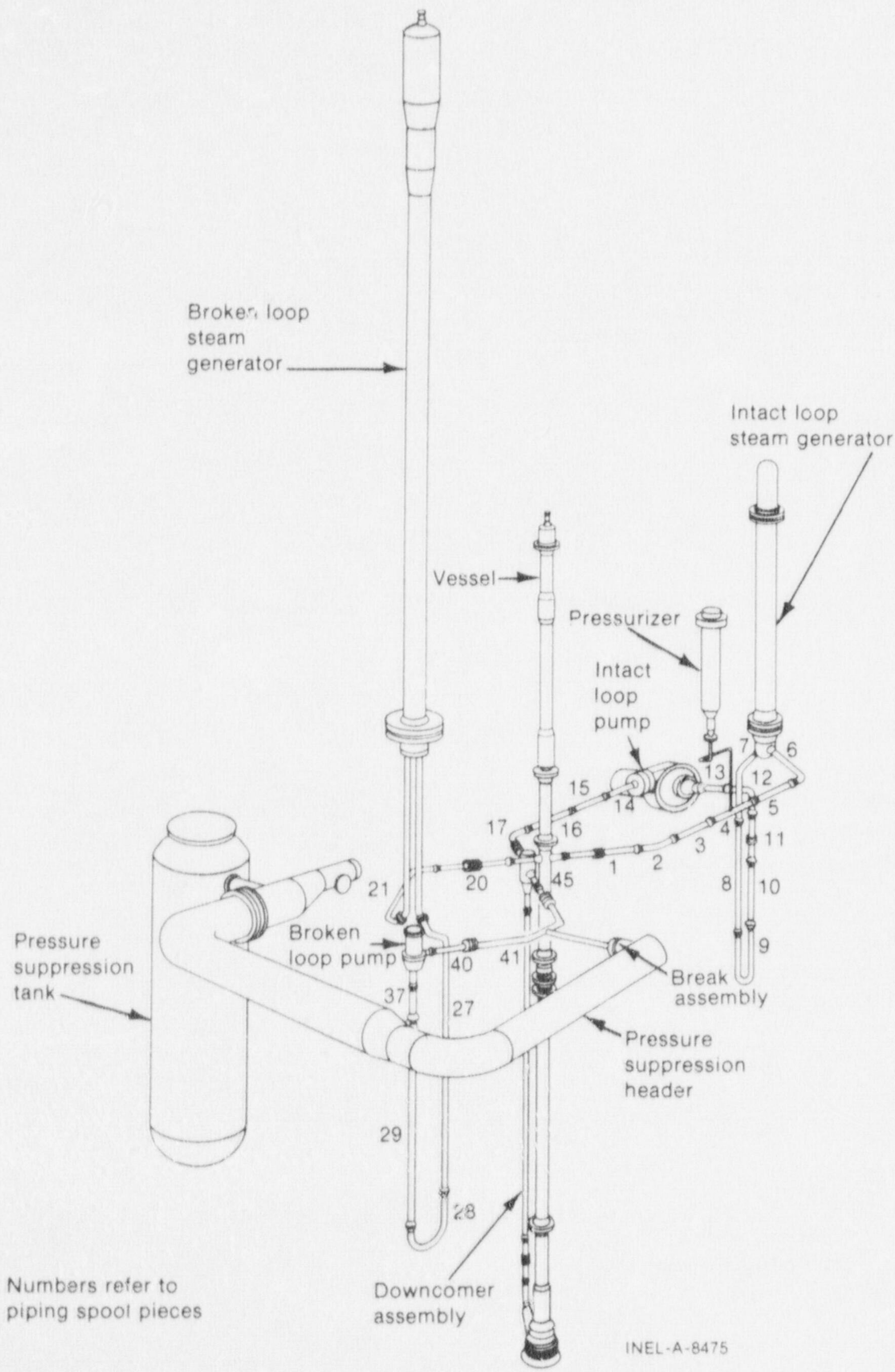


Fig. 2 Semiscale Mod-3 cold leg break configuration – communicative.

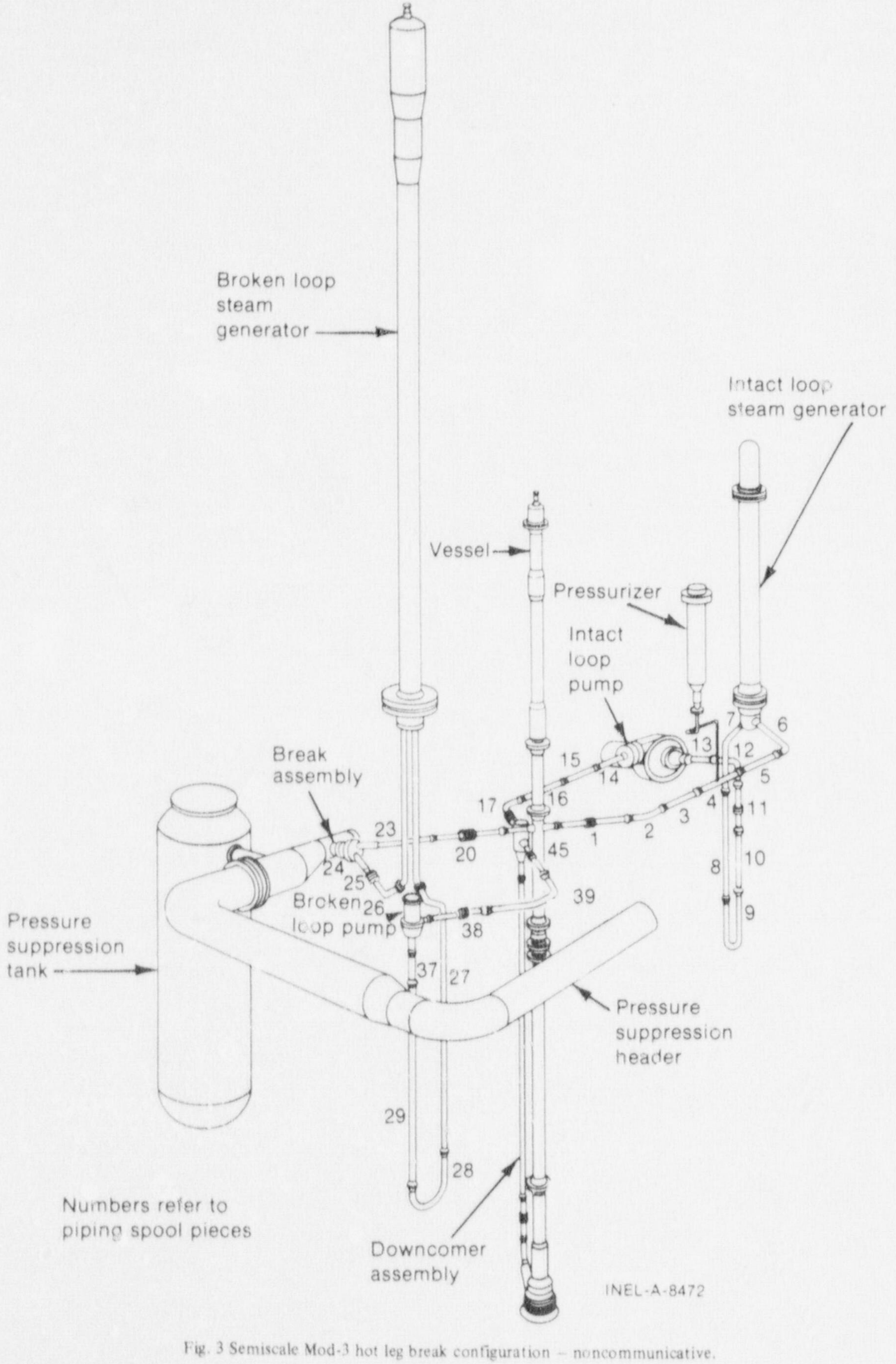


Fig. 3 Semiscale Mod-3 hot leg break configuration – noncommunicative.

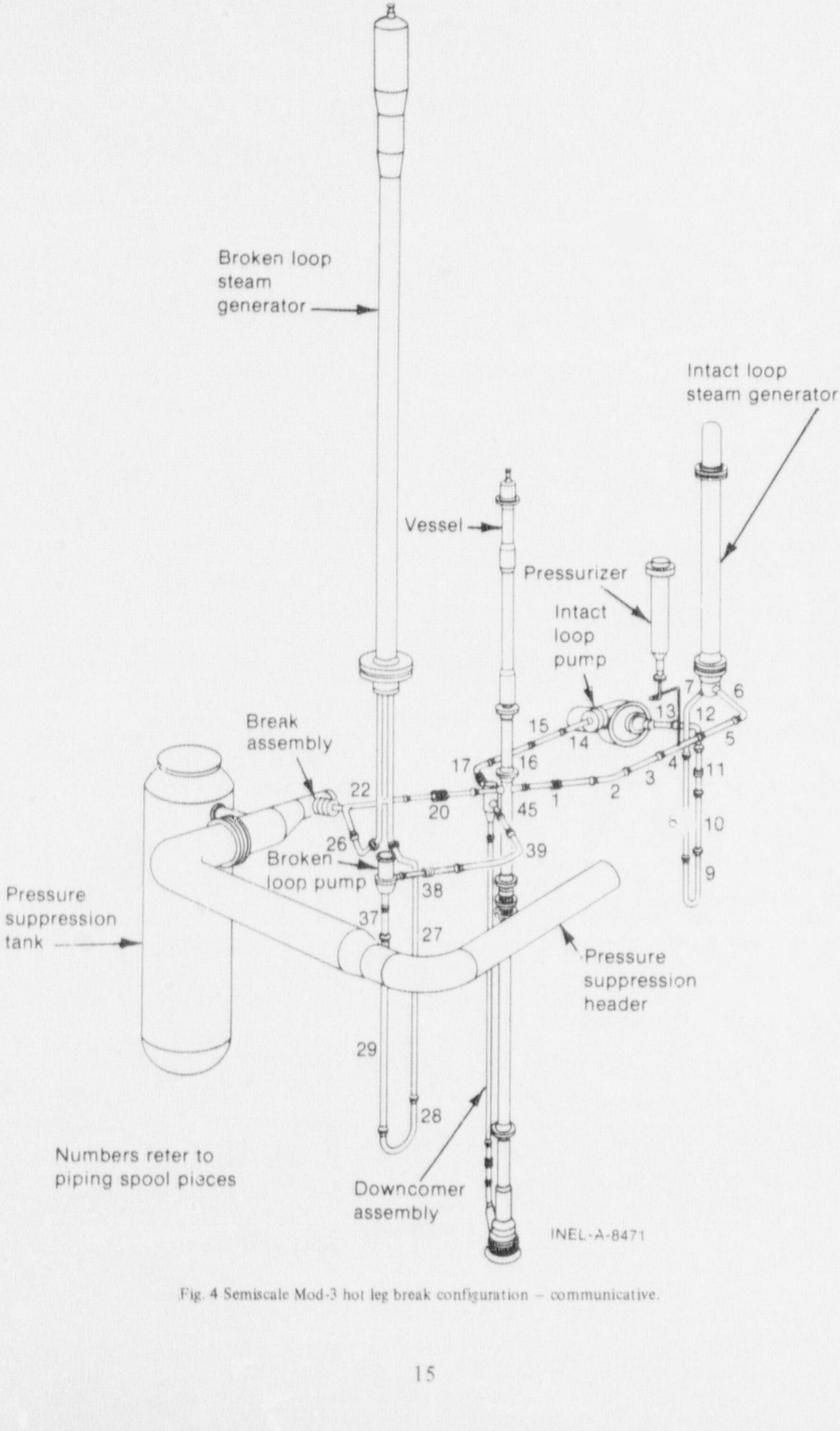


Fig. 4 Semiscale Mod-3 hot leg break configuration – communicative.

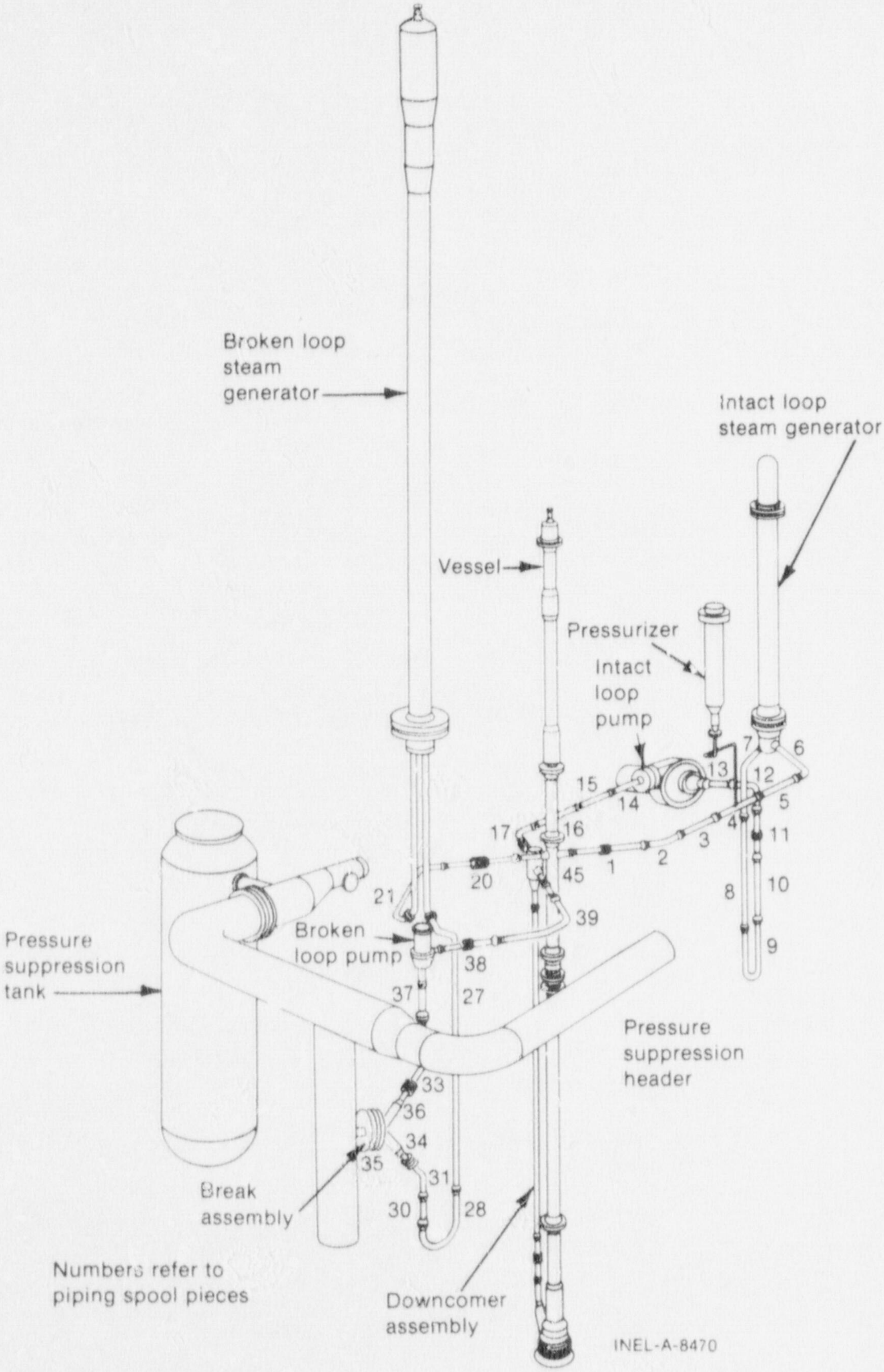


Fig. 5 Semiscale Mod-3 pump suction break configuration – noncommunicative.

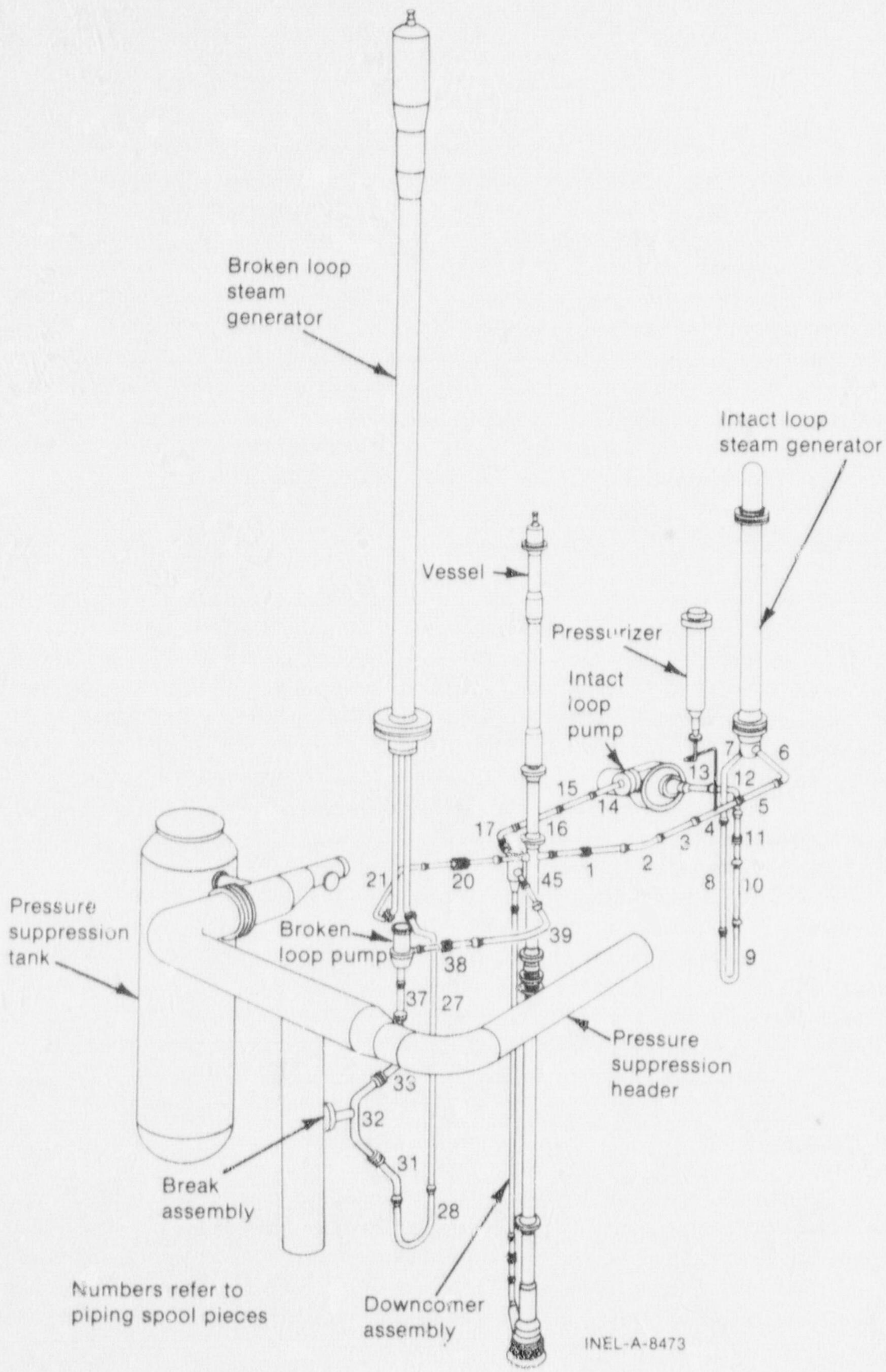


Fig. 6 Semiscale Mod-3 pump suction break configuration – communicative.

1. VESSEL ASSEMBLY

The Semiscale Mod-3 vessel assembly consists of a multisectional pressure vessel with internal assemblies forming five major internal regions: the upper head, the upper plenum, the core, the lower plenum, and the external downcomer. During system operation, coolant enters the vessel from the intact and broken loops at the downcomer inlet annulus through the cold leg inlet nozzles. Coolant then flows into the lower plenum region through the downcomer pipe. From the lower plenum, coolant is directed up through the electrically heated core and into the upper plenum region. The coolant then exits the vessel via the two hot leg outlet nozzles. Approximately 4% of the coolant flow may be directed from the downcomer inlet annulus to the upper head, bypassing the core. The vessel assembly incorporates several instrumentation devices, including liquid level detectors, flowmeters, momentum flux detectors, and density transducers, which are integral components of the vessel design. The major regions of the assembled vessel are shown in Figure 7.

1.1 Pressure Vessel

The pressure vessel is an integral part of the system pressure boundary. The pressure vessel subassembly consists of 11 sections which are designated as the upper head, upper head extension, upper plenum extension, hot leg extension, heater rod ground hub, core housing seal hub, core, lower plenum extension, lower head, downcomer pipe, and downcomer inlet annulus. These sections, when assembled, enclose the five regions of the reactor simulator. The pressure vessel sections are constructed primarily of 6-in. Schedule XX pipe (downcomer extension is 3-in. Schedule 160) with integral Grayloc flange hubs at conjoining sections ends. Stainless steel Grayloc clamps and seal rings are used to connect the vessel sections.

The assembled vessel, with the pressure vessel sections identified, is shown in Figure 8. The assembled pressure vessel is approximately 10.1 m long and is connected to the system by four 3-in. Grayloc nozzles, two outlet nozzles in the hot leg extension section which interface with the intact and broken loop hot legs, and two inlet nozzles in the downcomer inlet annulus which interface with the intact and broken loop cold legs. Additional penetrations are provided for the upper head, downcomer inlet annulus, and lower plenum region ECC injection lines, flow bypass lines, and instrumentation.

1.2 Upper Head Region

The upper head region of the vessel, shown in Figure 9, is considered to be the volume above the upper core support plate and enclosed by the upper head and upper head extension sections of the pressure vessel. Internal to the pressure vessel are the upper head ECC injection line, a liquid level probe, filler piece and insulator, the upper end of a simulated control rod guide tube, and at the lower end a simulated upper core support plate and the upper ends of two simulated-core support columns.

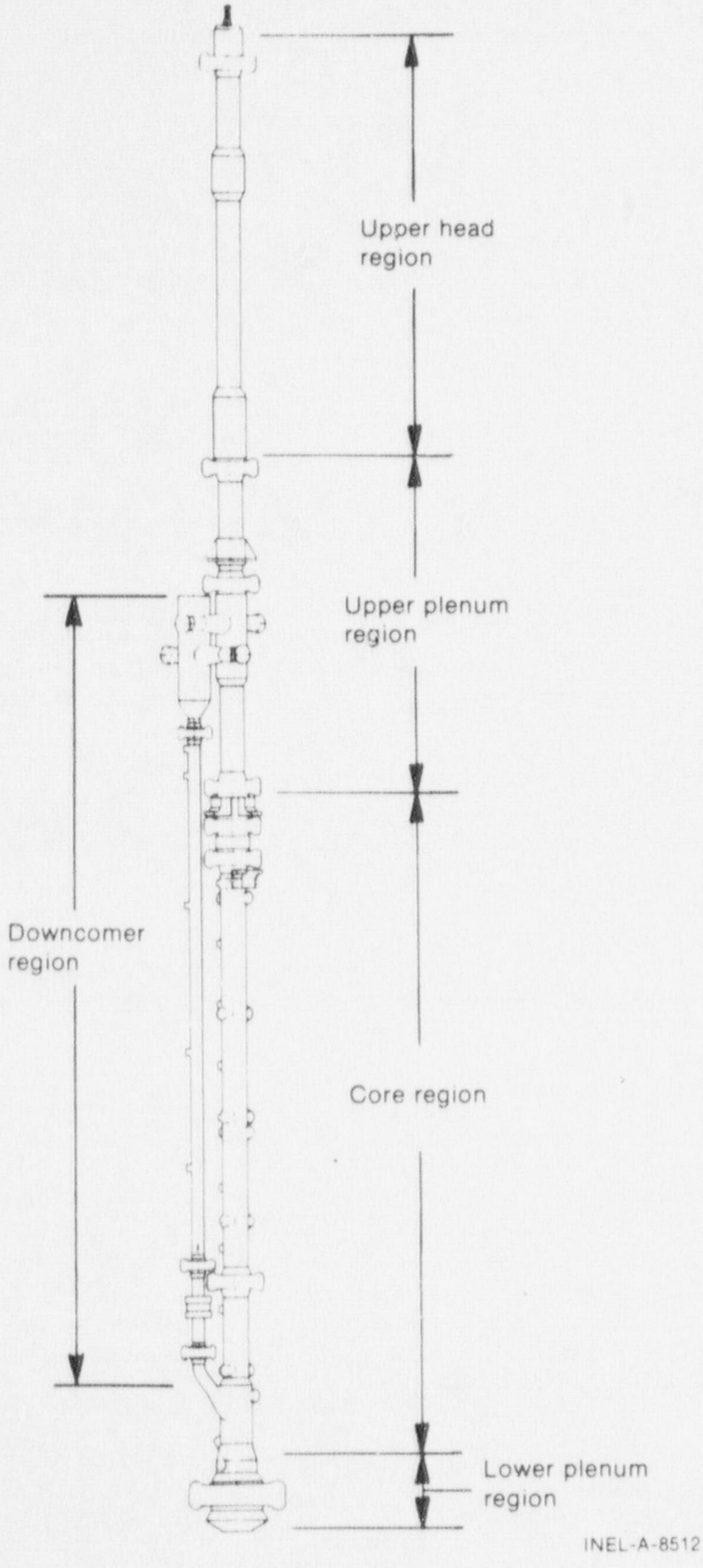


Fig. 7 Semiscale Mod-3 vessel showing major regions.

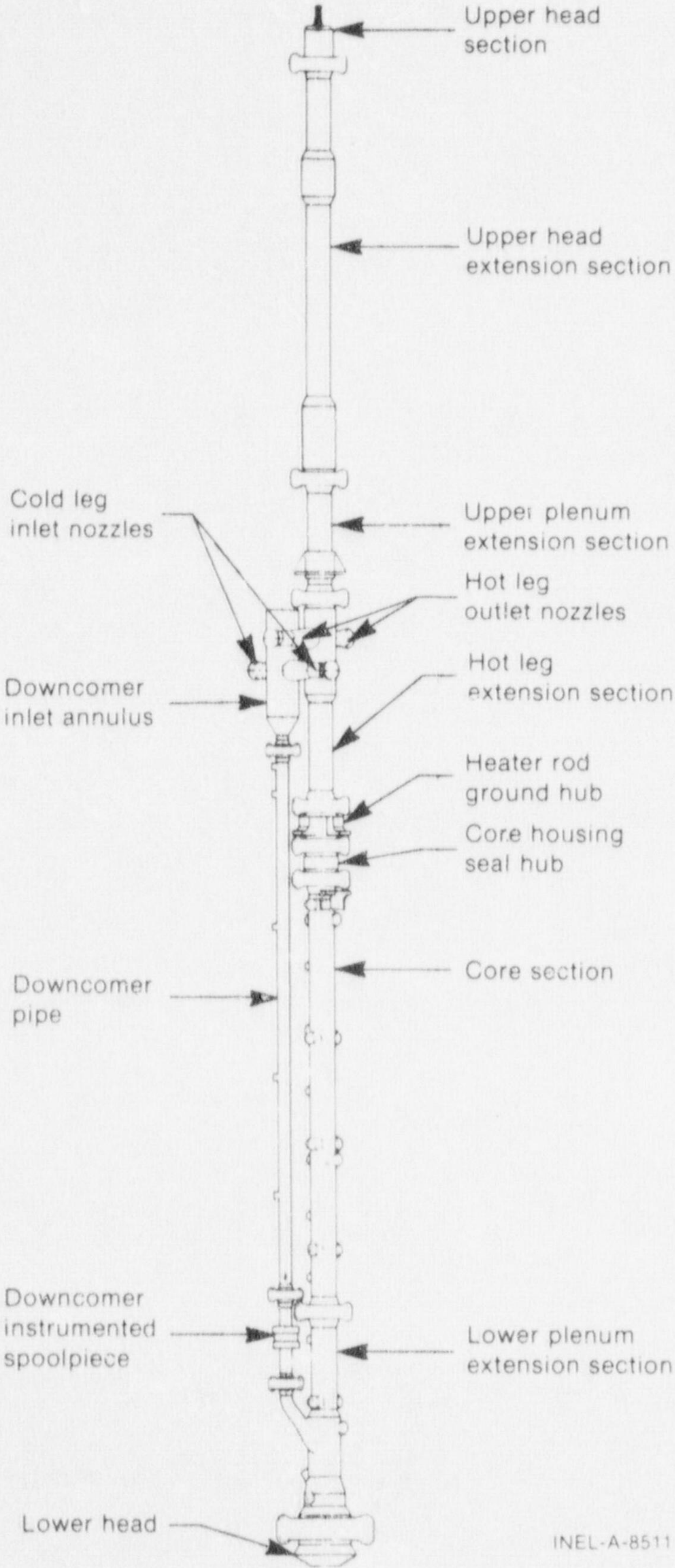


Fig. 8 Semiscale Mod-3 vessel showing pressure vessel sections.

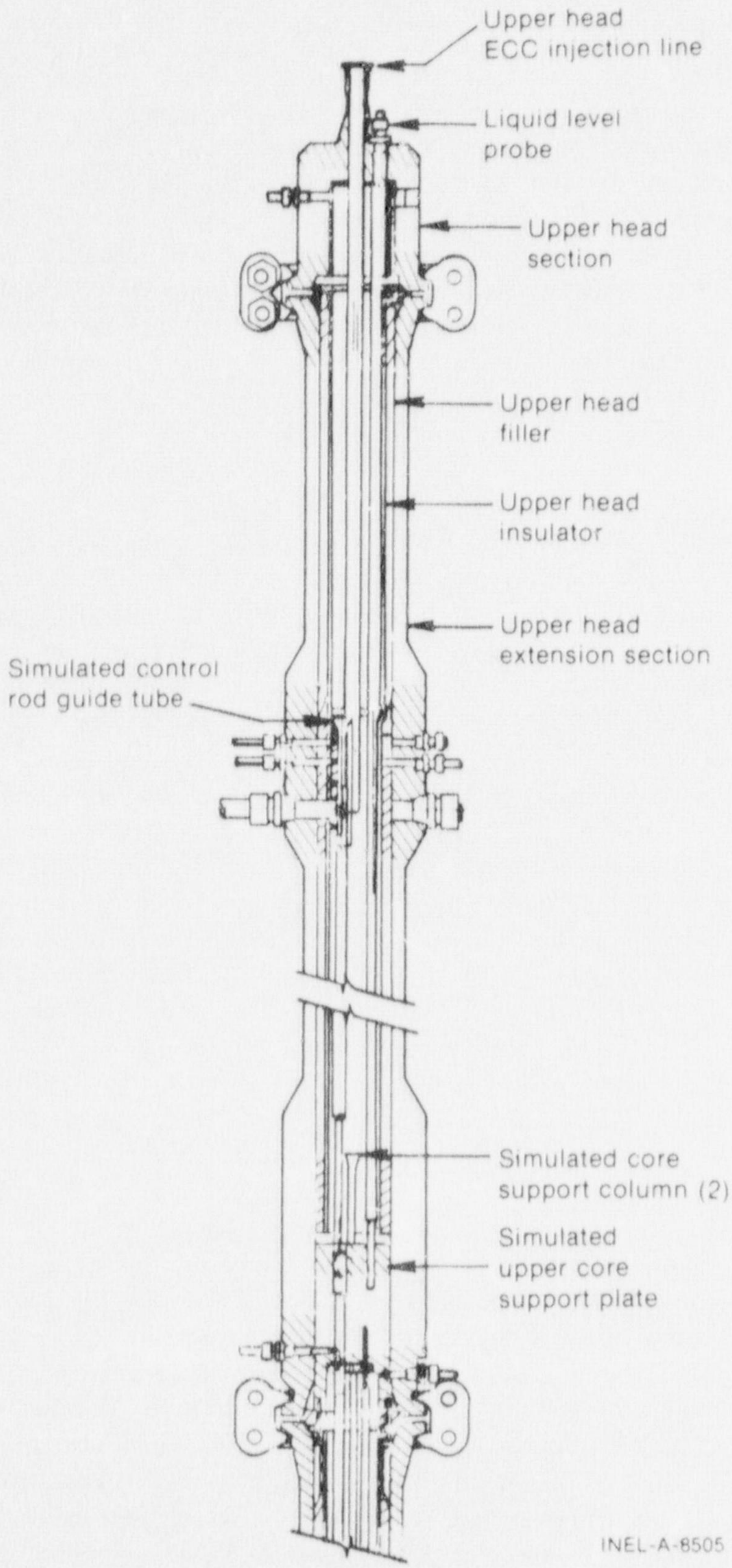


Fig. 9 Semiscale Mod-3 vessel upper head region.

1.3 Upper Plenum Region

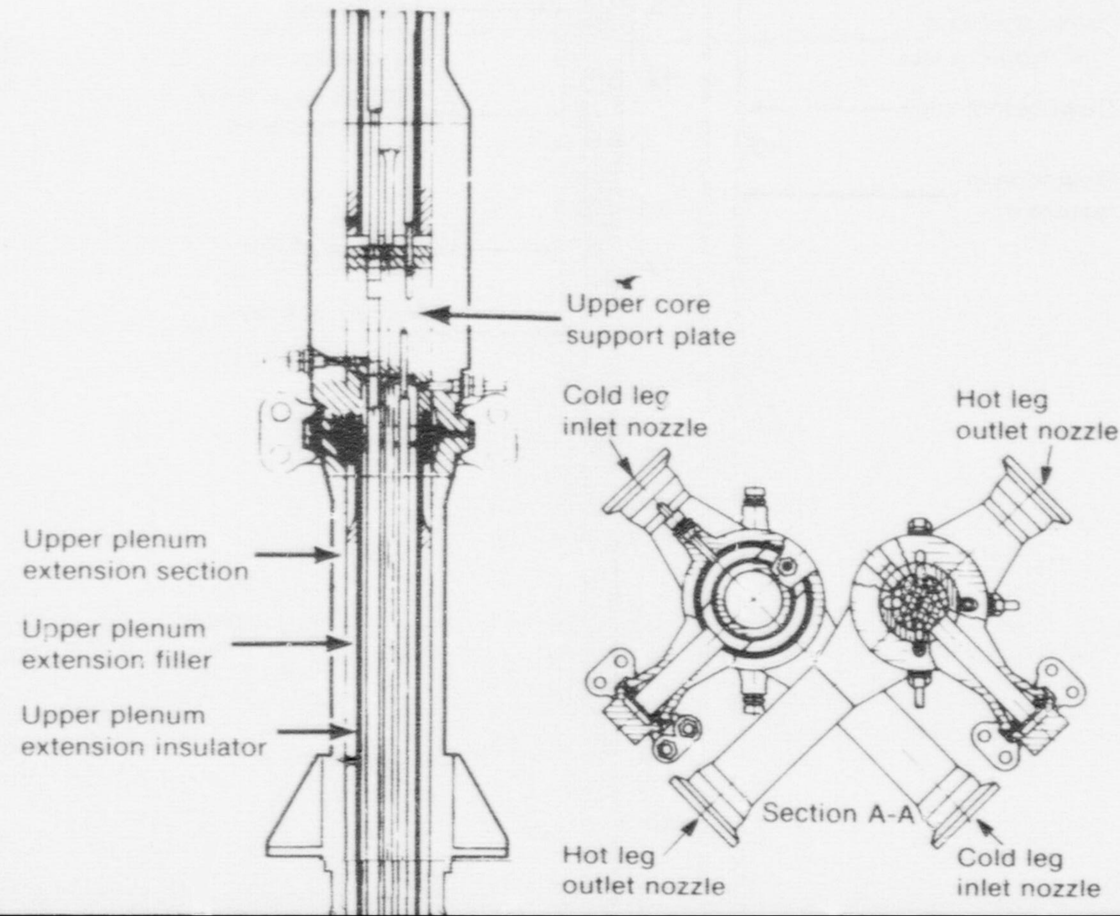
The upper plenum region of the vessel, shown in Figure 10, is the volume bounded by the lower end of the upper core support plate and the top of the upper core plate and enclosed by the upper plenum and hot leg extension sections of the pressure vessel. Internal components of this region include fillers and insulators, a simulated control rod guide tube, two simulated core support columns, a core flow measurement station, and a cross flow restrictor assembly. The measurement station and flow restrictor effectively subdivide the upper plenum region into upper and lower sections, each of which is provided with a liquid level probe. Internal measurement apparatus at the core flow measurement station includes a drag screen and a turbine flowmeter. The upper section of the upper plenum region includes the hot leg outlet nozzles.

1.4 Core Region

The core region, shown in Figure 11, is considered to be the volume bounded by the simulated upper core plate at the top and the simulated lower core plate at the bottom. The pressure vessel sections enclosing this region include the heater rod ground hub, the core housing seal hub, the core section, and the lower plenum extension section. Internal to the core region are two subassemblies, the core assembly and the core housing assembly.

The core assembly consists of 24 electric heater rods and one liquid level probe supported in a 5 by 5 matrix by grid spacers as shown in Figure 12. The heater rods and the liquid level probe are 1.07 cm in diameter and are located on 1.43-cm centers in the matrix (typical PWR fuel rod diameter and pitch). The heater rods and liquid level probe penetrate the pressure vessel through the lower head and are clamped to it. A collar, welded on each heater rod and the probe, seats on a "V" type pressure seal and on the seal spacer plate as shown in Figure 13. Below the heater rod collars are 36 cruciform shaped heater rod retainers. The 16 inside retainers share four rod collars, and the outside and corner retainers clamp two rods and one rod, respectively. Each retainer has a socket-head cap screw through its center which serves to clamp the rods to the vessel lower head. The ten core grid spacers are located on 40.01-cm centers along the length of the active zone of the core assembly and are secured in the core housing.

The electric heater rods, illustrated in Figure 14, have a heated length of 3.66 m, which is identical to the heated length of the reference PWR nuclear fuel rod. The pressure boundary of each heater rod is a dual composite sheath assembly with the inner sheath creased concavely (relative to the outside diameter) at six places equally spaced circumferentially around the sheath. The concave creases run the length of the rod sheath to accept six 0.064-cm-diameter stainless steel sheathed thermocouple assemblies. The outer sheath is assembled over the creased tube after installation of the thermocouples, and the subassembly is swaged to form the composite sheath. The heating element of the heater rod is 55% copper/45% nickel alloy wire, coiled with varying pitch and numbers of wires, and is sized to develop the required power profile. Compacted boron nitride insulates the heater element and lead-in conductor from the composite sheath.


Upper core
support plate
Cold leg
inlet nozzle
Hot leg
outlet nozzle
Upper plenum
extension section
Upper plenum
extension filler
Upper plenum
extension insulator
Section A-A
Hot leg
outlet nozzle
Cold leg
inlet nozzle

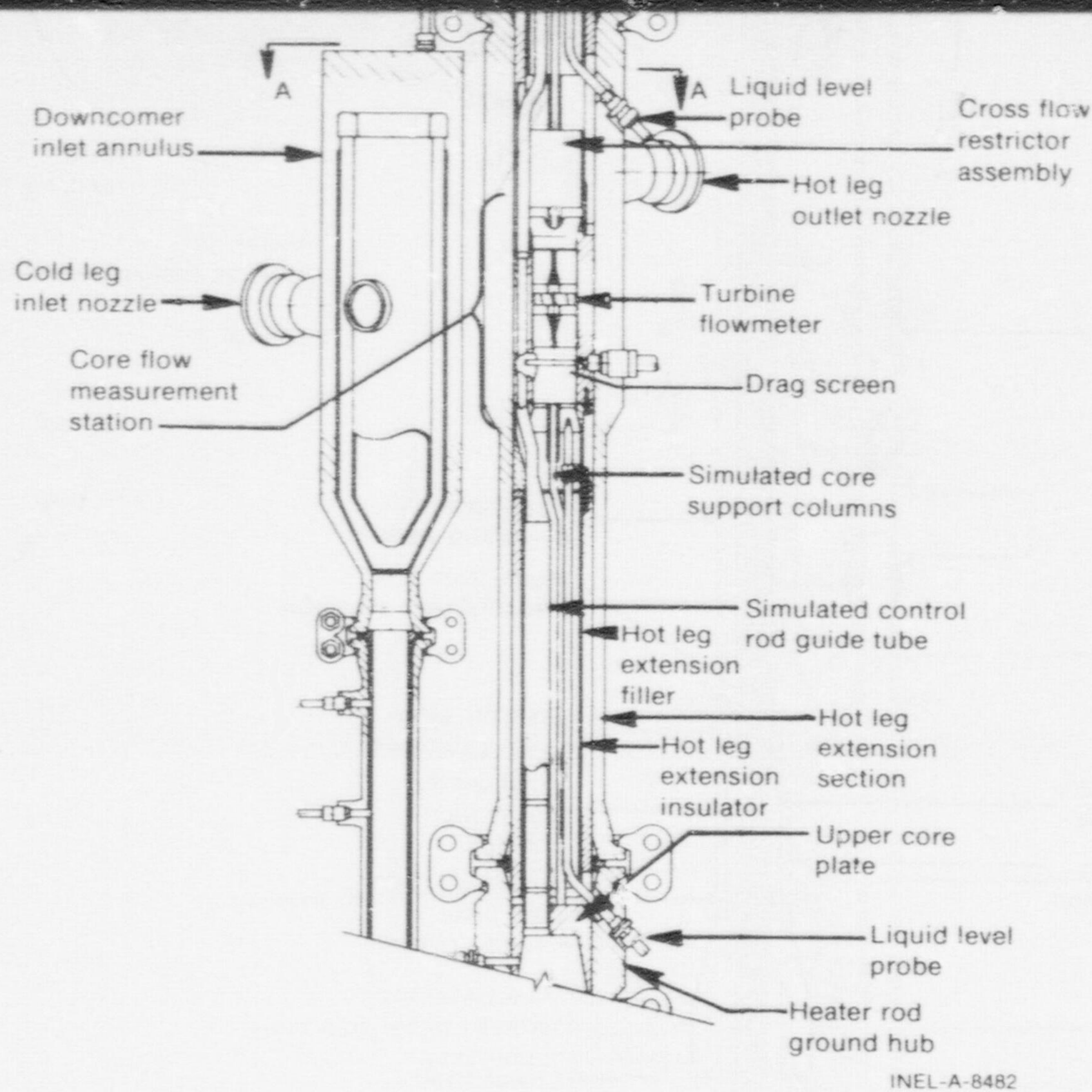
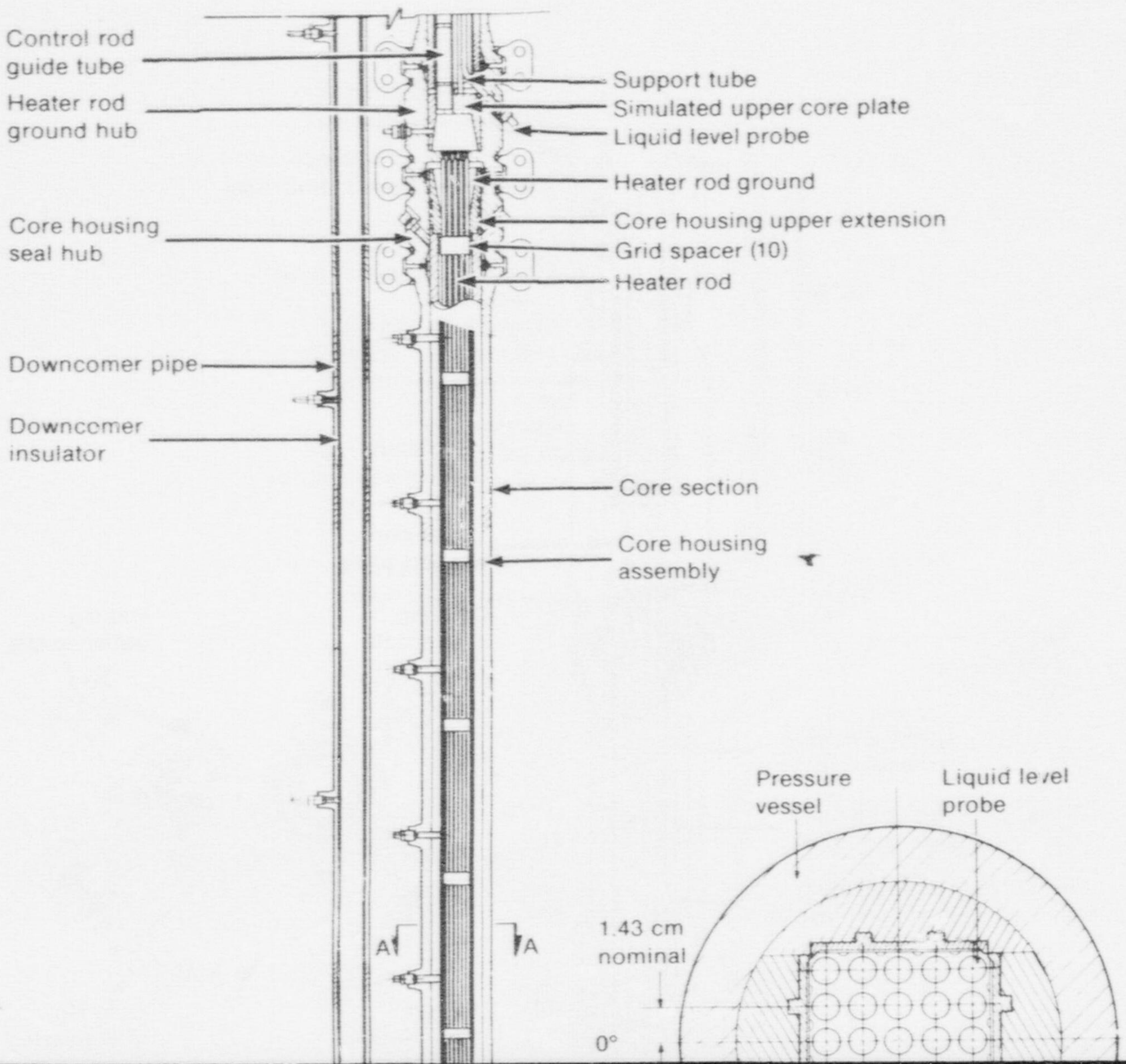


Fig. 10 Semiscale Mod-3 vessel upper plenum region and downcomer inlet annulus.



d downcomer pipe.

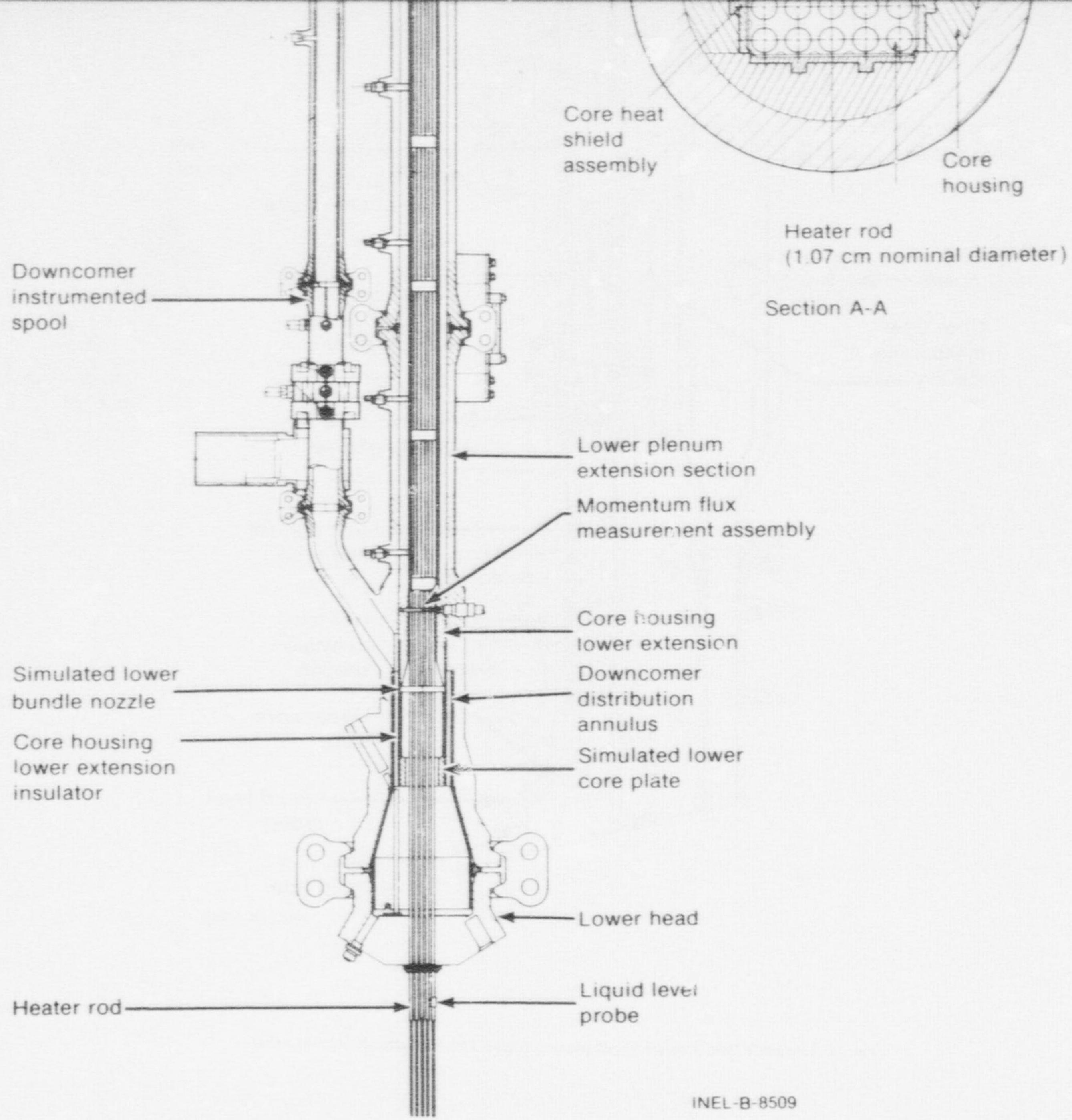


Fig. 11 Semiscale Mod-3 core region a

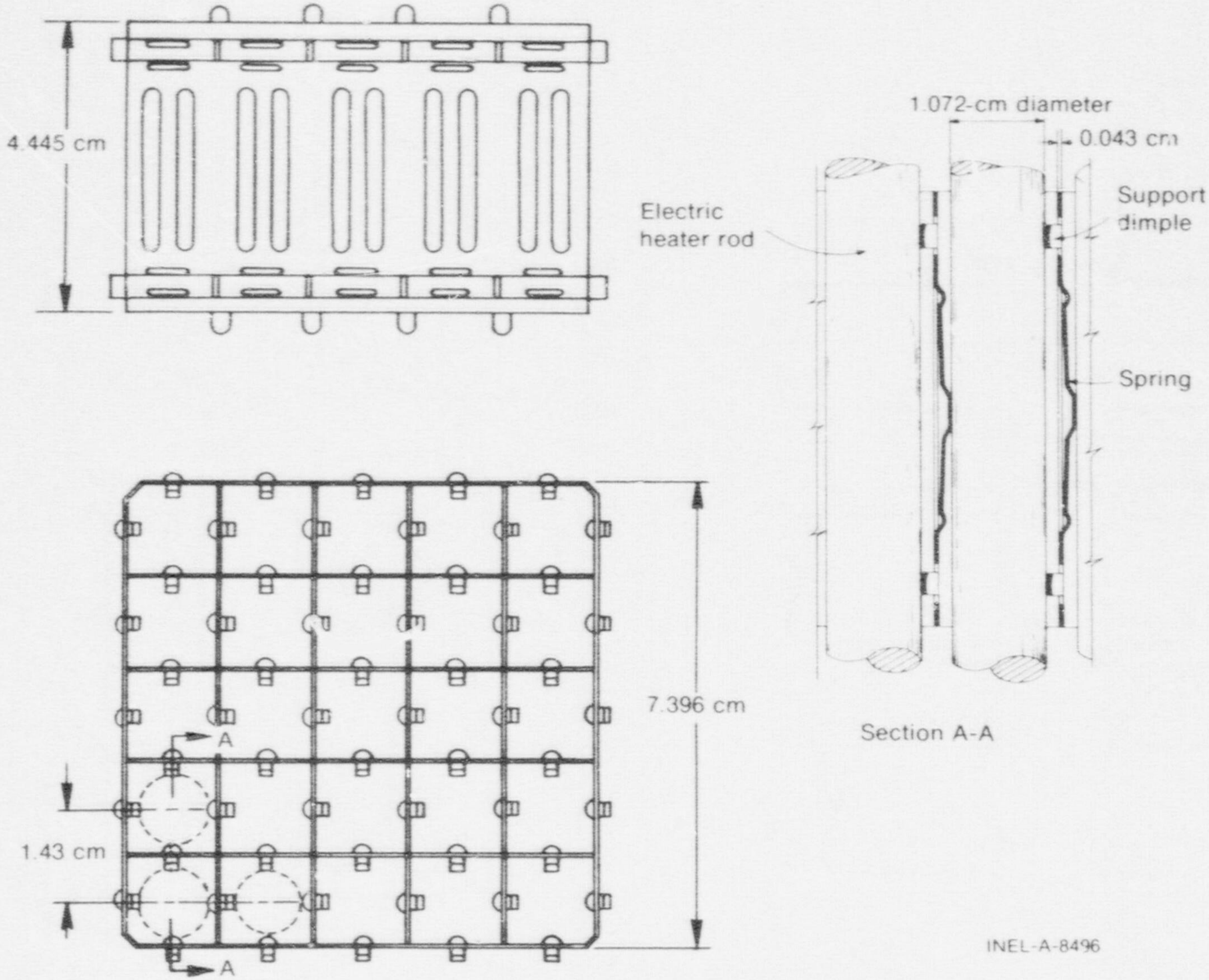


Fig. 12 Semiscale Mod-3 grid spacer.

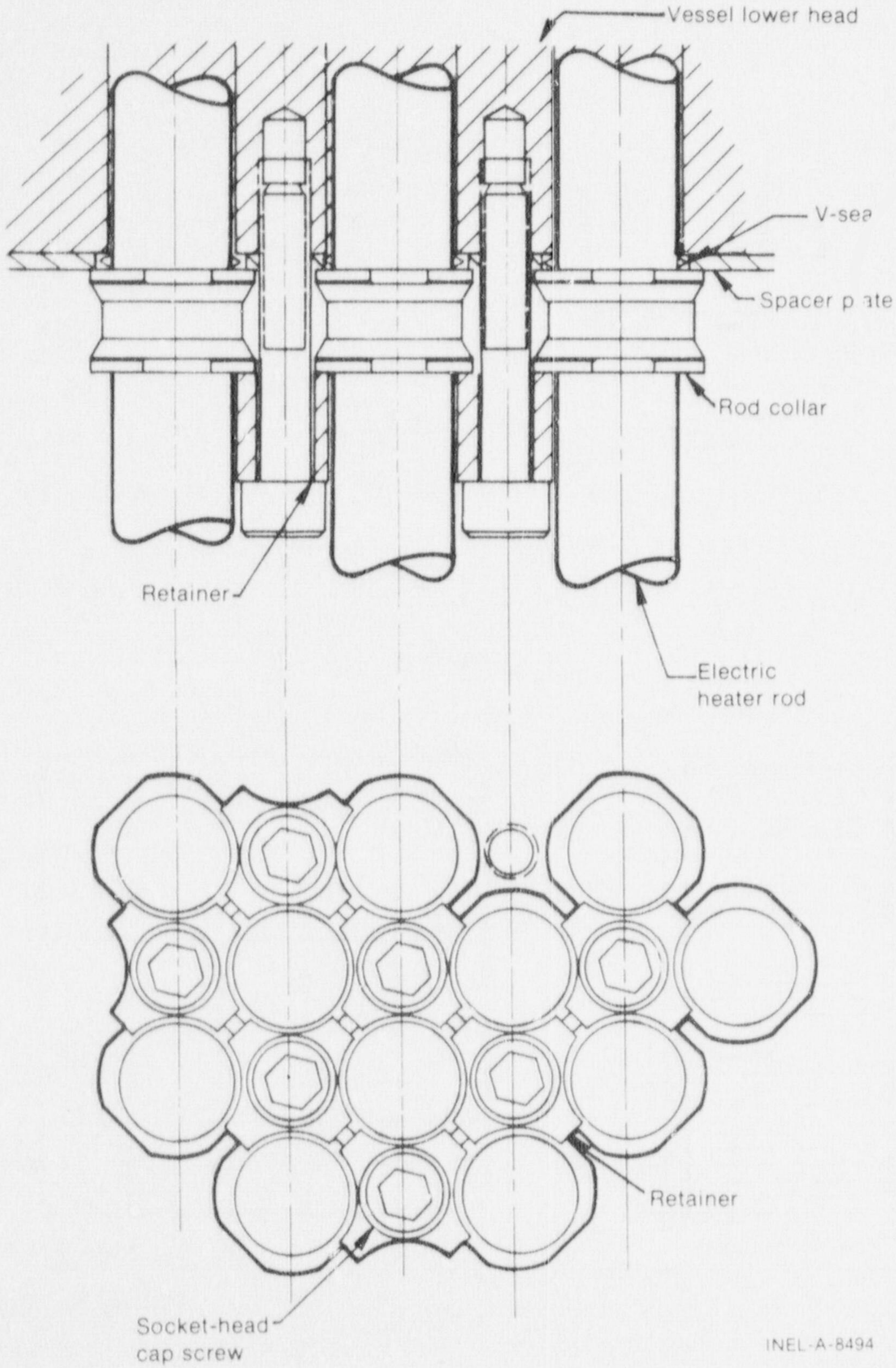


Fig. 13 Heater rod mounting and pressure seal in vessel lower head.

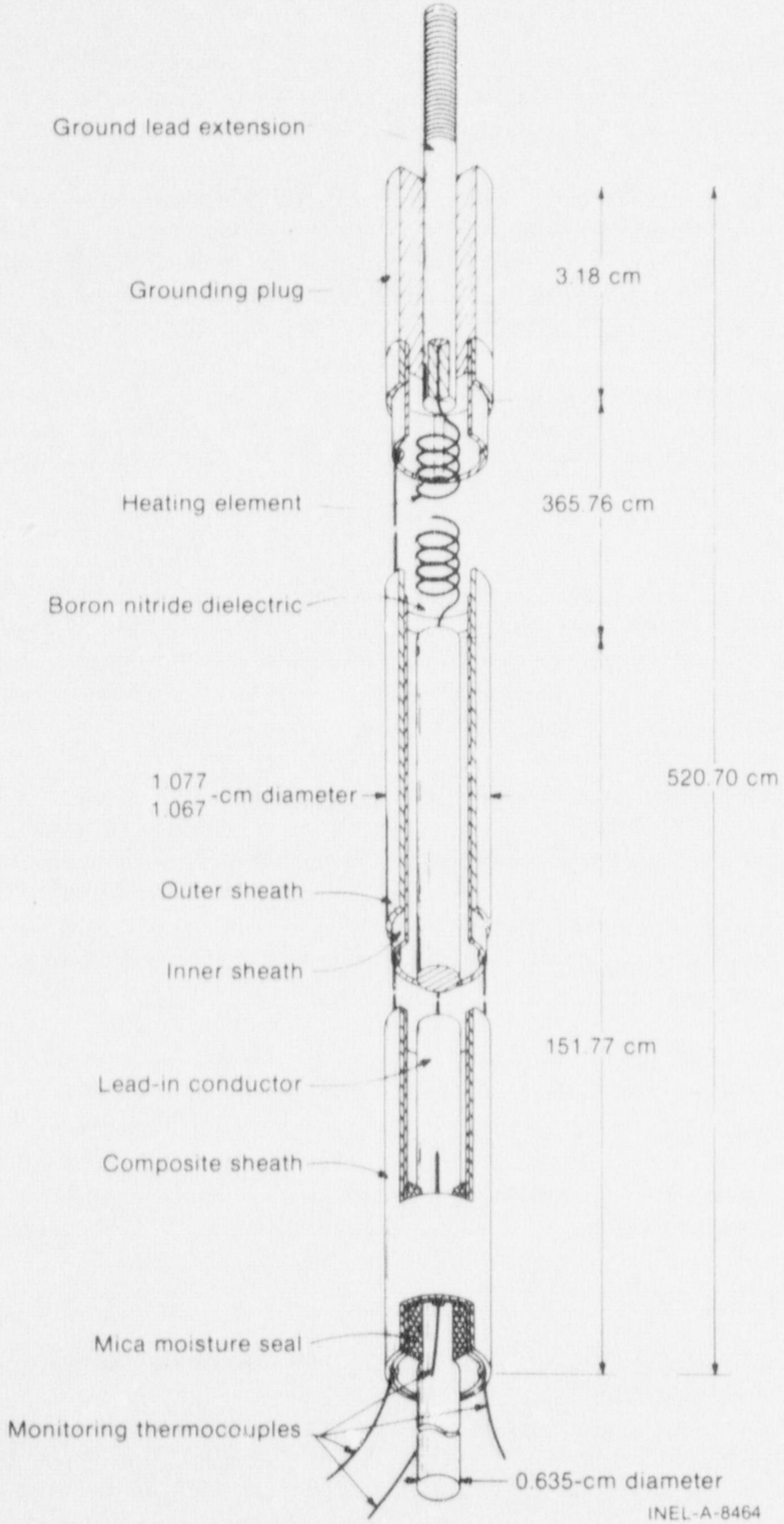


Fig. 14 Semiscale Mod-3 electrical heater rod.

Power is brought into the heater rod with a 0.63-cm-diameter copper rod. The heater rods are grounded to the outer pressure vessel by 10-gauge copper wires connected between the upper end of the rods and the heater rod ground hub.

The core housing assembly consists of a core housing, core housing upper and lower extensions, and 36 grid spacer support assemblies. The core housing is 3.71 m long and is made up of four side plates, assembled with machine screws and dowels. The outer surface of the assembled housing is cylindrical to interface with the pressure vessel, and the internal cross section is square to house the square core assembly configuration. Thirty-six grid spacer support assemblies are secured to the inner surfaces of the core housing in groups of four, spaced on 40.01-cm centers along the length of the housing. The assemblies support the ten grid spacers. Integral with the grid spacer support assemblies are gold plated heat shield assemblies which face the core assembly. The heat shield assemblies are mounted to provide a steam gap type thermal insulation between the heat shields and the grid support plates during the experimental transient.

The core housing upper extension is attached to the upper end of the core housing by machine screws. The extension is machined to fit into the core seal hub and is provided with glands on the outside surface for asbestos packing seals between the extension and hub. The core housing upper extension provides a transition from the square cross section of the core assembly to the circular cross section of the upper plenum region.

The core housing lower extension attaches to the lower end of the core housing by machine screws. It consists of a weldment of four parts: a transition piece which provides a transition from the square cross section of the core assembly to the circular cross section of the lower plenum, a simulated lower fuel bundle nozzle, a simulated lower core plate, and an outer insulator. The outside wall and insulator of the lower core housing extension serve as the inside wall of the downcomer distribution annulus and isolate fluid flow in the annulus from the hot wall of the lower extension.

Internal to the core region also are provisions for making core fluid density and momentum flux measurements. Provisions for core density measurements are located at seven elevations along the length of the core. A cross section of a typical core fluid densitometer assembly is shown in Figure 15. The core momentum flux measurement assembly is located near the bottom of the core region and is positioned between the core housing assembly and the core housing lower extension assembly as shown in Figure 11.

1.5 Lower Plenum Region

The lower plenum region, shown in Figure 16, is defined as the volume below the simulated lower core plate. The pressure vessel sections enclosing the region are the lower portion of the lower plenum extension section and the lower head. The lower plenum extension contains the 3-in. nozzle for the downcomer and is the outside wall of the downcomer distribution annulus. The lower head provides penetrations for 24 heater rods and one in-core liquid level probe. The lower plenum extension section and the lower head are joined with a Grayloc seal ring and clamp and are insulated to provide steam gap type

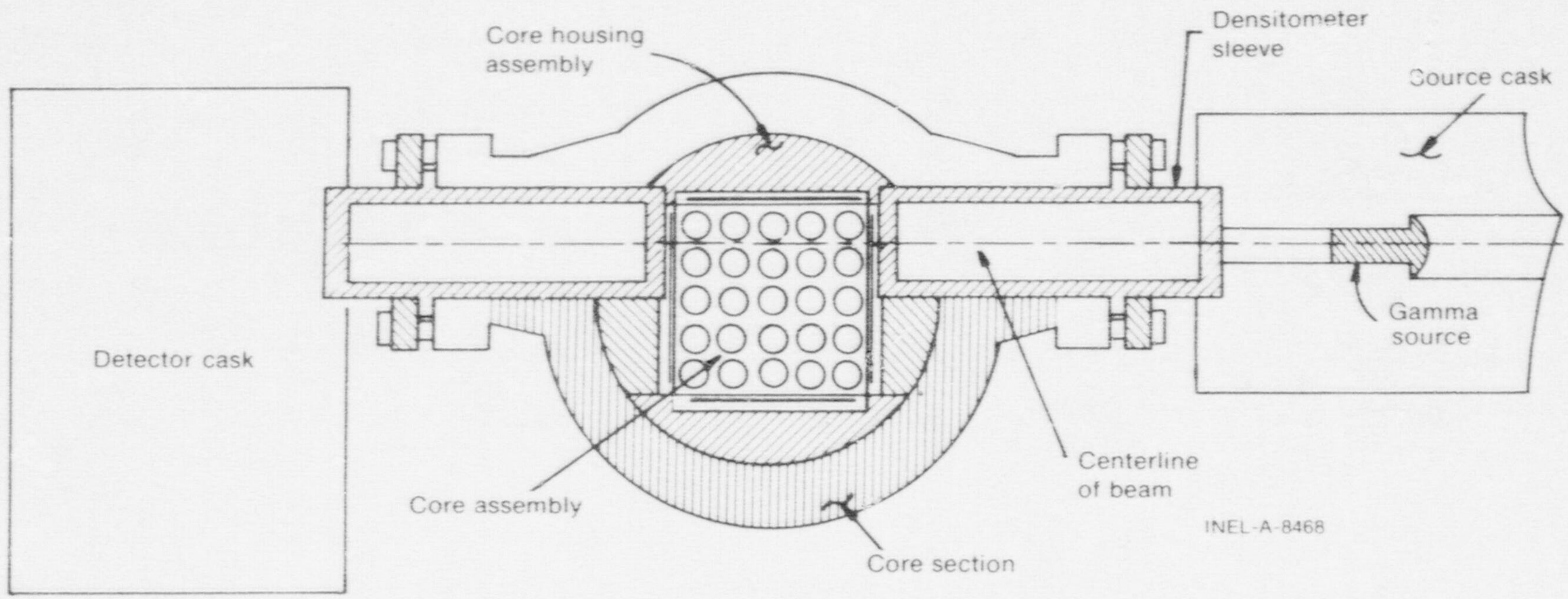


Fig. 15 Semiscale Mod-3 core fluid densitometer.

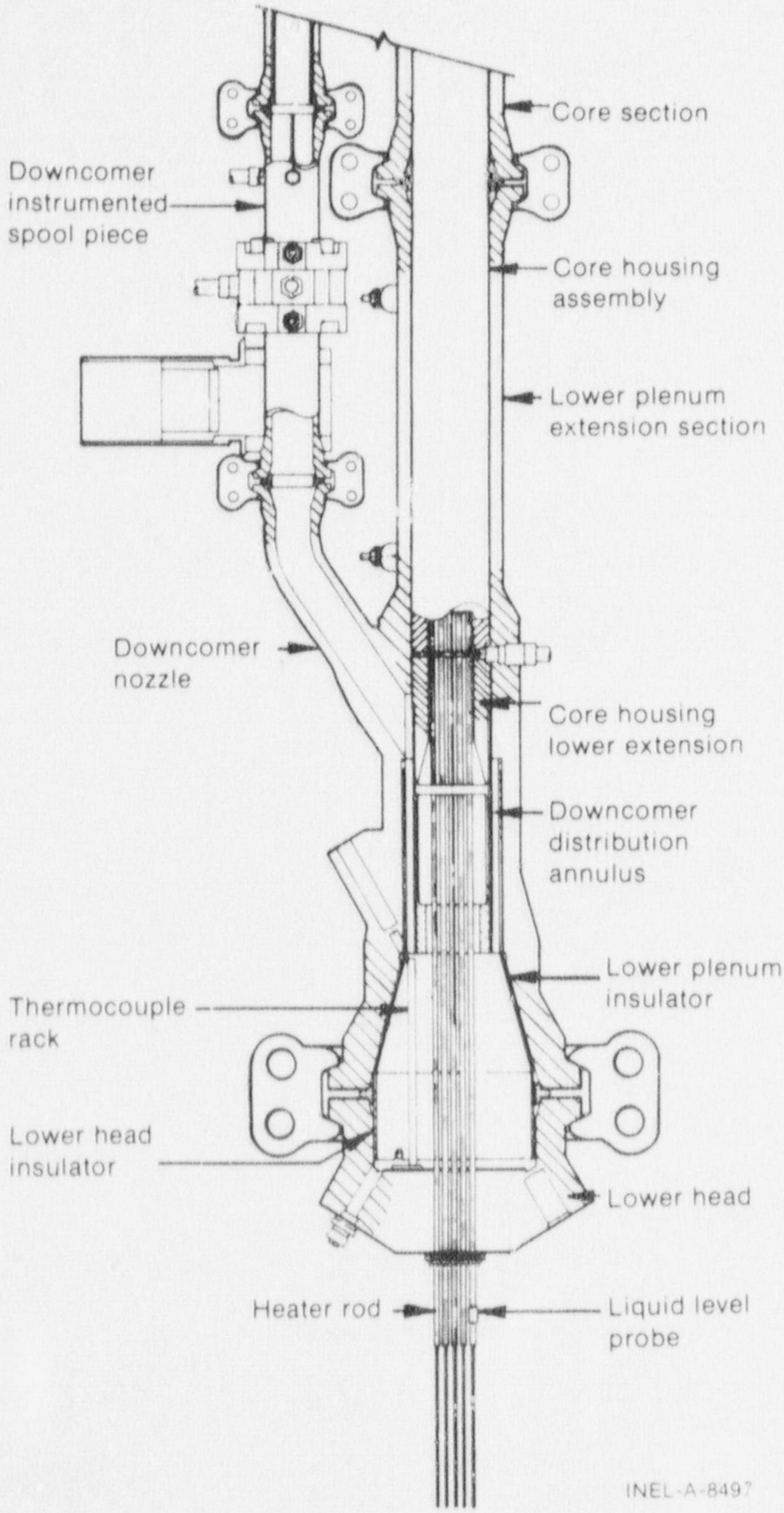


Fig. 16 Semiscale Mod-3 vessel lower plenum region and downcomer instrumented spool.

insulation between the outer walls and the fluid in the lower plenum. The lower head also supports a thermocouple rack which extends up into the lower plenum.

1.6 External Downcomer Region

The region defined to be the downcomer includes the volume from the cold leg inlet annulus to the downcomer distribution annulus. The pressure vessel sections enclosing this region are the downcomer inlet annulus assembly, the downcomer pipe, and the downcomer instrumented spool piece, which are shown in Figures 10, 11, and 16, respectively. The inlet annulus assembly contains the cold leg nozzles and is designed to provide an annular inlet geometry similar to that of the reference PWR. The inlet annulus assembly is provided with insulators on both walls, instrumentation ports, and a bypass-line port through which approximately 1% of the flow through the vessel may be routed to the upper head, bypassing the core. The lower end of the inlet annulus assembly is designed to funnel the flow into the downcomer pipe. The downcomer pipe is constructed from 3-in. Schedule 160 pipe with Grayloc hubs on each end. The pipe is equipped with several instrumentation ports and thermal insulation on the inner surface. The instrumented spool piece is located between the lower end of the downcomer pipe and the downcomer nozzle.

2. INTACT LOOP

The Semiscale Mod-3 intact loop is composed of piping sections, called spool pieces; a steam generator; a pressurizer; and a coolant pump. The intact loop spool pieces are numbered sequentially around the loop beginning at the vessel hot leg outlet nozzle. This configuration is illustrated in Figure 1.

2.1 Intact Loop Piping

Piping spools 1, 2, 3, 6 to 12, 15, 16, and 17 are constructed from 3-in. Schedule 160 stainless steel pipe, and the remaining spools are 3-in. Schedule 160 carbon steel pipe. The piping spool sections are joined by 3-in. Grayloc connectors. Spools 1, 11, 16, and 17 are instrumented spools (described in Section V-1); provisions are made in other spools for additional instrumentation.

2.2 Intact Loop Steam Generator

The intact loop (Type I) steam generator is designed to model the LOFT steam generator from volume scaling as well as component elevation considerations. The steam generator is of the tube-and-shell design having a double-pass tube side of the U-bend configuration and a single-pass shell side. The primary coolant passes through the tube side; and the secondary coolant, with resultant steam generation, passes through the shell side. The steam generator is situated in the vertical position with the primary inlet-outlet ports located in the head of the primary side inlet-outlet plenum. A cutaway view is shown in Figure 17.

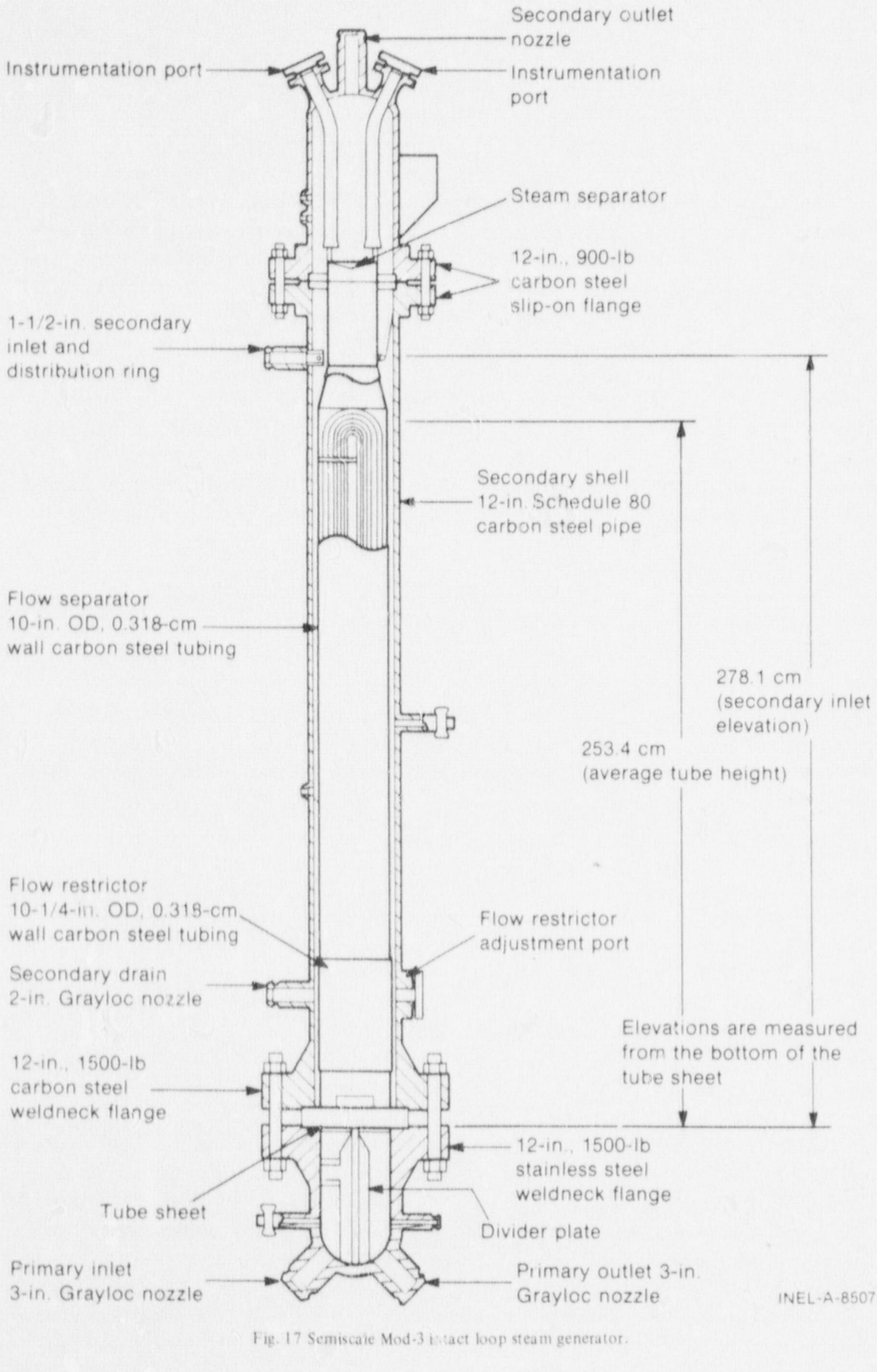


Fig. 17 Semiscale Mod-3 intact loop steam generator.

Major subassemblies of the unit are: the primary side inlet-outlet plenum, the tube bundle assembly, and the secondary containment shell and internals.

The primary side inlet-outlet plenum consists of a hemispherical head welded to a 12-in., 1500-lb weld neck flange which mates with the lower surface of the tube sheet. The plenum has external inlet and outlet nozzles for the primary system connections and contains an internal divider plate which separates the flow between the U-tube inlet and outlet openings on the lower surface of the tube sheet. The inlet-outlet plenum assembly is constructed of Type 316 stainless steel.

The tube bundle assembly consists of an Inconel tube sheet, 9.208 cm thick, and 54 U-bend tubes. The tubes are constructed of Inconel 600 and have an outside diameter (OD) of 1.021 cm and a wall thickness of 0.124 cm. They are arranged on a 1.91-cm triangular pitch and have an average length of 5.14 m. Six baffle plates extending about halfway across the bundle are spaced at equal intervals along the tube length.

Major components of the secondary shell and internals are: the shell, the feedwater inlet nozzle and distribution ring, the flow separator assembly, and the flow restrictor.

The secondary shell consists of two sections of 12-in., Schedule 80 pipe, 2.67 and 0.488 m long, connected with 900-lb, 12-in. slip-on flanges. The assembly is enclosed on the upper end with a pipe cap. A 1500-lb, 12-in. weld neck flange is welded to the lower end and interfaces with the upper end of the tube sheet. Nozzles and fittings are provided for the feedwater supply line, steam exhaust line, secondary system drains, and instrumentation.

The inlet nozzle spray ring is constructed of carbon steel pipe and is situated between the downcomer sleeve and the outer shell assembly. This ring is connected to the feedwater supply system by a 1-1/2-in. Grayloc nozzle extending through the secondary shell wall. The circumference of the distribution ring has 24 openings, each of 0.475-cm diameter; the openings permit feedwater to be injected downward into the downcomer annulus.

The flow separator assembly is constructed from Type 304 stainless steel tubing with a 25.4-cm outside diameter and 0.318-cm-thick walls.

The secondary flow restrictor is constructed from 25.58-cm inside diameter (ID) Type 304 stainless steel tubing with 0.266-cm-thick walls.

2.3 Pressurizer

The pressurizer is an electrically heated vessel normally connected to a horizontal section of the intact loop hot leg piping but can be connected to the broken loop hot leg by changing the interconnecting tubing. The Mod-3 pressurizer operates similarly to its counterpart in a typical PWR system in that the vessel is partially filled with water and maintained at the saturation temperature corresponding to the desired system pressure.

The pressurizer, shown in Figure 18, is made of 10-in. Schedule XXS, Type 304 stainless steel pipe, and is 169.0 cm high. It is design rated for 17 240 kPa and 626 K and has a volume of 0.027 4 m^3. Heat is supplied by 24 heaters, each rated at 0.05 kW that are inserted in thermal wells made of 2.22-cm OD stainless steel tubes sealed at the bottom. Overpressure protection is provided by a relief valve and burst diaphragm that operates at 18 960 kPa. Instrumentation is provided for liquid level, pressure, fluid flow, and various temperature measurements.

2.4 Intact Loop Pump

The intact loop pump is a volute-type heavy duty horizontal centrifugal pump. The pump is rated for a nominal flow of 22.6 ℓ/s at a total head of 1336 kPa when operated at the rated speed of 367 rad/s. The construction material for the wetted parts; that is, the casing, impeller, hub disc, and shaft, is Type 316 stainless steel. The remainder of the pump is of cast iron and steel. The pump is designed for 17 240 kPa and 616 K. The specific speed of the pump is 930, and the impeller diameter is 27.94 cm. The characteristic curves for the pump are shown in Figure 19. The curves for the pump modified by a venturi type nozzle welded inside the pump outlet (as shown in Figure 19) reflect a throat diameter of 2.70 cm, while the nozzle which is installed in the pump has a throat diameter of 3.175 cm.

The pump is powered by an 18.65-kW, 262 rad/s, dc motor which has a speed variation system which allows pump speed reduction to any desired operating point.

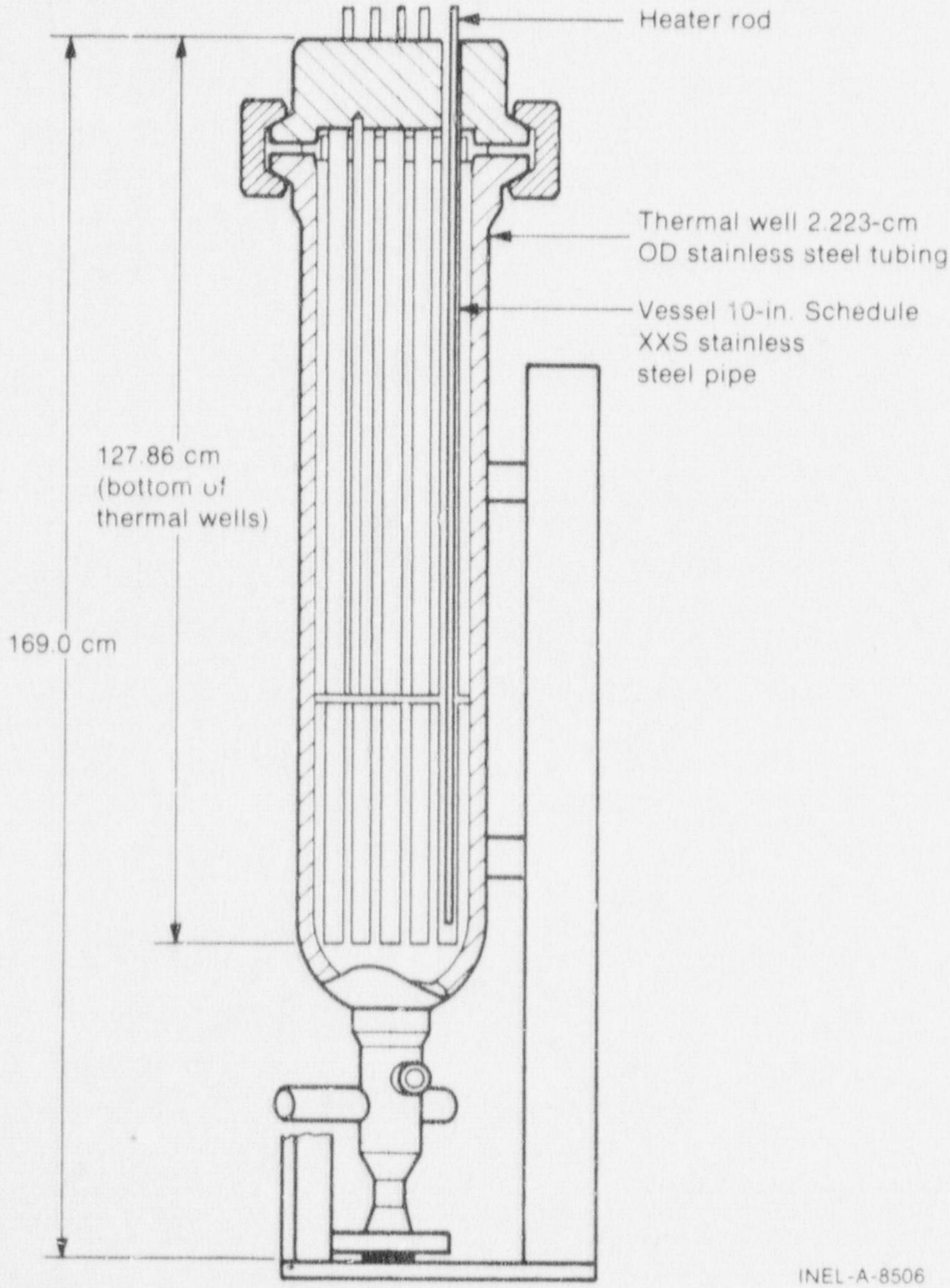


Fig. 18 Semiscale Mod-3 pressurizer.

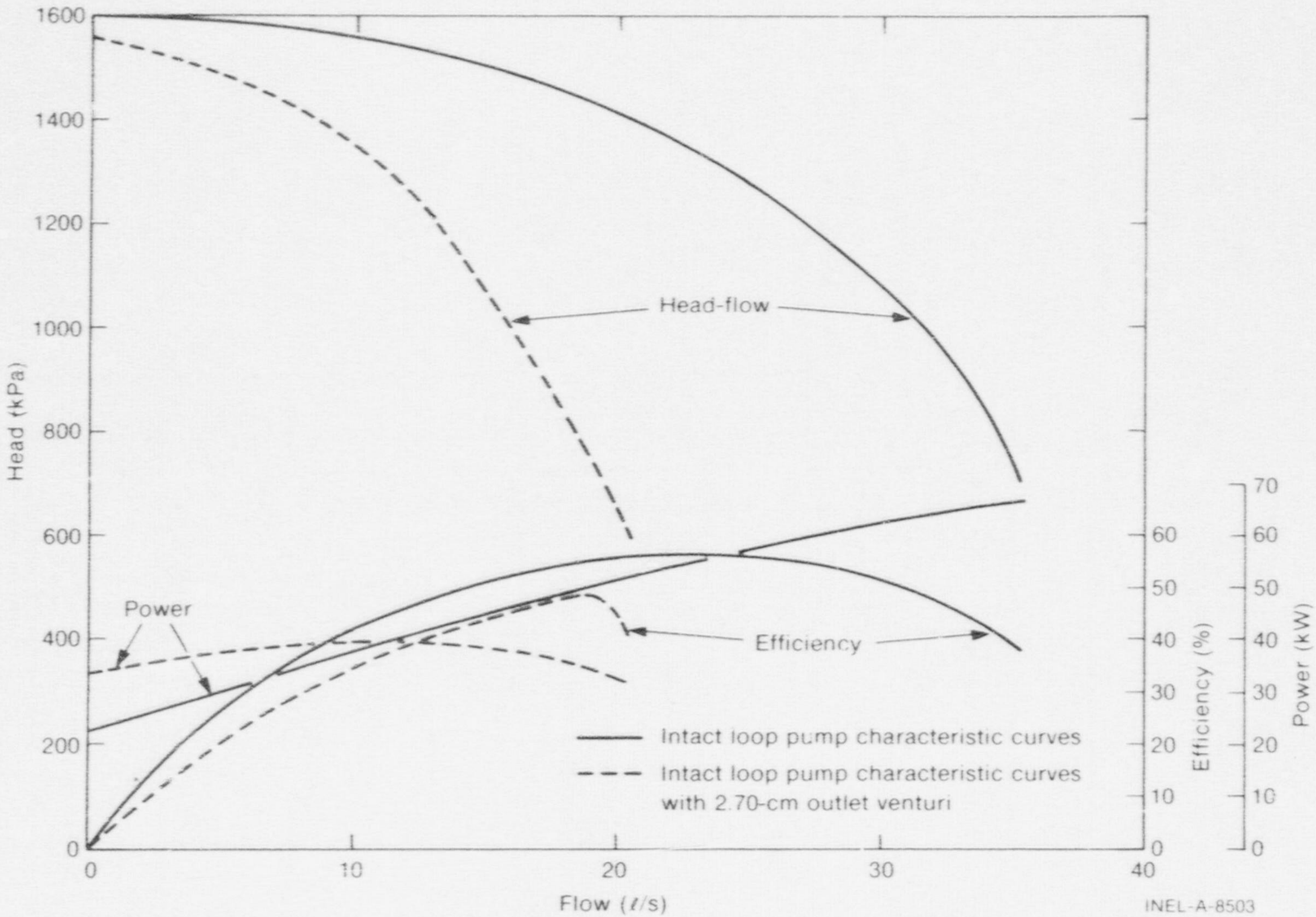


Fig. 19 Semiscale Mod-3 intact loop pump characteristic curves.

3. BROKEN LOOP

The Semiscale Mod-3 broken loop consists of piping sections, called spool pieces; a steam generator; a coolant pump; and rupture assembly. Six broken loop piping configurations are possible including hot, cold, or pump suction leg rupture locations with either a noncommunicative or communicative break arrangement at each location. The broken loop piping spools are numbered sequentially around the loop beginning at the vessel hot leg outlet nozzle. The various piping configurations are shown in Figures 1 through 6.

3.1 Broken Loop Piping

All broken loop spool pieces are constructed from 1-1/2-in. Schedule 160 pipe, which is seamless, austenitic steel pipe. With the exception of the flanges holding the rupture assemblies and the drag measurement instrument washers, all pipe spool piece connections are made with Grayloc connectors. Spools 20, 37, 45, and either 26, 30, or 40 (depending upon rupture location) are instrumented spools (described in Section V-1).

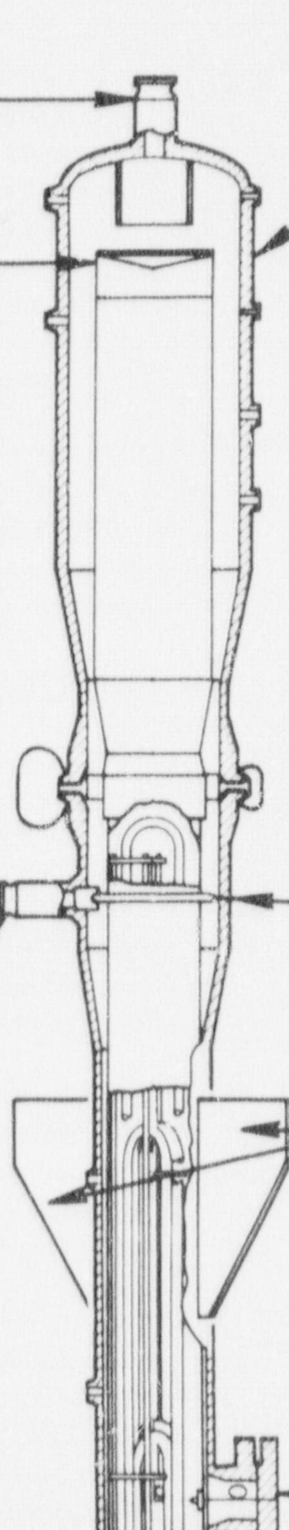
3.2 Broken Loop Steam Generator

The broken loop (Type II) steam generator is designed to model the Trojan PWR system steam generators. The principal differences from the intact loop (Type I) steam generator are the height of the tube bundle and the number and size of the U-tubes. The Type II steam generator is sized so that it can be installed in either the broken loop or the intact loop to study steam generator design effects on system behavior. For installation in the broken loop, an appropriately scaled primary side plenum assembly is utilized and several U-tubes are plugged to provide the scaled heat transfer surface area. The broken loop steam generator is shown in Figure 20.

The Type II steam generator is of the tube and shell design having a double pass tube side of the U-bend configuration and a single-pass shell side. The primary coolant passes through the tube side, and the secondary coolant with resultant steam generation passes through the shell side. The steam generator is situated in the vertical position with primary inlet-outlet ports located at the bottom of the inlet-outlet plenum assembly.

The broken loop inlet-outlet plenum assembly consists of sections of 1-1/2-in. Schedule XS, Type 316 stainless steel pipe; transition hubs which serve as hot and cold leg interface connections; an adapter flange; and a transition piece. The transition piece mates with the bottom of the tube sheet and provides a transition from the circular flow cross sections of the inlet-outlet piping to the rectangular tube bundle inlet and outlet areas. The plenum assembly is constructed of Type 316 stainless steel.

The tube bundle assembly consists of a tube sheet and 11 U-bend tubes. For installation in the broken loop, nine tubes are plugged. The tube sheet, constructed from a carbon steel forging with an Inconel weld overlap on the primary side surface, is 53.34 cm thick from the lower flange surface to the top of the upper flange. The tubes are



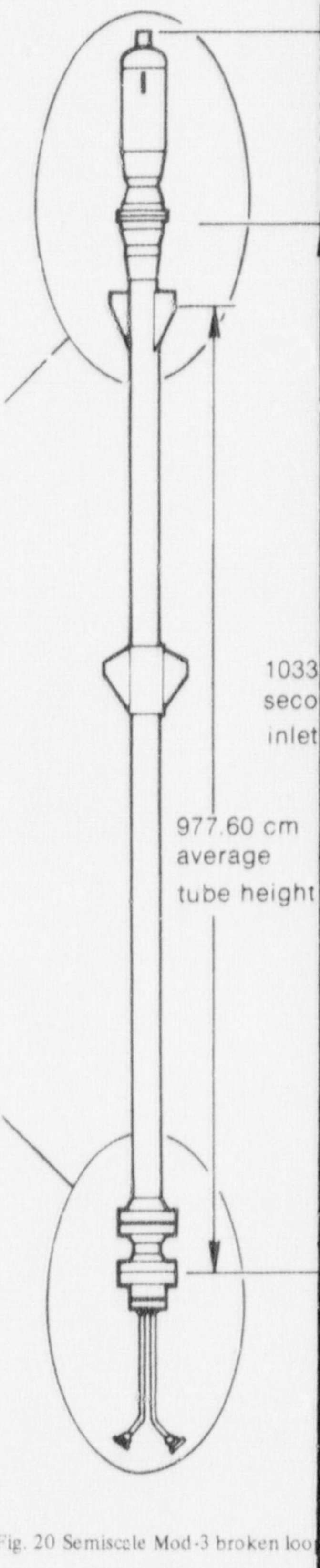
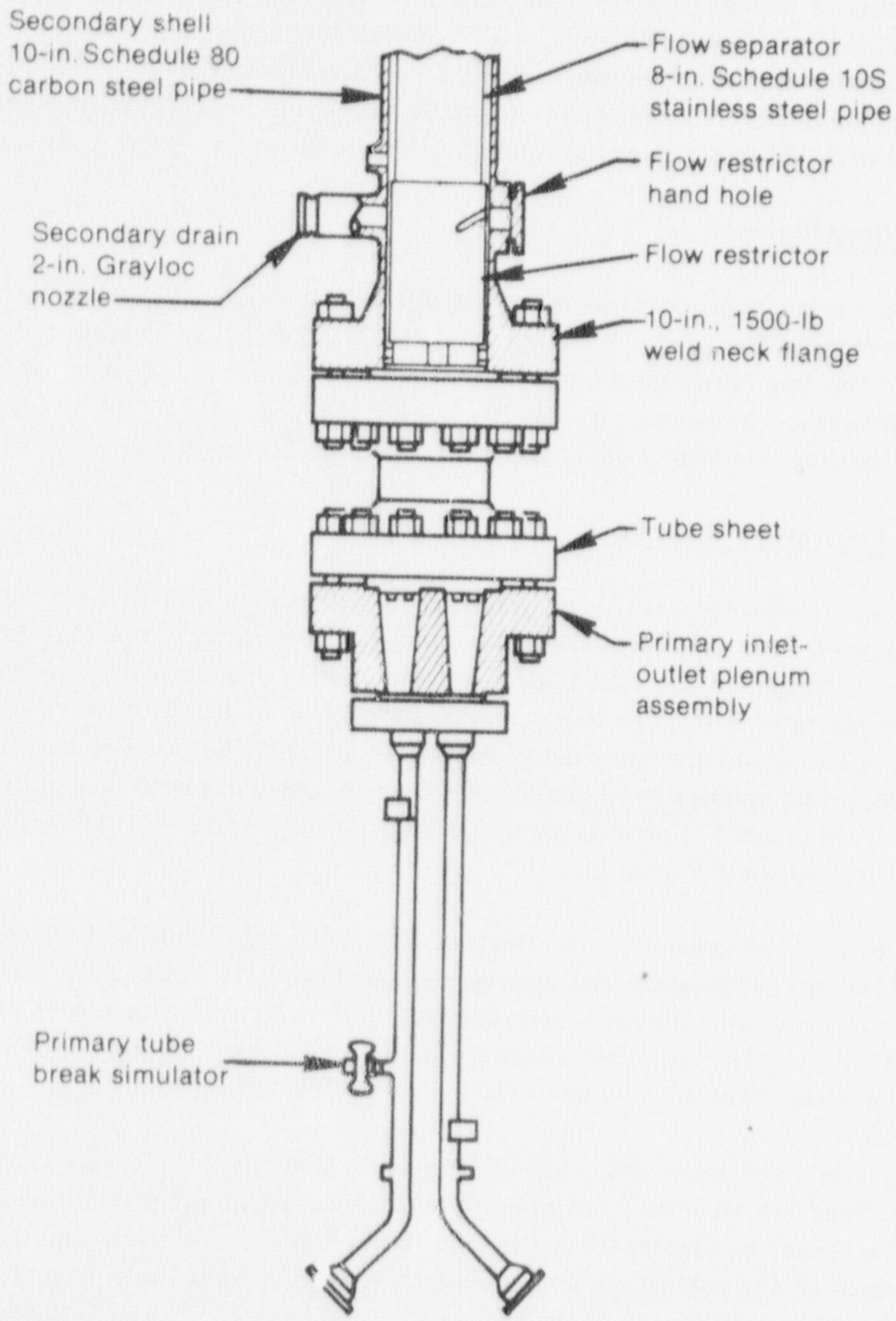


Fig. 20 Semiscale Mod-3 broken loo

.18 cm



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rator.

constructed of Inconel 600 and have an ID of 1.02 cm and a wall thickness of 0.012 5 cm. They are arranged on a 3.175-cm triangular pitch and have an average length of 19.552 m. Fifteen baffle plates extending approximately halfway across the bundle are spaced at equal intervals along the tube length. The assembly includes several Inconel spacers and tie rods as supportive apparatus.

Major components of the secondary shell and internals consist of the shell and steam dome assembly, the inlet nozzle distribution spray ring, the flow separator assembly, and the secondary flow restrictor.

The secondary shell is constructed from a section of 10-in. Schedule 80 carbon steel pipe with a 10-in., 1500-lb weld neck flange welded to the lower end and a 14- by 10-in. Schedule 80 concentric reducer and 14-in. butt-weld Grayloc hub welded to the upper end. The steam dome assembly consists of a section of 18-in. Schedule 80 carbon steel pipe 75.44 cm long with an 18- by 14-in. Schedule 80 carbon steel concentric reducer and 14-in. butt-weld Grayloc hub welded to the lower end and an 18-in. Schedule 80 pipe cap enclosing the upper end. Nozzles and fittings are provided for the feedwater supply line, the steam exhaust line, secondary system drains, and instrumentation.

The inlet nozzle distribution ring of carbon steel pipe is situated between the flow separator and the secondary shell. The ring is connected to the feedwater supply system by a 1-1/2-in. Grayloc nozzle which penetrates through the secondary shell wall. The circumference of the distribution ring has 24 openings, each of 0.475-cm diameter that permit feedwater to be injected into the downcomer annulus.

The flow separator assembly, which fits between the secondary shell and tube bundle, is constructed from 8-in. Schedule 10S stainless steel pipe with an OD of 21.91 cm.

The flow restrictor, which fits over the flow separator, is constructed from Type 316 stainless steel and has an ID of 21.93 cm and a wall thickness of 0.356 cm.

3.3 Broken Loop Pump

The broken loop pump is a centrifugal pump with vertical inlet and horizontal outlet nozzles. The pump is driven from an integral high speed squirrel cage induction motor. The pump characteristics are scaled to be representative of those of the Trojan PWR primary system pump.

The maximum pump operating conditions are 2390 kPa head and 4.43 ℓ/s flow at 2095 rad/s and 186.5 shaft kW. These conditions correspond to a specific speed of 1114; however, the impeller is designed for a specific speed of 1550 to create a flow path geometry similar to full-scale reactor pumps. The design point conditions are 780 kPa head and 3.4 ℓ/s flow. The head-flow and efficiency curves for the pump are shown in Figure 21.

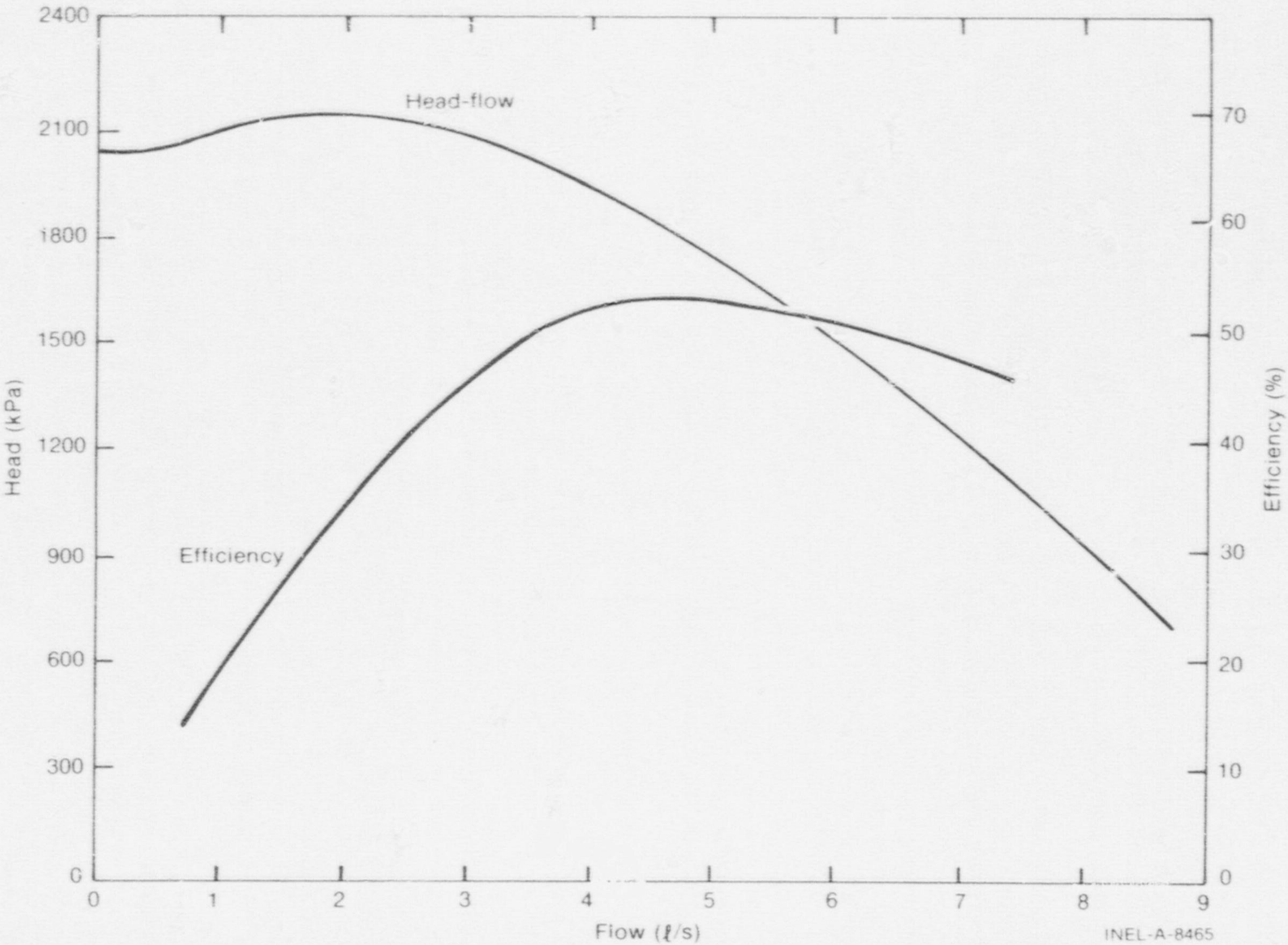

Fig. 21 Semiscale Mod-3 broken loop pump head-flow and efficiency curves.

The pump is designed to withstand an overspeed condition of up to 3665 rad/s without damage. A Data Track speed control system is provided to obtain blowdown transient overspeed characteristics which are typical of a large PWR pump. A mechanical disc brake is provided which is capable of decelerating the pump from 3665 rad/s to zero within two seconds.

All coolant wetted pump parts are constructed of corrosion resistant materials. The materials specified for major components are: Inconel 625 for the pump casing backplate, motor housing, and upper bearing housing; Type 316 stainless steel for the casing and discharge flange; Inconel 718 for the shaft; Inconel 600 for the impeller and stator; and Type 300 series stainless steel for the motor stator water jacket.

3.4 Break Simulator

The break simulator subassembly consists of the rupture disc assembly and break nozzle hardware. These hardware assemblies can be arranged to provide either a noncommunicative break configuration (in which coolant from both sides of the simulated break is forced out through two nozzles located on either side of the break) or a communicative break configuration (in which coolant escapes through a single nozzle and mixing of fluid on both sides of the simulated break is possible). The assemblies can be installed in the hot leg, cold leg, or pump suction locations by rearrangement of the piping hardware. The various break simulator configurations are shown in Figures 22 through 25.

The rupture disc assembly, as shown in Figure 26, consists of two 3-in. rupture discs (inside and outside) separated by an instrument washer which is bolted between either the break head forging and a 3-in., 1500-lb flange or between two 3-in., 1500-lb flanges. Each rupture disc is rated for $\simeq$ 9300 kPa so that the discs in series are required to withstand the system design and operating pressure. During normal operation and prior to rupture, the interdisc cavity is maintained at a pressure of approximately half of the system pressure such that at operating pressure the interdisc cavity is $\simeq$ 7600 kPa and the loop pressure is $\simeq$ 15 510 kPa. To initiate the simulated LOCA, the interdisc cavity pressure is instantaneously increased to $\simeq$ 15 500 kPa which exceeds the outer rupture disc pressure rating, and it is thus sheared. With the outside disc sheared the interdisc cavity pressure drops instantaneously, overpressuring the inner disc which is then sheared also, initiating the simulated LOCA condition.

The break head forging, rupture disc assembly, and suppression system piping have been sized to prevent communication of the system back pressure on the break flows. The noncommunicative break head assembly inlet nozzles are offset by about 18 degrees to provide the noncommunicative flow mixing characteristics for the break simulator. The communicative break mode assembly allows three different break nozzle positions as shown in Figures 23 through 25.

The break area is controlled by either slip-in (communicative break mode) or clamp-on (noncommunicative break mode) break nozzles. The break nozzles are convergent/divergent nozzles with the convergent nozzle inlet section modified to provide a

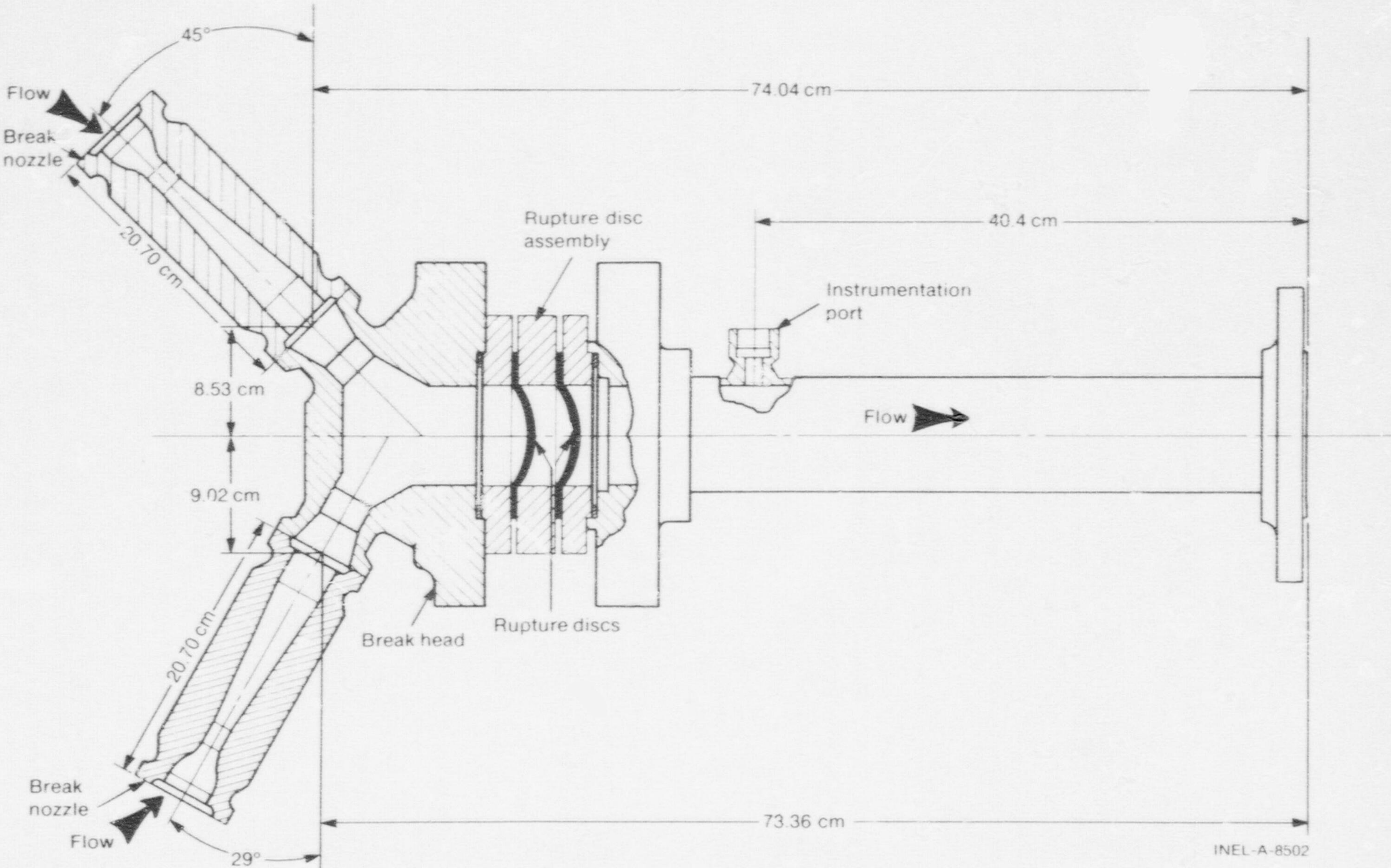

Fig. 22 Semiscale Mod-3 noncommunicative break simulator assembly.

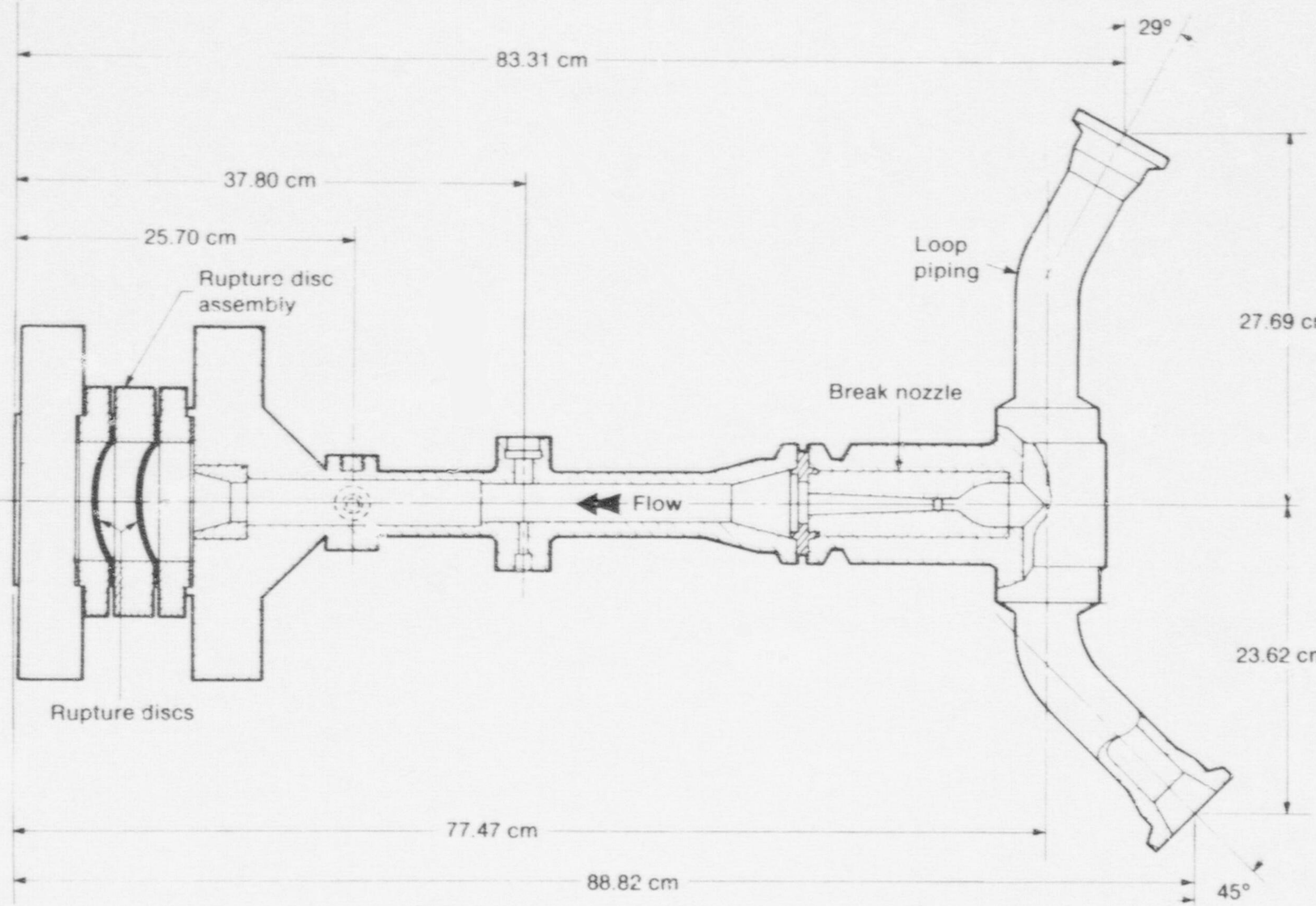

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Fig. 23 Semiscale Mod-3 communicative break simulator configuration with break nozzle near loop piping.

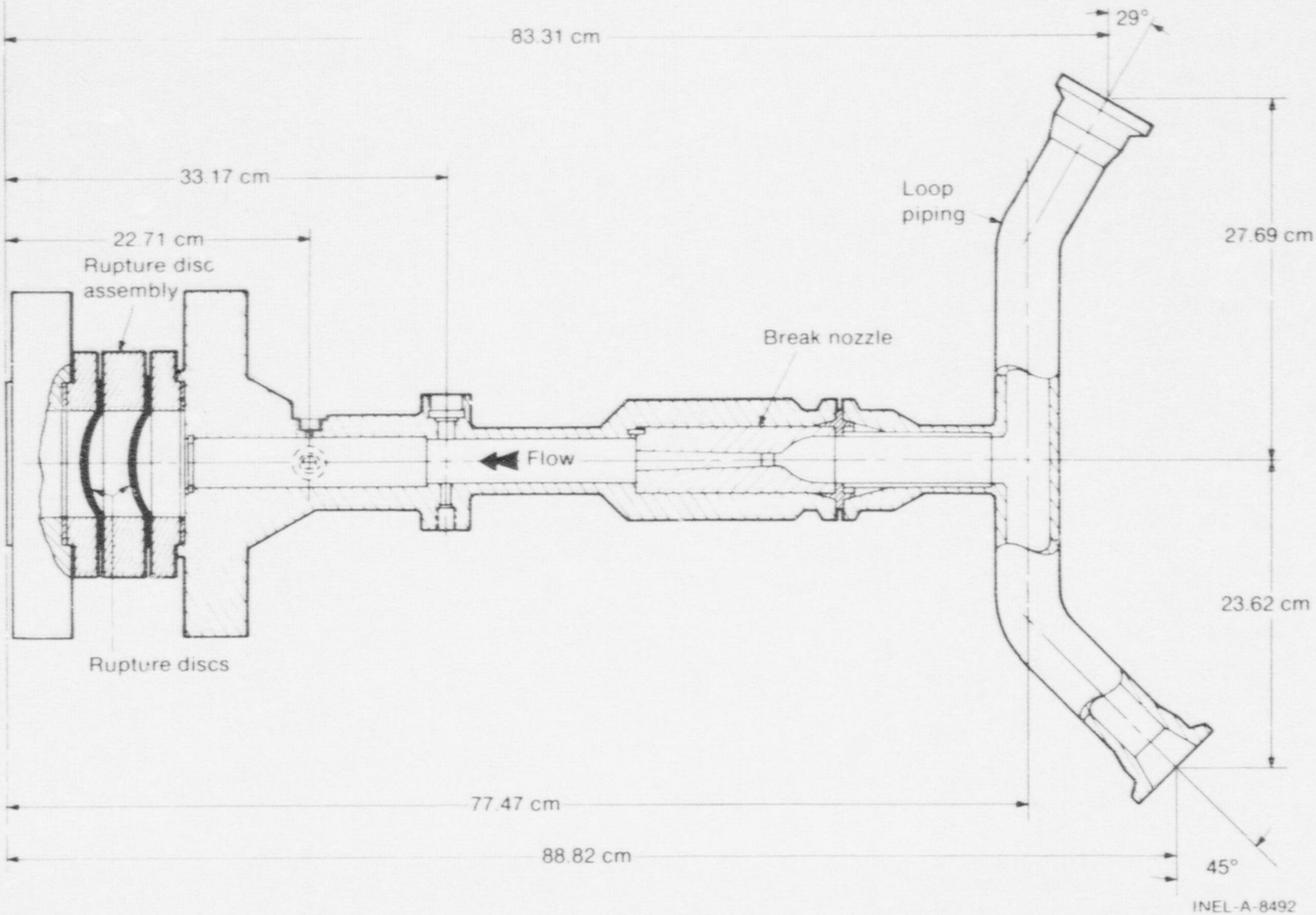


Fig. 24 Semiscale Mod-3 communicative break simulator configuration with break nozzle between loop piping and rupture assembly.

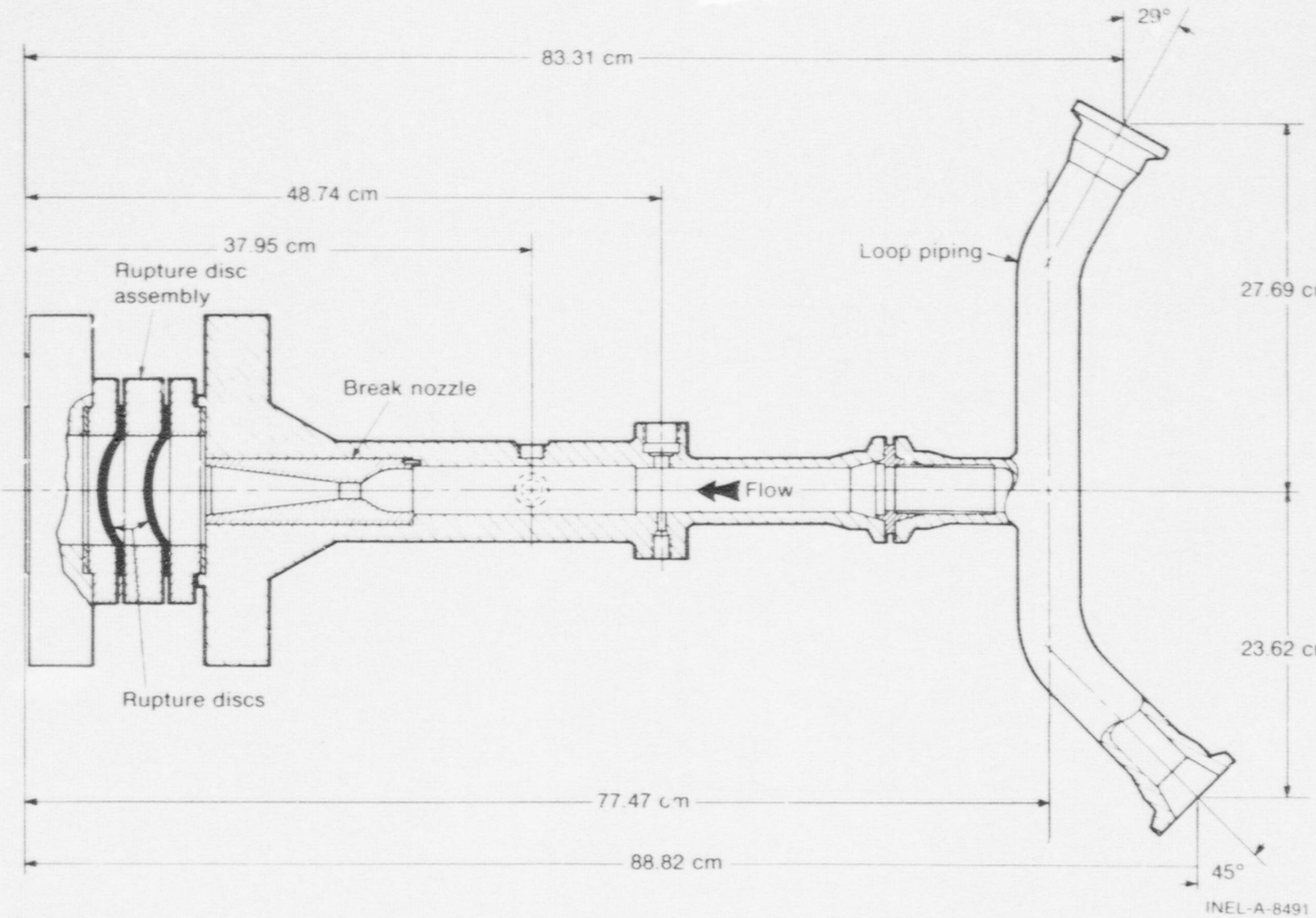


Fig. 25 Semiscale Mod-3 communicative break simulator configuration with break nozzle near rupture assembly.

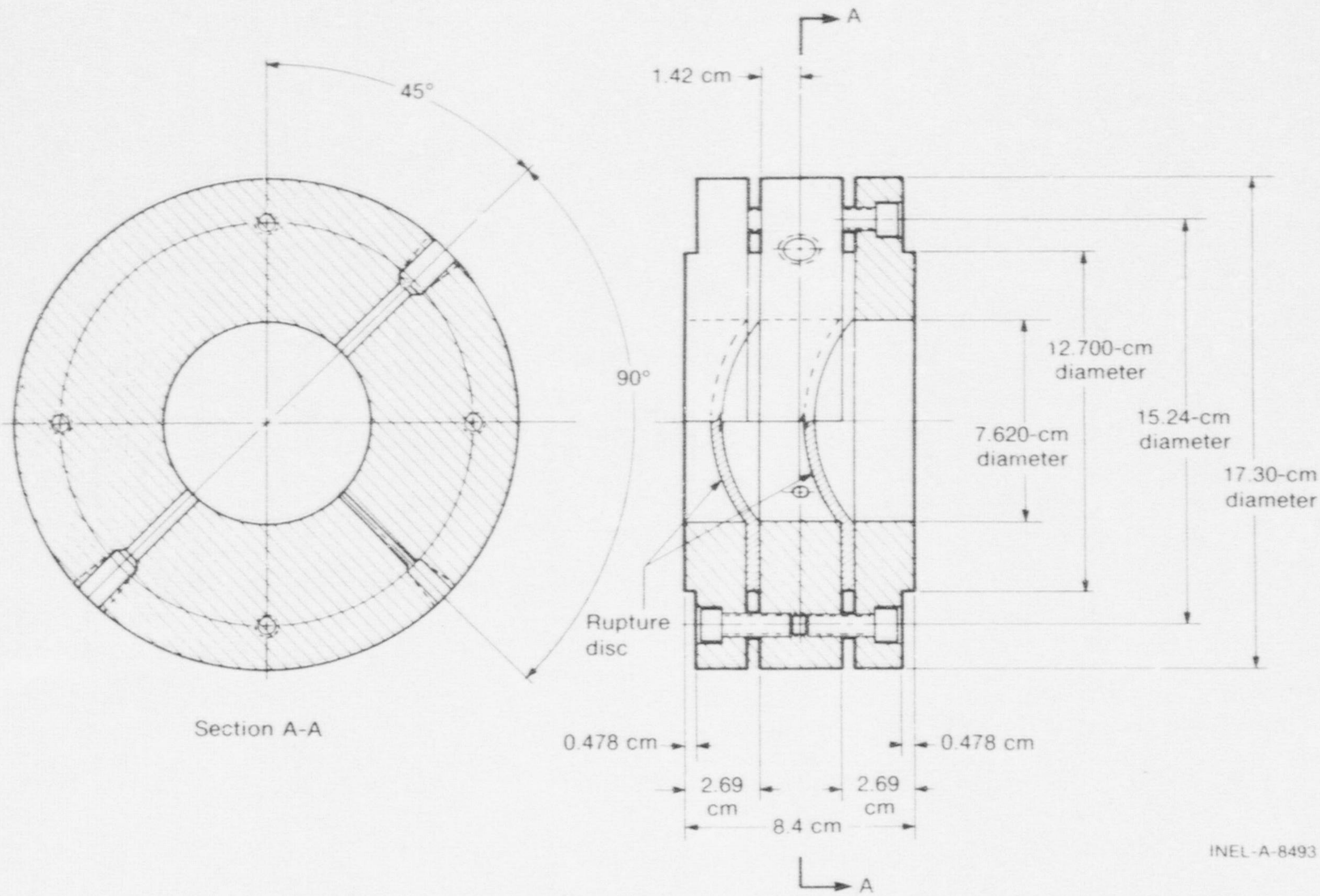


Fig. 26 Semiscale Mod-3 rupture disc assembly.

smooth transition entrance to the throat. The break area and nozzle configuration are determined by the specific test to be simulated and can be sized up to that representative of a 200% break which is 5.48 cm^2 for the Mod-3 test system.

The maximum break area is determined from the ratio of the maximum break area to the primary liquid volume of a PWR system applied to the primary liquid volume of the Semiscale Mod-3 system.

4. PRESSURE SUPPRESSION SYSTEM

The pressure suppression system consists of a pressure suppression vessel with an internal downcomer and the pressure suppression header. The cold or hot leg break and pump suction break configurations are depicted in Figures 27 and 28. The effluent is discharged from the broken loop (through a 3-in. Schedule 160 pipe) into a Schedule 40 header that simulates, in general, the drywell in a typical PWR pressure suppression system and, specifically, the LOFT 42-in. header. The effluent flows from the header into the vessel water pool through an 8-in. Schedule 40 downcomer. The pressure suppression vessel is oriented vertically to achieve the desired distances from the downcomer to the water surface and to the bottom of the vessel.

4.1 Pressure Suppression Vessel

The pressure suppression vessel is shown in section view in Figure 29. The total vessel volume is 2.55 m^3, and it is sized so that, when the vessel is 50% full of water, the downcomer pipe extends 0.762 m below the water surface. A flanged connection is provided for the downcomer pipe. An 18-in., 150-lb flange and matching blind flange located in the top of the vessel provides access to the vessel internals. The vessel is also provided with immersion heaters and a thermocouple rack which are installed in the lower half of the assembly to provide temperature control and measurement of the suppression pool. An external pump and piping system provide suppression coolant circulation.

4.2 Pressure Suppression Vessel Downcomer

The 21.91-cm OD downcomer pipe, shown in Figure 29, penetrates through the side of the pressure suppression vessel near the top and extends horizontally to the axial center of the vessel and then downward to a point 0.91 m from the bottom. Inside the pressure suppression vessel, the downcomer pipe has a bolted connection which allows replacement of the vertical portion of the downcomer.

4.3 Pressure Suppression Header

The pressure suppression header is designed so that no water traps exist. Accordingly, the downcomer pipe connection is on the bottom of the header. A pressure relief device,

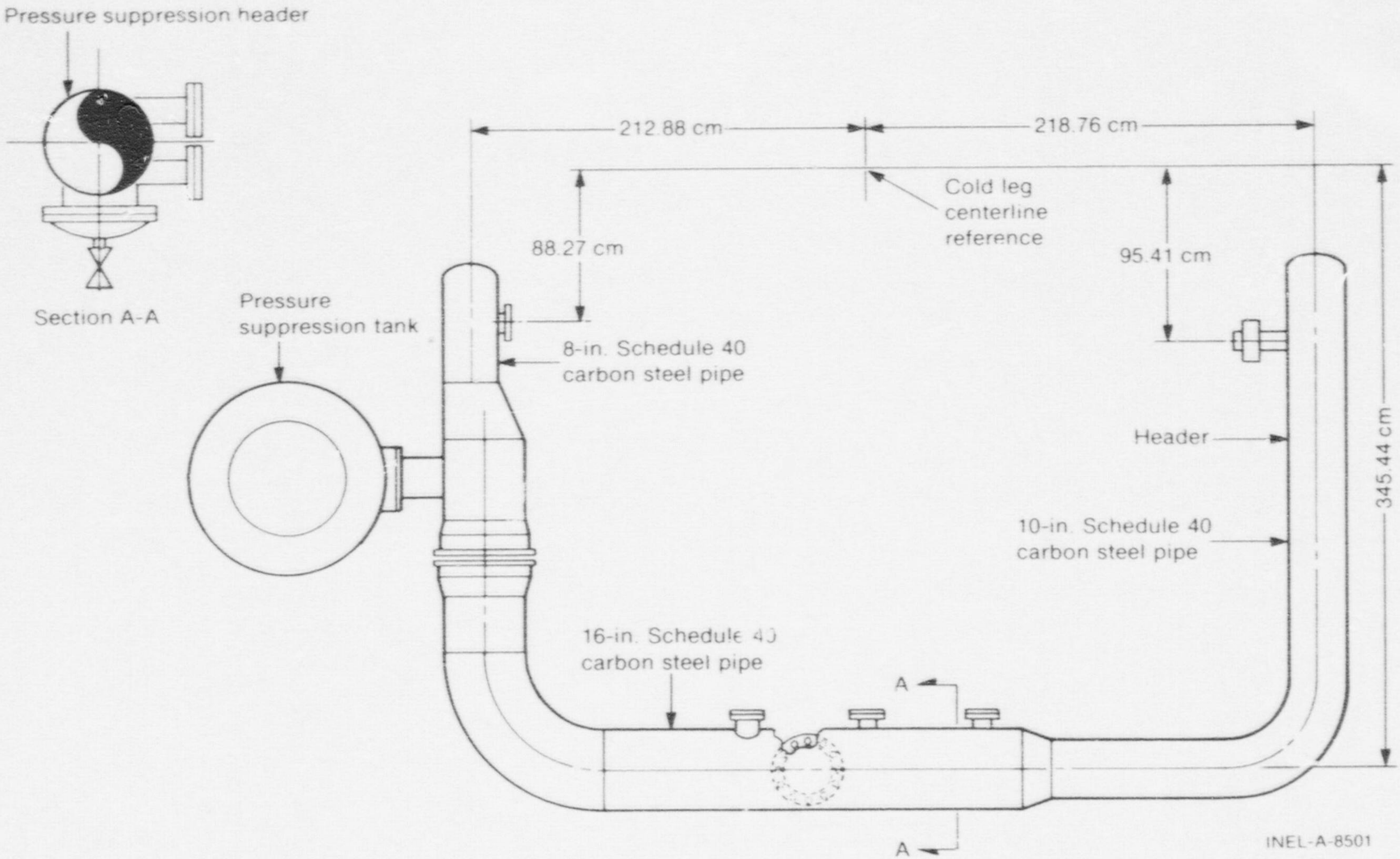


Fig. 27 Semiscale Mod-3 pressure suppression system – cold or hot leg break configuration, plan view.

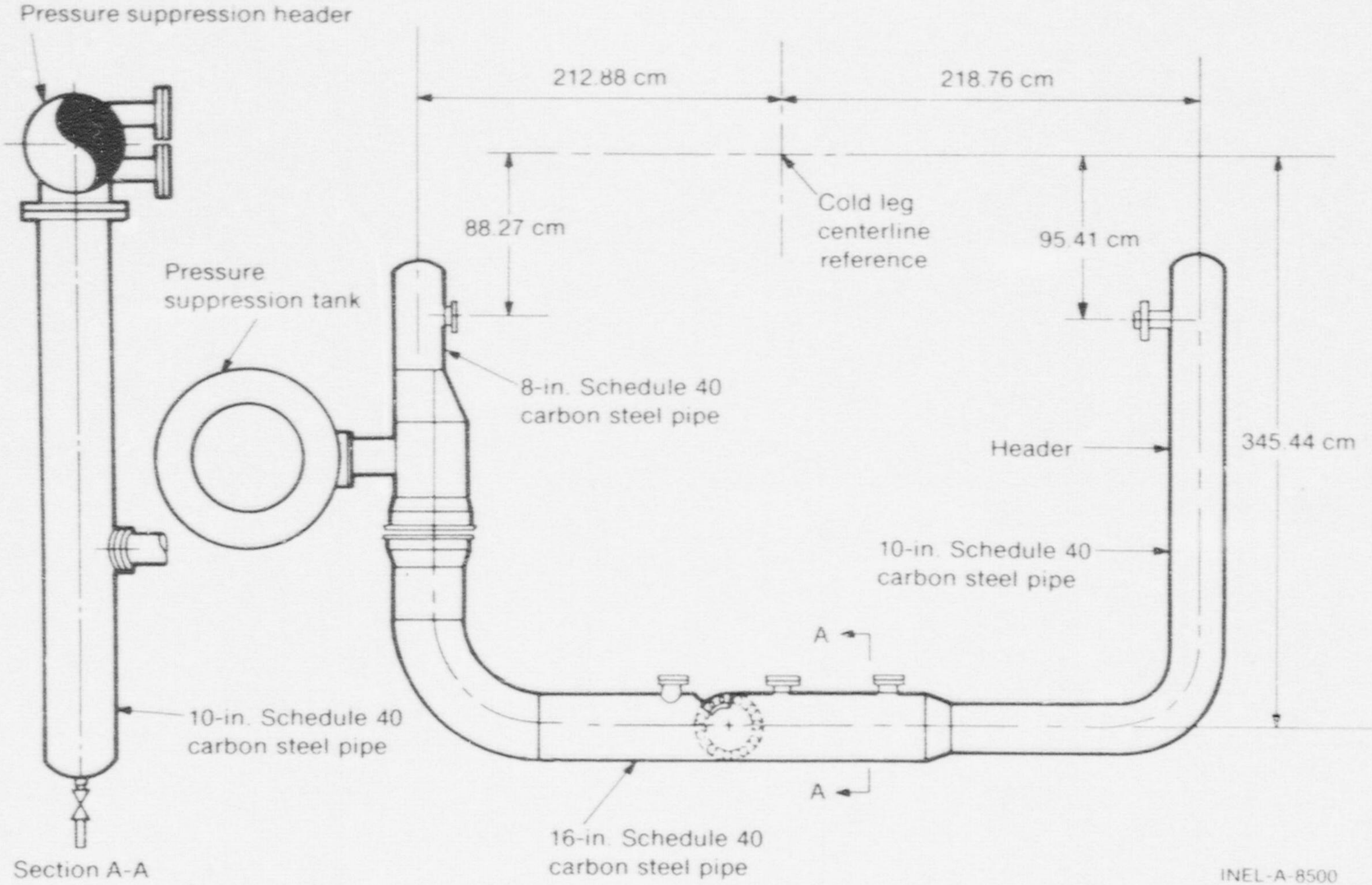


Fig. 28 Semiscale Mod-3 pressure suppression system – pump suction break configuration, plan view.

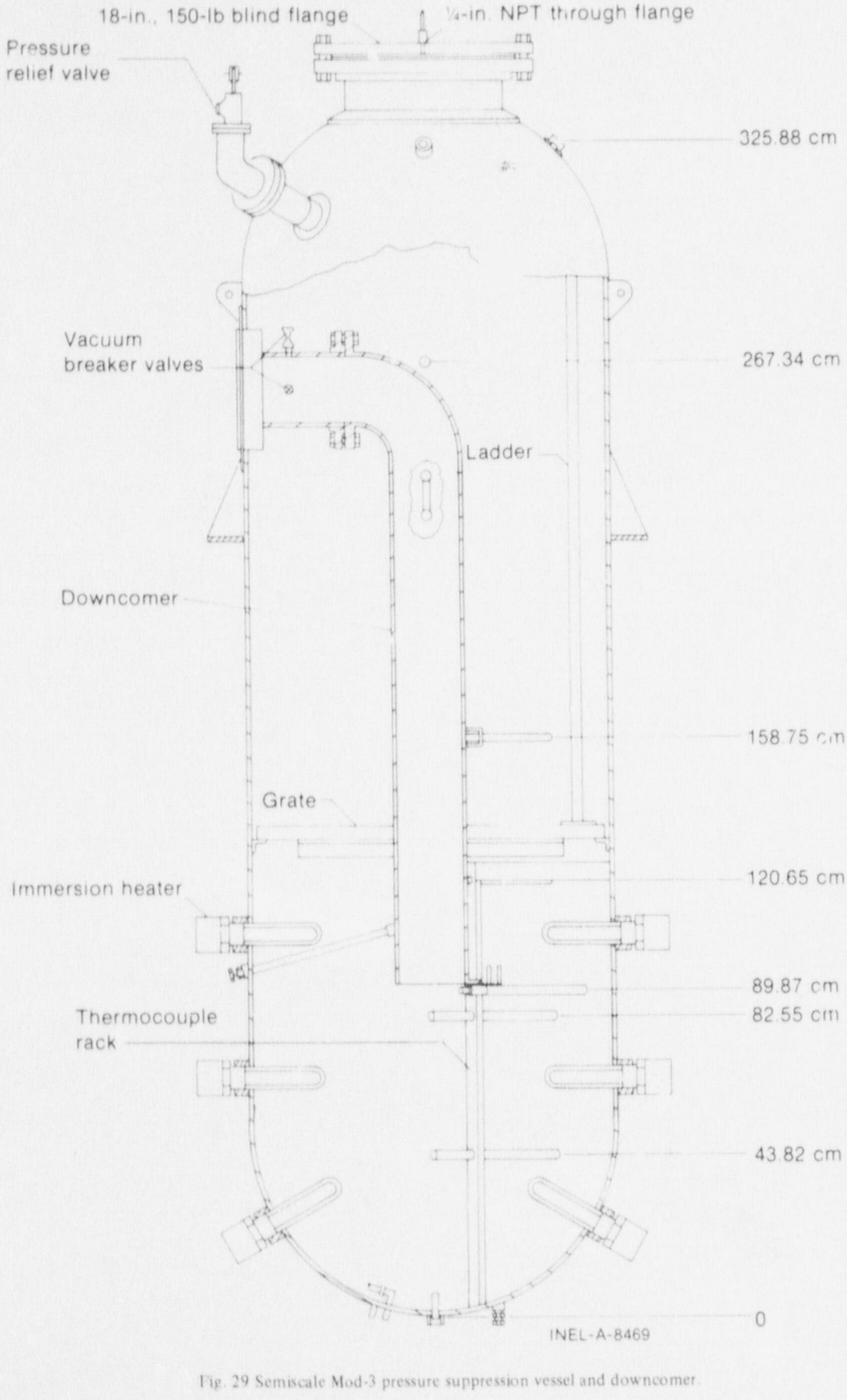


Fig. 29 Semiscale Mod-3 pressure suppression vessel and downcomer.

designed for a minimum capacity of 2.95 kg/s of saturated steam at a pressure of 1140 kPa is mounted on the header. The header piping can be arranged to accommodate any of the planned broken loop rupture location configurations.

5. PRESSURE SUPPRESSION STEAM SUPPLY SYSTEM

The pressure suppression steam supply is designed as an auxiliary system to the pressure suppression system. The steam supply system is designed to inject steam into the pressure suppression system for the purpose of maintaining the header pressure within ±13.8 kPa of a specified constant value between 138 and 552 kPa. The system is capable of supplying up to 0.23 kg/s of steam at 415 kPa and 0.14 kg/s at 138 kPa. The system is also used to maintain pressure suppression header pressure at a specified operating value during tests.

6. COOLANT INJECTION SYSTEM

The Semiscale Mod-3 coolant injection system is designed to be representative of the ECC system operation of a typical PWR system. The injection parameters used will reflect various conditions and configurations which might be present in the reference PWR system. The coolant injection systems for the intact and broken loops are each composed of three systems: the high pressure injection system (HPIS), the low pressure injection system (LPIS), and the accumulator injection system (AIS). An accumulator injection system is provided for ECC injection into vessel locations. Systems injecting coolant into the blowdown loop, intact loop, and vessel all function independently from one another. The piping design for these systems is shown in Figure 30.

6.1 Intact Loop Injection System

The intact loop injection system consists of an HPIS, LPIS, and AIS, with associated piping and valving. The intact loop HPIS can inject into the hot leg, cold leg, vessel upper head, vessel lower plenum, downcomer, or pump suction leg individually or in any combination. The system is piped to its respective loop injection points separate of the AIS and LPIS injection lines and injected into the loop through an injection point common with the AIS and LPIS lines. The HPIS water supply comes from a makeup system storage tank (Tank MU-T-2) and is available at temperatures from ambient to 355 K. Activation of the HPIS is based on primary coolant pump outlet pressure; actuation setpoint may be set in the range of 10 340 to 12 410 kPa. An alternate mode of injection actuation is based on actuating the pump after rupture. The intact loop HPIS pump is a positive displacement Cat Pumps Corporation pump, Model 624, having a rated flow rate of 0.196 ℓ/s at 20 680 kPa. The pump is provided with a 22.4-kW variable speed motor which is used to provide injection rates over the range of 0.003 to 0.095 ℓ/s. The motor employs a speed feedback control system such that the flow rate is stable with changing back pressure conditions.

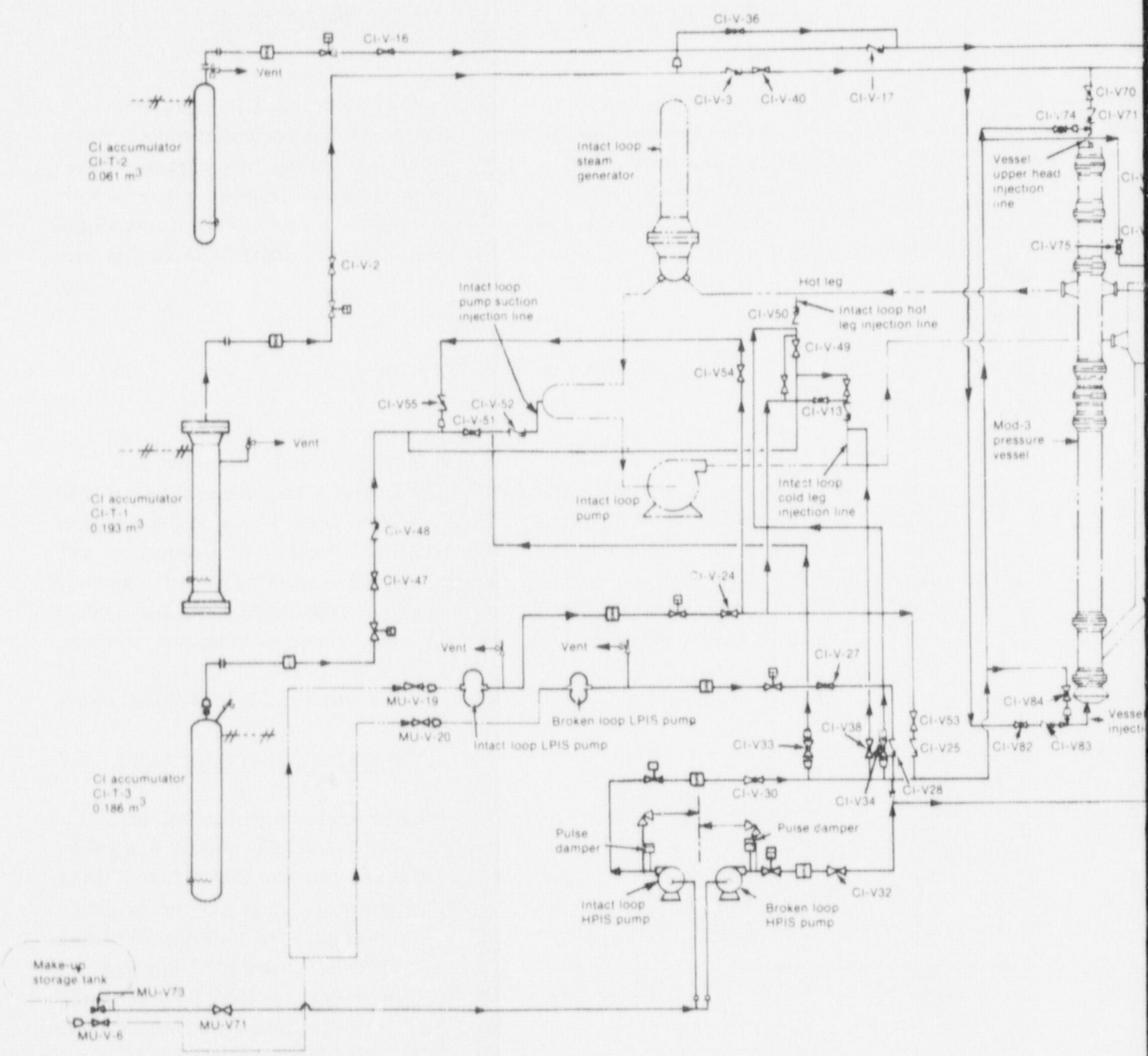
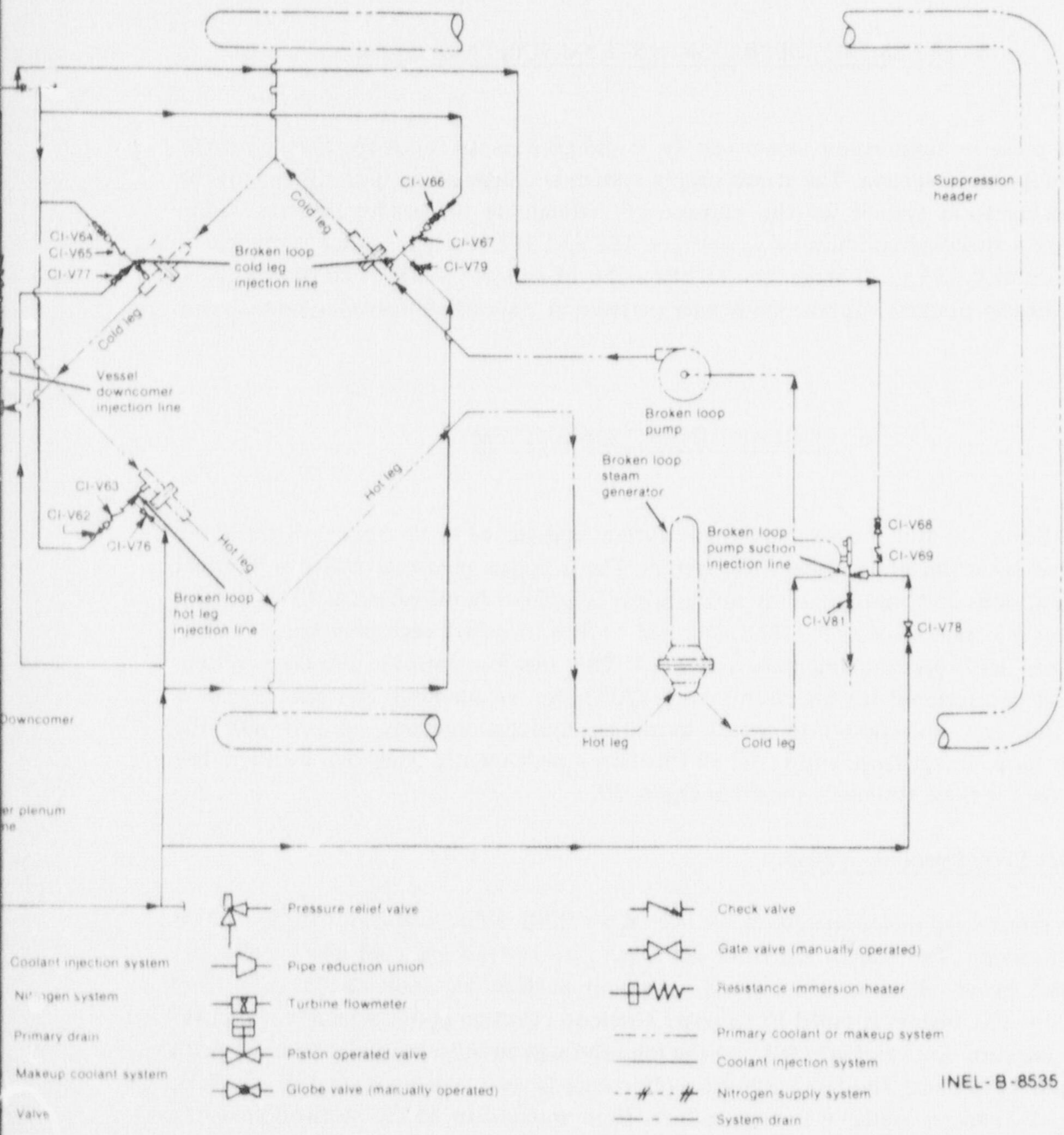


Fig. 30 Semiscale Mod-3 coolant injectio



stem – schematic.

The intact loop LPIS shares the same injection locations as the HPIS and can inject into any combination of injection points. Activation of the LPIS injection occurs at an intact loop system pressure of 689 kPa or at a predetermined time during a test. The temperature of the water supplied to the LPIS from the makeup system tank is adjustable from ambient to 355 K. An Oberdorfer Model 3000 gear pump serves as the intact loop LPIS pump, which at 180 rad/s has the capacity of 0.379 ℓ/s at an injection pressure of 689 kPa. The pump is powered by a 22.4-kW variable speed motor similar to the HPIS pump motor so that the injection rate can be adjusted to the desired value.

The intact loop AIS is composed of an accumulator tank, a remotely operated block valve at the accumulator, an isolation valve near the injection point, check valves, a manual adjustable valve for throttling flow, and piping for coolant injection. Injection locations are the intact loop cold leg, hot leg, or pump suction leg.

The accumulator is isolated from its respective injection point by a remotely operated isolation valve and check valves located in the line to prevent reverse flow. The accumulator is isolated from alternate injection locations (that is, locations other than the point desired) by a manual isolation valve located adjacent to the test system. Nitrogen gas overpressure in the accumulator provides the driving force for injecting the stored coolant at flood rates similar to those of a PWR system.

For the intact loop, broken loop, and pressure vessel accumulators the effective liquid volume capable of discharge and the gas-to-liquid volume ratios for each are controlled by various combinations of liquid level and lengths (changeable) of the respective discharge pipes extending from the top of the tank down through the nitrogen gas and into the liquid. The effective liquid volume is determined by the depth the pipe extends into liquid. Heaters are provided in each accumulator for coolant temperature control from ambient to 355 K.

The accumulator tank for the intact loop (Tank CI-T-3) is designed and fabricated of Type 316 stainless steel and has a volume of 0.186 m^3. It is a vertical vessel consisting of 12-in. Schedule XS pipe with a 12-in. butt-welded cap on each end. The top cap is modified with a small weld neck flange. The tank is 2.813 m long.

Fittings are provided on the accumulator tank for filling, draining, and sampling. Gas overpressure is supplied by the nitrogen system through a pressure regulator and shutoff valve. The tank is provided with a pressure relief valve set to open at 8270 kPa.

Each injection point has a check valve and manual gate located as close to the injection point as physically possible. Each of the injection systems (HPIS, AIS, and LPIS) has a check valve and remotely operated shutoff valve near the pump or accumulator discharge point.

6.2 Broken Loop Injection System

The broken loop injection system consists of an HPIS, LPIS, and AIS with associated piping, valving, and instrumentation.

The broken loop HPIS can inject into the hot leg, cold leg, pump suction, or any combination of these locations. In addition, the injection points for the hot and cold legs can be selected so that they are between the vessel and the break assembly or between the break and pump or steam generator assembly, respectively.

The HPIS is piped to its respective loop injection points separate of the AIS but in conjunction with the LPIS. Injection into the loop is through an injection point common with the AIS line. HPIS water is supplied from the makeup system storage tank and is available at temperatures from ambient to 355 K. Activation of the broken loop HPIS is based on primary coolant pump outlet pressure, and the activation setpoint may be set in the range of 10 340 to 12 410 kPa. An alternate mode of injection initiation is based on activating the pump discharge valve at a predetermined time after rupture. The broken loop HPIS pump is a positive displacement Cat Pumps Corporation pump, Model 624, having a rated flow rate at 0.038 ℓ/s at 20 680 kPa. The pump is provided with an 11.2-kW variable speed motor which is used to provide injection rates over the range of 0.009 to 0.032 ℓ/s. The motor employs a speed feedback control system such that the flow rate is stable with changing back pressure conditions.

The broken loop LPIS shares the same injection lines and locations as the HPIS and can inject into any combination of the injection points. Activation of LPIS injection occurs at an intact loop pump outlet pressure of 689 kPa or at a predetermined time during a test. The temperature of the water supplied to the LPIS from the makeup system storage tank is adjustable from ambient to 355 K. An Oberdorfer Model 1000 gear pump serves as the broken loop LPIS pump. The pump has the capacity of 0.189 ℓ/s at 689 kPa and 180 rad/s and is required to provide a range of from 0.0063 to 0.189 ℓ/s. The pump is powered by an 11.2-kW variable speed motor.

The broken loop AIS is composed of an accumulator tank, a remotely operated block valve at the accumulator, an isolation valve near the injection point, check valves, an adjustable manual valve for throttling flow, and piping for coolant injection. The injection locations are the same as for the broken loop LPIS.

The accumulator is isolated from its respective injection point by a r[illegible]ly operated isolation valve and check valves located in the line to prevent reverse flow. [illegible]e accumulator is isolated from alternative injection locations (that is, locations other than the point desired) by a manual isolation valve located adjacent to the test system. Nitrogen gas overpressure in the accumulator provides the driving force for injecting the stored coolant at flood rates similar to those of the reference system.

The broken loop accumulator tank (Tank CI-T-2) is constructed of 8-in. Schedule 80 carbon steel with 8-in. butt-welded pipe caps on each end. The tank is mounted vertically and is 2.02 m long. The tank has a volume capacity of 0.061 m^3.

Fittings are provided on the accumulator tank for filling, draining, and sampling. Gas overpressure is supplied by the nitrogen system through a pressure regulator and shutoff valve. The tank is provided with a pressure relief valve set to open at 8270 kPa.

6.3 Vessel Injection System

The vessel injection system is composed of an accumulator tank, a remotely operated block valve at the accumulator, an isolation valve near the injection point, check valves, an adjustable manual valve for throttling flow, and piping for coolant injection. The system can inject into the vessel upper head, lower plenum, or downcomer at an individual location or in any combination of locations.

The accumulator is isolated from its respective injection point by a remotely operated isolation valve and check valves located in the line to prevent reverse flow. The accumulator is isolated from alternative injection locations (that is, locations other than the point desired) by a manual isolation valve located adjacent to the test system. Nitrogen gas overpressure in the accumulator provides the driving force for injecting the stored coolant at predetermined flood rates.

The reactor simulator accumulator tank (Tank CI-T-1) is constructed from a section of 12-in. Schedule 80 stainless steel pipe with 12-in., 900-lb weld-neck flanges butt-welded to each end. The top and bottom of the tank are enclosed with 12-in., 900-lb blind flanges. The top closure flange has been modified to accomodate a 1-1/2-in. weld-neck flange on the tank discharge piping.

Fittings are provided on the accumulator tank for filling, draining, and sampling. Gas overpressure is supplied by the nitrogen system through a pressure regulator and shutoff valve. The tank is provided with a pressure relief valve set to open at 12 070 kPa.

V. INSTRUMENTATION AND CONTROL SYSTEMS

The Semiscale Mod-3 instrumentation system provides for the acquisition, processing, and presentation of test data. The instrumentation system is composed primarily of individual detectors, signal conditioning equipment, and display equipment. Figure 31 schematically displays the instrumentation, data acquisition, and processing system. Individual detectors at selected locations in the test system provide data in the form of electrical signals. The data signals are then subjected to a signal conditioning procedure in which they are processed through low level voltage amplifiers and, when necessary, through additional signal conditioning electronics.

After the signal conditioning process is performed, the data are recorded on tape in analog form or digitized and recorded on tape in digital form. The digital data thus obtained are then presented in tabular or graphic form.

The Semiscale Mod-3 system employs feedback control systems in the electrically heated core and steam generators.

The core power control system (Section V-3.1) employs a computer which matches the heat flux profile within the core to a desired profile whose characteristics are stored in the computer memory.

The steam generator control systems (Section V-3.2) utilize operational amplifiers which use the input and output mass flow rates in the steam generator secondary side as a heat transfer control basis.

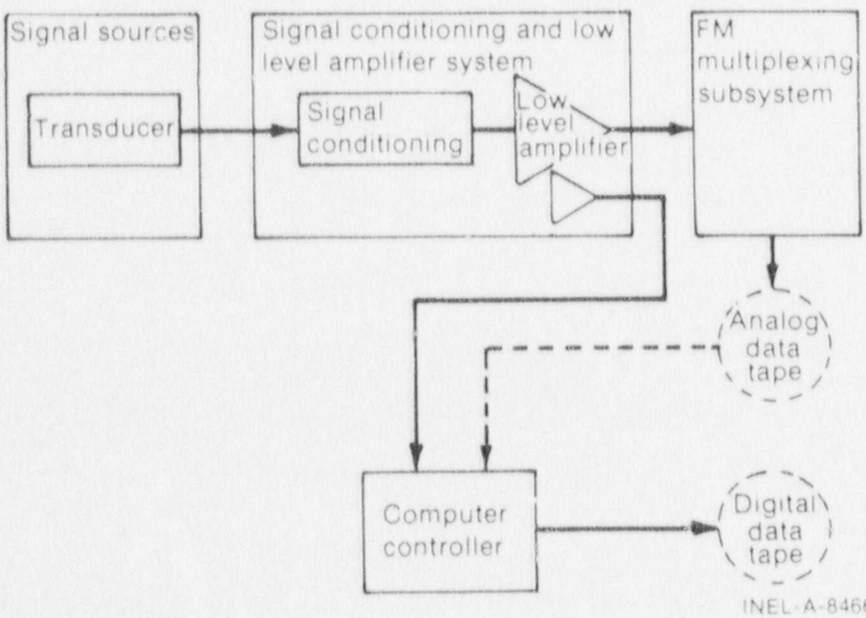


Fig. 31 Semiscale Mod-3 instrumentation, data acquisition, and processing system – schematic.

1. INSTRUMENTATION USED TO OBTAIN TEST DATA

Detectors located in the Semiscale Mod-3 system measure the test variables. Detectors are provided for measuring: fluid and material temperatures and pressure; volumetric flow rate; momentum flux; density; liquid level; pump torque, power, and speed; and core current, voltage, and power. The nomenclature used to designate specific detectors consists of a ten-digit (maximum) alphanumeric group with two or three subgroups. The first group indicates the type of detector and the general location in the system. The remaining subgroups specify the location of the detector from a reference point in the system. For example, TFI-17 designates a thermocouple measuring fluid temperature in the intact loop at spool piece 17. The alphabetic symbols used for various detectors and measurements are shown in Table IV. The reference locations for the system, with some of the symbols in parentheses, are:

Intact loop (I)	Specific locations are referenced by spool piece numbers.
Broken loop (B)	Specific locations are referenced by spool piece numbers.
Core (C)	References locations in the core region of the Mod-3 vessel.
Downcomer (D)	References detectors located in the downcomer region of the Mod-3 vessel. The symbols DIA designate the downcomer inlet annulus.
Vessel (V)	References detectors located in the Mod-3 vessel in regions other than the core or downcomer regions.
Steam Generators (SG)	Divide hot and cold legs. References detectors located in steam generators other than the steam generator steam dome, tube, or secondary side which are designated as SDS, SGT, or SS, respectively.
Vessel cold leg centerline	References vertical vessel locations. Arabic numerals indicate distances from the cold leg centerline. Angular vessel locations are in degrees clockwise from the intact loop cold leg centerline as viewed from the top of the vessel. Letter designations of angular locations are given in Table V.

TABLE IV

SEMISCALE MOD-3 MEASUREMENT SYMBOLS

Measurement	Symbol
Thermocouple temperature	T
Resistance bulb temperature	R
Heater rod cladding thermocouple temperature	TH
Electric current	A
Electric pressure	V
Electric power	W
Pump speed	S
Pump torque	Q
Differential pressure	D
Pressure (static)	P
Density	G
Momentum flux	M (drag disc) N (drag screen)
Volumetric flowrate	F
Liquid level	L

TABLE V

SEMISCALE MOD-3 VESSEL ANGULAR DISPLACEMENT NOMENCLATURE

A = 0°	I = 120°	R = 240°
B = 15°	J = 135°	S = 255°
C = 30°	K = 150°	T = 270°
D = 45°	L = 165°	U = 285°
E = 60°	M = 180°	V = 300°
F = 75°	N = 195°	W = 315°
G = 90°	P = 210°	X = 330°
H = 105°	Q = 225°	Y = 345°

Vessel centerline	References detector locations in the hot legs of the intact and broken loops. Arabic numerals indicate distances from the vessel centerline along the centerline of the hot leg.
Downcomer centerline	References detector locations in the cold legs of the intact and broken loops. Arabic numerals indicate distances from the downcomer centerline along the centerline of the cold leg.
Core heater rods	Reference core fluid and material thermocouple locations. As indicated in Figure 32, any rod in the core can be described by two coordinates in terms of the columns (alphabetic symbols) and rows (arabic numerals).
Bottom of the heated length of the core heater rods	References material thermocouple locations. Arabic numerals represent distances above the bottom of the heated length of the core heater rods.
Core grid spacers (G)	Reference fluid thermocouple locations. Arabic numerals identify the grid spacers on which the thermocouples are located. The grid spacers are numbered consecutively from 1 through 10, with 10 at the top.

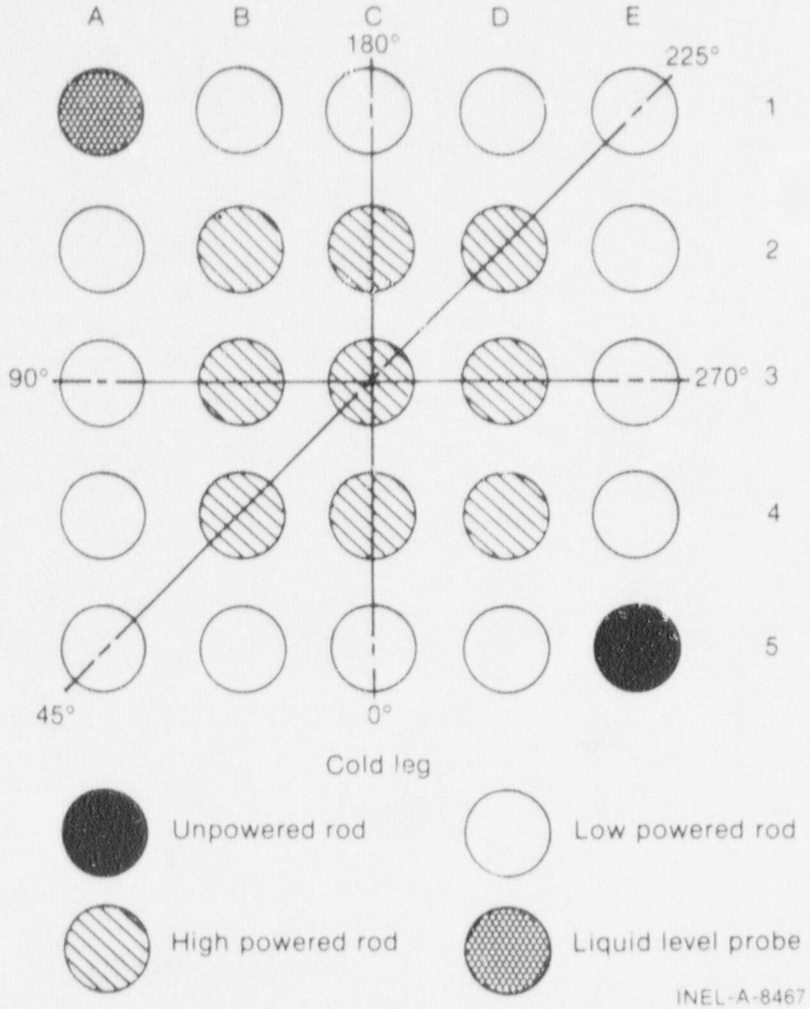


Fig. 32 Semiscale Mod-3 core heater rod configuration – top view.

Piping Spool ID	References material thermocouple locations. Arabic numerals represent distances from the piping spool inside diameter. For example, 16 = 0.16 cm, 64 = 0.64 cm.
Bottom of steam generator tube sheet	References locations in the steam generator. Arabic numerals represent distances from the bottom of the tube sheet.

Additional alphabetic symbols which are used to designate detector types and locations in the Mod-3 system are listed in Table VI. In the case of the differential pressure measurements, each detector has high and low pressure tap locations associated with it. The two locations are designated similarly to other instrument locations. However, the order in which the locations are given designates the polarity of the data; the first location indicated is the positive reference. For heater rod cladding thermocouples the three-digit number following the coordinate location refers to the elevation above the bottom of the heated length, that is, TH-A5-198 means heater rod thermocouple at location A5, 198 cm above

TABLE VI

SEMISCALE MOD-3 ADDITIONAL MEASUREMENT SYSTEM SYMBOLS

Temperature	
F-	Fluid temperature
M-	Metal temperature
H-	Heater rod surface temperature
IF-	Insulation gap fluid temperature
IM-	Insulator metal temperature
GF-	Guide tube fluid temperature
GM-	Guide tube metal temperature
SF-	Support tube fluid temperature
SM-	Support tube metal temperature
CM-	Core support plate metal temperature
Momentum Flux	
G-	Guide tube momentum flux
S-	Support tube momentum flux
Density	
B-	Beam through main body
T-	Beam near tangential position to body
HR-	Single-beam shot horizontal
VR-	Single-beam shot vertical
C-	Indicates a composite of T and B density shots
Material Temperature	
B-	Bottom
T-	Top

TABLE VI (continued)

Coolant Injection System	
ACC1 ≡	ECC Accumulator CI-T-1
ACC2 ≡	ECC Accumulator CI-T-2
ACC3 ≡	ECC Accumulator CI-T-3
ACC1-LL ≡	Liquid level measurement in Accumulator CI-T-1
ACC2-LL ≡	Liquid level measurement in Accumulator CI-T-2
ACC3-LL ≡	Liquid level measurement in Accumulator CI-T-3

the bottom of the heated length. Core fluid thermocouples, which are located on the ten grid spacers, use nomenclature which identifies the four adjacent rod positions by using pairs of alphabetic symbols and arabic numerals.

The instrumented spool pieces used in the intact loop, broken loop, and downcomer employ several detectors including thermocouples, resistance bulb temperature devices, pressure probes, momentum flux drag screens or drag discs, turbine flowmeters, and gamma beam densitometers. The intact loop and downcomer utilize 3-in. instrumented spool pieces. Some of these detectors utilize water cooled transducers or pickups. Figures 33 and 34 show typical installations for detectors in intact and broken loop instrumented spool pieces, respectively.

Table VII indicates types of measurement capability, the manufacturer of the detector, the type of measurement device, the general range of the detector, and the total expected uncertainty in the reported data assuming transducer output signals result from homogeneous flow conditions.

The total expected uncertainty is obtained by applying the root-sum-square summation technique to all individual uncertainties occurring in the instrument, acquisition, and processing systems. All individual uncertainties are considered to be independent, to be normally distributed, and to represent 95% confidence limits.

Physical conditions which occur during pretest warmup and during the blowdown test overrange some detectors in the system. Detectors in the system are capable of withstanding the overrange conditions without any change in operation or measuring characteristics when the physical conditions are again within the detector range.

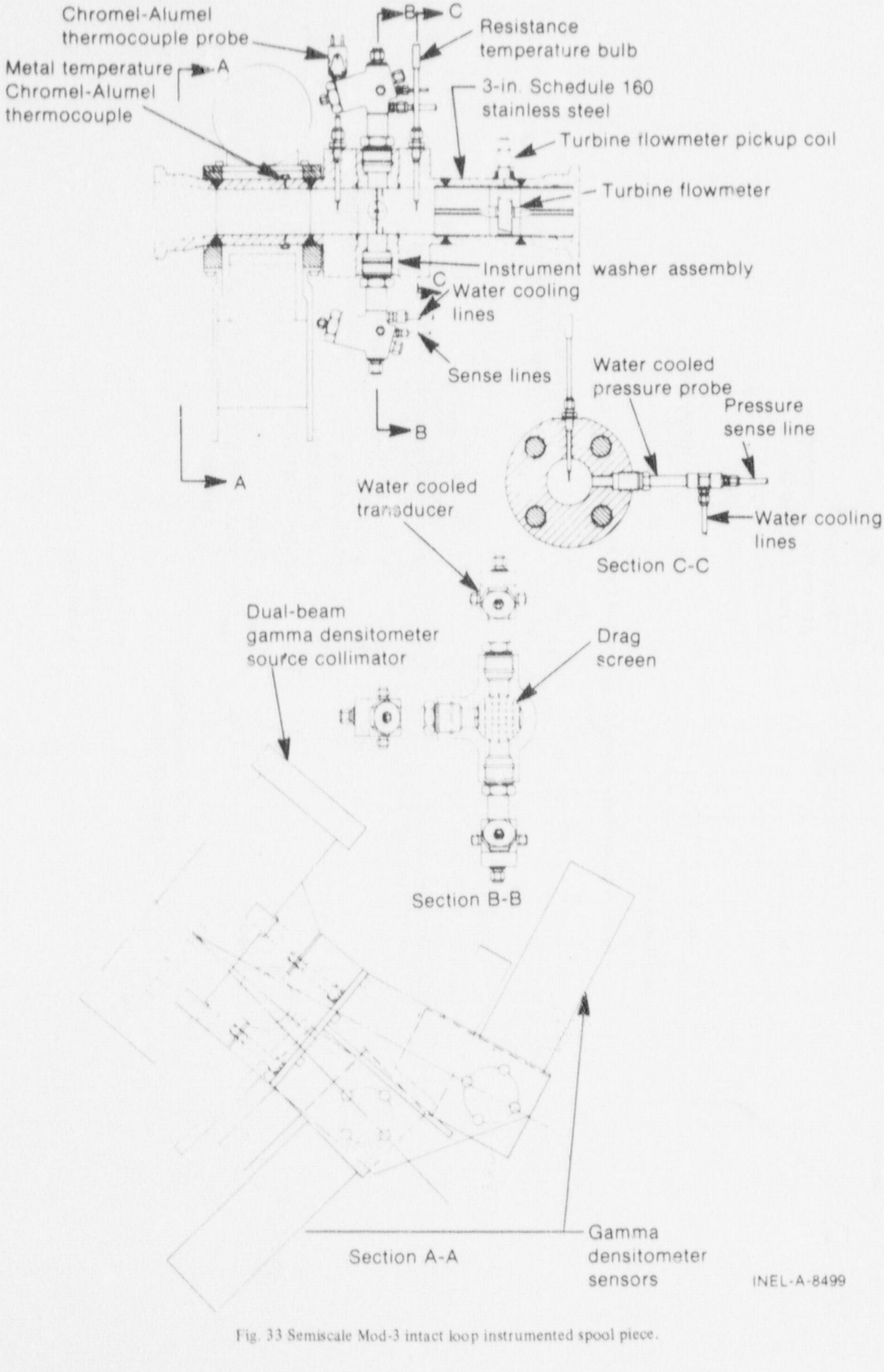
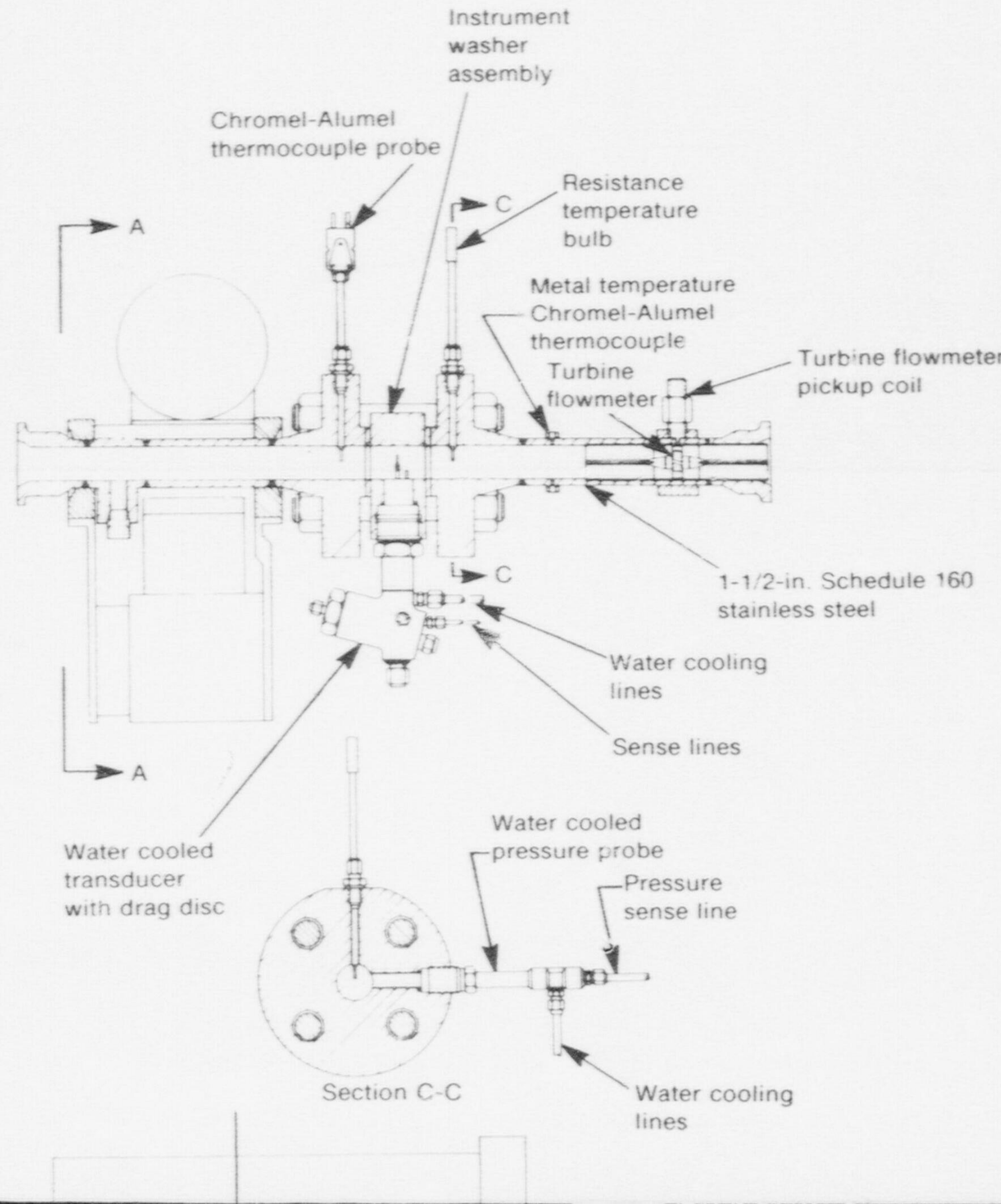


Fig. 33 Semiscale Mod-3 intact loop instrumented spool piece.



Instrument
washer
assembly
Chromel-Alumel
thermocouple probe
C
Resistance
temperature
bulb
A
Metal temperature
Chromel-Alumel
thermocouple
Turbine
flowmeter
Turbine flowmeter
pickup coil
C
1-1/2-in. Schedule 160
stainless steel
Water cooling
lines
Sense lines
A
Water cooled
transducer
with drag disc
Water cooled
pressure probe
Pressure
sense line
Section C-C
Water cooling
lines

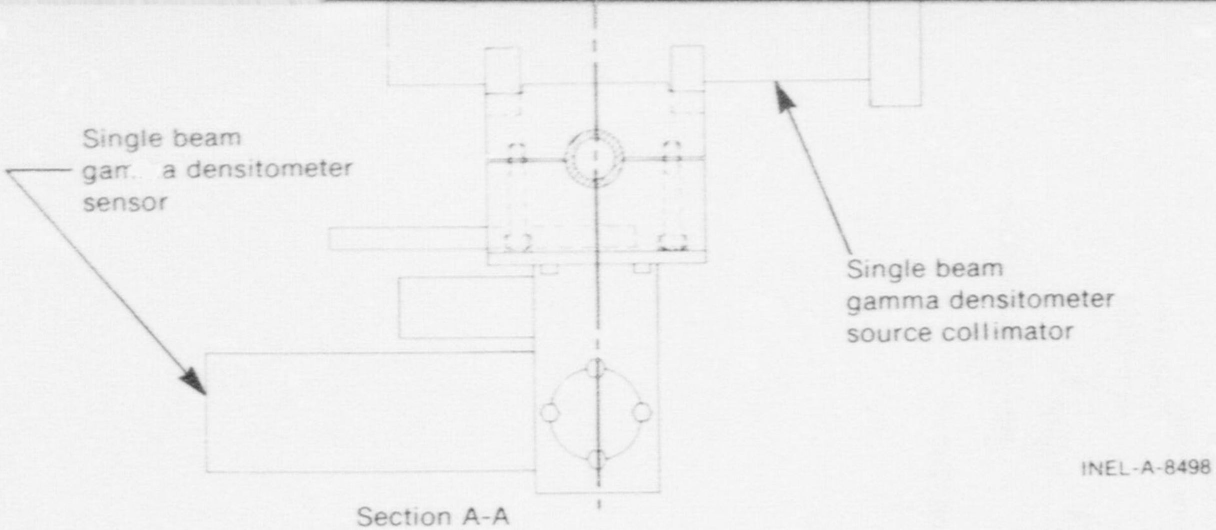


Fig. 34 Semiscale Mod-3 broken loop instrumented spool piece.

TABLE VII

DETECTOR CHARACTERISTICS AND MEASUREMENT SYSTEM TOTAL EXPECTED UNCERTAINTY

Measurement	Manufacturer	Type	Detector Range	Measurement System Total Expected Uncertainty[a]
Fluid temperature	ARI Industries and EG&G Idaho, Inc.	Type K thermocouple exposed junction	255 to 1533 K	±1.7 K at 550 K increasing to ±2.9 K at 1250 K
	Rosemount Engineering, Inc.	Platinum resistance detector	255 to 811 K	±0.28 K
Material temperature	EG&G Idaho, Inc.	Type K thermocouple grounded, spaded junction	255 to 1533 K	±3.3 K to 550 K increasing to ±4.0 K at 1250 K
Fluid pressure	Precise Sensors, Inc.	Flush diaphragm-bonded strain gauge	100 to 690 kPa	±0.44% full scale[b]
			100 to 5170 kPa	±0.44% full scale[b]
			100 to 20 680 kPa	±0.44% full scale[b]
	Bell & Howell Corp., CEC Division	Sputtered strain gauge	100 to 6890 kPa 100 to 17 240 kPa	Not available
Differential pressure	BLH Electronics, Inc.	Diaphragm-bonded strain gauge	±4.96 to ±10 340 kPa	±1.1% to ±2.0% full scale[b]
Volumetric flow rate	Flow Technology, Inc.	Turbine	Up to 6.31 ℓ/s	±0.1 ℓ/s
			12.6 ℓ/s	±0.4 ℓ/s
			25.2 ℓ/s	±0.6 ℓ/s

TABLE VII (continued)

Measurement	Manufacturer	Type	Detector Range	Measurement System Total Expected Uncertainty[a]
Fluid velocity	Flow Technology, Inc.	Turbine	0 to 5.5 m/s	$\pm$5% full scale[b]
			0 to 11.0 m/s	$\pm$5% full scale[b]
			0 to 15.2 m/s	$\pm$5% full scale[b]
Momentum flux	Ramapo Instrument Company, Inc.	Strain-gauged contilever beam with target	Up to 1.95×10^5 $kg/m{\cdot}s^2$	$\pm$300 to $\pm$1490 $kg/m{\cdot}s^2$
	EG&G Idaho, Inc.	Variable reluctance transformer	Up to 2.2×10^5 $kg/m{\cdot}s^2$	$\pm$180 to $\pm$2200[c] kg/ms^2
Fluid density	Technical Operations, Inc., and Measurements, Inc.	Gamma attenuation	0.16 to 1600 kg/m^3	$\pm$16.02 kg/m^3
Intact loop pump torque	Lebow Associates, Inc.	Strain gauged torque cell	$\pm$56.49 N·m	$\pm$0.05 N·m
Intact loop pump speed	Lebow Associates, Inc.	60-tooth gear and magnetic coil pickup	0 to 377 rad/s	$\pm$3.8 rad/s above 10.5 rad/s
Broken loop pump speed	EG&G Idaho, Inc.	Notched brake disc and magnetic coil pickup	0 to 3665 rad/s	$\pm$37 rad/s

TABLE VII (continued)

Measurement	Manufacturer	Type	Detector Range	Measurement System Total Expected Uncertainty[a]
Liquid level	EG&G Idaho, Inc.	Conductivity Probe	Up to 3.91 m	±4.2 to ±12.2 cm[d]
Core current	EG&G Idaho, Inc.	Shunt circuit	0 to 10	±1% of full scale
Core voltage		Digital voltmeter	0 to 400	±1% of full scale

[a] The total expected uncertainty is obtained by using the root-sum-square summation technique applied to all the individual uncertainties occurring in the instrument, acquisition, and processing systems. All uncertainty components are considered to be independent, normally distributed, and to represent 2σ confidence limits.

[b] Full scale refers to detector full-scale range.

[c] Expected uncertainty is specified for only an all-water condition.

[d] Expected uncertainty is specified for increasing/decreasing water conditions.

1.1 Fluid Temperature Measurements

Fluid temperature measurements are made using thermocouples and variable resistance devices. Zero offsets and nonlinearities occurring during acquisition are corrected during data processing. The total expected uncertainty for thermocouples is ±1.7 K at 550 K increasing to ±2.9 K at 1250 K. Total expected uncertainty for variable resistance devices is ±0.28 K.

1.2 Material Temperature Measurements

Material temperature measurements are made using thermocouples. Zero offsets and nonlinearities occurring during data acquisistion are corrected during data processing. The total expected uncertainty is ±3.3 K for thermocouple at temperatures up to 550 K, then increases to ±4.0 K at 1250 K.

1.3 Pressure Measurements

Pressure measurements are obtained with calibrated pressure transducers. Some of the transducers are flush mounted and some are mounted in water-cooled standoffs. Pressure data corrections are made for discrepancies noted between pressure measurements made with the Precise Sensor and CEC transducers and pressure measurements made with a precision pressure gauge at steady state system conditions. The total expected uncertainty is ±0.44% of transducer full scale for the Precise Sensor detectors.

1.4 Differential Pressure Measurements

The differential pressure measurements are made with calibrated differential pressure transducers. Transducer pressure sensitivity is corrected for by recording transducer voltage output as a function of pressure during pretest hydrostatic operation and then applying the resulting correction curve to the recorded test data through use of a computer program. Total expected uncertainties vary from approximately ±0.8 to ±1.8% of transducer full scale. The average total expected uncertainty used for all differential pressure transducers used in the system is ±2.0% of transducer full scale.

1.5 Volumetric Flow Rate Measurements

Volumetric flow rate measurements are made with turbine flowmeters through which all fluid within a given flow channel passes. The digital signal from the flowmeter is concerted directly to volumetric flow rate through use of calibration data obtained from the manufacturer and verified by EG&G Idaho. The total expected uncertainties, which vary with transducer range, are given in Table VII.

1.6 Momentum Flux Measurements

Momentum flux measurements are made with drag screen or drag disc devices. Drag discs used are of two basic types: (a) strain-gauged cantilever beams with enlarged target

areas on one end protruding into a flowing fluid, and (b) balance beam targets with ranging springs and linear variable reluctance coil sensing elements. Drag screens incorporate target screens across the flow path and utilize the transducer with balance beam, ranging spring, and variable reluctance coil sensors. The analog output is proportional to fluid density times fluid velocity squared (ρv^2). On the basis of the initial fluid density and the calibration curve, the initial voltages from the instruments are assigned values commensurate with initial pretest steady state flow conditions. In order to compensate for the thermal sensitivity of strain-gauged detectors, the voltage output of these devices as a function of temperature is recorded during pretest warmup at zero-flow conditions. The resulting correction curve, plus the hysteresis conditions and the instrument calibration curve, is applied to the recorded test data through use of a computer data conversion program. The total expected uncertainty using strain-gauged devices varies from about ±300 to ±1490 kg/m·s^2 depending upon the transducer range. Total uncertainty from the variable reluctance devices will vary from ±180 to ±2200 kg/m·s^2.

1.7 Density Measurements

Fluid density data are obtained by a gamma-attenuation technique that provides a measurement of the average fluid density across the section being monitored. A gamma source is placed on one side of the section, and a gamma detector is placed on the opposite side. The gamma beam is collimated and passed through the pressure boundary and fluid to a photoscintillation detector. The output signal from the scintillation detector is amplified, recorded as voltage, and processed using a computer data conversion program based on a derived calibration factor and on the calculated initial fluid density. The total expected uncertainty is approximately ±16.02 kg/m^3. Other density measurements are obtained using a dual-beam gamma densitometer which operates on the same principle of gamma attenuation as does the single-beam gamma densitometer. Each beam originates from the same gamma source and is allowed to pass through separate portions of the piping cross-sectional flow area to obtain an average density measurement in that particular region.

1.8 Liquid Level Measurements

Liquid levels are determined through the use of differential pressure cells and capacitance type liquid level probes. The liquid level probes are used primarily in vessel and core measurement locations. Total expected uncertainty from differential pressure cells ranges between ±0.8 and ±1.8% of the detector full-scale range. Total expected uncertainty for liquid level probes ranges between ±4.2 and ±12.2 cm depending upon detector full-scale range.

1.9 Mass Flow Rate Measurements

Mass flow rate is not measured directly but is computed from density and either of the directly measured quantities: volumetric flow rate or momentum flux. The mass flow rates with the system during the blowdown transient are calculated with a digital computer from either

$$m = [\rho(\rho v^2)A^2]^{1/2}$$

for density and momentum flux measurements, or

$$m = \rho v A$$

for density and volumetric flow rate measurements

where

m	=	fluid flow rate (kg/s)
ρ	=	measured density (kg/m^3)
v^2	=	measured momentum flux ($kg/m \cdot s^2$)
v	=	velocity (m/s)
A	=	cross-sectional flow area (m^2).

1.10 Pump Characteristic Measurements

The torque transmission to the impeller of the intact loop pump is measured by use of a torque cell attached directly to the pump shaft. The total expected uncertainty is ± 0.05 N · m.

Intact loop pump speed data are obtained by the use of a gear and sensor pickup coupled with electrical frequency processing. The sensor produces a voltage signal as each tooth passes by the sensor. The total expected uncertainty for data above 10.5 rad/s is ± 3.8 rad/s; the measuring system is not capable of providing meaningful data below 10.5 rad/s.

The broken loop pump speed is determined with the use of a proximity probe which reads notches in the pump brake disc. The corresponding pump speed is determined through electrical frequency processing of the probe voltage output.

Voltage and current measurements are obtained for the intact loop pump motor and multiplied in the computer to yield the applied pump power. The broken loop pump motor has a factory installed and calibrated power measurement output terminal. The total uncertainty for each of these measurements is expected to be less than $\pm 5\%$.

1.11 Core Characteristic Measurements

A shunt circuit is used to measure the total core current. The shunt circuit technique uses a voltage measurement across a known precision resistor in the shunt circuit to provide current data. The total expected uncertainty is $\pm 1\%$ of full scale.

Core voltage data are obtained by using a digital voltmeter; the total expected uncertainty is ±1% of full scale.

The total core power is derived in the computer by combining the measured core voltage and current.

2. DATA ACQUISITION AND PROCESSING SYSTEM

The data acquisition and processing system interfaces with the detectors and processes the data for warm-up, monitoring, and presentation in engineering units.

The Semiscale Mod-3 data acquisition system consists of two hardware subsystems, an analog data acquisition system (ADAS) and a digital data acquisition and processing system (DDAPS).

The ADAS consists of 80 channels which are recorded on one tape transport in an FM multiplex mode at bandwidths of 250 Hz and 1 kHz.

The DDAPS is an online system capable of recording up to 240 channels of data at frequencies of less than 50 Hz on disc type memory devices. This system is capable of producing data plots of all DDAPS channels and can also be used to digitize and plot the data recorded on the ADAS.

The DDAPS plots created have a resolution on the vertical axis of system full scale divided by 1000. The horizontal axis, used to indicate time, represents 920 equally spaced data samples. The data curves are produced by connecting the sample points with straight lines.

During Semiscale Mod-3 system testing, the DDAPS is used to record about 200 measurements. The ADAS is used to record up to 80 measurements, most of which are a duplicate recording of the measurements recorded on the DDAPS. The data presented in the experiment data reports are obtained from the DDAPS system. The DDAPS system is used for convenience because this system provides digital data directly. The analog data could be digitized using the CDC 173/7600 computer to obtain improved frequency response. However, for graphs for the time duration presented in data reports, no improvement in data resolution is realized.

The ADAS has calibration signals recorded with the data to allow gain and offset corrections to the data during processing of the detector signals. The DDAPS has an internal self-check and calibration system which, during the acquisition and processing of the detector signals, automatically corrects for gain and offset variations in the data. Further corrections and processing of the digital data are performed with the DDAPS and applied to the data to produce corrected digital magnetic tapes for X-Y plots and for subsequent processing on CDC 173/7600 computer. The total uncertainty induced by the DDAPS is ±0.1% of full scale.

Estimated electronic system nonlinearity and instability contribute ±0.05% of full scale to the data uncertainty. Estimated electrical pickup noise in transmission lines is ±0.1% of full scale. The root-sum-square summation technique applied to the individual acquisition and processing uncertainty estimates yields a probable uncertainty of ±0.15% of full scale.

The preceding is descriptive of the data acquisition and processing system as it will be used during the baseline test series (Test Series 7). Modifications to the system are planned which will increase both the capacity and capability of the present system. The modifications will be continuously made to the system throughout testing.

3. CONTROL SYSTEMS

The Semiscale Mod-3 electrically heated core and both intact and broken loop steam generators employ the use of feedback mechanisms which facilitate the control of the power profile in the core and secondary water levels in the steam generators. A brief description of the operation of these systems is given below.

3.1 Core Power Control System

The electrically heated core employs a computer to maintain the desired power profile following blowdown. The core power computer is a Digital Equipment Corporation PDP11/55 general purpose computer. When under computer control, the power control signal from the core power operator is routed through the computer. The control system operates in an open-loop mode during warm-up and steady state operations. When the computer receives a sequencer signal that the blowdown transient has been initiated, active control of the transformer control signal is automatically transferred to the computer and the control system becomes a closed-loop system. Operation is as follows: The computer has stored in its memory the surface heat flux decay profile of a scrammed nuclear rod in a typical PWR. The computer receives as inputs (a) measured core power, (b) high and low power rod temperatures, and (c) high and low power coolant temperatures from high and low power regions inside the core. The computer continuously compares the Semiscale electric rod surface heat flux profile with that of the nuclear rod model stored in its memory, and adjusts the transformer control signal so as to match the two profiles. This results in the Semiscale electric rod closely matching the surface heat flux decay profile of a typical PWR scrammed nuclear rod.

3.2 Steam Generator Level Control System

The intact and broken loop steam generators are each equipped with control systems which serve to maintain the proper secondary coolant and steam flow during system operation. The control system operation is centered around a three element steam generator level control system logic, which consists of three operational amplifiers (op-amps). In operation, signals representing the steam output mass flow rate and the feedwater input

mass flow rate are fed to the differential input of an op-amp. As long as the two signals are equal, indicating an unchanging level, the output of the op-amp comparison is zero. This comparison output is fed to a second op-amp. The other input of the second device is a signal representing the comparison of the steam generator level with the level set point. The output from this op-amp is used in conjunction with a feedwater input flow controller to maintain a steady state condition of the steam generator heat transfer characteristics.

VI. REFERENCES

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