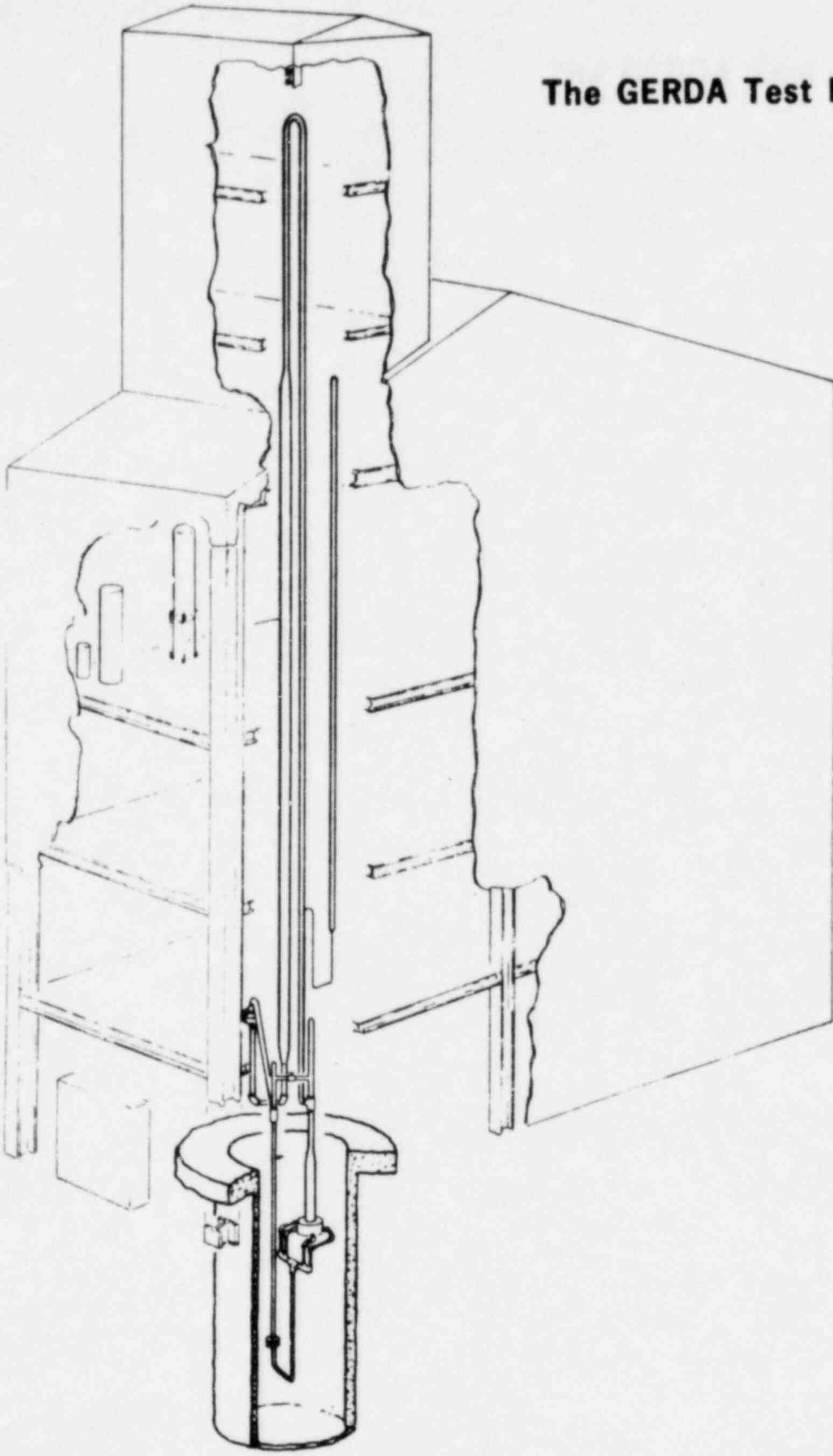
The GERDA Test Facility



Babcock & Wilcox
a McDermott company

OVERVIEW OF THE

GERDA

TEST FACILITY

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1.0 INTRODUCTION

The GERDA[1] test facility was designed by B&W personnel and constructed at B&W's ARC facility in Alliance, Ohio. This facility is currently under contract to the Brown-Boveri Reaktor (BBR) GmbH of Mannheim, Germany and all test plans and sequences are being developed to BBR specifications. The general facility description, the scaling involved in design of the loop, instrumentation, and preliminary schedule for testing are subjects of the following sections.

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[1]GERDA is an acronym for Geradrohr Dampferzeuger Anlage meaning straight-tube steam generator (test) facility.

2.0 GENERAL FACILITY DESCRIPTION

GERDA has been designed for the peformance of both separate effect and overall system tests at simulated powers up to 5% of 3760 MWt. The primary side of the loop has been configured using a single 19-tube OTSG, a simulated reactor and pressurizer, a single hot leg, and a single cold leg. Reactor decay heat, following a scram, will be simulated in the test loop by electrical heaters in the reactor vessel. The total reactor vessel heat capacity will be 180 KW, which is approximately 8% of scaled power (neglecting heat losses). The primary side also has simulations of high pressure injection (HPI), reactor vessel vent valves (RVVV), and high point vents (HPV).

The major secondary side components include the OTSG, a water-cooled condenser, a hot well, a circulating pump, feedwater heaters, and control valves.

The general arrangement of the GERDA loop is shown schematically on Figure 2.1. The elevation and horizontal plane relationships between the steam generator, reactor vessel, and pressurizer are shown on Figure 2.2. To be more specific, the major components have been simulated as follows:

- Reactor Vessel

An electrically heated reactor vessel will provide heat input to the primary fluid to simulate reactor decay heat levels up to 5% simulated full power (neglecting heat losses). Based on a power rating for the Muelheim Kaerlich (MK) plant of 3760 MWt and on the ratio of the number of tubes in the model generator to MK OTSG's (19/32,000), 5% simulated full power corresponds to 112 KW. The total reactor vessel heat input capacity will be 180 KW.

The stainless steel reactor vessel is composed of three (3) regions; a lower plenum, a heated section, and an upper and top plenum. The overall length of the reactor vessel is about 32 feet, and the net internal volume is approximately 3700 in.^{3}. The reactor vessel is shown in Figure 2.3.

- Steam Generator

The 19-tube OTSG as shown on Figure 2.4 is a single pass, counterflow, tube and shell heat exchanger. It consists of 19 Alloy 600 tubes with an outside diameter of 5/8 inch spaced on a triangular pitch of 7/8 inch on centers. The tube bundle is enclosed in a hexagonal shell 3.935 inches across flats and is held in place by 16 carbon steel tube support plates spaced at approximately 3 foot intervals. The tube support plates are 1-1/2" thick and are drilled in a manner to simulate the broached pattern of a full-size OTSG tube support plate.

Primary flow enters at the top of the steam generator, flows downward through the tubes, and exits at the bottom. The secondary fluid enters the steam generator through auxiliary feedwater injection penetrations, boils on the outside of the tubes, and exits at the top. Auxiliary feedwater can be injected at either a high or low elevation, as indicated on Figure 2.4.

- Pressurizer

The pressurizer vessel was fabricated from a 3" SCH 160 stainless steel pipe. The length of the pressurizer is approximately 487". The SB LOCA pressurizer has been scaled to tne Muelheim Kaerlich (MK) plant first on fluid volume, and second on elevation. A schematic of the pressurizer is shown in Figure 2.5.

- Primary Venting System

Five leak locations for primary fluid venting and leak flow simulation are available. These locations are at the bottom of the reactor vessel, the apex of the hot leg U-bend (HLUB), the top of the pressurizer, and two in the cold leg (one upstream and one downstream of the pump spillover). The vent systems proposed for use at all locations, except the HLUB and pressurizer, assume that subcooled liquid conditions exist at the leak. At the HLUB and the pressurizer, the existence of a two-phase steam-water and non-condensible gas (NCG) mixture is possible.

The primary functions of the venting system are:

- the controlled release of the primary fluid with or without NCGs through critical flow orifices,
- the indirect measurement of the flowrate of the vented liquid and NCG,
- the measurement of the total vented mass,
- leak flow simulation.

- Non-condensible Gas Addition and Sampling System

Intermittent or continuous metering of known quantities of NCG will be performed by expanding the NCG at an initial pressure and temperature from a known volume (reservoir plus tubing routed to injection point) into the primary loop. Measurement of the NCG pressure and temperature will be taken to establish the quantity and/or rate of NCG addition. Figure 2.6 shows the planned locations for NCG addition to the primary loop.

The function of the non-condensible gas (NCG) injection and sampling system is:

- the metering of known quantities of NCG into the primary loop in either a continuous or intermittent manner,

- and the detection of NCG presence on the primary side at sampling locations by intermittent measurements.

- Computer and Data Acquisition System (DAS)

The GERDA Test Facility has a Digital Equipment Corporation (DEC) PDP[1] 11/34 minicomputer and Analogic ANDS5400 data acquisition system dedicated to the facility for data acquisition and data processing. A number of input/output devices are attached to the PDP 11/34 for user communication to the DAS and prompting of data display options. In addition, a DECNET[2] link from the PDP 11/34 to the existing VAX[1] PDP 11/780 computer at the Alliance Research Center will be used for direct communications with this computer. The GERDA data acquisition system is shown by Figure 2.7.

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[1] PDP and VAX are trade names for families of DEC minicomputers.

[2] DECNET is a hardware/software communication link for interconnecting compatible computers.

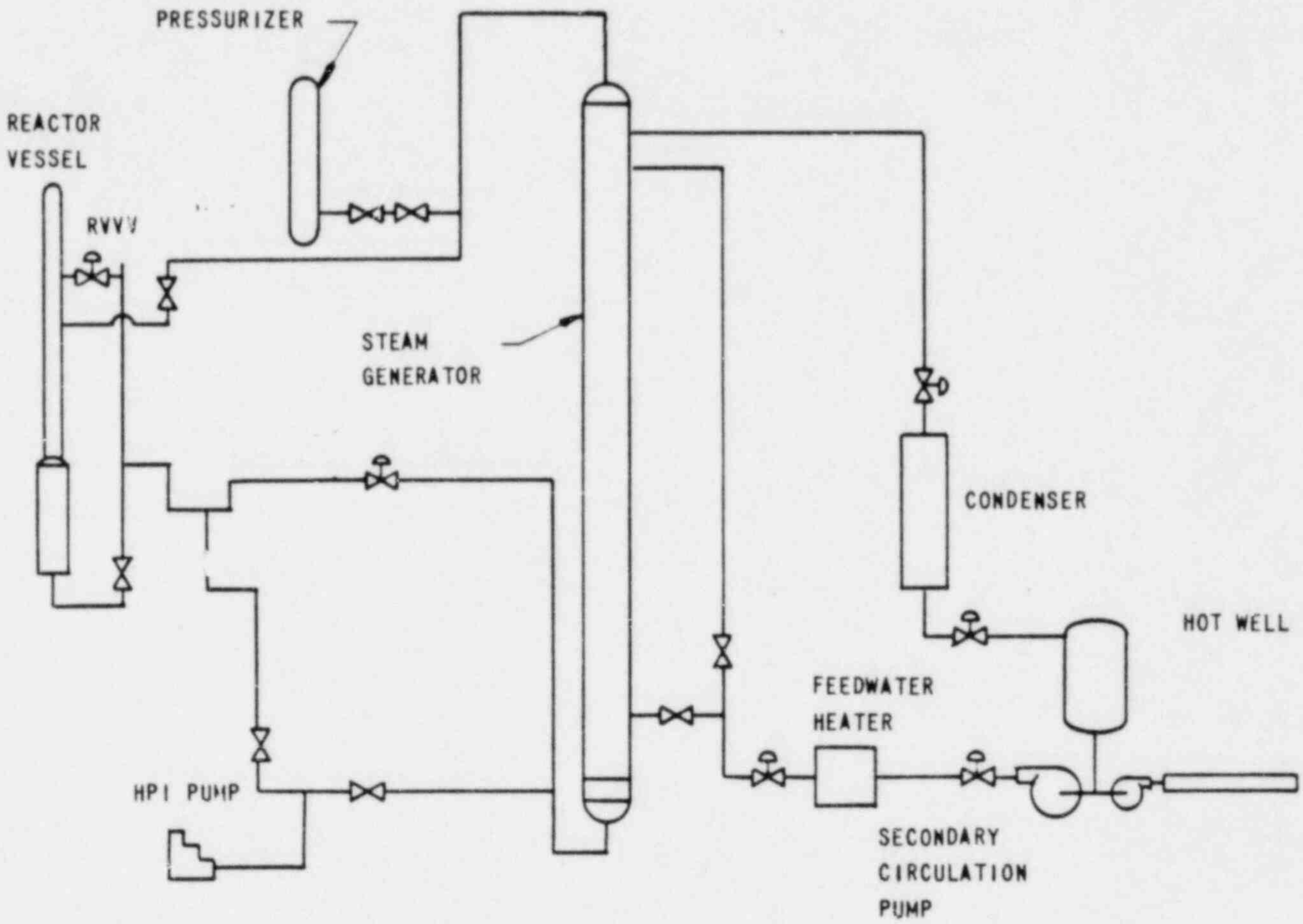


Figure 2.1 GENERAL ARRANGEMENT OF GERDA FACILITY

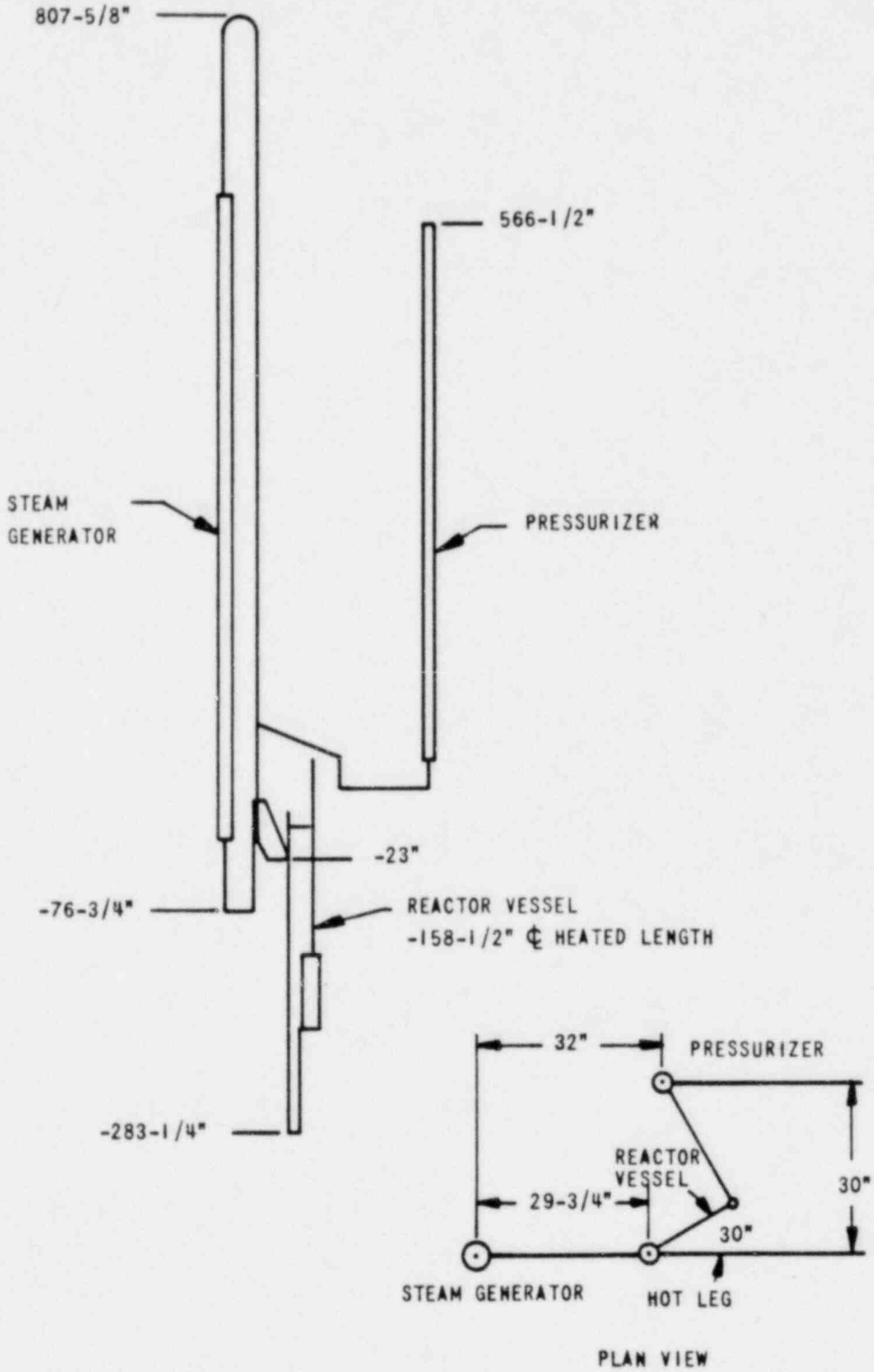
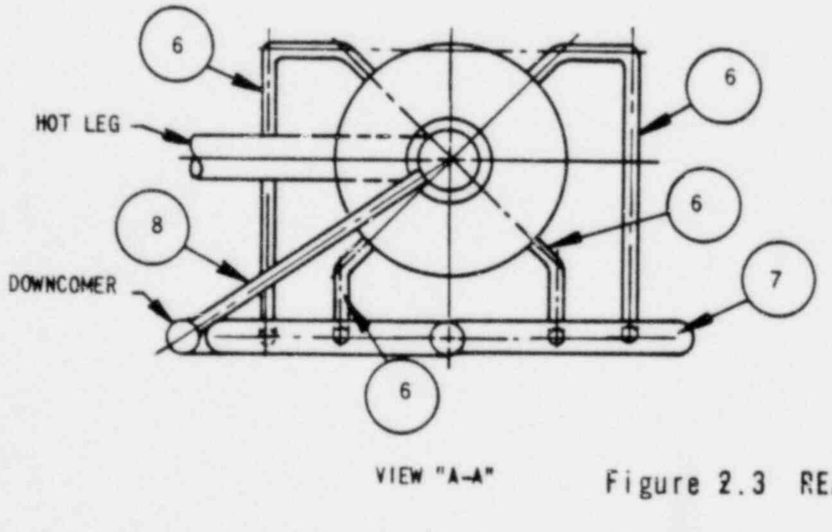


Figure 2.2 ELEVATIONS IN GERDA FACILITY

MK	COMPONENT
1	2" SCH 160 PIPE
2	6" SCH 160 PIPE
3	4" SCH 160 PIPE
4	6"x4" SCH 160 CONCENTRIC REDUCER
5	4"x4"x3" SCH 160 TEE
6	1" SCH XXS PIPE
7	2" SCH 160 PIPE
8	1 1/2" SCH 160 PIPE
9	2"x2"x2" SCH 160 TEE

NOTE: ELEVATIONS ARE RELATIVE TO SECONDARY FACE OF THE OTSG LOWER TUBESHEET.



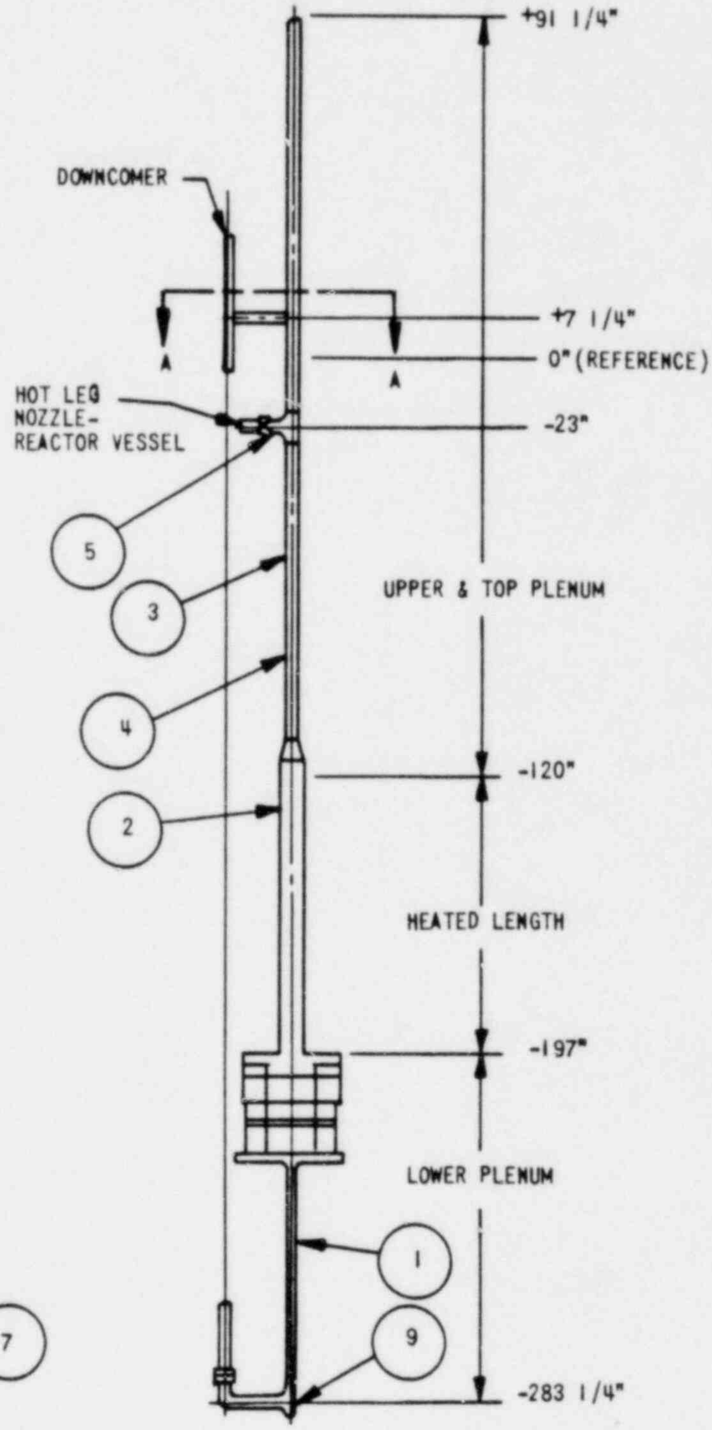


Figure 2.3 REACTOR VESSEL

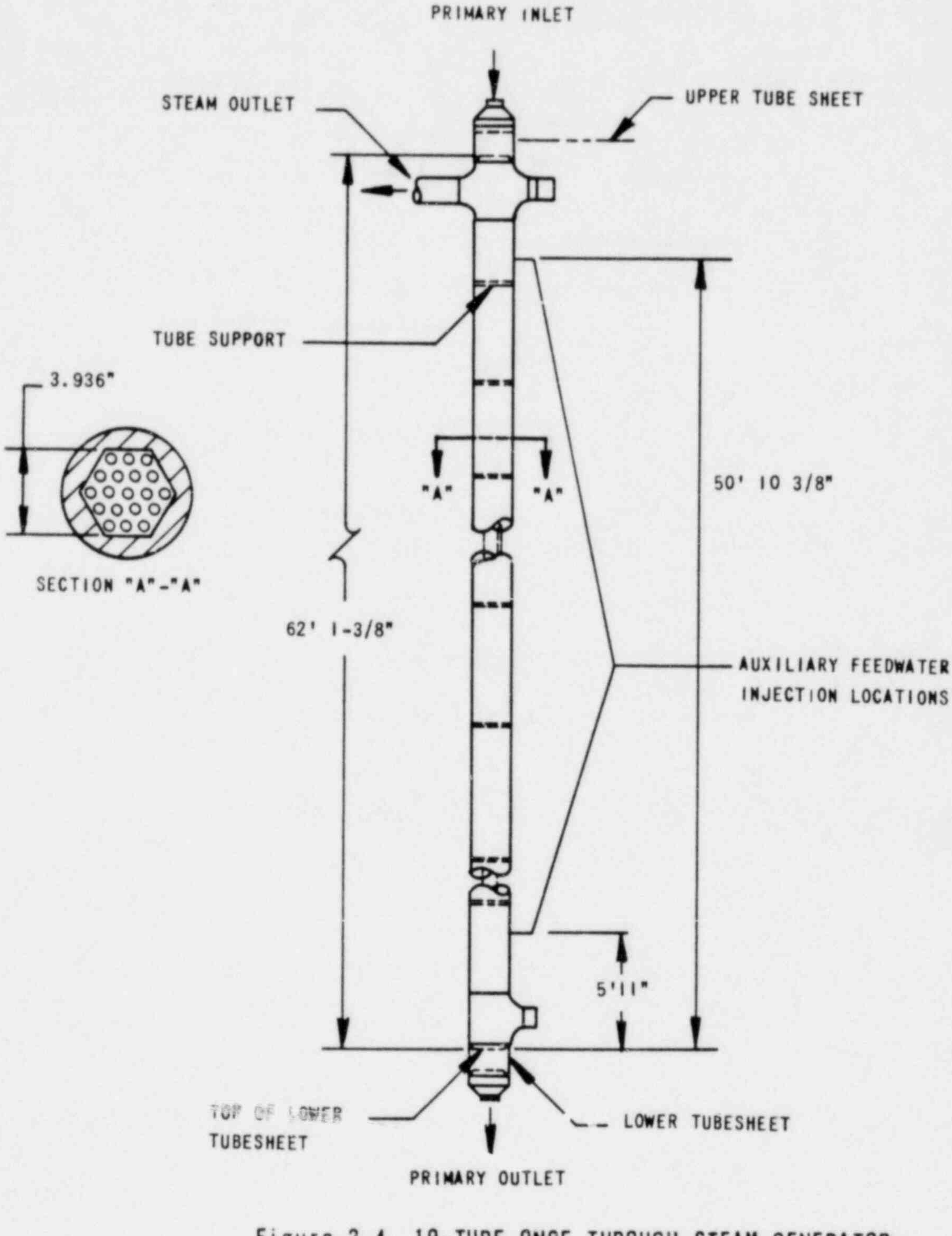


Figure 2.4 19-TUBE ONCE THROUGH STEAM GENERATOR

MK	DESCRIPTION
1	BLANK SPACER
2	MANUALLY OPERATED ISOLATION VALVE,
	3/4" SEALED STEAM Cv = 1.2
3	SAFETY RELIEF VALVE
4	3" SCH 164 = 40'-7 1/4"
5	1" SCH 80 PIPE
6	3/8" SCH 80 PIPE
7	AUTOMATIC OPERATED VALVE
	3/8" SEALED STEM Cv = 1.0

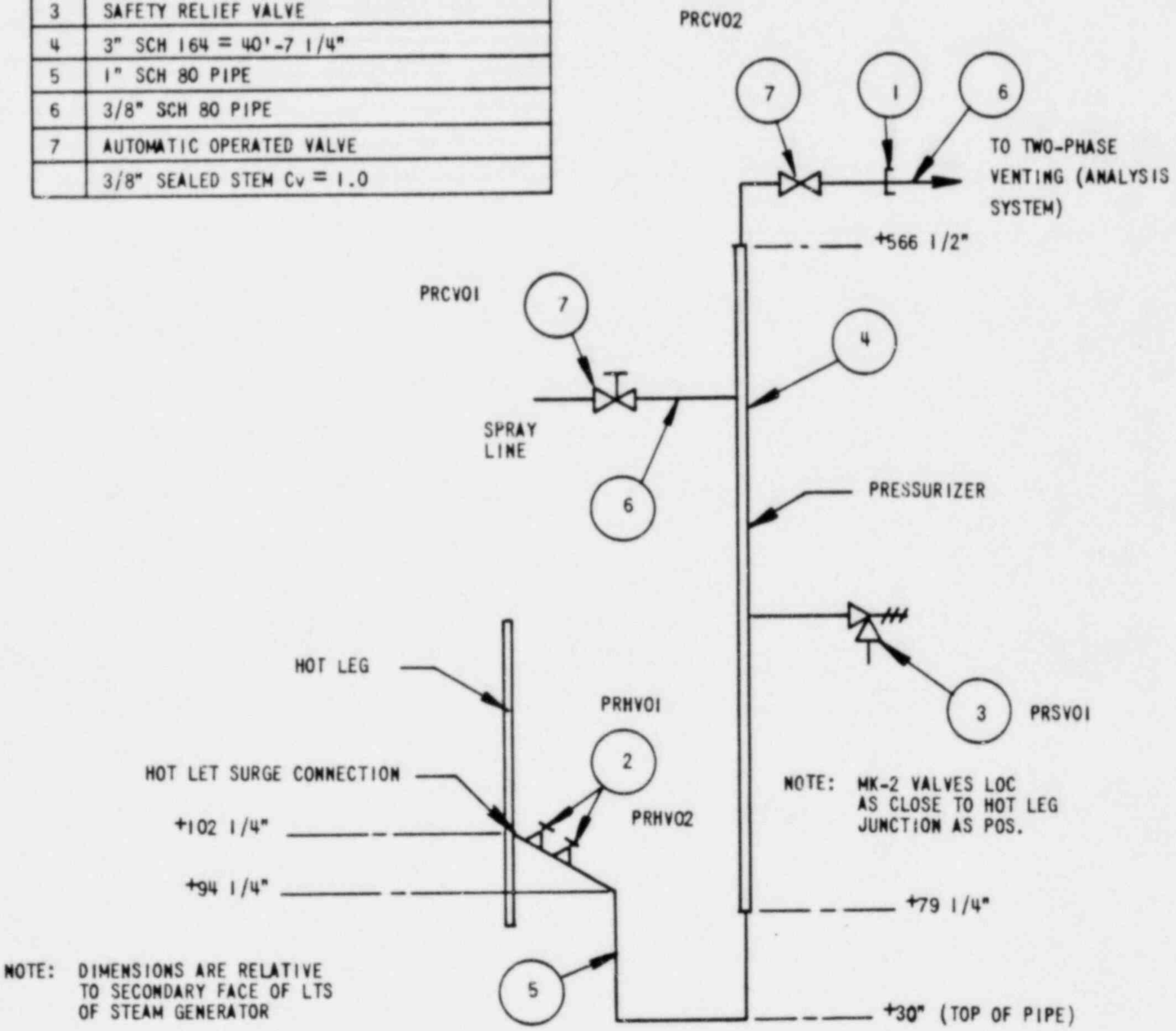


Figure 2.5 PRESSURIZER

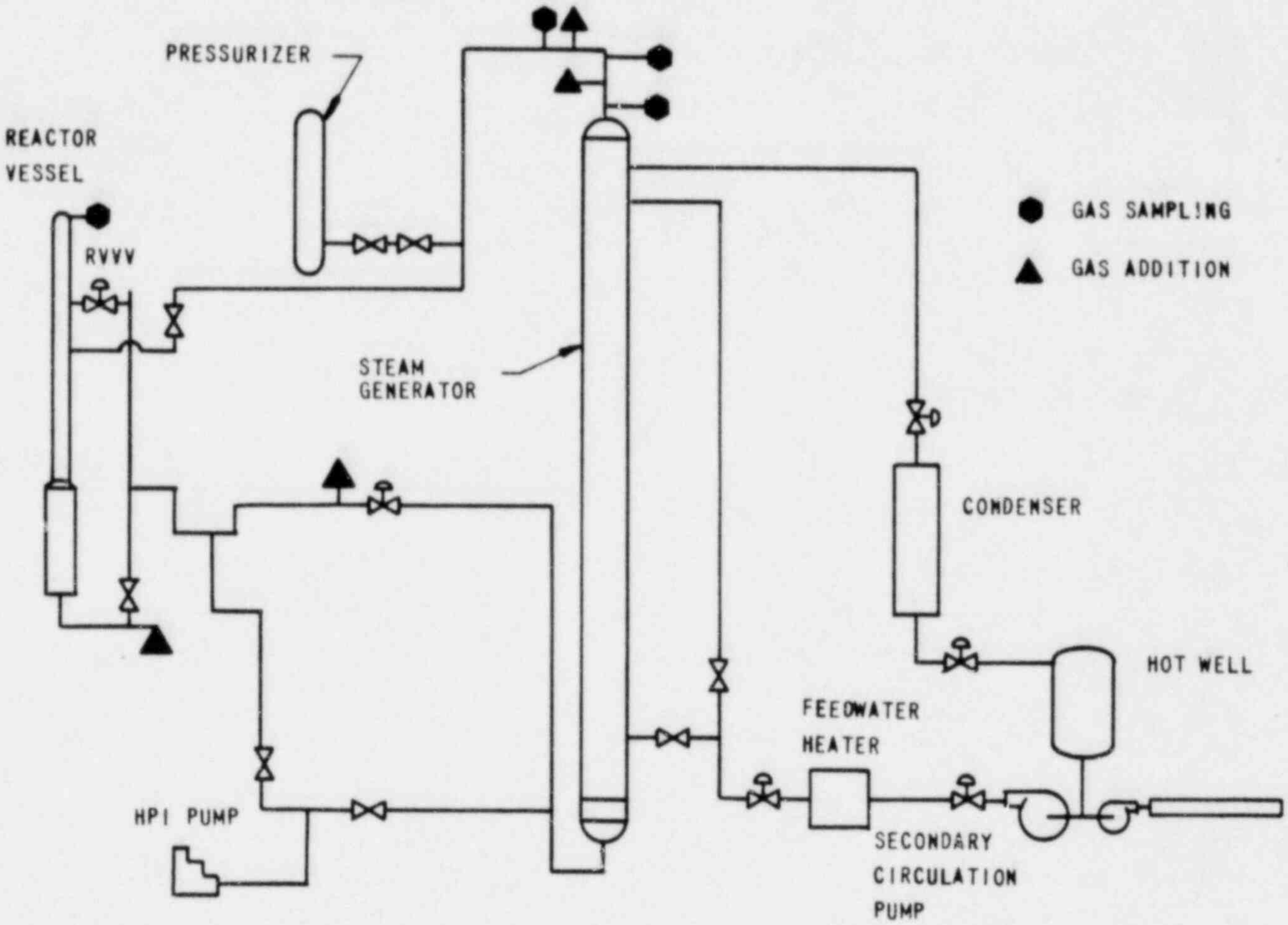


Figure 2.6 LOCATIONS FOR GAS ADDITION AND GAS SAMPLING

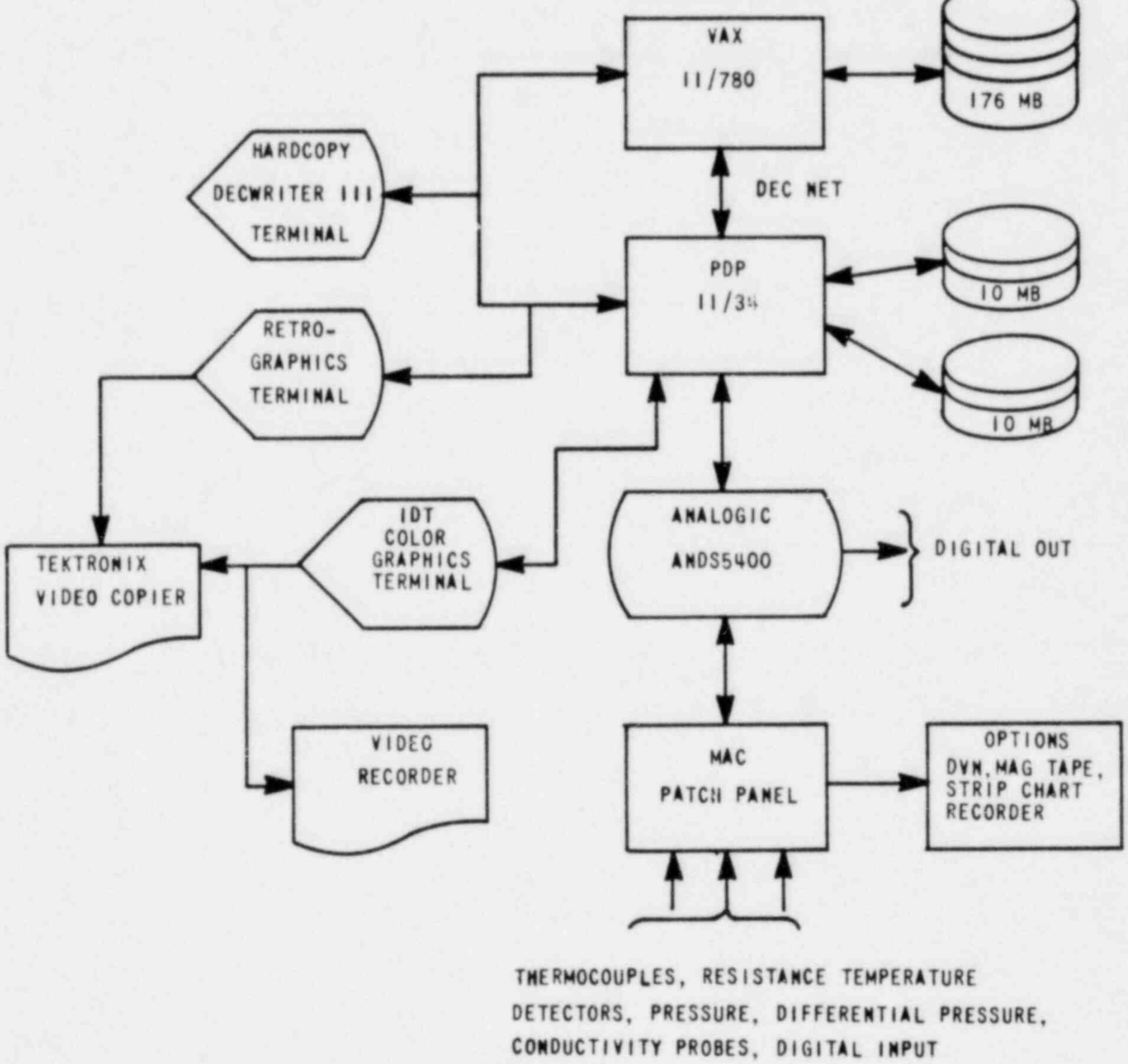


Figure 2.7 GERDA DATA ACQUISITION SYSTEM

3.0 SCALING OF THE GERDA FACILITY

Since SB LOCA fluid behavior is typically buoyancy-driven, full-elevation modeling is assigned first scaling priority. Full elevations do not guarantee plant-typical post-SB LOCA phenomena, therefore, governing phenomena are determined, evaluated, and accomodated as a second scaling criteria. Volumetric scaling in the loop is assigned third priority. Finally, loop irrecoverable losses are conserved as a final major scaling criterion.

These four ordered scaling criteria are interdependent, thus scaling errors (model atypicalities) are inevitable.

- Elevation

  Full-elevation scaling preserves gravitational fluid forces, replicates MK refill and control levels, and conforms to the model OTSG which is full length between tube sheets. Elevation scaling begins with the MK elevations related to a convenient reference plane. The steam generator lower tube sheet upper face (SGLTSUF) was selected as this reference elevation in GERDA. The SGLTSUF plays a significant role in setting SG-to-core elevation difference, and thus in driving natural circulation.

  The GERDA components are centered at the counterpart MK elevations: MK and GERDA SGLTSUF elevations are equated by reference selection, thus the plant elevations over the secondary heat-transfer length are preserved; the GERDA core mid-height is matched to that of MK, -13.2 ft (the GERDA heated length is ~7'); and the pressurizer bottom elevations are matched at +6.6 ft.

  GERDA piping generally models the MK spill-over and spill-under elevations: The GERDA HLUB is at the elevation of the MK HLUB.

- Phenomena

Second scaling priority is given to "phenomenological scaling". This involves the determination of significant SB LOCA phenomena, a comparison of the scaling dictates among the various phenomena, and the selection of a single most-appropriate scale.

Certain phenomenological scaling criteria require power-to-volume scaling, i.e., system volume scaled as (core) power. GERDA power and volume scaling originates with the size of the model OTSG. Nineteen full-length and plant-typical tubes represent the 2 x 16013 tubes of MK, thus defining S:

$$S \stackrel{\Delta}{=} \frac{2 \times 16013}{19} = 2 \times 842.8 = 1686.$$

Alternately, consider the model OTSG to represent one MK OTSG; then the ratio between 1/2-MK and GERDA is:

$$S_{1/2} = \frac{16013}{19} \stackrel{\Delta}{=} 842.8, \text{ but } S = 2 \times S_{1/2} \text{ is unchanged.}$$

Model core power is set to preserve (OTSG) fluid conditions; therefore, with the model OTSG sized to S, S also scales core power.

GERDA retains the MK-ratio of pressurizer-volume to system-volume. Thus pressurizer volume is scaled directly as S.

Leak, injection, venting, and relief valve mass flowrates are also to be scaled as system volume, to retain real-time fluid levels and fractional inventories. Critical flowrates are proportional to flow area, even with the relatively small orifices encountered in GERDA. Thus discharge flow areas are also scaled directly with S.

SB LOCA phenomenological scaling is of most concern in the hot leg (HL), and involves two-phase behavior at low mass flowrates. This hot-leg scaling is performed by relating the pipe-diameter scaling factor, S_D, to the overall power and volume scaling factor, S, using this relation:

$$S_D = S_{1/2}\ 0.4$$

This HL scale preserves Froude number, and thus the ratio of inertial to buoyant forces, which certainly influence HL behavior.

The same criteria - Froude number perservation - has been applied to the cold leg (CL) piping The resulting GERDA HL, CLS (suction), and CLD (discharge) diameters bracket (and are each closest to) 3" Schedule 160 pipe, with 2.626" (66.7 mm) id. This standard pipe is used throughout.

- Volume

Volume scaling, reducing model component volumes by the same factor as model power, is commonly invoked but rarely adhered to. Volumetric scaling would obtain a 1" GERDA HL - a pipe size not likely to preserve MK two-phase phenomena even in near-stagnant flow.

Thus volume scaling is ranked after elevation and phenomenological scaling in importance. Volume scaling would preserve both real time and, obviously, the relative significance of component fluid volumes in post-SB LOCA core cooling.

Loop Irrecoverable Losses

The model loop fluid irrecoverable momentum loss characteristics need to approximate those of MK, to obtain similar natural-circulation performances. If component rather than system loss characteristics were preserved, the relative influence of fluid viscous forces, as well as those of buoyant and inertial forces, could be retained. But the higher-priority scaling criteria have precluded this possibility.

Preliminary pressure loss calculations at natural circulation flowrates indicate that GERDA piping is not as restrictive as that of MK. GERDA also has less core-region form loss, and lacks the stalled-RCP loss of MK. The GERDA loop irrecoverable loss coefficient (Eu) has been increased to that of MK by the addition of orifice plates.

These four ordered scaling criteria are interdependent resulting in model atypicalities such as:

- Surface-to-volume Ratio

Piping heat transfer area is proportional to pipe diameter, but contained fluid volume varies as diameter squared, thus the ratio of heat transfer surface area to associated fluid volume varies inversely with diameter. As pipe diameter is reduced, surface heat transfer effects become increasingly significant. The fluid and wall-surface temperatures become more closely coupled, and the system-to-ambient heat losses increase.

GERDA, planned with SB LOCA performance in mind, has miminum instrumentation cooling losses, no (in-line) RCP cooling, few flanges, and guard heaters on the pressurizer and hot leg to compensate for heat loss.

- Metal Mass

High-pressure reactor system models unavoidably encounter metal-mass scaling errors. As pipe diameter is reduced, the ratio of metal-to-fluid cross-sectional area increases (roughly as the sqaure root of pipe diameter). MK and GERDA can be compared on the bais of "R", the ratio of component metal volume to enclosed fluid volume. GERDA is predictably atypical, with primary R's approximately twice those of MK.

To meet pressure-boundary code requirements, the model OTSG was fabricated from a 5.563" od (circular) piece. The internal geometry is hexagonally-shaped with 3.935" (100 mm) between flats, thus the model OTSG shell has significant exess metal. Its secondary metal-to-water ratio is more than three times that of MK (using the MK tube-region-only fluid volume).

Such excess model metal may dampen transients and preclude rapid system cooldowns since GERDA fluid-to-metal coupling is much stronger that that of MK. These effects are being evaluated by code predictions of planned GERDA transients.

- Leakage

To achieve minimum leakage in GERDA, the number of leak-susceptible fittings at higher elevations is minimized. Required valves in this region employ welded bonnets. Leak-prone components are isolatable. System integrity tests will be used to check leakage.

- Maximum Primary Pressure

MK safeties protect the system against overpressurization. GERDA uses safeties for the same purpose (and as legally required). These (operational) safeties must not be lifted during planned testing, to preclude subsequent valve-seat leakage. The GERDA simulation of the MK safeties (and/or PORV) are set for pressures below the operational Mk safeties, with allowances for lift-setting inaccuracies. The GERDA safety-valve simulation lifts ~200 psi below the MK setpoints.

Other than the obvious modeling differences, this lift pressure atypicality is expected to have a negligible effect on test suitability.

- One-dimensionality

GERDA, with full length and a small-scale cross-section, is a predominantly one-dimensional model. The simulation of multi-dimensional phenomena is limited. Some of these limited simulations may be addressed through parameterization. The plant HPI split between the injection points located upstream and downstream of the pump spill-over elevation is imposed in GERDA, permitting comparison of test behavior with various HPI assumptions. The impact of RVVV flow may be assessed by controlling both RVVV actuation and flowrate in the model.

The one-dimensionality of the model OTSG secondary is more restrictive. The nineteen-tube array of the model SG may be too small to simulate directly plant secondary behavior with high-elevation AFW injection. Therefore, AFW tests with minimum (tube) wetting and maximum wetting nozzles will be used to derive qualitative estimates of multi-dimensional secondary effects.

4.0 INSTRUMENTATION

GERDA loop instrumentation includes pressure and differential-pressure (DP) measurements; thermocouple (TC) and RTD measurements of fluid, metal, and insulation temperatures; level indications by heated RTD, heated TC, and conductivity probes as well as by DP; and ultra-sonic measurements of low natural-circulation flowrates. In addition to these loop instruments, loop boundary conditions are metered: HPI, HPV, (controlled) leak, relief, and secondary steam and feed flow are measured. NCG injections are controlled and metered, NCG discharges with the two-phase primary effluent streams are measured; and the aggregate primary effluents are cooled and collected for integrated metering. Instrumentation and available penetration in the primary natural circulation loop and in the secondary side of the OTSG are shown on Figure 4.1.

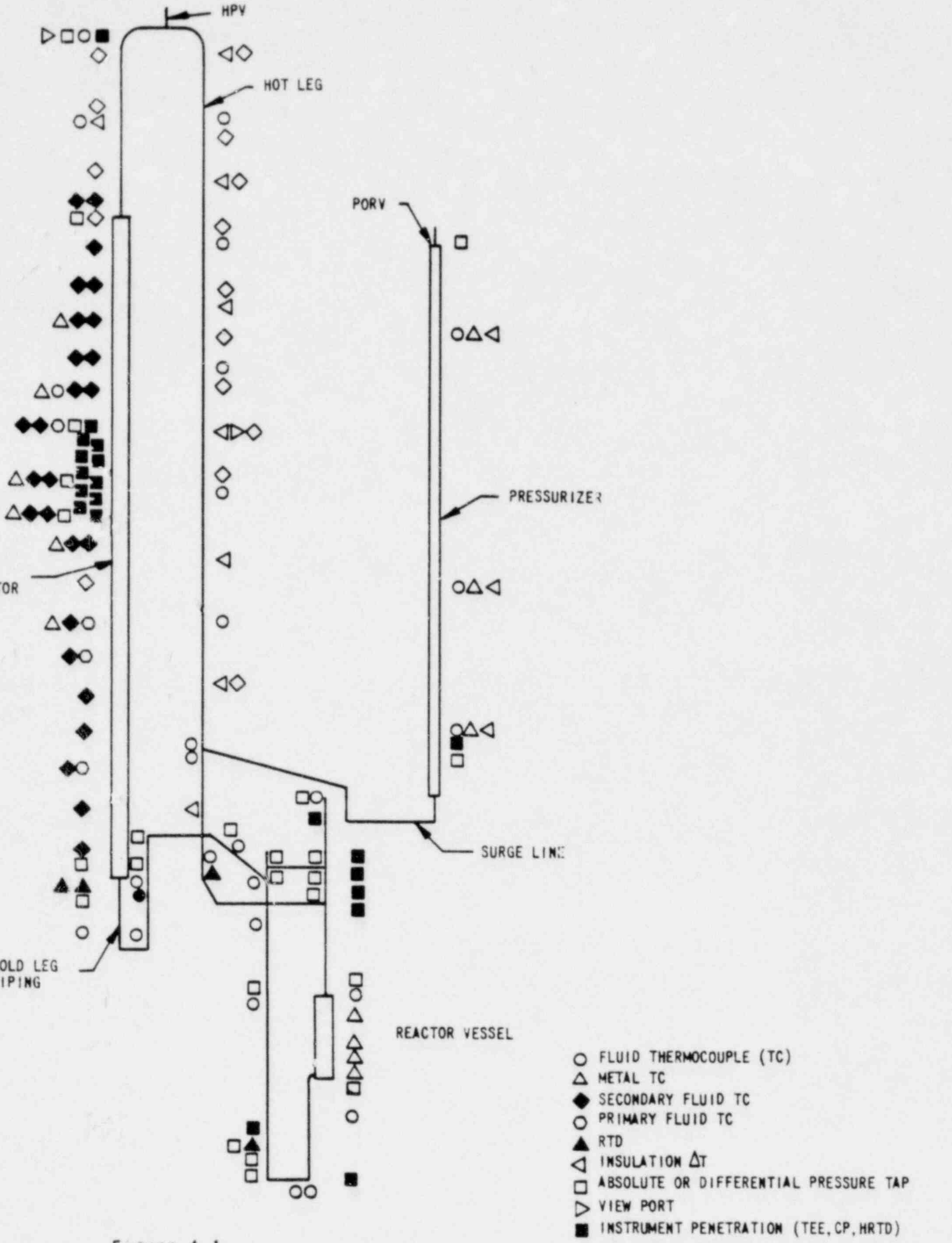


Figure 4.1

PRIMARY CIRCULATION LOOP INSTRUMENTATION AND PENETRATIONS

5.0 SCHEDULE FOR TESTING

The planned GERDA testing period will extend roughly from April, 1982 through mid-January, 1983, inclusive. This nine and one-half month period is divided into three portions. The first weeks are relegated to "Phase 0" testing, for loop checkout and characterization. The middle period is for "Phase 1" basic variations, and the final period is for supplementary variations.

The intital loop tests will serve to characterize the system and to test its as-built performance. These tests have been labelled "Phase 0" to differentiate them from the contractual test phase. The results of these tests will be used for the subsequent interpretation of loop response, and on code modelling of the test facility.