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MARK II 4T CONDENSATION OSCILLATION (4TCO) TEST PROGRAM
FINAL TEST REPORT

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GLOSSARY

Air Content	Percent by weight of air in a steam-air mixture.
Blowdown	Depressurization of the steam generator vessel by releasing steam and/or liquid through the blowdown line into the drywell vessel. This simulates the action of a BWR pressure vessel following a postulated Loss-of-Coolant Accident (LOCA).
CO	Condensation Oscillation
Dip-Tube	An "L" shaped pipe approximately 10 inches in diameter installed in the steam generator vessel such that the fluid released during a blowdown is steam taken from the upper part of the steam generator vessel.
EU	Engineering Units
Evaluation Frequency	Any one of the frequencies at which the PSD values are reported.
Freespace	That part of the wetwell internal volume which is above the water surface and outside of the vent.
Harmonic Amplitude	The peak-to-zero value of a harmonic signal with reference to PSD calculation. The harmonic amplitude is the peak-to-zero amplitude of one of the sinusoidal signals which composes the time history. The harmonic amplitude at a given frequency can be determined by integrating the PSD over a frequency band, usually over 3 evaluation frequencies. The harmonic amplitude is equal to the square root of twice this integral value. The frequency assigned to this amplitude is the center frequency of the integration band. An explanation of harmonic amplitude is given in Subsection 4.2.
Jet Deflector	A flat plate larger in diameter than the vent and mounted in the drywell 11.5 inches above the vent inlet. Used in the 4TCO Test Program to simulate the prototypical Mark II configuration.
Liquid Blowdown	A blowdown that does not have the dip-tube installed in the steam generator vessel such that the fluid discharged into the blowdown line at the venturi is nearly single phase liquid until the liquid level in the steam generator nearly falls to the elevation of the venturi. A liquid blowdown simulates a postulated recirculation line break in a BWR containment.

PSD	Power Spectral Density is a representation of the energy at various frequencies in a signal. A PSD may be thought of as a decomposition of a time history signal into an infinite number of individual sinusoidal components of varying amplitude and phase. In practice, the PSD consists of a finite number of evenly spaced frequencies representing a finite number of sinusoids (the number and spacing of the frequencies is dependent on the data digitization rate and the duration of the particular history). A PSD value is calculated at each evaluation frequency. The energy at each of the evaluation frequencies can be determined by examining the PSD.
Real-Time	Refers to test data that is digitized and recorded in digital form during the test.
rms	Root mean square, a numerical value used to represent the "average" amplitude of a time varying signal. In the 4TCO pressure data, rms is calculated from the digital values of the dynamic part of the pressure signal, P_i using the equation:

$$\text{rms pressure} = \left(\frac{1}{n}\sum_{i}^{n} P_i^{\,2}\right)^{1/2}$$

Replay	Refers to test data that was recorded on analog magnetic tape during this test and digitized later by playing the tape back through the data acquisition system at a slower speed to increase the frequency resolution.
Run Description Codes	For convenience in comparing plots from runs having different initial conditions each plot has a description code. This code describes the runs as follows:

Example BDN-VEN-TEMP-SUB-RIS

where

BDN = Blowdown type Steam or Liquid

VEN = Venturi diameter code:

Diameter (in)	Code
3.82	3.8
3.00	3.0
2.50	2.5
2.125	2.1

TEMP = Initial suppression pool temperature, °F

SUB = Initial vent submergence, ft.

RIS = Presence of vent riser

R - vent riser present
N - no vent riser

See Table 1 of this glossary for a list of the codes for each run.

Steam Blowdown	A blowdown that has the dip-tube installed in the steam generator vessel such that the fluid released into the blowdown line is high quality steam. A steam blowdown simulates a postulated steam line break in a BWR containment.
Suppression Pool	The volume of water on the bottom of the wetwell that surrounds the lower end of the vent and condenses the vent steam flow during the blowdown.
Transfer Function	A numerical value equal to the square root of the ratio of two PSD values at a given evaluation frequency.
Vent	A 24-in o.d. pipe, 45.3 feet long, placed vertically between the drywell and the wetwell (see Figure 3-1).
Venturi	A converging/diverging nozzle installed as part of the blowdown line and located at the discharge nozzle of the steam generator vessel. In the 4TCO Test Program, the choked flow at the venturi throat simulates the flow through a postulated steam or liquid line break. Venturi with different throat diameters were used to vary the blowdown flow rate.
Vent Riser	Part of the vent which extends into the drywell above the drywell floor. The vent riser used in the 4TCO Test Program was a 2-ft long spool-piece with a flange at each end.
Wetwell	In the 4TCO tests the wetwell is the 4T vessel (see Figure 3-1).

DESCRIPTION CODE SUMMARY

Test Series	Run No.	Description Code
5200	1	S-3.0-69-11-N
	2	L-3.0-76-11-N
	3	L-3.8-74-11-N
	4	L-3.8-74-11-R
	5	L-3.0-79-11-N
	6	L-3.8-71-11-N
	7	L-3.0-93-11-N
	8	L-3.8-111-11-N
	9	L-3.0-114-11-N
	10	L-3.0-73-9-N
	11	L-3.0-74-13.5-N
	12	L-2.5-109-11-N
	13	L-2.1-109-11-N
	14	L-2.1-70-11-N
	15	L-2.1-71-11-R
	16	S-3.0-75-11-R
	17	S-3.0-71-9-R
	18	S-3.0-71-13.5-R
	19	S-3.0-71-13.5-R
	20	S-2.5-68-11-R
	21	S-2.5-68-11-R
	22	L-3.0-109-11-N
	23	L-3.8-108-11-N
	24	L-3.8-111-11-R
	25	L-2.5-111-11-R
	26	L-3.0-111-11-R
	27	L-3.0-110-9-R
5200	28	L-3.0-110-11-R
5101	27	S-3.0-70-11-N
	29	S-2.5-70-11-N
	31	S-3.0-68-9-N
5101	34	S-3.0-69-13.5-N

ABSTRACT

This report presents the results of a twenty-eight blowdown test series performed for the purpose of investigating condensation oscillation (CO) phenomena in the Mark II Pressure Suppression Containment System. The test facility was a single-vent, full-scale model of the Mark II geometry with conservatively sized suppression pool and drywell volumes. Test parameters that varied were initial suppression pool temperature, initial vent submergence, simulated line break size and blowdown type (liquid or steam), initial drywell air content, and vent/drywell configuration. Emphasis was placed on the comparison of suppression pool boundary loads with an existing design specification for these loads. Data tables and illustrations show the effects of the various system parameters on CO induced loads and frequency content. These data are examined and conclusions made as to the parametric effects.

1. INTRODUCTION

In 1975 the General Electric Pressure Suppression Test Facility (PSTF) and the Temporary Tall Test Tank (4T) provided the first full-scale data on the dynamic response of a Mark II pressure suppression containment during a simulated BWR reactor pressure vessel blowdown. In these tests (Test Series 5101) the test instrumentation, the facility configuration and the test matrix were designed specifically for the purpose of investigating pool swell phenomena. Condensation oscillation (CO) and chugging data were recorded along with the pool swell data. The CO data from these tests were used to develop a Mark II CO load specification which was documented in the Dynamic Forcing Function Information Report (Reference 1), hereafter referred to as the DFFR Rev. 3 specification.

As CO data from other containment experiments became available and more theory was developed to explain the CO phenomena, two areas of uncertainty were defined relative to the DFFR Rev. 3 specification. The first area involved the effect of test facility vent length. Theory and experiment seemed to indicate that the vent acoustic frequency (seemingly dependent on vent length) was a principal component in the CO pool dynamic pressure, and the 4T vent length was approximately twice the length of the prototypical Mark II vent. The second area of uncertainty concerned the effect of liquid in the blowdown mixture which enters the suppression pool along with the vent steam and air flow during a simulated recirculation line break. CO data from other tests indicated that such liquid may have an important influence on dynamic pressure amplitudes and frequencies. Test Series 5101 data base included only two simulated liquid breaks and the results from these two test runs were thought unlikely to have reliably demonstrated any effect of such liquid, because the side-by-side arrangement of drywell and wetwell tended to promote retention in the drywell of liquid released from the simulated reactor vessel. As a result of these uncertainties, a program was undertaken to modify the 4T facility and perform a series of simulated reactor steam line and recirculation line blowdowns which together cover the range of CO conditions postulated for domestic Mark II plants.

This test series, the Mark II 4T Condensation Oscillation (4TCO) Test Program, Test Series 5200, was performed to:

a. Provide data for confirmation of the Mark II Condensation Oscillation Load Specification (DFFR Rev. 3).

b. Evaluate the effects on CO of vent length and vent liquid flow over the range of Mark II conditions.

To accomplish these objectives, the PSTF and the 4T vessel were modified to include a new drywell vessel mounted above the wetwell in the prototypical Mark II arrangement with a straight vertical vent of length representative of Mark II plants. A matrix of 28 liquid and steam blowdowns was developed to provide CO dynamic pressure data to determine:

a. The effect of simulated break size over the range of Mark II Loss-of-Coolant-Accident (LOCA) conditions.

b. The effect of initial suppression pool temperature.

c. The effect of vent exit submergence in the pool.

d. The effect of the presence of a prototypical vent riser and a prototypical jet deflector at the vent entrance.

e. The effect of vent length-by testing at conditions duplicating previous 4T tests.

f. The effect of air content in the vent flow mixture.

g. The degree of repeatability attainable in the test results.

A test plan was prepared with the instrumentation, test matrix and data analysis specified particularly for condensation oscillation related information; although data was recorded for the entire transient including chugging.

The test facility modifications were completed in September 1979, and the first of three shakedown tests was performed on September 18. The last of the 28 matrix tests was completed on February 15, 1980. This report documents the results of this program.

2. OBSERVATIONS AND CONCLUSIONS

2.1 GENERAL

The DFFR Rev. 3 specification does not completely bound the measured CO loads at all conditions tested. Some frequencies in the test data fall outside of the range specified in DFFR Rev. 3, and at some combinations of bulk pool temperature and mass-flux the rms amplitude of the pool boundary pressure is higher than the equivalent rms amplitude inferred by DFFR Rev. 3 (see Subsection 4.2).

Blowdowns having the same nominal initial conditions were observed to have repeatable CO durations and system thermodynamic performances. Pool boundary and vent exit rms pressure values and frequencies, while not identical, show similar trends and magnitudes (see Subparagraph 4.5.1.6).

Mapping of CO rms pressure values for liquid blowdowns without the vent riser shows a strong dependence on a combination of vent steam mass flux and bulk pool temperature (see Paragraph 4.5.2).

The rms pressure value and frequency content at a given elevation in the suppression pool is independent of circumferential location (see Subparagraph 4.5.1.5).

The majority of significant CO frequencies seen in all blowdowns was below 15 Hz. The frequency which most often had the largest amplitude was in the 1.5-3 Hz range (see Subsections 4.4 and 4.5).

At vent air content above 1 percent and with constant vent steam mass flux, the pool boundary loads decrease with increasing air content. Below 1 percent air content there is no direct correlation between pool boundary loads and vent air content (see Paragraph 4.5.2).

2.2 FACILITY CONFIGURATION EFFECTS

A comparison of steam blowdown CO data with previous 4T tests (see Reference 2) (94-ft vent length) shows no identifiable change in pool pressure amplitudes attributable to vent length. Both test series show two major frequency components; one in the 1 - 4 Hz range, and one in the 6 - 9 Hz range. The longer vent produced pressures which had a more stable approximate 6 Hz component than the prototypical 45-ft vent (see Subsection 4.3).

Based on a comparison of two steam blowdowns, the presence of a jet deflector on the vent entrance had no effect on CO amplitude, frequency content, or CO duration (see Subsection 4.3).

The presence of a vent riser in liquid blowdowns generally resulted in a higher dominant CO frequency. The CO duration was not affected except in the 2.125-in venturi liquid blowdown with the riser where a 10-second decrease in CO duration was observed. The pressure amplitude was increased by the vent riser under some conditions and decreased under other conditions, but no simple or consistent relationship between pressure magnitude and the amount of liquid entering the vent was observed. The presence of a vent riser did not have any significant effect on CO amplitude, duration, or frequency for steam blowdowns (see Paragraph 4.4.2).

2.3 INITIAL CONDITION EFFECTS

A 3.82-in venturi liquid blowdown performed with the initial drywell air mass reduced by 27 percent produced the same CO amplitudes and frequencies, and had the same CO duration, as a similar blowdown performed with no reduction in initial drywell air mass. The similarity between these two blowdowns was seemingly due to the rapid purging of air from the drywell that resulted in nearly identical vent air contents during CO. No extrapolation can be made of this result to smaller venturi blowdowns or to blowdowns having greater reductions to the initial drywell air mass (see Subparagraph 4.5.1.1).

A decreased initial vent submergence resulted in increased peak wetwell bottom center rms pressure values for liquid blowdowns with no vent riser. Initial vent submergence had no identifiable effect on CO frequencies. CO duration was increased with decreased initial vent submergence in liquid blowdowns. For steam blowdowns, the CO duration is independent of initial submergence (see Subparagraph 4.5.1.3).

Increasing the simulated break area (venturi size) does not always increase pool boundary pressure rms values. Maximum wetwell bottom center and vent exit pressure rms values were attained during liquid blowdowns with the 3.00-in venturi. CO duration increased as venturi size was decreased. The 3.82-in and 3.00-in venturi blowdowns had significant 7 to 8 Hz components that were as strong in the 2.50-in and 2.125-in venturi blowdowns (see Subparagraph 4.5.1.2).

Initial suppression pool temperature did not have any identifiable effect on CO duration over the range of temperatures tested. Increased initial pool temperature resulted in increased wetwell bottom center rms pressure values in the 3.82-in and 3.00-in venturi liquid blowdowns, The opposite effect was observed in the 2.125-in venturi liquid blowdown. Colder initial pool temperature tended to produce stronger high frequency components (see Subparagraph 4.5.1.4).

3.0 TEST DESCRIPTION

3.1 TEST FACILITY

The test program described in this report was performed in the Pressure Suppression Test Facility (PSTF) located at the General Electric site in San Jose, California. The facility is configured as a prototypical unit cell from an expected bounding load Mark II containment. The existing Temporary Tall Test Tank (4T) vessel was used as the wetwell, with a new drywell positioned above the 4T vessel to provide a prototypical Mark II over/under geometry. Figure 3-1 is a schematic of the reconfigured facility.

The PSTF reactor simulator (steam generator) is an electrically heated flash boiler having a nominal internal volume of 160 ft^3. The vessel is rated at 1160 psig and 564°F. The blowdown nozzle located 2.5 feet above the vessel bottom is connected to an 8-in, Schedule 80 blowdown line which includes a critical flow venturi, double rupture disk assembly and an 8-in gate valve. The line terminates with a tee located high in the drywell vessel to provide rapid air purging and thus conservative condensation loads.

Test Series 5200 included both liquid and steam blowdowns. A 10.37-in i.d. dip-tube was installed on the blowdown line inside the boiler to achieve steam blowdowns. On test initiation the liquid in the boiler flashes producing steam that flows through the dip-tube/blowdown line to the drywell vessel. When the dip-tube is removed, saturated liquid flows through the blowdown line, thus providing a liquid blowdown.

The 4TCO drywell is a 12-ft diameter cylindrical vessel with an internal height of approximately 18.7 feet. Total drywell volume is nominally 1910 ft^3, the same as for previous tests in the 4T vessel. A gas-fired fin tube heater is installed in the drywell to preheat the shell, floor and head such that surface condensation is minimized during a blowdown. The drywell floor is configured to provide a prototypical Mark II vent entrance geometry, including a jet deflector. A removable riser provides prototypical water holdup volume inside the drywell.

The 4TCO vent consists of a straight, vertical 24-in, Schedule 20 pipe, 45.3 feet in length (not including the 2-ft vent riser) and is centered along the axis of the 4T vessel. This vent length is near the average for Mark II plants. The 4T vessel simulates the Mark II suppression pool and is an 84-in o.d. cylindrical tank with an internal height of 52.5 feet and with 5/8-in thick walls. This same vessel was used for previous Mark II testing. Auxiliary systems provide for draining, filling and heating of the vessel water and for pressurizing of the freespace.

A comparison of the 4T facility dimensional parameters was made with the Mark II plant parameters in References 2 and 3 to show how well the 4T facility represents a single vent "cell" of a Mark II containment. The geometric changes in the facility for the 4TCO Test Program have provided an arrangement which is now even more prototypical of the Mark II plants.

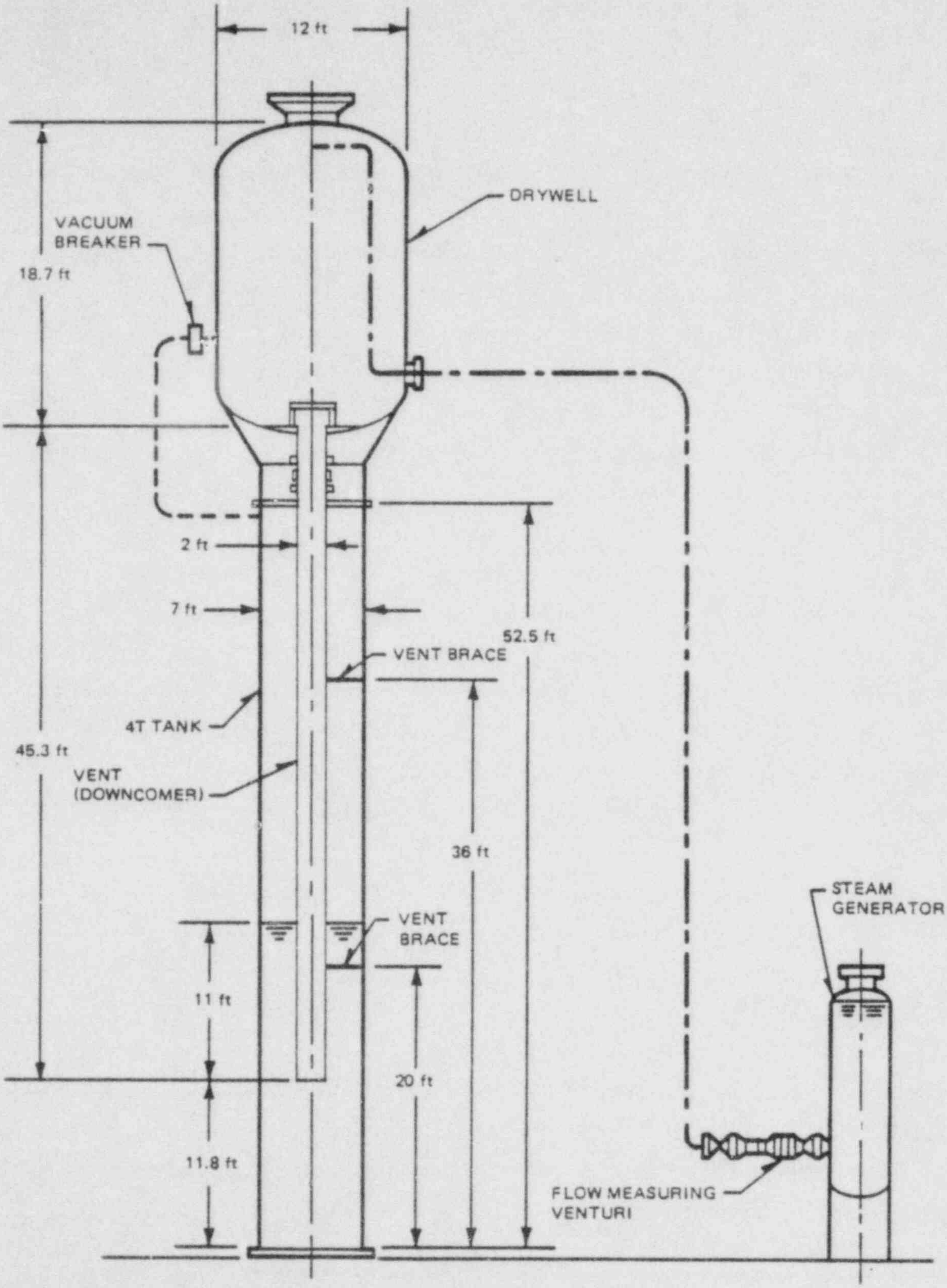

Figure 3-1. Test Configuration for Mark II 4T Condensation Oscillation (4TCO) Tests

3.2 TEST INSTRUMENTATION AND DATA ACQUISITION

3.2.1 Data Acquisition System

The PSTF Data Acquisition System (DAS) consisted of sensor signal conditioners, amplifiers, filters, a multiplexer/analog-digital converter unit, a Hewlett-Packard minicomputer, and a digital tape handler. The multiplexer/analog-digital converter received analog voltage signals from the test instrumentation and converted these to digital counts. The computer gathered the digital information from the multiplexer, processed it and recorded the information on a digital tape. A total of 64 DAS channels were used for Test Series 5200. All channels were scanned and recorded on tape every 9.3 msec (approximately 100 samples per second) during the blowdown. This is referred to as "real-time" data acquisition.

Those signals containing frequencies too high to be resolved in the 9.3-msec scan time of the DAS were recorded by a Honeywell 28-channel analog record/playback tape machine at one tape speed during the test for post-test playback through the DAS at a slower tape speed. This data recording process resulted in an increased effective data acquisition scan rate referred to as "replay data" acquisition.

Figure 3-2 illustrates the data flow for the real-time data acquisition during the test and for the replay data acquisition after the test.

3.2.2 Test Instrumentation

The type, locat and ranges of the instruments used in Test Series 5200 were specifically selected for the purpose of measuring the CO phenomena. These instruments were also adequate for measuring most chugging and pool swell phenomena.

Although signals for all instruments connected to the 64 DAS channels were recorded during real-time data acquisition, 37 of these instruments were designated as real-time instruments and 27 as replay instruments.

Real-time instruments were primarily used to measure the thermodynamic performance of the steam generator, blowdown line, drywell, vent, suppression pool and wetwell freespace. These applications did not require frequency resolution beyond the 30-Hz cutoff provided by the 9.3 msec scan rate of the real-time data acquisition. All real-time pressure signals were filtered by a 30-Hz, low-pass, 3-pole Bessel filter prior to digitization to prevent aliasing. Aliasing is the misinterpretation of the frequency composition of digital data. To avoid aliasing of a given frequency it is necessary to record at least two data points per cycle. Thus, 30-Hz is a conservative high cutoff frequency which can be resolved with the 9.3 msec scan time.

Replay instrumentation was used in locations where the signal frequency content is broad and frequency components above the real-time 30-Hz cutoff frequency were of interest. Signals from those transducers designated as replay transducers were low-pass filtered at 10 kHz and recorded during the test on analog tape using the 28-channel analog recorder. Following completion of the test the analog tape was replayed at reduced speed (8:1 reduction) and the recorder output was sampled by the DAS. The reduced speed coupled with a slightly higher DAS scan rate increases the effective sample rate of the replay data to 1000 samples per second on each channel. To prevent aliasing of the replay data, the analog recorder output was filtered by a 30-Hz, low-pass, 3-pole Bessel filter for an effective low-pass frequency of 240 Hz (8 x 30 Hz). Table 3-1 lists the analog record/replay parameters used to attain the 1000 samples per second channel scan rate.

Table 3-1
ANALOG RECORD/REPLAY PARAMETERS

Record Speed	30 ips	DAS Scan Rate	8 ms
Replay Speed	3-3/4 ips	Low-Pass Filter Frequency	30 Hz
Expansion	8:1	(Effective Frequency 8 x 30 Hz = 240 Hz)	

The signals from the transducers designated as replay instruments were digitized during the test and recorded directly on magnetic tape as well as being recorded by the analog recorder. This digitized output of the replay instruments was recorded on the same tape as real-time data. However, since the signals from the replay instruments were initially filtered at 10 kHz, the real-time digitization of this data was susceptible to aliasing errors. Consequently, the real-time data from the replay instruments are not generally used in the subsequent spectral analysis.

Two types of pressure transducers were used. Flush-mount type pressure transducers were used for measurements where high frequency components are expected. Cavity-type differential pressure transducers were used, with the low side of the transducer open to the atmosphere, for measuring system response of the steam generator, venturi throat, drywell dome and wetwell freespace pressures. The transducers used to determine steam generator and wetwell water levels were also differential pressure transducers, but they had their high and low taps connected so they only responded to changes in the water level and not to changes in system pressure. Both the flush-mount and the cavity-type differential pressure transducers use the strain gage diaphragm principle for measuring pressure. One characteristic of the flush-mount pressure transducer is the thermal sensitivity due to the change in resistance of the strain gage element. Large thermal gradients across some of the flush-mount pressure transducers during a blowdown produced substantial thermal drift of the output at some locations. However, this thermal drift did not affect the dynamic portion of the pressure signals, and it was eliminated from analysis by linear trend removal (see Subsection 3.5). This linear trend removal preserved the original amplitude and frequency content of the dynamic portion of these pressure signals. All flush-mount transducers were replay instruments and all cavity-type transducers were real-time instruments.

Thermocouples were 1/8-in stainless steel sheathed, iron-constantan (Type J) with grounded tip reduced to 0.09-in diameter. The thermocouples were real-time instruments. Eight thermocouples were filtered at 10 Hz and eight others were filtered at 3 Hz. Filtering was accomplished using an L-C crossover network.

Accelerometers were of the piezoelectric type. The accelerometers were connected to the DAS through a one-microfarad capacitor and a one-megohm shunt resistor to eliminate DC offset. These AC coupled accelerometers had a low-frequency cutoff of approximately 1 Hz into the DAS. This arrangement was found to be very sensitive to thermal transients, i.e., a sudden change in temperature would cause the accelerometers to become inoperative for several seconds. To avoid this condition, the accelerometers were thermally isolated by bonding them to 1/2-in phenolic pads that were in turn bonded to the metal surfaces of the facility. Installation boxes were also installed around the accelerometers that were immersed in the wetwell pool. The response of the accelerometers mounted on phenolic pads was changed by less than 10 percent from 1 Hz to 500 Hz. The phenolic pads had a resonance in the range of 1000 to 2000 Hz.

Conductivity probes consisted of two insulated wires with 1/2-in of insulation removed from the ends and separated 1/2-in apart. The current through the circuit changes as a function of the conductivity of substance between the ends of the probe. Thus, if the probe is submerged in water, the conductivity is high. A probe surrounded by air or steam has low conductivity.

A capacitance probe was used to indicate the water holdup in the drywell. The probe consisted of two concentric cylinders placed vertically in the base of drywell. As the water level rose in the drywell more of the probe was covered with water and caused a change in the electrical capacitance of the probe which was measured and converted to a voltage output. This measurement was filtered at 30 Hz in Runs 2, 3, 4 and 16 and at 3 Hz for the remainder of the test runs. A sight glass installed on the drywell was used to check the capacitance probe output at the conclusion of each blowdown.

In addition to the measurements recorded on the PSTF DAS and analog tape, two types of data were recorded other ways. Each of the three lower vent lateral restraint arms were instrumented with axial strain gage bridges. Output from these strain gage bridges was recorded on an analog chart recorder.

The air content in the vent flow was monitored by the Steam-Air Sample System and the Oxygen Analyzer System. These systems shared a common vent sample probe and sample line. The Steam-Air Sample System served as the primary measurement system and the Oxygen Analyzer System was a backup. The Steam-Air Sample System consisted of an exhaust manifold with five sample chambers and a time-sequence-and-duration controller for sequential sampling. All sample chambers were evacuated prior to the start of testing. The initiation of the blowdown activated the time-sequence controller. On the completion of the test the sample pressure, temperature and volume of condensed vapor of each sample chamber were measured and recorded for subsequent calculation of the steam-air ratio.

The Oxygen Analyzer System measured the air content of the vent flow by detecting a voltage generated across a heated element. The voltage produced is proportional to the difference in partial pressures of oxygen between the sampled gas mixture and a reference gas. The system converts the measured voltage to a signal which is proportional to the sample oxygen content. The signal was passed to the PSTF DAS and recorded onto magnetic tape as part of real-time data acquisition.

Flow in the vent was monitored by an nubar flow measuring device which operates on the same principle as a pitot tube ut mechanically averages the stagnation pressure across the flow path to accou for the veloci y profile.

3.2.2.1 Steam Vessel Instrumentation

Instrumentation on the steam vessel consisted of ten cavity-type differential pressure transducers. One transducer was used to measur the overall vessel pressure relative to atmospheric and another transducer was used to measure the venturi throat pressure relative to atmospheric. The others were used to measure the vessel liquid/steam mass. The type, range, location and DAS hookup information for the steam vessel instruments are listed in Table 3-2. Figure 3-3 illustrates the location of instrumentation on the steam vessel.

The vessel was divided into seven "nodes" (see Figure 3-3) to measure the vessel steam/liquid mass. Seven transducers measured the differential pressure across each node, and one transducer measured the differential pressure over the total height of the vessel. The nodal transducers effectively measured the density of the steam/liquid mixture in each node, which, when multiplied by the nodal volume, gave the mass of fluid in each node.

All instruments on the steam generator were real-time instruments.

3.2.2.2 Drywell Instrumentation

The drywell instrumentation consisted of three thermocouples, one cavity-type pressure transducer, one flush-mount pressure transducer, and a capacitance-type level probe. The type, range, location and DAS hookup information for the drywell instrumentation are listed in Table 3-3. Figure 3-4 illustrates the positioning of these instruments.

A drywell thermocouple located inside the blowdown line was used to measure the temperature of the flow into the drywell. Two thermocouples were used to measure the drywell temperature. One thermocouple was located in the upper dome of the drywell and another was located in the lower region of the drywell.

The cavity-type pressure transducer was used to measure the drywell pressure relative to atmospheric. The flush-mount was used to measure the dynamic component of the drywell pressure.

The capacitance-type level probe was used to measure the liquid holdup in the drywell for those runs which had the vent riser installed.

All the instruments on the drywell were real-time instruments except the flush-mount pressure transducer.

3.2.2.3 Vent Instrumentation

The vent instrumentation included one thermocouple, five flush-mount pressure transducers, two cavity-type pressure transducers, two accelerometers, a conductivity-type level probe, and a probe supplying the Oxygen Analyzer and

Steam-Air Sample Systems. The type, range, location and DAS hookup information for the vent instruments are listed in Table 3-4. Figure 3-5 illustrates the positioning of these instruments on the vent.

A thermocouple located inside the vent approximately 15 feet from the entrance was used to measure the fluid temperature.

Two cavity-type pressure transducers were used in conjunction with an annubar flow measuring device to measure the vent flow rate. One pressure transducer measured the vent pressure relative to atmospheric pressure and the other measured the differential pressure across the annubar.

The five flush-mount pressure transducers were located at approximately uniform intervals along the vent. They were used to determine if standing acoustic pressure waves were present in the vent during CO.

The two accelerometers were located at the tip of the vent. They measured accelerations in the horizontal direction at two locations 90° apart. Their primary purpose was to indicate the termination of CO. The data is also available for the assessment of vent lateral loads.

The conductivity-type level probe located 6 inches from the vent tip was used to determine when water first reentered the vent as the definition of the initiation of chugging.

A sampling probe was located approximately 4 feet below the vent inlet. Piping from the probe carried steam and air to the Oxygen Analyzer and Steam-Air Sample Systems. This 1/2-in pipe was approximately 10 feet in length. Both of these systems were used to measure the vent air content.

3.2.2.4 Wetwell Instrumentation

The wetwell instrumentation consisted of twelve flush-mount pressure transducers, two cavity-type pressure transducers, six accelerometers, twelve thermocouples, and three strain gages. The type, range, location and DAS hookup information for each of the wetwell instruments are listed in Table 3-5.

Eleven thermocouples located in the suppression pool measured the temperature distribution in the pool to establish an estimate of the bulk average pool temperature. These thermocouples were suspended by 1/4-inch steel cables attached to the pool wall. The twelfth thermocouple was located near the top of the wetwell to measure the wetwell airspace temperature. The position of each wetwell thermocouple is shown in Figure 3-6.

Eleven of the flush-mount pressure transducers were located on the wetwell wall. The twelfth flush-mount pressure transducer was located on the center of the wetwell floor. These transducers measured the pool boundary pressure loads due t CO.

Two accelerometers located near the outside top of the wetwell were oriented so they would record horizontal accelerations in two orthogonal directions. In Runs 25, 26, 27 and 28 these accelerometers were reoriented to a vertical position to obtain a measurement of facility vertical acceleration.

Two accelerometers located on the wetwell wall were oriented so they would record the radial wall accelerations. Another accelerometer measured vertical acceleration on the center of the wetwell floor plate. An accelerometer located external to the pool on the wetwell bottom flange was oriented so it would record gross facility vertical acceleration. In Runs 25, 26, 27 and 28, the accelerometer located on the wetwell wall at the 12-ft elevation was relocated on the wetwell floor at a location 2 feet from the center of the baseplate and at a vessel azimuth of 150°.

Two strain gages were located on the wetwell wall to measure the wetwell vessel hoop stress. Another strain gage was located on the wetwell floor to measure stress in the bottom plate. In Run 25, 26, 27 and 28, the strain gage located on the wetwell wall at the 12-ft elevation was relocated on the wetwell floor at a location adjacent to the baseplate strain gage.

One cavity-type pressure transducer was used to measure the wetwell airspace pressure relative to atmospheric pressure. For most of the runs in the test series, a second cavity-type pressure transducer was used to measure the wetwall pool level. In Runs 1, 17, 18, 19, 20, 21 and 23 this transducer was used to measure the wetwell-drywell differential pressure.

The location of the pressure transducers, accelerometers, and strain gages is shown in Figure 3-7. The location key Zaa Rbb Tcc is defined as:

aa = elevation from wetwell baseplate (ft).

bb = radial distance from wetwell centerline (ft).*

cc = azimuth with 0° North, 90° East (degrees).

3.2.2.5 Miscellaneous Instrumentation

A vacuum breaker valve installed in a 4-in line which connected the wetwell freespace with the drywell was instrumented to monitor the valve's position. This valve was not typical of a Mark II vacuum breaker, but used only as a safety device. During the early part of the test series, the pallet was equipped with a microswitch to indicate the valve open and closed position. During the latter part of the test series the valve was equipped with a variable potentiometer to determine the pallet's position in degrees. This measurement was filtered at 10 Hz.

Each of the lower three downcomer lateral restraint arms were instrumented with strain gages as shown in Figure 3-8. These strain gages were arranged in a half-bridge configuration so that only axial strain was measured and vertical bending strain was self-canceling. These strain gages were not monitored by the DAS system, but the data they provided were recorded on a strip chart recorder. Table 3-6 summarizes the miscellaneous instrumentation.

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*Wetwell wall radius is 3.5 feet.
Vent radius is 1.0 foot.

Table 3-2

STEAM VESSEL INSTRUMENTATION

Measurement	Instrument	Instrument Location	Instrument Range	Measurement Type	DAS Filter Frequency (Hz)
Vessel Pressure	Cavity ΔP Transducer	Vessel Upper Dome	0-2000 psi	Real-Time	30
Venturi Throat Pressure	Cavity ΔP Transducer	Venturi Throat	0-2000 psi	Real-Time and Replay*	30
Vessel Liquid/Steam Mass	Cavity ΔP Transducer	Vessel Node 1	0-5 psi	Real-Time	30
Vessel Liquid/Steam Mass	Cavity ΔP Transducer	Vessel Node 2	0-5 psi	Real-Time	30
Vessel Liquid/Steam Mass	Cavity ΔP Transducer	Vessel Node 3	0-5 psi	Real-Time	30
Vessel Liquid/Steam Mass	Cavity ΔP Transducer	Vessel Node 4	0-5 psi	Real-Time	30
Vessel Liquid/Steam Mass	Cavity ΔP Transducer	Vessel Node 5	0-5 psi	Real-Time	30
Vessel Liquid/Steam Mass	Cavity ΔP Transducer	Vessel Node 6	0-5 psi	Real-Time	30
Vessel Liquid/Steam Mass	Cavity ΔP Transducer	Vessel Node 7	0-5 psi	Real-Time	30
Vessel Liquid/Steam Mass	Cavity ΔP Transducer	Vessel Overall	0-10 psi	Real-Time	30

*This pressure was recorded on the analog tape as a blowdown initiation reference.

Table 3-3

DRYWELL INSTRUMENTATION

Measurement	Instrument	Instrument Location	Instrument Range	Measurement Type	DAS Filter Frequency (Hz)
Drywell Static Pressure	Cavity ΔP Transducer	Drywell Upper Dome	0-100 psi	Real-Time	30
Drywell Acoustic Pressure	Flush-Mount Pressure Transducer	Drywell Wall	0-100 psi	Replay	10k
Drywell Temperature	Thermocouple	Drywell Upper Dome	50-550 °F	Real-Time	10
Drywell Temperature	Thermocouple	Drywell Lower Dome	50-550 °F	Real-Time	10
Blowdown Flow Temperature	Thermocouple	Blowdown Line Exit	50-550 °F	Real-Time	10
Drywell Liquid Level	Capacitance Probe	Drywell Floor	0-26 in.	Real-Time	3

Table 3-4

VENT INSTRUMENTATION

Measurement	Instrument	Instrument Location[a]	Instrument Range	Measurement Type	DAS Filter (Hz)
Vent Acoustic Pressure	Flush-Mount Pressure Transducer	Z51.5R1T315	0-100 psi	Replay	10k
Vent Acoustic Pressure	Flush-Mount Pressure Transducer	Z42.5R1T315	0-100 psi	Replay	10k
Vent Acoustic Pressure	Flush-Mount Pressure Transducer	2.5R1T315	0-100 psi	Replay	10k
Vent Acoustic Pressure	Flush-Mount Pressure Transducer	Z22.5R1T315	0-100 psi	Replay	10k
Vent Acoustic Pressure	Flush-Mount Pressure Transducer	Z12.5R1T315	0-500 psi[d]	Replay	10k
Vent Flow Temperature	Thermocouple	Z42.5R0.0T180	50-550°F	Real-Time	10
Vent Air Content	Oxygen Analyzer	Z53R0.0T180	0-100% Air	Real-Time	30
Vent Air Content	Steam-Air Sample System[b]	Z53R0.0T180	0-100% Air	N/A	N/A
Vent Static Pressure	Cavity ΔP Transducer	Z42.5R1T310	0-100 psi	Real-Time	30
Annubar Differential Pressure	Cavity ΔP Transducer	Annubar at Z41.5	0-10 psi[e]	Real-Time	30
Chug Initiation	Accelerometer	Z12.5R1T55	±250g[f]	Replay	10k
Chug Initiation	Accelerometer	Z12.5R1T145	±250g[f]	Replay	10k
Vent Water Level	Conductivity Probe	Z12.5R1T310	N/A[c]	Real-Time	30

[a] This location code gives the location of the measurement in cylindrical coordinates; Z is elevation from wetwell floor in feet. R is distance from wetwell vertical axis in feet and T is the angular position in degrees from North.

[b] This measurement system is not part of data acquisition. (See Paragraph 3.2.2.)

[c] Detects only absence or presence of liquid.

[d] 0-100 psi for Runs 13 and 16

[e] 0-50 psi for Runs 4 through 17 and 22.

[f] ±60g for Runs 2 and 16, ±100g for Run 3.

Table 3-5

WETWELL INSTRUMENTATION

Measurement	Instrument	Instrument Location[a]	Instrument Range	Measurement Type	DAS Filter (Hz)
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z20R3.5T45	0-100 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z200R3.5T225	0-100 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z20R3.5T315	0-100 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z12R3.5T0	0-500 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z12R3.5T45	0-100 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z12R3.5T225	0-100 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z12R3.5T315	0-100 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z06R3.5T0	0-500 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z02R3.5T45	0-100 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z02R3.5T225	0-100 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z02R3.5T315	0-100 psi	Replay	10k
Pool Boundary Pressure	Flush-Mount Pres. Trans.	Z0.75R3.5T0	0-100 psi[b]	Replay	10k
Suppression Pool Temp.	Thermocouple	Z20R3.5T202.5	50-550°F	Real-Time	10
Suppression Pool Temp.	Thermocouple	Z13R2.0T180	50-550°F	Real-Time	10
Suppression Pool Temp.	Thermocouple	Z13R3.5T180	50-550°F	Real-Time	10
Suppression Pool Temp.	Thermocouple	Z09R0.0T180	50-550°F	Real-Time	10
Suppression Pool Temp.	Thermocouple	Z09R2.0T180	50-550°F	Real-Time	3
Suppression Pool Temp.	Thermocouple	Z09R3.5T180	50-550°F	Real-Time	3
Suppression Pool Temp.	Thermocouple	Z07R0.0T180	50-550°F	Real-Time	3
Suppression Pool Temp.	Thermocouple	Z07R2.0T180	50-550°F	Real-Time	3
Suppression Pool Temp.	Thermocouple	Z05R0.0T180	50-550°F	Real-Time	3
Suppression Pool Temp.	Thermocouple	Z05R3.5T180	50-550°F	Real-Time	3

Table 3-5

WETWELL INSTRUMENTATION (Continued)

Measurement	Instrument	Instrument Location[a]	Instrument Range	Measurement Type	DAS Filter (Hz)
Suppression Pool Temperature	Thermocouple	Z02R3.5T180	50-550°F	Real-Time	3
Wetwell Airspace Temperature	Thermocouple	Z48R3.5T11.25	50-550°F	Real-Time	3
Facility Response	Accelerometer	Z0R3.5T45	±6g	Real-Time	30
Facility Response	Accelerometer	Z45R3.5T45	±6g	Real-Time	30
Facility Response	Accelerometer	Z45R3.5T315	±6g	Real-Time	30
Structural Response	Accelerometer	Z0.0R0.08T270	±60g	Replay	10k
Structural Response	Accelerometer	Z06R3.5T0.0	±60g	Replay	10k
Structural Response	Accelerometer	Z12R3.5T0[e]	±60g	Replay	10k
Structural Response	Strain Gage	Z0.0R0.0T0	±500μin/in	Replay	10k
Structural Response	Strain Gage	Z06R3.5T0	±500μin/in	Replay	10k
Structural Response	Strain Gage	Z12R3.5T0[f]	±500μin/in	Replay	10k
Wetwell Airspace Pressure	Cavity ΔP Transducer	Z51R3.5T225	0-100 psi	Real-Time	30
Suppression Pool Level[c]	Cavity ΔP Transducer	High Side-Z30, Low Side-Z20	0-5 psi	Real-Time	3
Wetwell-Drywell ΔP[d]	Cavity ΔP Transducer	Low Side-Vent	0-10 psi	Real-Time	30

[a] Location code identical to that used in Table 3-6

[b] Runs 1-26, 0-500 psi used for Runs 27 and 28

[c] Runs 1-16, 22

[d] Runs 1, 17-21, 23-28

[e] Relocated to Z0.0R2.67T180 for Runs 25, 26, 27 and 28

[f] Relocated to Z0.0R0.0T0 for Runs 25, 26, 27 and 28

Table 3-6

MISCELLANEOUS INSTRUMENTATION

Measurement	Instrument	Instrument Location[a]	Instrument Range	Measurement Type	DAS Filter (Hz)
Vacuum Breaker Position	Microswitch[a]	Vacuum Breaker	on-off	Real-Time	30
	Variable Potentiometer[b]	Vacuum Breaker	0-90°	Real-Time	30
Downcomer Lateral Loads[c]	Strain Gage	Lower Restraint Arm 0°	±500 μin/in	N/A	30
Downcomer Lateral Loads[c]	Strain Gage	Lower Restraint Arm 120°	±500 μin/in	N/A	30
Downcomer Lateral Loads[c]	Strain Gage	Lower Restraint Arm 240°	±500 μin/in	N/A	30

[a]Runs 2, 3, 4, 6, 8, 9, 12, 13

[b]Runs 1, 5, 7, 10, 11, 14, 15, 16, 17-28

[c]Recorded on strip chart recorder

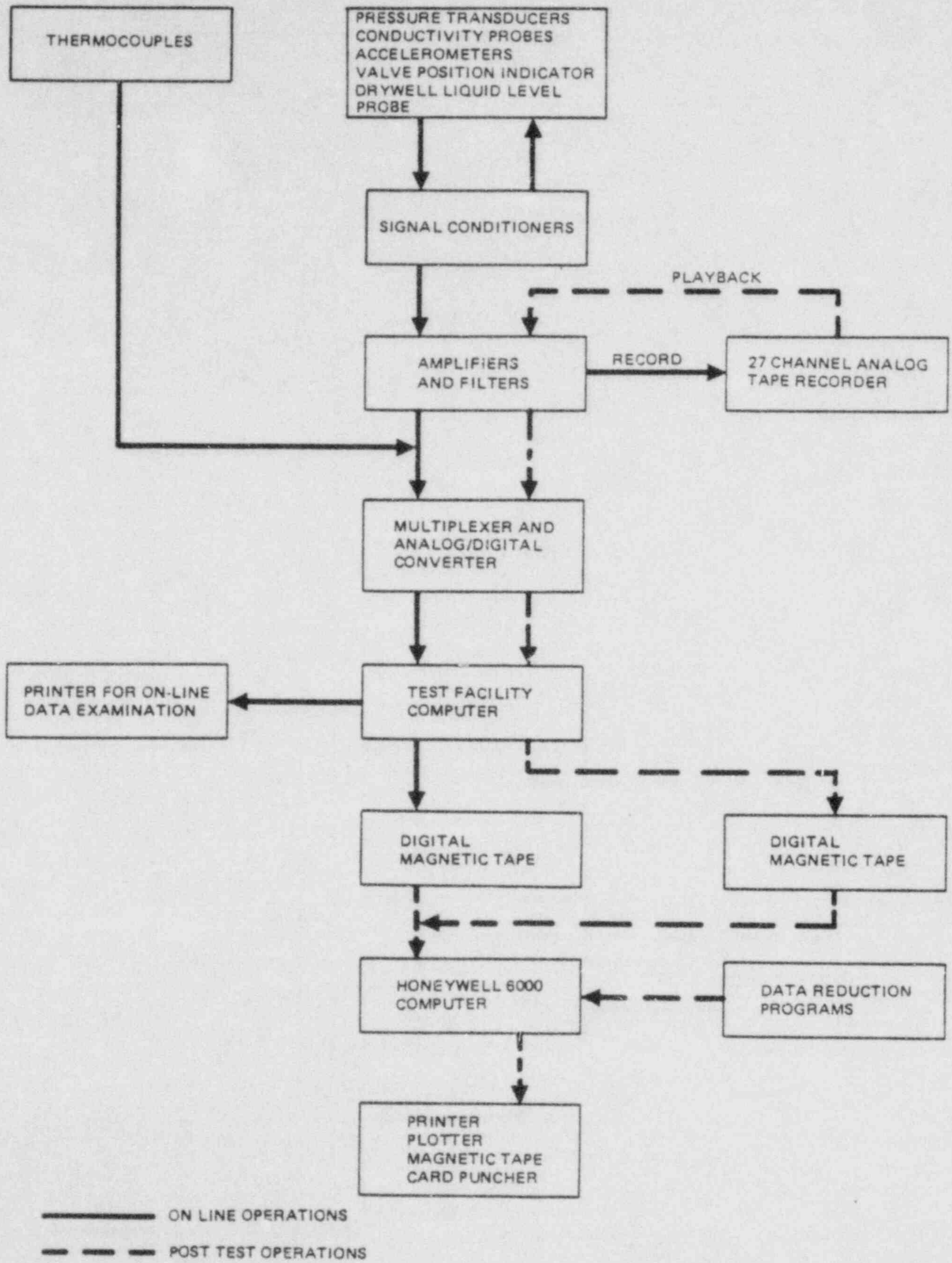

Figure 3-2. Pressure Suppression Test Facility Data Acquisition and Reduction System Block Diagram

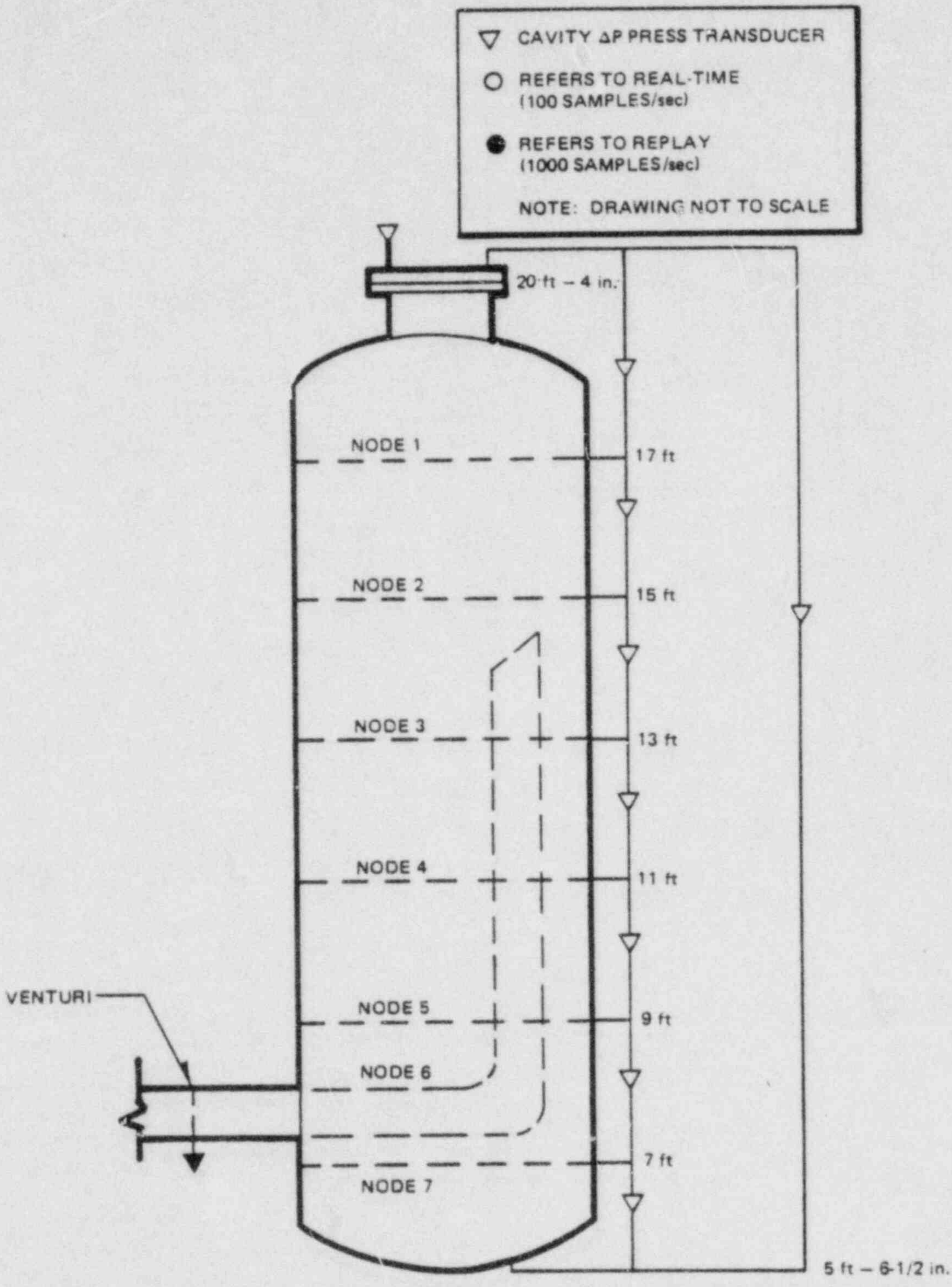

Figure 3-3. Steam Vessel and Blowdown Line Instrumentation

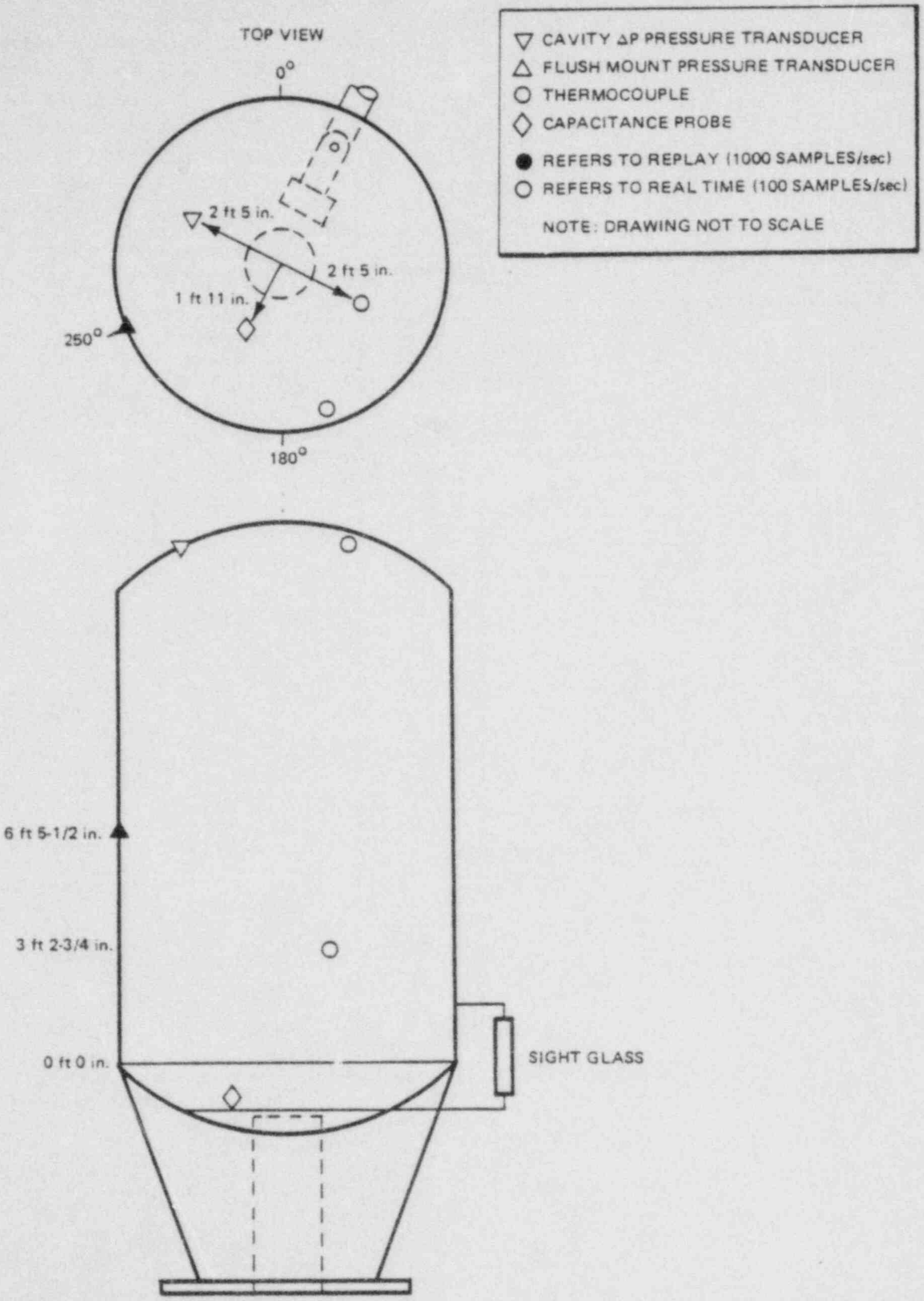

Figure 3-4. Drywell Instrumentation

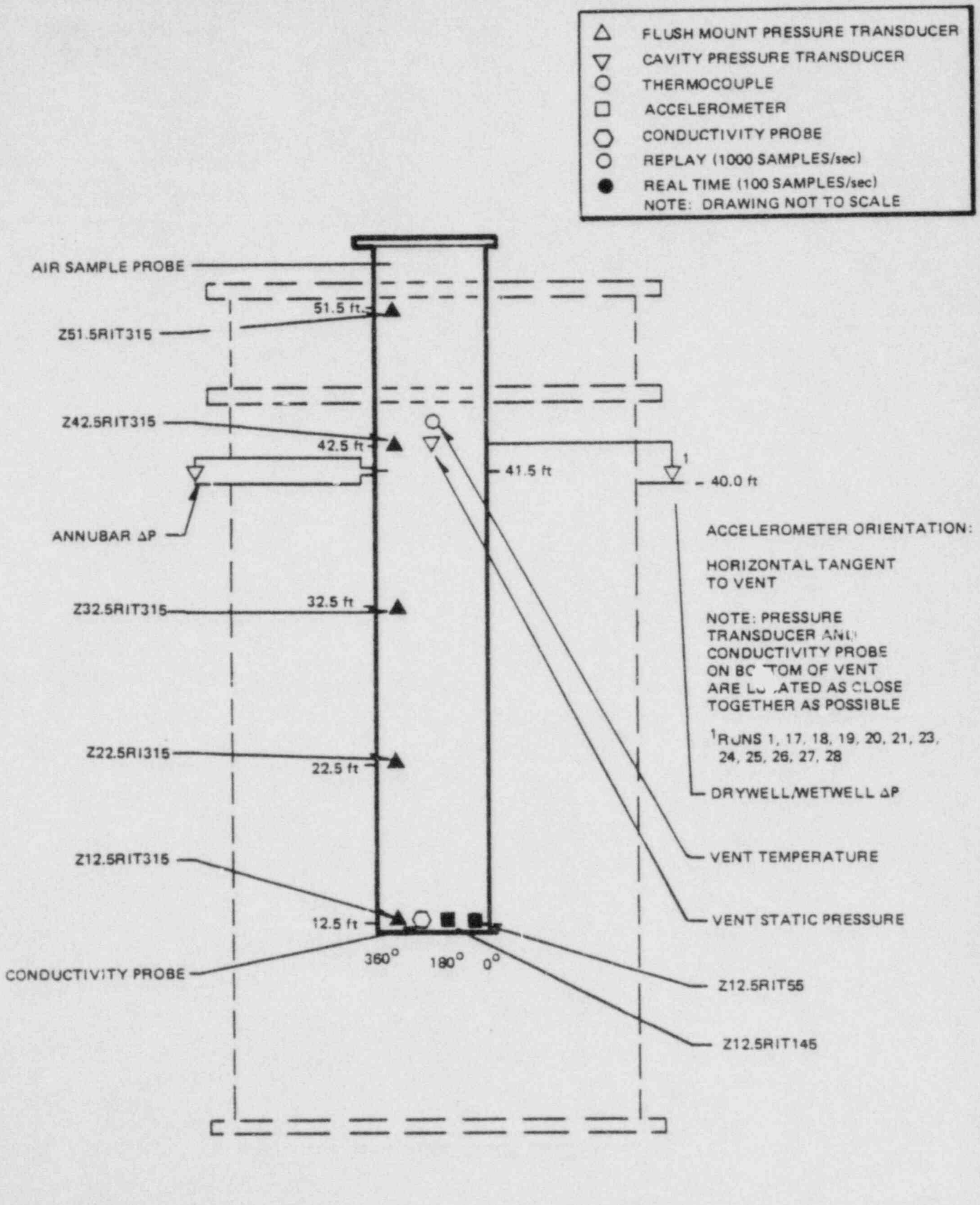

Figure 3-5. Vent Instrumentation

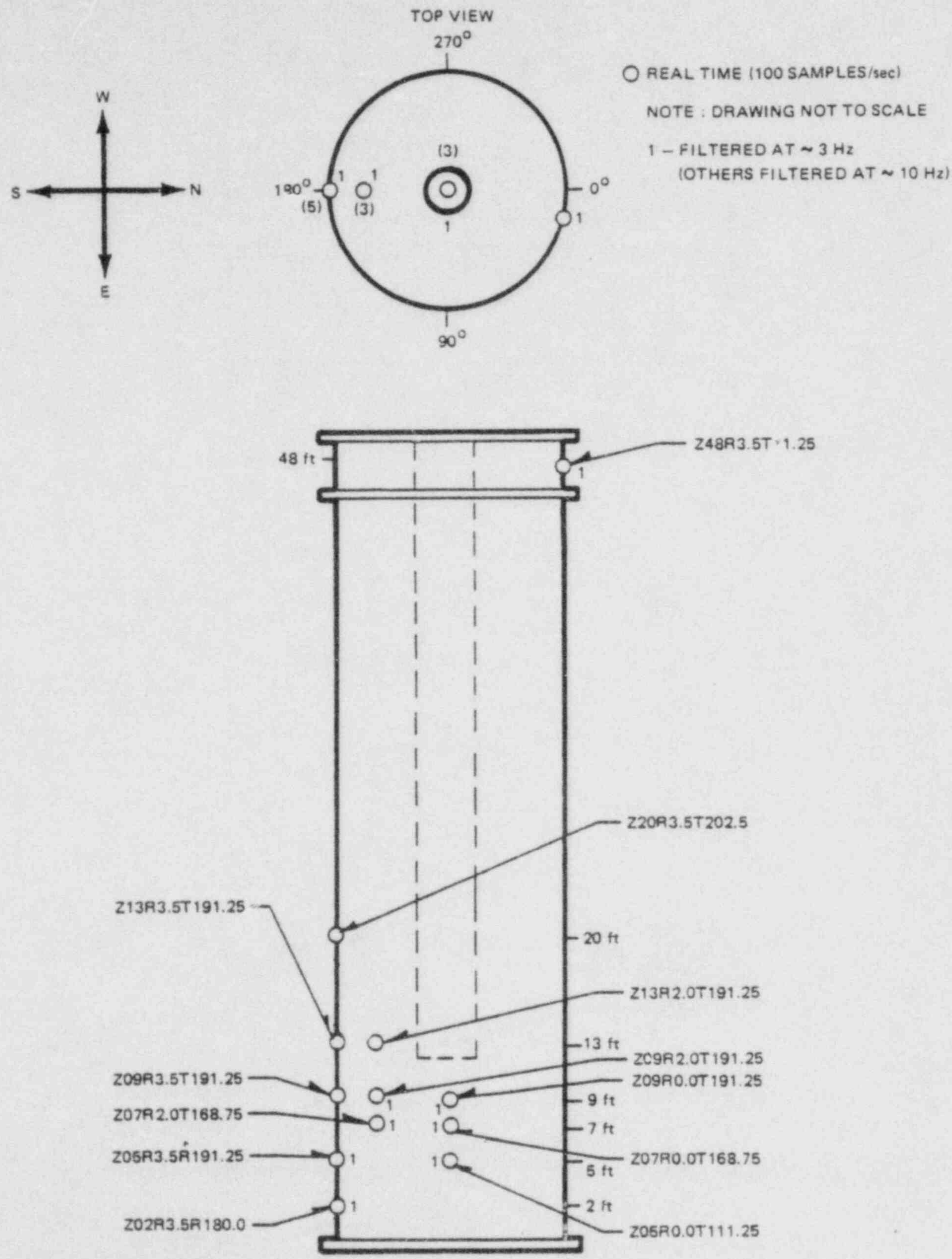

Figure 3-6. Wetwell and Suppression Pool
Instrumentation - Thermocouples

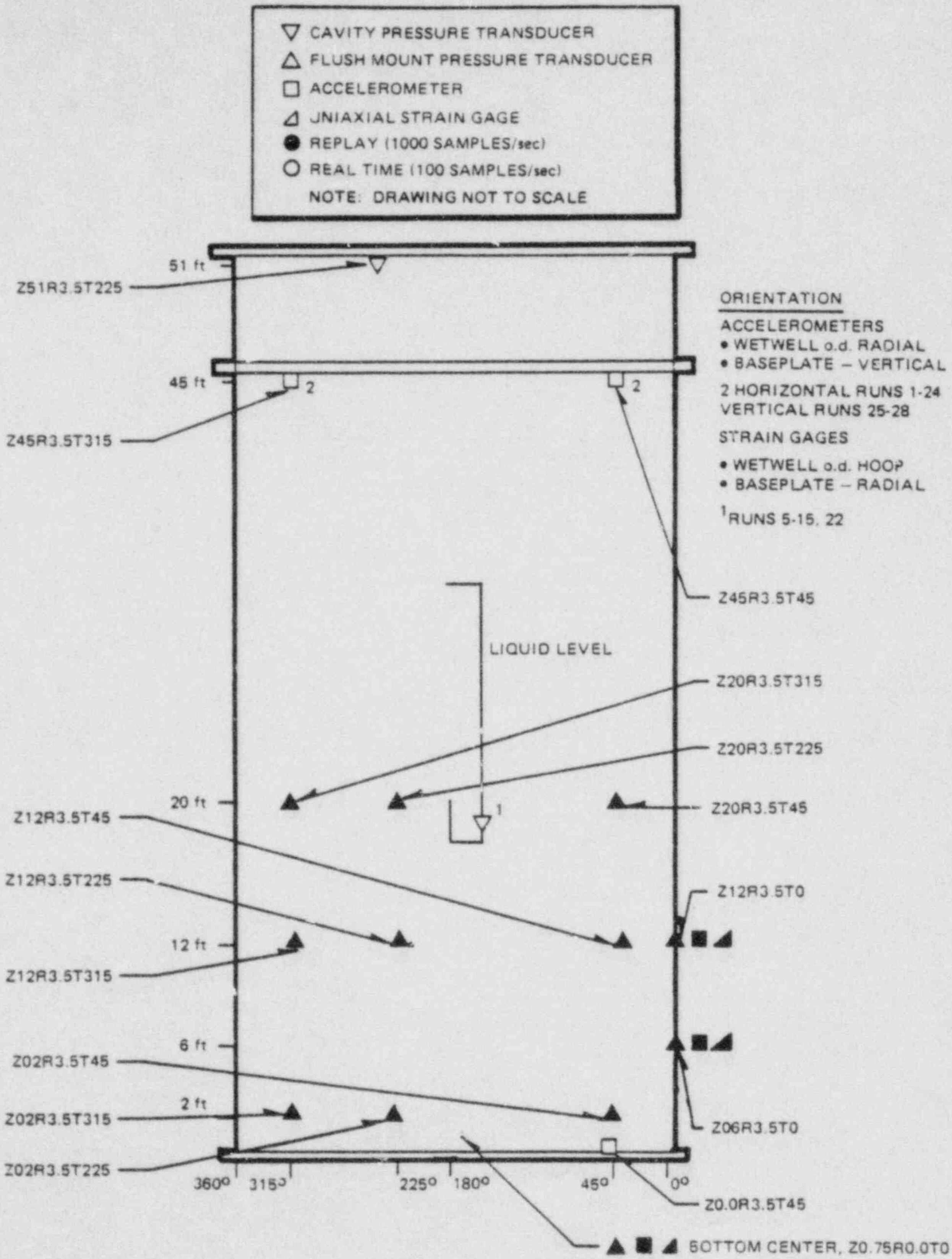

Figure 3-7. Wetwell and Suppression Pool Instrumentation-Pressure, Acceleration, and Strain

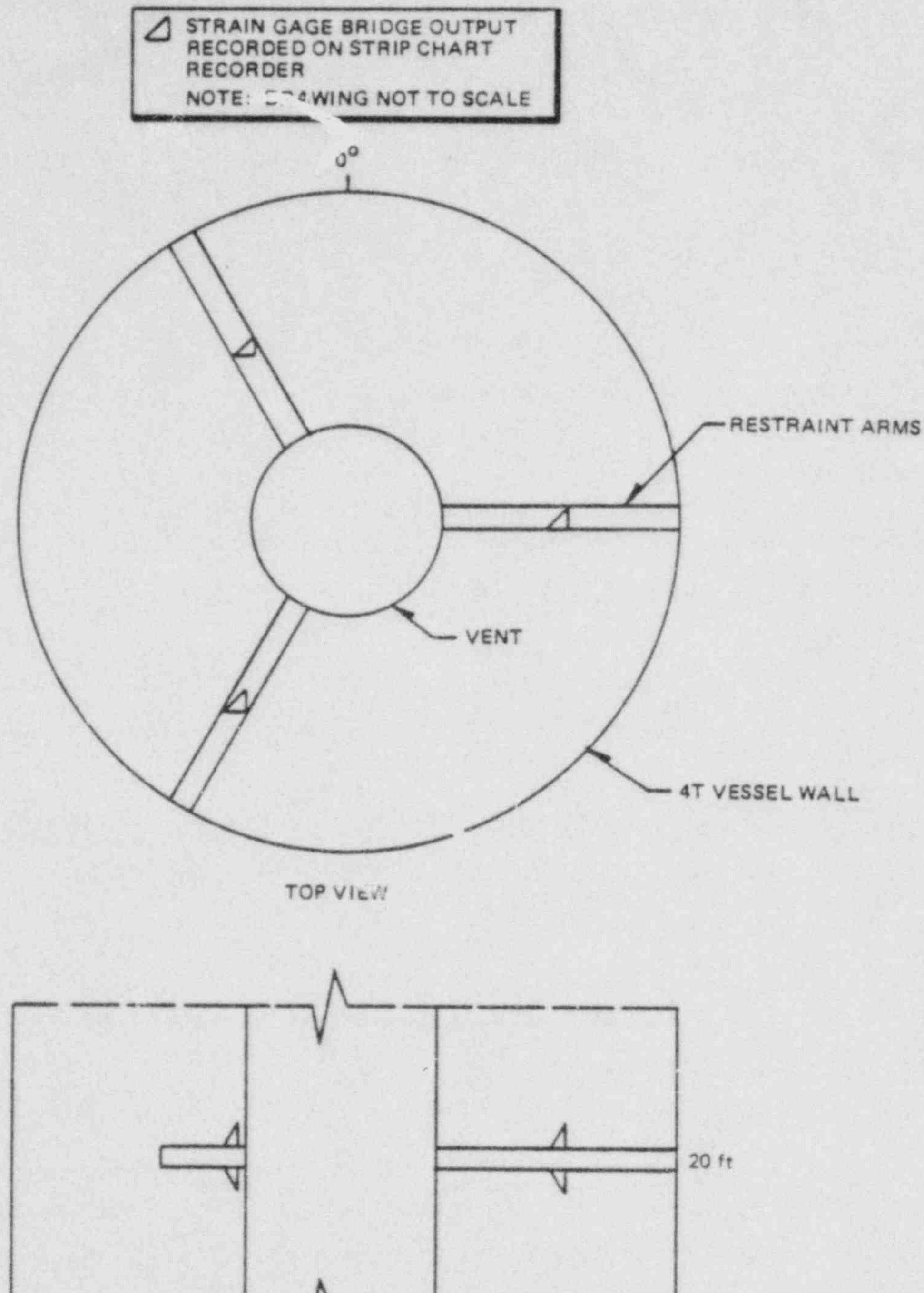

Figure 3-8. Downcomer Restraint Arm Instrumentation

3.3 TEST MATRIX

The development of the test matrix for the Mark II 4T Condensation Oscillation (4TCO) Test Program was a major effort in the plans and preparation for the tests. The independent test parameters were carefully selected to satisfy the principal program objectives which were:

a. Provide data for confirmation of the Mark II Condensation Oscillation Load Specification (DFFR Rev. 3).

b. Evaluate the effects on CO of vent length and vent liquid flow over the range of Mark II Condensation Oscillation conditions.

It was determined that these objectives could be accomplished if the test matrix were configured to include blowdowns which:

a. Bound the range of Mark II CO conditions, including pool temperature, vent steam mass flux, vent steam quality and vent air content.

b. Duplicate the independent test parameters of previous 4T Test Series 5101 test runs to determine the effect of the 4TCO vent length reduction on CO pool pressure amplitude and frequency content.

c. Have a vent riser installed to retain water in the drywell during a liquid blowdown to determine the effect of vent liquid flow on CO pool pressure amplitude and frequency content.

d. Provide data showing the effect of pool temperature, vent submergence and air content on CO pool pressure amplitude and frequency content.

e. Demonstrate the degree of repeatability of the test data.

The independent test parameters available for the test engineer to define the test matrix include blowdown type (liquid or steam), venturi size, initial steam vessel inventory, initial pool temperature, initial wetwell water level (submergence), the initial drywell air content, and a jet deflector and vent riser for the drywell that could be installed or removed.

A substantial amount of analysis was completed prior to testing to select combinations of blowdown type, venturi size, and initial pool temperature to bound the range of Mark II CO conditions. The Mark II conditions were established by plotting "maps" of predicted vent steam mass flux vent air content and vent steam quality as a function of pool temperature for postulated steam line and recirculation line breaks for the different Mark II plants.

The first result of this work was a recognition that, because of predicted level swell in the reactor vessel and subsequent carryover of liquid through the break, the steam quality in the drywell would be expected to be about the same for both steam line (quality ≈ 40 percent) and recirculation line breaks (quality ≈ 30 percent). Thus, in the 4TCO test facility both of these types of postulated reactor blowdowns are best simulated by liquid blowdowns (quality ≈ 33 percent). Therefore, liquid blowdowns were selected for all of the 4TCO test runs except those which were repeats of conditions tested in the 4T Test Series 5101 tests (see Reference 2).

The largest venturi size (3.82-in diameter) was selected to result in a vent steam mass flux which would slightly exceed the maximum postulated steam mass flux for any of the Mark II plant conditions. It was decided that the initial steam vessel inventory for all 4TCO liquid blowdowns should be the maximum possible in order to maximize the range of pool temperatures covered by each run. The range of initial temperature of 70°F to 110°F was selected on the basis that the final pool temperature calculated for the Mark II plants would be bounded by the 4TCO test runs. The 110°F initial pool temperature is in excess of the maximum Mark II initial pool temperature. A total of nine liquid blowdowns with 11-ft submergence, four different venturi sizes, and four different initial pool temperatures were selected to cover the range of Mark II CO conditions. These are Runs 2, 3, 5, 7, 8, 9, 12, 13 and 14 shown in Table 3-7. Additional information on the selection of venturi sizes and pool temperatures for the test matrix and comparison with Mark II predictions is presented in Appendix I.

Following a review of the test conditions for 4T Test Series 5101 (See References 2 and 3), four steam blowdown conditions were selected to determine the effect of the vent length change. These are Runs 16, 17, 18 and 20 shown in Table 3-7. Steam blowdowns were chosen because there were no liquid blowdowns with the 24-in diameter vent in 4T Test Series 5101.

The vent riser was installed during these tests to retain any liquid in the drywell which might be carried over from the steam vessel. This simulates the ground-level positioned drywell used in the 4T Test Series 5101. Run 21 is a repeat of the conditions for Run 20, except with the jet deflector removed. This run was included to verify that differences between the 4TCO data and the 4T Test Series 5101 data could be attributed to vent length, and were not a result of the jet deflector (not used in 4T Test Series 5101).

Runs 1, 4, 15, 24, 25 and 26 are repeats of other test conditions, except for the installation of the vent riser. This provides six pairs of blowdowns for evaluating the effect of the vent liquid flow on pool pressure signals.

Submergence variation between representative Mark II values of 9 feet and 13.5-feet for liquid blowdowns was provided by Runs 10, 11 and 27.

The drywell was partially prepurged with steam in Run 6 to investigate the effect of the initial drywell air content.

to establish repeatability, Run 19, 22, 23 and 28 were included with initial conditions that duplicated Runs 18, 9, 8 and 26, respectively.

The complete test matrix with both actual and nominal initial conditions is shown in Table 3-7. In conclusion, this conbination of steam and liquid blowdowns bounds the range of Mark II plant CO conditions and provides an adequate range of data to meet all the test program objectives.

Table 3-7

TEST MATRIX AND INITIAL CONDITIONS

Run Number	Date	Time	Blowdown Type	Venturi Dia. (in)	Initial Vessel Press. (psia)	Initial Drywell Metal Temp. (°F)	Nominal Vent Sub-mergence (ft)	Wetwell Initial Target (°F)	Pool Temp. Actual (°F)	Initial Wetwell Freespace Temp. (°F)	Vent Riser
1	1-7-80	11:55	S	3.00	1046	275	11	70	69	60	No
2	10-15-79	17:09	L	3.00	1041	280	11	70	76	83	No
3	10-19-79	17:40	L	3.82	1045	270	11	70	74	72	No
4	10-24-79	12:45	L	3.82	1047	278	11	70	74	73	Yes
5	11-27-79	11:45	L	3.00	1044	278	11	80	79	60	No
6	11-3-79	10:20	L	3.82	1045	275	11	70	71	80	No
7	11-28-79	12:10	L	3.00	1042	280	11	90	93	70	No
8	11-5-79	13:50	L	3.82	1054	275	11	110	111	79	No
9	11-7-79	13:25	L	3.00	1045	277	11	110	114	79	No
10	11-29-79	11:15	L	3.00	1047	277	9	70	73	68	No
11	11-30-79	10:50	L	3.00	1047	278	13.5	70	74	79	No
12	11-9-79	11:55	L	2.50	1049	274	11	110	109	77	No
13	11-12-79	11:15	L	2.125	1052	271	11	110	109	72	No
14	11-19-79	11:00	L	2.125	1045	278	11	70	70	60	No
15	11-16-79	10:30	L	2.125	1046	280	11	70	71	69	Yes
16	10-4-79	15:30	S	3.00	1050	298	11	70	75	76	Yes
17	12-5-79	11:20	S	3.00	1051	270	9	70	71	63	Yes
18	12-10-79	16:05	S	3.00	1048	273	13.5	70	71	65	Yes
19	12-21-79	15:55	S	3.00	1050	270	13.5	70	71	66	Yes
20	12-27-79	14:50	S	2.50	1045	270	11	70	68	59	Yes
21*	1-4-80	15:30	S	2.50	1047	275	11	70	68	61	Yes
22	11-21-79	11:38	L	3.00	1051	267	11	110	109	72	No
23	1-10-80	12:25	L	3.82	1045	278	11	110	108	69	No
24	1-29-80	15:05	L	3.82	1047	265	11	110	111	67	Yes
25	1-31-80	18:15	L	2.50	1046	271	11	110	111	69	Yes
26	2-2-80	10:58	L	3.00	1045	273	11	110	111	80	Yes
27	2-14-80	12:05	L	3.00	1045	270	9	110	110	71	Yes
28	2-15-80	15:26	L	3.00	1047	270	11	110	110	78	Yes

*Jet Deflector Removed

3.4 TEST OPERATIONS

Generally, facility preparation for each run began on the afternoon before the planned blowdown. If instrumentation changes or repairs resulting from the previous blowdown had required entry into the wetwell or drywell, the manway entrances were resealed and the vessel refilled. Heat-up of the drywell was initiated by turning on the gas-fired drywell heater and the electric blowdown line heaters. These heaters remained on overnight so the facility would be at operating temperature on the morning of the test. During the heat-up period the wetwell and drywell vents were left open.

The steam generator was also filled and electric heaters turned-on the afternoon before the test. The automatic controls were set to bring the vessel to approximately 500 psia and maintain that pressure. On the morning of the test, the vessel was heated to 1050 psia under the supervision of the test technicians.

Preparation and checkout of the instrumentation and DAS system was carried out under the direction of the test engineer. Instrument cables leading into the control room were checked to insure they were properly connected to the DAS. Amplifier gain and filter frequency settings for each DAS channel were set and verified. The calibration of the analog recorder was also checked before each test.

Miscellaneous pre-test activities included preparation of the Steam-Air Sample System, calibration of the Oxygen Analyzer, filling and heat-up of the suppression pool, and general facility configuration checkout.

The facility in readiness, the final instrument checkouts were made which consisted of a series of computer printouts of instrument readings. If any instruments were not reading as expected the problem was determined and corrected.

On completion of the final instrument checkout the final sequence activities were started. The drywell was purged with cold air. The wetwell and drywell vents were closed and the blowdown line gate valve opened. Data recording was started on the computer and the analog tape recorder, and the blowdown was initiated by depressurizing the cavity between the rupture disks.

At the completion of the blowdown, the computer and analog tape data recordings were stopped and the blowdown line gate valve closed. The drywell liquid holdup level was read from the drywell sight-glass and the facility vented.

After the facility was secure, the real time digital data was copied onto a separate tape. The data recorded on the analog tape recorder was played back at a slower speed through the DAS and digitized. The real-time copy and replay digital tapes were taken to the Computation Center for processing.

On completion of each test run, the data from all instruments were reviewed to determine if any instruments were inoperable or if any instruments had produced some questionable data. Time histories from the replay data were also reviewed to evaluate them for proper replay, recording, and playback of all replay instruments. The operability of each instrument used in each blowdown in Test Series 5200 is summarized in Table 3-8. Various symbols are used in this table to indicate the different types of malfunctions. This table also shows that overall a good instrument performance was maintained throughout the test series, particularly when noncritical instrumentation such as steam vessel nodal pressures are excluded.

Measurement	1	2	3	4	5	6	7	8
Vacuum Breaker Position								
Downcomer Liquid Level								
Oxygen Analyzer					Q2	I		
Steam-Air Sample System[a]								
Wtwlbase Plate Acc Vertical		I	I			I	Q1	I
Wtwl Vertical Acc Z0R3.5T45								
Wtwl Rad Acc Z6R3.5T0		Q1	I					
Wtwl Rad Acc Z12R3.5T0[b]		Q1	I	I		I		R
Wtwl Lat Acc Z45R3.5T45			I					
Wtwl Lat Acc Z45R3.5T315			Q1					
Dncmr Tan Acc Z12.5R1T55		I	QI	Q1				
Dncmr Tan Acc Z12.5R1T145		I	QI	Q1				
Wtwl Hoop Str Z12R3.5T0[c]								
Wtwl Hoop Str Z6R3.5T0								
Wtwl Bse Plt Str Z0R0T0								
Restraint Arm Str (3)								
Drywell Acoustic Pres.			R			I	R	
Vent Pres Z51.5R1T315								
Vent Pres Z42.5R1T315								
Vent Pres Z32.5R1T315								
Vent Pres Z22.5R1T315		I						
Vent Pres Z12.5R1T315					I		I	RU
Wetwell Pres Z20R3.5T45								
Wetwell Pres Z20R3.5T225		R						
Wetwell Pres Z20R3.5T315			R	RU				
Wetwell Pres Z12R3.5T0								
Wetwell Pres Z12R3.5T45								
Wetwell Pres Z12R3.5T225			I					
Wetwell Pres Z12R3.5T315						R		
Wetwell Pres Z06R3.5T0							R	R
Wetwell Pres Z02R3.5T45							I	
Wetwell Pres Z02R3.5T225								
Wetwell Pres Z02R3.5T315								
Wetwell Pres Z0.75R0.0T0								
Steam Dome Pressure								
Venturi Throat Pressure								
Drywell Dome Pressure								
Vent Static Pressure								
Wetwell Freespace Pres.								
Steam Vessel Total DP								
Steam Vessel Node 1 DP								
Steam Vessel Node 2 DP								
Steam Vessel Node 3 DP							I	
Steam Vessel Node 4 DP								
Steam Vessel Node 5 DP								

Table 3-8

TEST SERIES 5200 INSTRUMENTATION
OPERABILITY SUMMARY

Run Numbers

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
					I						I								
	Q2	Q2			I			I	I	Q2	Q2	Q2							
Q1			Q1			Q1	Q1				Q1	Q1	Q1	Q1	Q1	Q1			
						Q1								Q1		Q1			
						RU	Q1									Q1			
						RU	Q1									Q1			
									Q1	Q1	Q1								
							Q1												
							Q1												
						Q1					Q1				I	I	Q2	I	I
				I															
							I1												
						R													
							R												
			R			I		Q1				Q1							
							R												
															R	R	R	R	R
																			R
							I											R	R
R	R					Q1/ RU													
	I	I					Q1	I											
																			R
																	I		
				I															
															I	I			
			I																
	I	I	I																
															I				

Measurement	1	2	3	4	5	6	7	8
Steam Vessel Node 6 DP								
Steam Vessel Node 7 DP							I	
Annubar Differential Pres.[d]								
Wetwell Liquid Level DP								
Drywell Liquid Level								
Blowdown Line Exit Temp								
Drywell Dome Temp								
Drywell Lower Temp								
Vent Flow Temp								
Wtwl Pool Temp Z20R3.5T202.5								
Wtwl Pool Temp Z13R2.0T191.25								
Wtwl Pool Temp Z13R3.5T191.25								
Wtwl Pool Temp Z09R0.0T191.25								
Wtwl Pool Temp Z09R2.0T191.25								
Wtwl Pool Temp Z09R3.5T191.25								
Wtwl Pool Temp Z07R0.0T168.75								
Wtwl Pool Temp Z07R2.0T168.75								
Wtwl Pool Temp Z05R0.0T191.25								
Wtwl Pool Temp Z05R3.5T191.25								
Wtwl Pool Temp Z02R3.5T180.0								
Wtwl Freespace Z48R3.5T11.25								

I - instrument inoperative

I1 - One of the 3 restraint arm bridges failed.

Q1 - Instrument had questionable data due to thermal drift or satura

Q2 - Data had some drop outs.

R - Replay for this instrument not usable for analysis.

RU - Replay for this instrument had questionable resp[illegible] some c

[a]1 of the 5 chambers leaked during Runs 2, 3, 4, 6, 9, 10, 12, 13, 1

[b]This became the baseplate accelerometer (Z0.0R2.6T180) for Runs 25

[c]This became the baseplate strain gage (Z0.0R0.0T0) for Runs 25, 26

[d]The annubar differential pressure consistently contained large osc

Table 3-8

TEST SERIES 5200 INSTRUMENTATION OPERABILITY SUMMARY (Continued)

Run Numbers

9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
																	I		
							I												

tion.

f data still usable for analysis.

4, 15, and 19.

, 26, 27, 28.

, 27, 28.

llations which were impossible to interpret.

3.5 DATA REDUCTION

The data reduction is divided into four major parts; real-time data, replay data, PSD analyses, and non-computer data reduction. A description of these activities is presented in this subsection.

3.5.1 Real-Time Data

Plots and tables in engineering units (EU) of the signals from all real-time transducers were generated. The two time scales used were 0 to 40 seconds and 0 to 120 seconds.

Generally, the 0 to 40 second plots cover that portion of the blowdown when CO occurred, and the 0 to 120 second plots cover the entire blowdown. Print density on the plots is such that all data points are not plotted; consequently, peak-to-peak amplitudes taken from these plots will not be accurate. Plots and tables in EU were produced for the following calculated quantities:

a. Blowdown flow rate (total liquid + vapor)

b. Steam generator mass inventory

c. Water mass and volume holdup in drywell

d. Suppression pool liquid bulk temperature*

e. Suppression pool liquid local average temperature near vent exit*

f. Suppression pool time averaged local temperatures

g. Air content in vent [air mass/(steam + air mass)] on a continuous basis

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*The bulk pool temperature was measured by all eleven of the wetwell thermocouples, and the local bulk temperature was measured by the five thermocouples at the 9-foot and 13-foot elevations. These bulk temperatures were calculated using a weighted average of the wetwell thermocouples. Each thermocouple was given a representative pool volume. Then the thermocouple readings were averaged using their assigned volumes as the weighting factor.

Digital magnetic tapes* in EU of all the real-time data were produced for all runs. The vent restraint arm strain gage data were taken on strip chart recordings and examined for the largest loads occurring during CO.

3.5.2 Replay Data

Analog - Digital Conversion

All analog recorder channels (see replay instrumentation Tables 3-2 through 3-5) were replayed and digitized at an effective sample rate of 1000 samples/second over the duration of the blowdown. Plots and tables of this data over the duration of CO were produced. The data has only the dynamic components included, i.e., a rolling average trend removal routine using a 200-point average was used to remove DC and low frequency (∿ 2 Hz) signals. Plots were for 10-second segments for as many segments as necessary to cover the CO duration. The plot density is 100 points/inch so that some data were not plotted as in the case of the real-time data.

Digital magnetic tapes* of the analog data in EU as digitized without trend removal or averaging were generated.

3.5.3 PSD Analysis

PSD analyses were performed on the output of the following four transducers for all runs:

1. Drywell pressure
2. Vent pressure at 12.5-foot elevation (near vent exit)
3. Wetwell wall pressure at 12-foot elevation
4. Wetwell bottom center pressure

The transducers were grouped in three pairs for the PSD analyses; 1-2, 3-4, and 2-4. The PSD analyses included plots of the CPSD, relative phase, coherence, and transfer function as well as PSD plots. Analyses were made

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*Tapes are in binary-Honeywell 36-bit word format.

for each pair every two seconds (exactly 2.048 seconds) with an average of five two second blocks every ten seconds. The PSD plots have two curves on them. The usual PSD curve is shown as a solid line and the PSD values are read from the left hand ordinate. The other curve, a dotted line (one dot at each evaluation frequency) represents the cumulative fraction of the mean square signal power. The fraction of total power is read from the right hand ordinate.

Tabulations of the plotted values were made. The PSD analysis parameters are listed in Table 3-9.

Time history plots of the three pair of transducer signals were made for every 2 second interval spanning the CO duration. The plot scale was two seconds per page with no decimation of the plotted data. Linear trend removal was applied to each two-second block before plotting.

For a minimum of one liquid and one steam blowdown, PSD analyses were performed on all replay sensor outputs for selected two second periods. The selected periods covered the maximum amplitude CO period. These analyses were used to show circumferential symmetry of the wetwell wall pressures.

PSD analyses were performed on the wetwell freespace and bottom center pressure transducer outputs of selected runs and time (5 runs). These were examined for frequencies that were present in both the suppression pool and the wetwell freespace.

In selected runs, PSDs of the outputs from the five vent pressure transducers and the drywell pressure transducer were made. The analyses include CPSD, relative phase, coherence, and transfer function information. PSDs were made every two seconds over the CO duration. The pairing of the transducers is listed as follows:

a. Vent 12.5-ft - Vent 22.5-ft
b. Vent 12.5-ft* - Vent 32.5-ft

*If the 12.5-ft vent pressure transducer did not function properly during the blowdown, the 22.5-ft vent pressure transducer was used.

c. Vent 12.5-ft* - Vent 42.5-ft

d. Vent 12.5-ft* - Vent 51.5-ft

e. Vent 51.5-ft - Drywell pressure

PSD analyses including CPSDs were made on the outputs of the three strain gage-accelerometer-pressure transducer triplets for selected runs (4 runs). These have been used along with information from the load symmetry analysis to support the Fluid-Structure Interaction (FSI) investigation. The six pairings of the transducer outputs were as follows:

a. Pressure transducer - strain gage (3 locations)

b. Pressure transducer - accelerometer (3 locations)

PSDs of selected runs from Test Series 5200 were generated in the same manner as those for Test Series 5101. The pressure signals analyzed were the vent pressure, the wetwell wall pressure at the 12-ft elevation, and the wetwell bottom center pressure. PSDs from both series were then compared to determine the effects of vent length on CO.

3.5.4 Non-Computer Data Reduction

Various PSD analyses were hand tabulated and cross plotted to allow comparison of the data to determine parameter and other effects.

In all runs, the dominant frequencies which occur in each two-second time period for the four sensors identified in Paragraph 3.5.3, were identified and plotted as a function of time into the blowdown. Also, other significant frequencies as well as the total signal power were shown on the same plot. The dominant frequency was plotted using a circle whose radius is proportional to the square root of the PSD value. Second and third dominant frequencies were plotted using symbols of constant size. The plot of rms signal power is placed immediately below the frequency plot. These plots cover the duration of CO.

*If the 12.5-ft vent pressure transducer did not function properly during the blowdown, the [illegible].5-ft vent pressure transducer was used.

Based on the results from work discussed in the previous paragraph, the selected time periods and runs referenced in Paragraph 3.5.3 were determined. The criteria for selecting time periods and runs of interest are as follows:

a. Maximum signal rms values
b. Times/runs where changes in dominant frequency occur
c. Times/runs where "uncommon" dominant frequencies occur

The PSD analyses of vent transducers were used to determine whether a standing acoustic wave was present in the vent. The transfer functions between the vent exit and other vent transducers of the significant frequencies were plotted as a function of elevation in the vent. By examining the shape of this curve, the existence or absence of a standing wave can be determined.

Hand calculations were made to estimate the vent steam and liquid mass fluxes. These calculations were performed at several times in the blowdown using drywell pressure, drywell water retention, and blowdown flow rate.

Table 3-9

PSD ANALYSIS PARAMETERS

Block analysis time	2.048 sec
Points per block	2048
Time between points	0.001 sec
Trend removal	Linear each 2.048 sec
Frequency resolution	0.4883 Hz
Nyquist frequency	500 Hz
Data windowing	None

Analog data were filtered with a low-pass 240 Hz filter before digitization to avoid aliasing.

4. TEST RESULTS AND DISCUSSION

4.1 SYSTEM CONDITIONS FOR CONDENSATION OSCILLATION

4.1.1 Observed Condensation Oscillation

Table 4-1 summarizes the CO observed during Test Series 5200. The CO period is arbitrarily defined as beginning immediately after the end of pool swell and ending with the first reentry of water into the vent. Table 4-1 includes the beginning and ending times of CO, and the time and value of the maximum CO rms pressure values measured at 0.75 ft above the bottom of the wetwell by the bottom center pressure transducer for all runs. For consistent comparison of test runs, the start of CO data is defined as five seconds after test initiation because the actual "end" of pool swell is not easily identified. The exception to this was Run 6 where, due to reduced initial air content, the pool swell transient appears to have ended about three seconds after the test initiation. The tabulated CO ending times correspond to the time of first reentry of water into the vent. A sample of the vent conductivity probe time history for indicating the reentry of water into the vent is shown for Run 9 in Figure 4-1.

4.1.2 CO Beginning and Ending Conditions

Tables 4-2 and 4-3 summarize the observed conditions at the beginning and ending times of CO. The beginning time of five seconds after test initiation is used for consistent data comparison between runs. Table 4-2 includes steam mass flux, liquid mass flux, air content and measured bulk pool temperature at the start of the CO period for each run. Table 4-3 includes the end time, steam mass flux, liquid mass flux, air content and measured bulk average pool temperature at the end of the CO period for each run. In both tables Runs 25 and 26 have two entries which are due to the unusually early chugging periods measured in these tests. In all other runs, after the water had reentered the vent chugging continued for the remainder of the blowdown. During Runs 25 and 26, when water first reentered the vent, the system chugged two or three times. The vent subsequently cleared again and remained clear for durations of approximately fourteen seconds and eight seconds, respectively. These latter periods, in which the vent was clear of water, evidence CO-like dynamic pressure signatures on wetwell instrumentation and accordingly are regarded as CO. Therefore, the beginning and ending conditions for these periods are additionally listed in Table 4-1.

The air content at the beginning of CO was sometimes greater than the upper range measurable with the Oxygen Analyzer System. In such cases the Steam-Air Sample System data taken closest to five seconds was substituted for the air content measurement. During Runs 5, 6, 10, 11, 14, 17, 18, 19, 20 and 21 the Oxygen Analyzer System was not functional for the observation times. The Steam Air Sample System data or the Oxygen Analyzer system data from other observation times were substituted for the air content measurement in both Tables 4-2 and 4-3. The vent liquid mass flux was listed as zero for each steam blowdown run, because the presence of the riser assured that the vent steam quality was nearly 100 percent.

4.1.3 Observed Condensation Oscillation Parameters

Figure 4-2 shows the range of conditions for which CO was observed during Test Series 5200. Nine "trajectories" of vent steam mass flux versus measured bulk pool temperature were plotted to show the range of parameters tested. The start of the CO analysis and the end of the CO are marked on each trajectory. The bottom dashed line shows a postulated CO end boundary.

The following Tables are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

The following Figures are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

Figure 4-1 Sample downcomer Liguid Conductivity Probe Time History - Run 9 (L-3.0-114-11-N)

Figure 4-2 Condensation Oscillaiton Test Parameter Map

4.2 COMPARISONS OF PRESSURE LOADS WITH DFFR REV. 3

The DFFR Rev. 3 specification states that the pool pressure during CO contains a single frequency component in the range from 2 to 7 Hz, and when measured at the containment floor does not exceed a peak to zero amplitude of 3.75 psi. The results from Test Series 5200 were compared with the DFFR Rev. 3 specification by means of a PSD analysis. The PSD function describes the frequency composition of the data signal in terms of the power at each evaluation frequency. The PSDs for the bottom center pressure were calculated for time intervals of 2.048 seconds throughout the CO portion of the blowdown for each test run. Each PSD of interest was examined for the dominant frequencies in the pressure signal.

In the sine wave (see Figure 4-3)

$$Y = A \sin (2\pi f_o t) \tag{4-1}$$

where A = amplitude and f_o = signal frequency, the PSD function is as follows:

$$PSD(f) = \frac{A^2}{2} \delta(f-f_o) \tag{4-2}$$

where δ is the Dirac delta function at the frequency $f = f_o$. The Dirac delta has a zero value everywhere except at $f = f_o$ where it is equal to infinity; however, the area under the function equals one. An important property of the PSD function is its relation to the rms value of the signal. The mean square value is equal to the total area under the PSD function, i.e.

$$[rms(Y)]^2 = \int_0^\infty PSD(f)\, df \tag{4-3}$$

For the sine wave the integral becomes:

$$\int_{0}^{\infty} PSD(f)\ df = \int_{f_o^-}^{f_o^+} PSD(f)\ df = \frac{A^2}{2} \qquad (4\text{-}4)$$

Since the integral of the Dirac delta function (the infinite spike) is unity. Substituting Equation (4-4) into Equation (4-3) gives

$$rms(Y) = \sqrt{\frac{A^2}{2}} = \frac{1}{2}\sqrt{2}\ A \qquad (4\text{-}5)$$

which agrees with the calculation of rms using the definition of the rms of the sine wave. Therefore, the DFFR Rev. 3 specification peak to zero amplitude (A) of 3.75 psi corresponds to an rms value of $\frac{1}{2}\sqrt{2} \times 3.75$ or 2.65 psi.

A digitized random signal like that shown in Figure 4-3 has a similar result, i.e., from the definition of rms

$$rms(P_i) = \left[\frac{1}{N} \sum_{i} {P_i}^2\right]^{1/2} \qquad (4\text{-}6)$$

and

$$rms(P_i) = \int_{0}^{\infty} PSD(f)\ df \qquad (4\text{-}7)$$

In addition, the PSDs can be integrated for each individual "spike" or pulse in the PSD function to determine the amplitude of the corresponding frequency similar to the calculation for the sine wave function. Thus, the amplitude of the various dominant signal frequencies is computed from

$$A = \sqrt{2} \left[\int_{f_o - \Delta f}^{f_o + \Delta f} PSD(f)\, df \right]^{1/2} \tag{4-8}$$

where 2 Δf is the width of the spike.

After determining the dominant frequencies present in the pressure signal and their amplitude for a given time interval, a comparison of those test results was made with the DFFR Rev. 3 specification.

The results of the frequency-amplitude analysis are presented for the cases of the liquid and steam breaks which produced the largest values of total rms pressure at the wetwell bottom center location. The value of the "total rms" pressure is the rms of the measured pressure signal as computed from Equation 4-6. An analysis of the data for all the test runs shows that Run 9 had the largest value for the rms pressure (3.6 psi) for the liquid tests and Run 16 had the largest value (0.9 psi) in the steam tests. These two runs were thus taken as cases most likely to exceed the DFFR Rev. 3 specification. The results for Runs 9 and 16 are shown in Figures 4-4 through 4-11 for the time segment when the rms pressure was a maximum, as well as a time segment before and after the time of maximum rms pressure. The figures compare a plot of the harmonic amplitude versus frequency for each of the dominant frequencies present in the pressure signal with a plot representing the DFFR Rev. 3 specification. The PSD plots from which the amplitudes were determined are also presented in this group of figures.

The results for the liquid blowdown (Run 9), Figures 4-4 through 4-7, show that the rms pressure signal typically contains 7 or 8 dominant frequencies each with a harmonic amplitude of approximately 0.5 psi or greater.

The largest value of harmonic amplitude (3.2 psi) corresponds to a frequency of approximately 1.5 Hz. This amplitude is less than the value of 3.75 psi from the DFFR Rev. 3 specification. However, the 1.5 Hz frequency is below the lower frequency bound of 2 Hz from the specification. In addition, three or four frequencies whose harmonic amplitude is approximately 0.5 psi or greater are shown with a frequency greater than the upper bound of 7 Hz from the DFFR Rev. 3 specification. Results for the three different time segments presented in Run 9 show that as the total rms pressure value goes down, the amplitude of each frequency is reduced with only small changes in the value of the frequencies. Thus, the time of largest total rms pressure usually has the largest values of harmonic amplitude and contains frequencies typical of those present during most of the period of CO.

The results for the steam break (Run 16) with the highest CO load are shown in Figures 4-8 through 4-11. In this case, which is typical of the steam test runs, only two or three frequencies which have a harmonic amplitude of approximately 0.25 psi or greater are present in the CO signal. The largest amplitude component (0.9 psi) corresponding to a frequency of 2.44 Hz, does not exceed the DFFR Rev. 3 specification bounding value of 3.75 psi. This component was present at the time of maximum value of rms pressure at the bottom center of the wetwell (16 to 18 sec). In the time interval between 21 and 23 seconds a frequency components of 0.98 Hz (0.4 psi) and 9.28 Hz (0.5 psi) were found. These components are below the lower frequency bound of 2 Hz and above the upper frequency bound of 7 Hz, respectively, given in the DFFR Rev. 3 specification.

The results of Runs 9 and 16 are typical of the liquid and steam tests. Finding frequencies below and above the range of frequencies of the DFFR Rev. 3 specification was not unusual. However, it was unusual to find times in any test run which showed a harmonic amplitude for any frequency which exceeded those found in Run 9. One exception was found in Run 24 from 12 to 14 seconds as shown in Figures 4-12 and 4-13. Although the total rms pressure signal (3.1 psi) was smaller than the largest value found (Run 9 with 3.6 psi), Run 24 had the largest single frequency harmonic amplitude component (3.7 psi at 1.46 Hz) for all the test runs. Still, this value was less than the bounding value of

3.75 psi given in the DFFR Rev. 3 specification. Although typical test results show frequencies both above and below the range of frequencies of the DFFR Rev. 3 specification none of the tests show a harmonic amplitude greater than 3.75 psi during the time of CO.

The total rms pressure signal at the wetwell bottom center was found to exceed the 2.65 psi value (3.75 psi peak to zero amplitude) given in the DFFR Rev. 3 specification in Runs 9, 10, 12, 22, 24, 26 and 27 (all liquid blowdowns). Although those blowdowns exhibited many frequencies, no individual harmonic amplitude exceeded 2.65 psi, equivalent bound value; however, some frequencies were outside of the specified 2 to 7 Hz range. Because the DFFR Rev. 3 specification did not bound all the test data with respect to frequency or total signal power, this specification was considered to be "not confirmed" by the Test Series 5200 data.

Finally, note that the largest values of PSD and harmonic amplitude were found to occur for a very limited range of steam mass flux and bulk pool temperature. The effect of mass flux and pool temperature is discussed in Paragraph 4.5.2. Contours of constant values of total rms pressure signal at the wetwell bottom center for the liquid test runs that did not have a vent riser are presented in that paragraph.

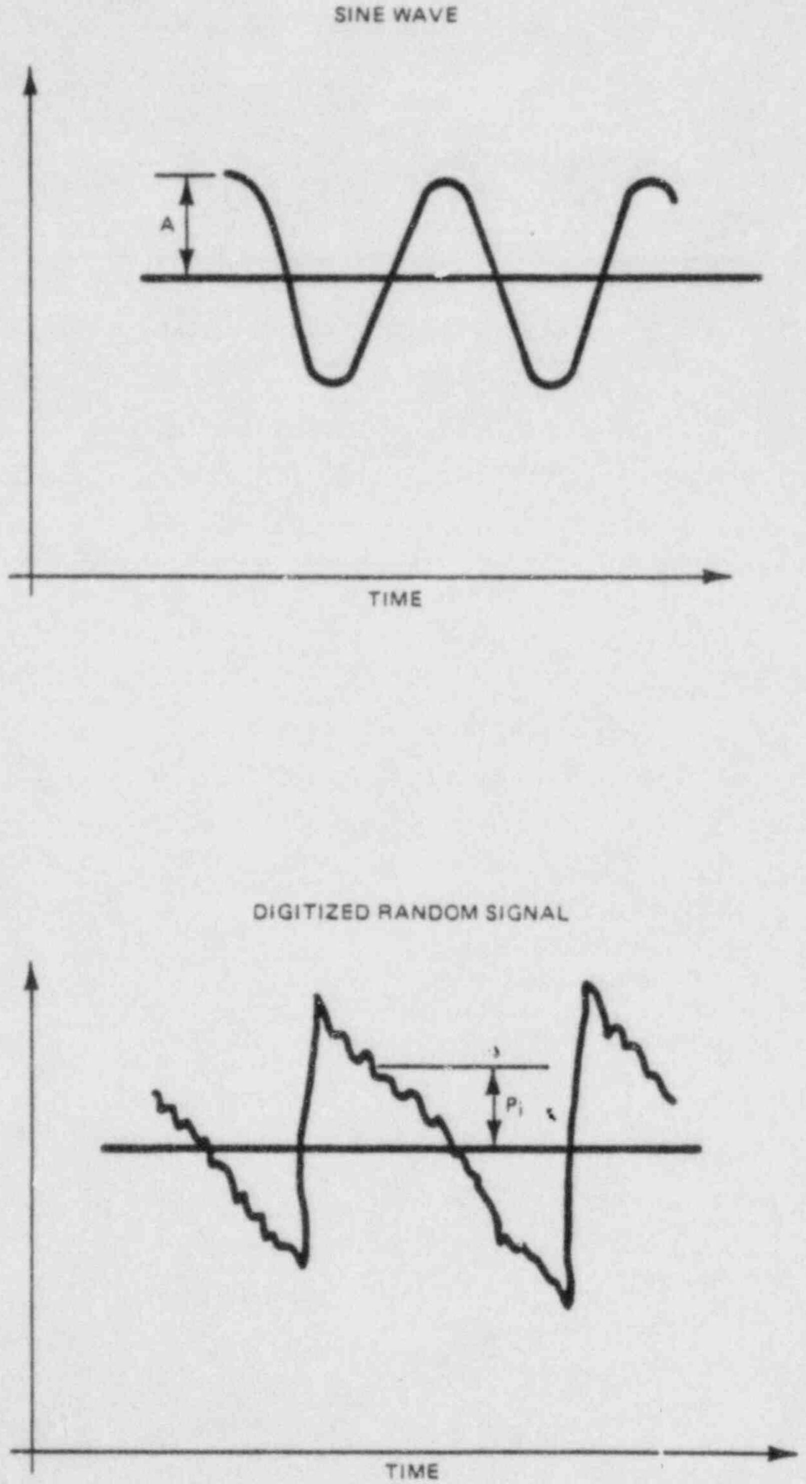

Figure 4-3. Sine Wave and Digitized Random Signals

The following Figures are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

Figure 4-4	DFFR Rev. 3 Comparison - Run 9 (L-3.0-114-11-N)
Figure 4-5	Power Spectral Density-Wetwell Bottom Center Pressure (16.14 - 18.19 sec) - Run 9 (L-3.0-114-11-N)
Figure 4-6	Power Spectral Density-Wetwell Bottom Center Pressure (20.00-22.05 sec) - Run 9 (L-3.0-114-11-N)
Figure 4-7	Power Spectral Density-Wetwell Bottom Center Pressure (26.14 - 28.19 sec) - Run 9 (L-3.0-114-11-N)
Figure 4-8	DFFR Rev.3 COmparison - Run 16 (S-3.0-75-11-R)
Figure 4-9	Power Spectral Density-Wetwell Bottom Center Pressure (10.14 - 12.19 sec) - Run 16 (S-3.0-75-11-R)
Figure 4-10	Power Spectral Density-Wetwell Bottom Center Pressure (16.14 - 18.19 sec) - Run 16 (S-3.0-75-11-R)
Figure 4-11	Power Spectral Density-Wetwell Bottom Center Pressure (21.14 - 23.19 sec) - Run 16 (S-3.0-75-11-R)
Figure 4-12	DFFR Rev.3 Comparison (12.19 - 14.24 sec) - Run 24 (L-3.8-111-11-R)
Figure 4-13	Power Spectral Denisty-Wetwell Bottom Center Pressure (12.19 - 14.24 sec) - Run 24 (L-3.8-111-11-R)

4.3 EFFECT OF VENT LENGTH ON CO LOADS

One consideration in the comparison of the current 4TCO test facility configuration with the previous 4T Test Series 5101 configuration was the length of the vent. A major objective of Test Series 5200 was to determine the influence of this vent length difference on the magnitude and frequency content of observed condensation oscillation in the vent and the wetwell. To accomplish this objective, the 4TCO test matrix was structured with a number of steam blowdowns having the same venturi size and initial test conditions as selected runs in Test Series 5101.

The runs in Test Series 5200 and 5101 that were compared are listed in Table 4-4. An expanded matrix of the test parameters, for these runs is given in Appendix F.

Comparison plots of the frequency distribution for the vent exit, wetwell wall at the 12-ft elevation and wetwell bottom center pressure are shown in Figures 4-14 through 4-33.

Circles on the plots show the dominant frequency at the indicated time. The radius of the circle is proportional to the square root of the PSD value at the indicated frequency. The triangles and squares represent the second and third dominant frequencies, respectively. Dominant frequencies having a PSD value less than 0.1 psi^2/Hz were not plotted. Also shown on these figures is a plot of the rms value of the pressure signal as a function of time illustrating which frequencies are dominant when the rms pressures are high.

The pressure signal rms values for the vent exit were calculated over the CO range and listed in Table 4-5. A study of Table 4-5 shows the average pressure signal rms values are within 0.15 psi for test comparisons. There is not any voerall dominance between either the Test Series 5200 or 5101 test pressure signal rms values.

Comparison of the Test Series 5200 and 5101 plotted frequencies shows that both test series have 1-4 Hz frequency components which continue throughout the blowdown. An analysis of the wetwell freespace pressure for some of the Test Series 5200 runs indicates the presence of this frequency. Apparently the 1-4 Hz signals are due to a pool mode which is compressing the air in the wetwell freespace. Since the configuration of the 4T test vessel did not change between Test Series 5200 and 5101 this frequency would not be expected to change.

The Test Series 5101 tests show a second significant frequency of approximately 6 Hz for all the runs studied. The Test Series 5200 runs are not as consistent in this respect, e.g., four of the seven runs studied did not have any significant frequency greater than 4 Hz in any of the three locations investigated. Significant in this case is defined as having a PSD value equal to or greater than 0.1 psi^2/Hz. The three remaining runs had more random significant frequencies ranging from 4 to 9.3 Hz. The difference in the behavior of these frequencies can be explained by differences in the coupling between the system and the condensation process frequencies. Reinforcement of these two frequencies in Test Series 5101 results in a stronger (higher PSD) single frequency. In Test Series 5200 the two frequencies do not reinforce each other so that a greater number of frequency components occur.

A minor difference in the current 4TCO test facility and the previous 4T test facility for the Test Series 5101 is the jet deflector present during the Test Series 5200. Runs 20 and 21 were performed to determine the effect of the jet deflector on the frequencies observed in the vent during a blowdown. These runs had similar initial conditions, except Run 21 had the jet deflector removed. The initial conditions for the two runs are listed in Table 3-7.

Figures 4-34 and 4-35 are plots of the rms pressure values at the wetwell bottom center and downcomer exit locations for Runs 20 and 21. Both figures show the higher rms pressure values which occurred for Run 21 from 8 to 14 seconds. The higher rms pressure value is not believed to be resulting from the presence of the jet deflector, but a combination of small differences in local pool temperatures, vent flow quality and vent air content between the two runs.

Where the jet deflector should have the greatest effect is in the downcomer. There the jet deflector could cause changes in the pressure drop from the drywell to the downcomer (due to a possible increased entrance loss coefficient) or could cause changes in the vent frequencies (due to modified boundary conditions at the end of the vent). Figures 4-36 through 4-47 are PSDs of the five vent pressures and the drywell pressure for Runs 20 and 21. An analysis time of 12.50 to 14.55 seconds was selected as typical CO. Both runs show a large approximately 1 Hz frequency which dominates the pressure signals at all elevations. This frequency becomes more dominant as the drywell is approached. Both runs also show PSD peaks at approximately 2 Hz, 6 Hz, and 14 Hz. The 2 Hz and 6 Hz signals decrease as the drywell is approached while the 14 Hz signal is maximum at the 32.5-ft elevation in the vent. A plot was made (see Figure 4-48) to show how the frequencies in the vent varied in magnitude at different locations and to determine if the jet deflector caused a change in this variation. Figure 4-48 is a plot of the transfer function between the vent exit pressure, the other four vent pressures, and the drywell pressure. The transfer function is the ratio of the PSD value at the given vent elevation to the PSD value at the vent exit elevation.

Four of the frequencies with the highest PSD values were examined in more detail. In Run 20 the frequencies were 0.98 Hz, 1.95 Hz, 6.35 Hz, and 13.67 Hz. In Run 21 the frequencies were 0.98 Hz, 1.95 Hz, 5.86 Hz, and 14.65 Hz. Figure 4-48 shows that for each of these frequencies examined the transfer functions are similar in both magnitude and distribution along the vent between the two runs. Therefore, it is concluded that the jet deflector has no effect on the vent pressures or frequencies.

In summary, the shorter vent length in Test Series 5200 resulted in higher frequency components during CO. In Test Series 5101, the longer vent length produced a lower system frequency which coupled with a condensation process frequency to give a stronger single frequency. There was no jet deflector effect.

Table 4-4

TEST SERIES 5200 AND 5101 COMPARISON RUNS*

5200-1 5200-16 5101-27	3.00-in venturi 11-ft vent submergence
5200-17 5101-31	3.00-in venturi 9-ft vent submergence
5200-18 5200-19 5101-34	3.00-in venturi 13.5-ft vent submergence
5200-20 5200-21 5101-29	2.50-in venturi 11-ft vent submergence

*All runs were steam blowdowns with 70°F nominal initial pool temperature.

The following Table is GENERAL ELECTRIC COMPANY PROPRIETARY and has been removed from this document in its entirety.

Table 4-5 Test Series 5200 and 5101 Average Pressure Signal rms Value Comparisons

The following Figures are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

Figure 4-14 Frequency Content and Pressure Signal rms Value Time Histories - Series 5200 and Run 27, Test Series 5101

Figure 4-15 Frequency Content and Pressure Signal rms Value Time Histories - Vent Lenght Effect Comparison - Wetwell Bottom Center - Run 1, Test Series 5200 and Run 27, Test Series 5101

Figure 4-16 Frequency Content and Pressure Signal rms Value Time Histories - Vent Length Effect Comparison - Wetwell Wall, 12-ft Elevation - Run 1, Test Series 5200 and Run 27, Test Series 5101

Figure 4-17 Frequency Content and Pressure Signal rms Value Time Histories - Vent Length Effect Comparison - Vent Exit - Run 27, Test Series 5101 and Vent 22.5-ft Elevation - Run 16, Test Series 5200

Figure 4-18 Frequency Content and Pressure Signal rme Value Time Histories - Vent Length Effect Comparison - Wetwell Bottom Center - Run 16, Test Series 5200 and Run 27, Test Series 5101

Figure 4-19 Frequency Content and Pressure Signal rms Value Time Histories - Vent Length Effect Comparison - Wetwell Wall, 12-ft Elevation - Run 16, Test Series 5200 and Run 27, Test Series 5101

Figure 4-20 Frequency Content and Pressure Signal rms Value Time Histories - Vent Length Effect Comparison - Vent Exit - Run 17, Test Series 5200 and Run 31, Test Series 5101

Figure 4-21 Frequency Content and Pressure Signal rms Value Time Histories - Vent Length Effect Comparison - Wetwell Bottom Center - Run 17, Test Series 5200 and Run 31, Test Series 5101

Figure 4-22 Frequency Content and Pressure Signal rms Value Time Histories - Vent Length Effect Comparison - Vent Ecit - Run 18, Test Series 5200 and Run 34, Test Series 5101

Figure 4-23 Frequency Content and Pressure Signal rms Value Time Histories- Vent Length Effect Comparison - Wetwell Bottom Center - Run 18, Test Series 5200 and Run 34, Test Series 5101

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The following Figures are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

Figure 4-34	Wetwell Bottom Center Pressure Signal rms Value Time History - Jet Deflector Effect Comparison - Runs 20 and 21
Figure 4-35	Vent Exit Pressure Signal rms Value Time History - Jet Deflector Effect Comparison - Runs 20 and 21
Figure 4-36	Power Spectral Density - Vent Exit Pressure (12.50 - 14.55 sec) - Run 20 (S-2.5-68-11-R)
Figure 4-37	Power Spectral Density - Vent Pressure, 22.5-ft Elevation (12.50 = 14.55 sec) - Run 20 (S-2.5-68-11-R)
Figure 4-38	Power Spectral Density - vent Pressure, 32.5-ft Elevation (12.50 - 14.55 sec) - Run 20 (S-2.5-68-11-R)
Figure 4-39	Power Spectral Denity - Vent Pressure, 42.5-ft Elevation (12.50 - 14.55 sec) - Run 20 (S-2.5-68-11-R)
Figure 4-40	Power Spectral Density - Vent Pressure, 51.5-ft Elevation (12.50 - 14.55 sec) - Run 20 (S-2.5-68-11-R)
Figure 4-41	Power Spectral Density - Drywell Pressure (12.50 - 14.55 sec) - Run 20 (S-2.5-68-11-R)
Figure 4-42	Power Spectral Density -Vent Exit Pressure (12.50 - 14.55 sec) - Run 21 (S-2.5-68-11-R)
Figure 4-43	Power Spectral Density - Vent Presure, 22.5-ft Elecation (12.50 - 14.55 sec) - Run 21 (S-2,5-68-11-R)
Figure 4-44	Power Spectral Density - Vent Pressure, 32.5-ft Elevation (12.50 - 14.55 sec) - Run 21 (S-2.5-68-11-R)
Figure 4-45	Power Spectral Density - Vent Pressure, 42.5-ft Elevation (12.50 - 14.55 sec) - Run 21 (S-2.5-68-11-R)
Figure 4-46	Power Spectral Density - Vent Pressure, 51.5-ft Elevation (12.50 - 14.55 sec) - Run 21 (S-2.5-68-11-R)
Figure 4-47	Power Spectral Density - Drywell Pressure (12.50 - 14.55 sec) - Run 21 (S-2.5-6.8-11-R)
Figure 4-48	Vent Pressure Magnitude Distribution at Peak Frequencies- Runs 20 and 21

4.4 EFFECT OF LIQUID ON CO LOADS

All the Test Series 5200 runs are identified as being either liquid or steam blowdowns. This subsection identifies differences in pool boundary loads, liquid and steam mass fluxes, and vent steam quality due to the presence of liquid in the vent during the 4TCO tests. Many comparisons of these parameters were obtained from identical liquid blowdown runs in which a vent riser was installed or removed. The main effect of the vent riser in this test series was to prevent the majority of the liquid in the blowdown flow from entering the vent.

4.4.1 Vent Riser Effect

To better understand the effect of liquid on CO loads, it is helpful to compare runs of equal vent steam mass flux where the amount of liquid entering the vent is changed. The total vent flux was used to calculate separate liquid and steam mass fluxes. This comparison was made with runs that had identical initial conditions. One run was with a vent riser installed and another had it removed.

The vent riser effect on CO loads can be studied for all venturi sizes used in liquid blowdowns because identical runs with and without the vent riser were made with each venturi size. A summary of the liquid blowdown runs compared, plus two steam blowdowns (Runs 1 and 16 with 3.00-in venturi), is given in Table 4-6. This table includes the time when CO ends, the time when the vent riser ceases to trap any additional liquid in the drywell, and the time when the venturi is uncovered by the liquid level in the steam generator. This indicates the beginning of two-phase flow through the venturi.

Vent mass flux time histories were computed for all the runs listed in Table 4-6. The vent mass flux curves for the small venturi blowdowns, Runs 13, 14 and 15 (2.125-in) and Runs 12 and 25 (2.50-in) did not extend beyond the time the venturi was uncovered because of difficulty in approximating the two-phase mass flow through the venturi for these runs. The vent mass flux curves for all other runs do include the two-phase flow regime. Time histories of the wetwell bottom center pressure, frequency distribution and approximate total mass entering the vent were also compiled for all of these runs. The summary given in Table 4-7 lists the figures of each run compared. Table 4-8 summarizes the maximum bottom center rms pressure, the time when the maximum occurred and the dominant frequencies at that time for each run used for comparison.

4.4.1.1 Comparison of Runs 14 and 15

Runs 14 and 15 were liquid blowdowns with a 2.125-in venturi, 11-ft submergence, and 70°F nominal initial pool temperature. Run 15 was equipped with a vent riser and Run 14 was not.

Figure 4-49 shows the bottom center rms pressure as a function of time during CO for Runs 14 and 15. In the first 25 seconds of the blowdown, there were no significant differences between the two curves. After 25 seconds the rms pressure in Run 15 tend to generally increase with time while the rms pressure in Run 14 decreased. This resulted in the vent riser run having higher bottom center rms pressure loads from 25 seconds to the end of CO.

The vent mass flux curves shown in Figures A-134, A-150 and the total mass into wetwell curve shown in Figure 4-50 for Runs 14 and 15 show no significant changes for either run at 25 seconds. In Run 14 at 25 seconds approximately 3300 lbm of liquid and steam had been discharged into the wetwell with a steam quality of approximately 30 percent. In Run 15 at 25 seconds approximately 1600 lbm of liquid and steam had been discharged into the wetwell with a steam quality of approximately 90 percent. Both runs had a steam mass flux of about 12 lbm/sec-ft^2 with a liquid mass flux rate of 29 lbm/sec-ft^2 for Run 14 and 0.5 lbm/sec-ft^2 for Run 15.

PSD analysis was used to determine the frequency content of the bottom center pressure signal. The PSD plots for the bottom center pressure for Runs 14 and 15 at the time of their maximum rms values are shown in Figures B-84 and B-86 in Appendix B. The frequency content time histories are shown in Figures B-27 and B-29 Appendix B. These figures show that at the time of maximum bottom center pressure, Run 14 had lower dominant frequencies of 2.4, 6.8 and 4.4 Hz compared to 8.5 and 9.8 Hz for the vent riser case Run 15. In general, Run 15 showed higher frequencies throughout the CO period.

4.4.1.2 Comparison of Runs 12 and 25

Runs 12 and 25 were liquid blowdowns with a 2.50-inch venturi, 11-ft submergence, and 110°F nominal initial pool temperature. Run 25 was equipped with a vent riser and Run 12 did not have a vent riser.

The bottom center rms pressure time histories for Runs 12 and 25 are shown in Figure 4-51. There were no significant differences between the loads of the two runs up to 15 seconds. There Run 12 (the no-riser run) began to show higher bottom center pressures than Run 25. (This trend did not occur in the 2.125-in venturi Runs 14 and 15.) Run 12 remained higher than Run 25 for the first 26 seconds. At that time Run 25 showed higher loads than Run 12 for the remainder of the CO duration.

As in the comparison of Runs 14 and 15, there were no significant changes in the vent mass flux curves for Runs 12 and 25 (see Figures A-104, A-245) and the total mass into wetwell curve (see Figure 4-52 at 15 and 26 seconds).

The frequency content curves in Figures B-23 and B-49 show low dominant frequencies at the time of maximum rms pressure in Run 12 (2.4, and 3.5 Hz) and high frequency for Run 25 (7.5 Hz). This trend is the same as that in Runs 14 and 15. As in Run 15, Run 25 showed high frequencies (>15 Hz) at the time of maximum rms pressure.

4.4.1.3 Comparison of Runs 9 and 28

Runs 9 and 28 were liquid blowdowns with a 3.00-in venturi, 11-ft submergence, and 110°F nominal initial pool temperature. Run 28 was equipped with a vent riser and Run 9 did not have a vent riser.

Figure 4-53 shows the bottom center rms pressure for Run 9 being greater than the rms pressure for Run 28 from the beginning of CO until about 28 seconds. There were no significant differences between the pressures of both runs for the remainder of the CO period. Figure 4-54 shows that at 28 seconds, approximately 3200 lbm of liquid had entered the wetwell in Run 28 and 5800 lbm in Run 9. As in Runs 12 and 25, Run 9 had higher loads during CO than the vent riser case.

The frequency content curves in Figures B-17 and B-55, show that at the time of maximum pressure load the dominant frequencies for Run 9 were 1.5, 6.3 and 3.4 Hz. The dominant frequency for the vent riser Run 28 (4.4 Hz) was much smaller than the dominant frequency shown for Run 25 (7.8 Hz) and Run 15 (8.3 Hz).

4.4.1.4 Comparison of Runs 3 and 4

Runs 3 and 4 were liquid blowdowns with a 3.82-in venturi, 11-ft submergence, and 70°F nominal initial pool temperature. Run 4 was equipped with a vent riser and Run 3 was not.

The bottom center rms pressure time histories for Runs 3 and 4 are shown in Figure 4-55. In the first 10 seconds of the blowdown, there were no significant differences in the loads of these runs. After 10 seconds, Run 4 showed higher rms pressure values than Run 3 until 18 seconds where Run 3 became greater. At 22 seconds Run 4 again became greater and remained higher than Run 3 for the remainder of CO. At 22 seconds, Figure 4-56 shows that approximately 4000 lbm of liquid had entered the wetwell in Run 3 and 6600 lbm in Run 4.

The dominant frequencies at the time of maximum rms pressure signal were 3.4 Hz for Run 3 and about 8 Hz for Run 4. This is the same trend seen in the 2.125-in and 2.50-in blowdowns. These frequencies are shown in Figures B-5 and B-7.

4.4.1.5 Comparison of Runs 8 and 24

Runs 8 and 24 are identical to Runs 3 and 4 except that Run 8 and 24 had an initial pool temperature of 110°F. Run 24 was equipped with a vent riser and Run 8 was not.

Figure 4-57 shows Run 24 with higher bottom center rms pressure loads than Run 8 for most of the initial 16 seconds, where at that time the two runs generally had the same pressure loads for the remainder of the CO period. The maximum rms pressure loads for these runs are greater than those in Runs 3 and 4, which indicates a temperature effect on CO loads.

Figures B-15 and B-47 show the frequency content for the bottom center pressure for Run 8 and 24. The dominant frequencies at the time of maximum bottom center rms pressure signal for Run 8 were 6.8, 1.5 and 5.4 Hz. The dominant frequencies at the time of maximum bottom center pressure for Run 24 were 1.5, 5.4 and 3.9 Hz. These frequencies show Run 24 (the vent riser run) as having a dominant frequency of 1.5 Hz which is lower than the dominant frequency of 6.8 Hz for Run 8 (the no vent riser run). This trend did not occur for the 2.83-inch venturi, Runs 3 and 4 comparison, indicating a temperature effect on CO frequency.

4.4.1.6 Comparison of Runs 1 and 16

Runs 1 and 16 were steam blowdowns with a 3.00-in venturi, 11-ft submergence, and 70°F nominal initial pool temperature. Run 16 was equipped with a vent riser and Run 1 was not.

Figure 4-58 shows Run 16 having a higher bottom center rms pressure than Run 1 for almost the entire CO duration. As the maximum bottom center rms pressure load difference was only 0.24 psi, the vent riser essentially had not effect on steam blowdowns. The dominant frequency for both runs was 2.9 Hz.

4.4.2 Drywell Liquid Holdup

The amount of liquid trapped by the vent riser during the liquid blowdown Runs 4, 15, 24, 25, 26, 27 and 28 is shown in Figures A-32, A-149, A-235, A-244, A-260, A-269 and A-285 of Appendix A. Initially, the steam generator had approximately 7300 lbm of liquid before each liquid blowdown. Isenthalpically expanding the liquid from the steam generator pressure to the drywell dome pressure flashes approximately 30 percent of the liquid to steam. The remaining 5100 lbm enters the drywell as liquid. In the runs listed previously, the total amount of liquid trapped by the vent riser at the end of each test was calculated as a percentage of the total liquid entering the drywell (approximately 5100 lbm). This percentage was plotted as a function of venturi size and shown in Figure 4-59. This figure shows that with larger venturi sizes the vent riser traps less liquid. This indicates that more liquid is entrained in the steam flow entering the vent for larger venturi sizes.

4.4.3 Liquid/Steam Comparison

Generally, in Test Series 5200 the liquid blowdowns produced higher pool boundary loads and a longer CO duration than the steam blowdowns. The CO duration times and the maximum bottom center pressure values for all the test runs are listed in Table 4-1. The values given in this table reflect the trend of higher CO pool boundary loads and longer CO durations for the liquid blowdowns compared to the steam blowdowns. A comparison of bottom center rms pressure for two runs (Runs 1 and 2) with equal venturi size and initial conditions for a liquid and steam blowdown is shown in Figure 4-60. Run 1 is a steam blowdown with a 3.00-in venturi, 70°F nominal initial pool temperature, 11 ft submergence and no vent riser. Run 2 is a liquid blowdown with a 3.00-in venturi and the same initial conditions as Run 1.

One of the major factors causing the differences in CO duration and pool pressure was the greater total mass flux obtained in the liquid blowdown Run 2.

The vent mass fluxes for Runs 1 and 2 and are shown in Figures A-8 and A-16 in Appendix A. Two distinct differences are shown in these two plots. The first difference is that Run 1 blowdown flow consisted of entirely steam while Run 2 consisted mostly of liquid. The second difference is the higher vent steam mass flux in the vent for Run 2 as compared to Run 1. Figure 4-61 shows the vent steam mass fluxes (down the vent) for Runs 1 and 2; as shown, the liquid blowdown Run 2 had a higher steam mass flux for a longer duration than the steam blowdown, Run 1. This was due to the liquid blowdowns characteristically maintaining a higher pressure in the steam generator than the steam blowdowns during the CO period.

4.4.4 Summary and Observations

The purpose of this subsection is to describe the effect of liquid on CO loads. To show this effect several pairs of runs with identical initial conditions were compared where each pair consisted of a run with a vent riser and a run without a vent riser.

Several observations can be made:

1. The vent riser had little effect on the CO duration for the 2.50-, 3.00-, and 3.82-in venturi liquid blowdowns.

2. For both the vent riser and without vent riser cases in the liquid blowdowns, a 1.5 to 2 Hz significant frequency was always present.

3. For the liquid blowdowns, the vent riser cases generally showed higher significant frequencies than the runs without the vent riser.

4. The pressure amplitude was increased by the vent riser at some conditions and decreased at other conditions but no simple or consistent relationship was observed between the amount of liquid entering the vent and the resulting CO pressure loads.

5. The vent riser trapped less liquid with increasing venturi size.

Table 4-6

VENT RISER RUNS - PARAMETER SUMMARY

This Table is GENERAL ELECTRIC COMPANY PROPRIETARY and has been removed from this document in its entirety.

Table 4-7

VENT RISER RUNS — FIGURE SUMMARY

REFERENCE FIGURES

Run Number	Vent Mass Flux	Bottom Center Pressure (rms)	Frequency Content	Vent Total Mass
14	A-134	4-49	B-27	4-50
15	A-150		B-29	
12	A-104	4-51	B-23	4-52
2[illegible]	A-245		B-49	
9	A-73	4-53	B-17	4-54
28	A-286		B-55	
3	A-24	4-55	B-5	4-56
4	A-33		B-7	
8	A-65	4.57	B-15	-
24	A-236		B-47	
1	A-8	4-58	B-1	-
16	A-166		B-31	

Table 4-8

VENT RISER RUNS - LOAD SUMMARY

This Table is GENERAL ELECTRIC COMPANY PROPRIETARY and has been removed from this document in its entirety.

The following Figures are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in theri entirety.

Figure 4-49 Bottom Center Pressure Time History - Runs 14 and 15

Figure 4-50 Total Mass Into Wetwell Time History - Runs 14 and 15

Figure 4-51 Bottom Center Pressure Time History - Runs 12 and 25

Figure 4-52 Total Mass Into Wetwell Time History - Runs 12 and 25

Figure 4-53 Bottom Center Pressure Time History - Runs 9 and 28

Figure 4-54 Total Mass Into Wetwell time History - Runs 9 and 28

Figure 4-55 Bottom Center Pressure Time History - Runs 3 and 4

Figure 4-56 Total Mass Into Wetwell Time History - Runs 3 and 4

Figure 4-57 Bottom Center Pressure time History - Runs 8 and 24

Figure 4-58 Bottom Center Pressure Time History - Runs 1 and 16

Figure 4-59 Venturi Size effect on Drywell Liquid Holdup

Figure 4-60 Bottom Center Pressure Time History - Runs 1 and 2

Figure 4-61 Vent Steam Mass Flux Comparison - Runs 1 and 2

4.5 SENSITIVITY OF CO LOADS TO SYSTEM PARAMETERS

The effects of system parameters on CO magnitude and frequency content are discussed in this subsection. The system parameters investigated include vent air content, initial pool temperature, venturi size, and initial vent submergence.

The discussion of this subsection deals with the sensitivity of CO loads to system parameters in two ways. First, runs with different initial conditions and different configurations are compared in terms of bottom center pressure rms value and frequency content time histories. Second, the runs were treated as a large data base and used to determine how pressure signal rms values vary with parameters such as vent air content, vent steam mass flux, and suppression pool bulk temperature.

Throughout this subsection there are references to plots of the wetwell bottom center pressure traces, PSDs, frequency content time histories, and rms value time histories. To avoid duplication of plots and provide a complete data base these curves were plotted for all runs and presented in Appendix B.

4.5.1 Parametric Run Comparison

4.5.1.1 Effect of Initial Drywell Air Content

To determine the effect of the initial air content on CO, two blowdowns, each with different initial drywell air content, were performed (Runs 3 and 6). Prior to initiating the blowdown for Run 6, the initial drywell air content was reduced by closing both the drywell and the wetwell vents and injecting steam from an auxiliary boiler into the drywell. This caused a mixture of air and steam to be forced down the vent into the wetwell. The steam was condensed in the suppression pool and the air discharged to the wetwell freespace, causing it to pressurize. After the freespace had been pressurized to a predetermined pressure, the blowdown was initiated. Post-test calculations indicated that the drywell initial air mass was reduced by approximately 27 percent prior to blowdown.

A comparison of the air content time histories for Runs 3 and 6 is shown in Figure 4-62. This figure shows that by the beginning of CO the air content for both runs was nearly the same. The rapid purging of the drywell air at the beginning of the blowdown negates the difference in initial drywell air content. Consequently, the initial drywell air content reduction of 27 percent had little effect on the vent air content time history during CO and, as a consequence, Runs 3 and 6 gave similar results.

Figure 4-63 is a comparison of bottom center rms pressure values between Runs 3 and 6. Both curves have similar shape and magnitude. Figures B-5 and B-11 of Appendix B are frequency content time histories of the wetwell bottom center pressure for Runs 3 and 6 respectively. The plots are similar and show the same trends.

Because the initial drywell air content reduction of 27 percent was not sufficient to significantly affect the vent air content time history during CO. No conclusion can be made as to the effect that a greater reduction in the initial drywell air content would have on CO pressures and frequencies.

4.5.1.2 Effect of Venturi Size

The effect of venturi size on CO was determined by performing tests using four venturi sizes in the blowdown line. The venturi controls the mass flux into the drywell and, consequently, controls the vent mass flux. Figure 4-64a shows the venturi flow rate time histories for the four venturi used. The range of venturi sizes was chosen to bound the range of Mark II plant blowdown flow rates as described in Subsection 3.3. The effect of venturi size was investigated using a nominal 110°F initial pool temperature, 11-ft initial vent submergence, and no vent riser in the drywell.

Figure 4-64b compares the bottom center pressure rms value time histories over the duration of CO for Runs 8, 9, 12 and 13 (3.82-in, 3.00-in, 2.50-in and 2.125-in diameter venturi, respectively).

As shown in Figure 4-64b, the peak rms pressure value occurred in Run 9 withe 3.00-in diameter venturi. The second largest maximum rms pressure value was recorded with the 2.50-in diameter venturi followed by the 3.82-in diameter venturi and the 2.125-in diameter venturi. The time of peak rms pressure value increases as the venturi diameter decreases. If the rms pressure value was strongly dependent on a certain vent mass flux value, the peak rms values would be expected to occur at similar vent mass flux values.

Table 4-8 lists the vent steam mass fluxes at the time of maximum rms pressure values for Runs 8, 9, 12 and 13. Because the mass fluxes are not constant at the time of maximum rms pressure values and the maximum rms pressure value did not occur for the largest venturi size, it is evident that vent mass flux is not the sole determinant of pressure magnitudes.

The relatively wide range of mass fluxes over which the peak rms pressures occur supports the conclusion that the peak rms pressures are not dependent on mass flux alone.

The duration of CO is also listed in Table 4-9. CO duration varies inversely with the venturi size as expected, because a larger venturi size allows the steam generator inventory to deplete more rapidly causing vent steam mass flux to decrease below the CO threshold sooner than a smaller venturi would.

The frequency content time histories of the bottom center pressure for Runs 8, 9, 12, and 13 are shown in Figures B-15, B-17, B-23, and B-25 respectively. PSD plots for the four runs at the times of maximum bottom center rms pressure are shown in Figures B-72, B-74, B-80 and B-82. Runs 8 and 9 had frequency components of 1.5 to 2 and 7 to 8 Hz which existed during much of CO. In contrast, Runs 12 and 13 have weak 7 to 8 Hz components. The bottom center pressure frequency content time history for Run 13 was very different from those of Runs 8, 9 and 12. The bottom center pressure rms value time history was also lower and peaked less in Run 13 than in Runs 8, 9, 12. This may be because the mass flux obtained using the 2.125-in venturi was not sufficient to excite system resonances which were excited by the larger venturi.

Comparison of the rms pressure value time histories and PSDs at the vent exit and on the wetwell wall at the 12-ft elevation for the four runs also reveals some effects of venturi size.

Figures 4-65 and 4-66 are comparisons of rms pressure value time histories at the vent exit and on the wetwell wall at the 12-ft elevation for Runs 8, 9, 12 and 13. Figures 4-67 through 4-74 are PSDs of the vent exit and wetwell wall pressures at the 12-ft elevation taken at the time of maximum bottom center pressure rms value. Table 4-10 compares the peak rms pressure value, time of maximum rms pressure value, and dominant frequencies at time of maximum bottom center pressure rms value for vent exit, wetwell wall at the 12-ft elevation, and bottom center pressures. The shape of the curves in Figures 4-65 and 4-66 are similar to the corresponding curves for the bottom center pressure. The order of the maximum rms pressure values was the same for the wetwell wall at the 12-ft elevation pressure as it was for the bottom center pressure, i.e. the 3.00-in venturi had the largest rms pressure value followed by the 2.50-in, 3.82-in and 2.125-in venturi, respectively. Note, however, the order of maximum rms pressure values for the vent exit are different from those of the wetwell bottom center pressure. The 2.50-in venturi produced the maximum vent exit rms pressure value followed by the 3.00-in, 3.82-in, and 2.115-in venturi. A study of Table 4-10 shows there is an approximate decrease of 33 percent in the rms pressure between the bottom center and vent exit in the 3.82 and 3.00-in venturi blowdowns. In the 2.50-in and 2.125-in venturi blowdowns the rms pressure reductions between these locations are 15 percent and 7 percent, respectively. This decrease is also shown in the PSDs. The PSDs of the three pressure signals, bottom center, vent exit, and wetwell wall at the 12-ft elevation are very similar for Run 13 (Figures B-82, 4-73, 4-74), but very different for Runs 8 and 9 (Figures B-72, 4-67, 4-68, and B-74, 4-69 and 4-70). In Runs 8 and 9 note that the 7 to 8 Hz frequency component that had relatively large PSD value at the bottom center location was greatly reduced at the vent exit and wetwell wall at the 12-ft elevation. This indicates that a pressure disturbance is present which attenuates as it approaches the suppression pool surface. However, a similar disturbance is not established in Runs 12 and 13; consequently, the large pressure attenuation from the wetwell bottom to the vent was not seen. It is not clear at this time whether this disturbance was caused by a condensation controlled process or by excitation of a system resonance, or a combination of both.

4.5.1.3 Effect of Initial Vent Submergence

The effect of initial vent submergence was investigated for both liquid and steam blowdowns. In each type of blowdown the initial vent submergences of 9 ft, 11-ft and 13.5-ft were tested. All tests used the 3.00-in diameter venturi with a nominal initial pool temperature of 70°F.

The three liquid blowdowns compared were Runs 10, 2, and 11 at 9-ft, 11-ft, and 13.5-ft initial vent submergences, respectively. Plots of the wetwell bottom center pressure rms value time histories are shown in Figure 4-75. The peak rms values and times of occurrence for both the liquid and steam blowdowns are summarized in Table 4-11. The maximum rms pressure value increases with decreasing submergence. Although this trend exists for the maximum rms values, it is not generally true throughout the CO period, as shown in Figure 4-75. Also, the trend for the lowest submergence to produce the highest rms pressure value was contradicted by two of the runs which used the vent riser. A comparison of Runs 26 and 27 (Figures B-52 and B-54, respectively) shows that Run 27 (11-ft submergence) had a slightly higher maximum rms pressure value than Run 26 (9-ft submergence).

The CO duration decreased with increased submergence as expected, because a deeper initial submergence creates a higher back-pressure at the vent exit causing it to reflood sooner. The 9-ft and 11-ft vent initial submergence curves are similar in shape with the 9-ft run having a larger peak rms value. The shape of the rms pressure time history curve for the 13.5-ft submergence run is different from that of the 9-ft or 11-ft submergence runs; the initial part of the curve from 4 to 20 seconds is similar, but then the 13-ft submergence curve continued to decrease while the other two curves peak. As a result, the maximum rms pressure for Run 11 occurred early in the blowdown while the maximums for Runs 10 and 2 occurred much later. These comparisons show that submergence alone does not have a well defined effect on the wetwell bottom center rms pressure over the duration of the blowdown.

Figures B-76, B-60, and B-78 are PSDs taken at the time of maximum wetwell bottom center pressure rms value for Runs 10, 2 and 11, respectively. All three PSDs show dominant frequencies in the 1.5 Hz range and a peak in the 6 to 7 Hz frequency range. Generally, the frequency distribution at the time of peak rms pressure value was similar for all three runs.

Figures B-19, B-3, and B-21 are frequency content time histories for Runs 10, 2 and 11. The three curves show the same trends. There was a low dominant frequency (1 to 2 Hz) in the early part of CO that gave way to a 7 to 9 Hz dominant frequency which prevailed during the middle portion of CO. Toward the end of CO the dominant frequency shifted to the 2 to 3 Hz range. Note, that the point in Runs 2 and 10 where the dominant frequency changes from the 7 to 9 Hz range to the 2 to 3 Hz range is also the point of maximum rms pressure value. This might suggest that a different frequency source is becoming dominant. The mass flow rate into the drywell began to decrease rapidly at about 23 seconds into the blowdown as the liquid level in the steam generator dropped to the venturi inlet and two-phase fluid entered the venturi. The change in mass flux may be the factor which causes the shift in frequency.

The variable submergence steam blowdowns (Runs 16, 17 and 19), like the liquid blowdowns with the vent riser installed, (Runs 26 and 27) did not produce the highest bottom center rms pressure with the lowest submergence.

Figure 4-76 shows a comparison of the rms pressure time histories for steam blowdown Runs 17, 16, and 19 with 9-ft, 11-ft and 13.5-ft initial vent submergence, respectively. The rms pressure time history curve for the 13.5-ft submergence blowdown was consistently below the same curves for the 9-ft and 11-ft submergences. This shows that the deeper submergence reduces the frequency source strength for the steam blowdowns. Maximum rms pressure values listed in Table 4-11. Runs 17 and 16 (9-ft and 11-ft submergence) had similar maximum rms pressure values while Run 19 (13.5-ft submergence) has a maximum value which was approximately 56 percent of the values for Runs 16 and 17. PSDs of the wetwell bottom center pressure at the time of maximum rms pressure are shown in Figures B-90, B-88 and B-94. The PSDs show one large dominant low frequency peak and another higher frequency peak. The dominant low frequency shown in Table 4-11 was lower for Run 19 than for either Runs 16 or 17. The frequency content time histories of the wetwell bottom center pressure are shown in Figures B-33, B-31, and B-37 for Runs 17, 16 and 19, respectively. The plots for Runs 16 and 17 are very similar and there appears not to be any submergence effect. The bottom center pressure signal was so small in Run 19 that very little information was plotted on the frequency content time history. However, Run 19 appeared to have a dominant ~1 Hz frequency that endured throughout CO.

In summary, the comparisons discussed above show that the deeper submergences have a tendency toward lower rms pressure values. However, the test data do not indicate a simple relationship. Increasing the submergence does not have any appreciable effect on the pressure frequency content, but it does decrease the CO duration.

4.5.1.4 Effect of Initial Suppression Pool Temperature

Initial suppression pool temperature effect on CO was investigated by performing a series of four blowdowns with varying initial pool temperature but otherwise identical initial conditions.

Figure 4-77 shows a comparison of the wetwell bottom center rms pressure value time histories for Runs 2, 5, 7 and 9 (76°, 79°, 93° and 114°F initial pool temperatures, respectively). All four runs were a 3.00-in diameter venturi, 11-ft initial vent submergence, no vent riser, liquid blowdowns. Figures 4-78 and 4-79 are similar comparisons of Runs 3 and 8 with 74° and 111°F initial pool temperatures and Runs 14 and 13 with 70° and 109°F initial pool temperatures. Runs 3 and 8 had a 3.82-in diameter venturi, 11-ft initial vent submergence, no vent riser, and liquid blowdown, while Runs 14 and 13 used a 2.125-in diameter venturi. Table 4-12 compares the three sets of blowdowns.

In both the 3.00-in and 3.82-in diameter venturi cases there was an increase in the peak rms bottom center pressure with increased initial pool temperature. However, the opposite trend was observed with the 2.125-in diameter venturi. Blowdowns performed using this small size venturi did not appear to excite the same frequency sources as the larger venturi sizes. Figure 4-78 (Run 3) shows the 74°F initial pool temperature rms pressure curve peaking after the 111°F curve (Run 8). The same result was observed in Figure 4-77 with the 76°F (Run 2) and 114°F (Run 9) curves. Note that in Figure 4-77 the 79°F (Run 5) and 93°F (Run 7) curves peak at 12 seconds while the 76°F (Run 2) and 114°F (Run 9) curves peak at 26 seconds and 21 seconds, respectively. This indicates there is no direct effect of the initial suppression pool temperature on the time of peak rms pressure.

Figures B-60, B-66, B-70, B-74, B-62, B-72, B-84 and B-82 are PSDs of the wetwell bottom center pressure at the time of maximum rms pressure for the runs listed in Table 4-12. All the 3.00-in venturi runs show a large 1.5 Hz component and a second dominant frequency of 6 to 7 Hz. The PSDs for Runs 3 and 8 are not as closely matched as those for Runs 2 and 9. However, both Runs 3 and 8 did show a large 1.5 Hz frequency component, although it was not the dominant frequency for either run. PSDs for Runs 13 and 14 are not particularly similar, although both do show some high frequencies. This might suggest that some significant differences in conditions are operative to account for different phenomena which are occurring in the 2.125-in venturi blowdowns.

Frequency content time histories for Runs 2, 5, 7, 9, 3, 8, 14 and 13 are shown in Figures B-3, B-9, B-13, B-17, B-5, B-15, B-27 and B-25, respectively.

The frequency content time histories for the 3.82-in diameter venturi show the 1.5 Hz component. Run 3 shows dominant frequency components in the range of 1 to 3 Hz that was not present in Run 8.

Frequency content time histories for the 3.00-in diameter venturi show that in the 3.82-in venturi blowdowns the low initial pool temperature blowdown has a higher dominant frequency in the 14- to 20-second time period than the higher initial pool temperature blowdowns. In addition, the highest initial pool temperature blowdown had more low frequency (1-2 Hz) dominant signals than the other three blowdowns. All four of the 3.00-in venturi blowdowns had maximum bottom center rms pressure values when the low frequency (1 to 2 Hz) signals were dominant.

The frequency content time histories of Run 13 and 14 are similar with Run 14 showing more frequencies, because the higher signal strength allows more frequencies to rise above the threshold level for plotting.

Data in Table 4-12 show little or no dependence of CO duration on initial pool temperature. Also, Figure 4-2 shows a weak dependence of the end-of-CO vent steam mass flux on bulk pool temperature. Because the bulk pool temperatures are directly dependent on initial pool temperatures it can be concluded that the end-of-CO vent steam mass flux is only weakly dependent on the initial suppression pool temperature.

4.5.1.5 Load Symmetry

Runs 9 and 17 (one liquid and one steam) were selected to show load symmetry on the wetwell wall. Run 9 was used because it had the highest maximum wetwell bottom center rms pressure of the liquid blowdown runs; and Run 17 was used because it was the second highest of the steam runs. The steam runs with the highest rms pressure was not used in this case because an inoperative pressure transducer at the 12-ft level would have made comparisons difficult.

PSDs of pressure from each of three levels (2-ft, 12-ft and 20-ft) and several circumferential locations were taken at the time of maximum bottom center rms pressure and their rms values calculated. Table 4-13 shows the deviation from the mean for these rms pressure values. Data in this table shows that the rms pressure values on the wetwell wall at the three levels given were symmetrical to within ±0.12 psi which is well within reading accuracy of the pressure transducers. The PSD plots for each of these locations were identical.

4.5.1.6 Repeatability of Tests

The test matrix specifically included several blowdowns with the same nominal initial conditions to demonstrate the repeatability of the measurements and the influence or presence of any random phenomena in the experiments. Due to the transient nature of the tests, it would be expected that the steam flow into the pool would result in turbulent flow patterns in the wetwell which would not be identical for any two tests. To determine the effect of any such phenomena, four tests were defined in the test matrix which would duplicate as closely as possible a previous test. Runs 22 and 23 were repeat tests of Runs 9 and 8, respectively. Both were liquid blowdowns without a riser. Run 28 (a repeat of Run 26) was a liquid blowdown with a vent riser. In addition, Run 19 repeated Run 18 which was a steam blowdown with a vent riser.

The results of these blowdowns and the comparison between the pressure and air content measurements are given in Appendix H. The difference between the rms bottom center pressure values for these blowdowns are presented in Table 4-14 for the same time periods in each test. It can be seen that the agreement varies between 10 and 50 percent, however, the agreement generally averages approximatel 20 percent for all times of the four comparisons. On comparing the frequency charts of the repeated runs in Appendix B, an agreement can be seen between the frequency content and the harmonic amplitudes of the bottom center pressures.

4.5.2 Parametric Sensitivities for CO

Several observations have been made in the previous paragraphs relative to the values of rms pressure associated with CO under a variety of conditions from the 4TCO Test runs. The Test Series 5200 matrix included tests to measure the effect of all thermodynamic conditions thought to be most significant. Two parameters which strongly influenced the rms pressure during the liquid blowdowns were the mass flow rate and pool temperature.

Data from 12 test runs are available to evaluate the effect of vent steam mass flux and pool temperature on the rms pressure for the liquid blowdown tests without a vent riser. These tests were performed to investigate initial pool temperatures from 70°F to 114°F with the four different venturi sizes and a constant vent submergence of 11 feet. The results of Runs 2, 3, 5 through 9, 12, 13, 14, 22 and 23 are shown in Figures 4-80 through 4-84 as the instantaneous values of steam mass flux and bulk average pool temperature corresponding to the specific values of rms pressure at the bottom center of the wetwell. After careful examination of the test results, the vent steam mass flux and bulk pool temperature* were determined for the values of rms pressure of 0.5, 1.0, 2.0, 2.5, and 3.0 psi from the data for each test and presented in Figures 4-80 through 4-84. From the data points, the approximate conditions of mass flux and pool temperature that produced a specific value of rms pressure were then shown as contour lines of constant rms pressure. Despite some scatter in the data points, a consistent set of contour lines was fitted to the data. This set of contour lines is shown in Figure 4-85. These contour lines show relative large values of rms pressures values for vent steam mass flux depending on pool temperature. As the pool temperature

*Bulk pool temperature calculation is described in Paragraph 3.5.1.

increased the two regions of large rms pressure values merged to produce the largest values of rms pressure. As the pool temperature increased the values of rms pressure decreased for nearly all values of vent steam mass flux.

The bottom center rms pressure contour lines are shown in Figures 4-86 and 4-87 along with a series of test run trajectories, i.e. the vent steam mass flux and pool temperature combinations that were measured during the time of CO for a test run. The four trajectories for the 3.00-in venturi liquid blowdowns are shown in Figure 4-86 with initial pool temperatures of 76°, 79° 93°, and 114°F for Runs 2, 5, 7, and 9, respectively. The trajectories show that CO started in a region of low rms pressures and proceeded to cross through both regions of increased values of rms pressures. The trajectory for Run 9 passes directly through the region of largest measured rms pressures. The trajectories in Figure 4-87 correspond to the four different venturi sizes with a nominal initial pool temperature of 110°F. The trajectory of Run 8 shows that the pool temperatures were usually higher than those of the other three tests. As a result of the reduced values of rms pressure for Run 8, the conclusion is that combinations of high steam flux and high pool temperature produce lower-than-maximum values of rms pressures. The repeat test of Run 23 (not shown in Figure 4-87) verified the result of Run 8 as being valid and correct.

Vent air content is another important parameter effecting CO. Although this parameter was not systematically varied in the test matrix, it was investigated by comparing the measurements at different time segments in the liquid blowdowns. The effect of vent air content was evaluated by plotting the bottom center rms pressure as a function of air content for essentially constant values of bulk pool temperature and vent steam mass flux. The measured values in all time segments of 2.048 seconds were sorted for all the liquid blowdown runs without a vent riser to produce the results shown in Figures 4-88 through 4-94. Each figure is a plot for constant mass flux with values of 0-10, 10-15, 15-20, 20-25, 25-30, 30-35 and 35-40 $lbm/sec\text{-}ft^2$, and the rms pressure for pool temperature ranges of 90-100°, 100-110°, 110-120°, 120-130°, 130-140°, and 140-150°F are plotted versus air content. For the values of mass flux between 10 and 30 lbm/sec-ft^2 the rms pressure was reduced for the large values of air content; however, for the smaller values no particular correlation appears to hold. No data points are available for the large air content values in Figure 4-88 because the smallest venturi had a mass flux that exceeded 10 lbm/sec-ft^2 over most of the test run. Therefore, no correlation of rms pressure appears to hold for air content less than approximately 0.10 percent when the mass flux is less than 10 lbm/sec-ft^2. Figures 4-89 and 4-90 show a consistent reduction in rms pressures when the air content is greater than approximately 0.30 percent. If a dependence of rms pressure on the bulk pool temperature is present, the measurements available are not strong enough to identify it. Therefore, only a single curve has been drawn through the data points. The data points with a mass flux of 20-25 lbm/sec-ft^2 did not show any correlation for air content values less than 1.0 percent in Figure 4-91. The data points shown in Figure 4-92 with a mass flux of 25-30 lbm/sec-ft^2 show a correlation for values of air content greater than 2.5 percent. The results for the largest values of mass flux presented in Figures 4-93 and 4-94 show no correlation for the range of data presented.

The three curves of rms pressure versus air content are shown together in Figure 4-94 for three ranges of vent steam mass flux. These results show that for a given value of air content in the range where the correlation holds the rms pressure is highest for the largest value of vent steam mass flux. In addition, for a constant vent steam mass flux, and with air content greater than 0.3 percent, the rms pressure decreases as air content increases.

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Figure 4-90 Wetwell Bottom Center Presure rms Value Dependence on Vent Air Content at Vent Mass Flux of 15-20 lbm/sec-ft^2

Figure 4-91 Wetwell Bottom Center Pressure rms Value Dependence on Vent Air Content at Vent Mass Flux of 20-25 lbm/sec-ft^2

Figure 4-92 Wetwell Bottom Center Pressure rms Value Dependence on Vent Air Content at Vent Mass Flux of 25-30 lbm/sec-ft^2

Figure 4-93 Wetwell Bottom Center Pressure rms Value Dependence on Vent Air Content at Vent Mass Flux of 30-35 lbm/sec-ft^2

Figure 4-94 Wetwell Bottom Center Pressure rms Value Dependence on Vent Air Content at Vent Mass Flux of 35-40 lbm/sec-ft^2

Figure 4-95 Wetwell Bottom Center Pressure rms Value Dependence on Vent Air Content and Steam Mass Flux

5. REFERENCES

1. "Mark II Containment Dynamic Forcing Function Information Report," NEDO-21061, Revision 3, June 1978.

2. T. R. McIntyre, M. A. Ross and L. L. Myers, "Mark II Pressure Suppression Test Program," NEDO-13442, June 1976.

3. W. A. Grafton, T. R. McIntyre and M. A. Ross, "Mark II Pressure Suppression Test Program Phase II and III Tests," NEDO-13468, March 1977.

APPENDIX A
SYSTEM PERFORMANCE DATA

This appendix contains time histories of selected pressures, temperatures and flow rates for all 28 Test Series 5200 4TCO runs.

Included for each run is a 40-second time history plot of the following parameters, listed in the order as they appear:

a. Drywell dome, vent static, and wetwell freespace pressures

b. Blowdown flow temperatures

c. Wetwell pool temperatures at the 20- and 13-ft elevations

d. Wetwell pool temperatures at the 9-ft elevation

e. Wetwell pool temperature at the 2-ft elevation and the wetwell freespace temperature

f. Wetwell local and total bulk temperatures

g. Blowdown flow rate

h. Drywell liquid mass (vent riser runs only)

i. Blowdown vent mass fluxes

In those runs where the CO ending time was greater than 40 seconds, 120-second time history plots are also included. Runs 10, 12, 13, 14, 15, 25 and 27 include these 120-second time history plots.

The vent mass flux plots were calculated from data using the following assumptions.

For steam blowdowns:

a. 100% steam quality at venturi inlet.

b. Vent steam flow is equal to venturi steam flow.

For liquid blowdowns:

a. Isenthalpic flow from steam generator to the drywell.

b. Two-phase flow from the steam generator after the venturi is uncovered.

c. Saturated liquid at venturi inlet until venturi is uncovered.

Although there is some liquid carried over from the steam generator to the drywell during the steam blowdowns, this additional liquid is expected to have only a minimal effect on the steam mass flow calculated using the assumptions listed previously for steam blowdowns.

The liquid and steam mass flux curves for the 2.50- and 2.125-in venturi runs do not extend beyond the venturi uncovering time, because of difficulty in approximating the two-phase mass flow through the venturi for these runs.

The blowdown flow rate plots contain two curves for liquid blowdowns and one curve for steam blowdowns. In the liquid blowdowns, the upper curve is calculated assuming a venturi inlet quality of zero, and the bottom curve is calculated assuming a venturi inlet quality of 1. The actual mass flow through the venturi in the early portion of the liquid blowdowns (from blowdown initiation to the uncovering of the venturi) is represented by the upper curve, while the lower curve is representative of the mass flow at the end of the blowdown. In the steam blowdowns, the blowdown flow rate curve is based on a venturi inlet quality of 1.0.

Also included in this section is a summary of specific thermodynamic parameters for each run. These parameters include the initial and final values of the drywell pressure, wetwell pressure, wetwell freespace temperature, and the bulk pool temperature. Also included is the total blowdown duration time and the time to uncover the venturi in the liquid runs. This summary is located in Table A-1.

Run No.	Drywell Press. (psia) Initial	Final[a]	Wetwell Press. (psia) Initial	Final[a]
1	14.7	48.0	14.7	43.6
2	14.8	49.2	14.8	46.1
3	14.7	44.3	14.7	42.6
4	14.7	48.1	14.7	44.2
5	14.8	53.1	14.8	49.1
6	27.4	51.7	27.2	48.2
7	14.8	51.9	14.8	48.9
8	14.8	52.7	14.8	48.9
9	14.6	52.9	14.6	47.6
10	14.8	48.9	14.8	45.8
11	14.8	56.5	14.8	51.2
12	14.8	53.3	14.8	48.3
13	14.8	55.5	14.8	50.0
14	14.8	54.7	14.8	48.8
15	14.8	48.1	14.8	43.8
16	14.8	44.4	14.8	40.2
17	14.8	42.8	14.8	40.6
18	14.8	49.3	14.8	45.8
19	14.7	50.7	14.7	46.1
20	14.8	46.8	14.8	42.2
21	14.7	48.0	14.7	43.3
22	14.8	54.7	14.8	49.3
23	14.7	51.8	14.7	48.6
24	14.7	50.3	14.7	46.4
25	14.8	50.3	14.8	45.9
26	14.8	51.8	14.8	46.4
27	14.5	46.9	14.5	43.4
28	14.6	50.9	14.6	46.2

[a] Values at the time of termination of computer sc

[b] Values estimated from bottom center trace-level p

Table A-1

FACILITY THERMODYNAMIC RESPONSE

Wetwell Free-space Temp (°F) Initial	Final[a]	Bulk Pool Temp (°F) Initial	Final[a]	Blowdown Length (sec)	Computer Scan Termination Time (sec)	Time to Uncover Venturi (sec) (Liquid only)
60	140	69	88	58.0	82.0	-
83	153	76	128	48.0	100.5	23.0
72	148	74	130	31.0	117.0	15.0
73	149	74	126	33.5	59.5	15.0
60	146	79	129	46.5	72.5	22.5
80	171	71	133	32.0	60.0	15.0
70	152	93	142	46.5	82.5	22.0
79	157	111	161	32.0	67.0	15.0
78	155	114	166	48.0	75.0	22.5
68	144	73	132	46.5	101.0	22.5
79	151	74	123	46.5	62.0	22.0
77	153	109	159	66.0	93.0	30.0
72	155	109	158	94.0	109.5	39.0
60	155	70	119	94.0[b]	99.0	39.0
69	147	71	110	94.5	119.0	37.0
76	160	75	99	64.0	109.0	-
63	140	71	98	66.0	112.0	-
65	146	71	85	49.5	107.0	-
67	147	71	87	54.0	88.5	-
59	140	68	87	80.0[b]	118.5	-
61	142	68	86	80.0	102.0	-
72	152	109	155	45.0	67.5	21.5
67	143	108	158	32.0	91.5	15.0
68	145	111	157	34.0	63.0	15.0
68	145	111	151	71.0	90.0	31.5
80	150	111	153	48.0	76.0	23.0
71	145	110	153	52.0	106.5	23.0
78	150	110	153	47.5	74.0	22.5

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APPENDIX B

REFERENCE PRESSURE DATA

This appendix contains reference pressure data used throughout the report to make comparisons and form conclusions as to the significance of the test results. The data in this appendix include pressure-time histories, PSD plots, frequency content-time histories or "star charts" and rms pressure time histories. The data is presented in three sets of plots for all 28 tests.

The first set of plots are time histories of the wetwell bottom center absolute pressure over the duration of CO. This is shown on a 0-40 second plot when CO duration is less than 40 seconds. When the CO duration is greater than 40 seconds a 0-120 second plot is also included.

The second set consists of a plot of the time history of the wetwell bottom center pressure for the time of maximum rms pressure and the corresponding PSD plot, for each run. In each run, the two-second interval which produced the highest bottom center pressure rms value was plotted. The data was adjusted using linear trend removal over the two second segment. The PSD analysis of each of these two second segments is also presented. The PSDs are presented on a scale from 0-60 Hz. The PSD value plotted as the ordinate is scaled to fit the page. An overlay on the PSD indicates the fraction of total power which is included from 0 Hz to the frequency of interest. A cumulative fraction less than 1.0 at 60 Hz indicates that there is additional signal power above 60 Hz. This additional power is typically a very small fraction of the total signal power. When the cumulative fraction is not close to 1.0 at 60 Hz, a noisy transducer is usually indicated. However, this does not affect the frequency distribution below 60 Hz.

Frequency content time histories of the wetwell bottom center pressure are presented in the third set of plots. These plots were generated from PSDs taken at two-second intervals over the duration of CO. The dominant frequency on the PSD was plotted using a circle whose radius is proportional to the square root of the PSD value at that frequency. Second and third dominant frequencies were plotted using symbols of constant size. One group of points is plotted for each two-second PSD analysis. The points are plotted at the midpoint of the two-second period. Occasionally points on the plots are spaced 1 second apart. This indicates that overlapping PSD analyses have been made, e.g., a PSD taken from 10-12 seconds would have its frequencies plotted at 11 seconds, while a PSD taken from 11-13 seconds would have its frequencies plotted at 12 seconds.

Also presented in the third set of plots are the rms pressure time histories over the duration of CO for the wetwell bottom center, wetwell wall at the 12-ft elevation and the vent exit. The rms values plotted represent the total amplitude of the signal from 0-60 Hz. This excludes the noise which is present in some of the signals and gives a more accurate representation of the pressure signal due to the condensation process. Each point shown represents an rms pressure value computed over a two-second interval. The points are plotted at the midpoint of the two-second interval.

The plots for Runs 25 and 26 have portions of the rms pressure time history curves shown as dashed lines. During these times one or two unexpected chugs occurred. Following the chug, CO resumed and continued for several more seconds. The rms pressure values for these chugs are not indicative of CO loads. Therefore, they have been excluded from the plots.

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APPENDIX C

VENT ACOUSTIC PRESSURE DATA

A spectral analysis of the five vent pressure transducers and the drywell acoustic pressure transducer was performed for three test runs. These runs included two liquid blowdowns, one with and one without the vent riser (Runs 9 and 26) and one steam blowdown with the vent riser (Run 1). The specific conditions for these runs can be found in the Test Matrix, Table 3-7. The two-second time period of the analysis included the time of maximum bottom center rms pressure for each run.

The frequency content of the pressure signals at five locations in the vent and the drywell during the 20 to 22 second time period of Run 9 are shown in the PSD plots Figures C-1 through C-6. Similarly the frequency content of these transducer signals for Run 26 and Run 1 are shown in Figures C-7 through C-18.

The transfer function from one transducer location to another is defined as the square root of the ratio of the PSD values at the frequency of interest. The transfer function from the vent exit to each of the other transducer locations in the vent and drywell is shown for peak frequencies at the time of analysis for the three runs in Figures C-19, C-20 and C-21. The amplitude of the transfer functions at these locations can be thought of as that rms pressure that would result from a sinusoidal 1 psi rms pressure at the vent exit at that frequency.

No conclusions have been made on the basis of this analysis. This data is provided in this appendix as information.

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APPENDIX D

MEASUREMENT UNCERTAINTIES

The instrumentation in the 5200 Test Series measured such parameters as temperature, pressure, strain, acceleration, air content, and liquid levels. Each measurement has some uncertainty associated with it. These uncertainties were evaluated using the Kline and McClintock* uncertainty equation,

$$\sigma_y = \left[\sum_{i=1}^{n} \left(\frac{\partial y}{\partial x_i} \sigma_{x_i} \right)^2 \right]^{1/2}$$

where the uncertainty in the measured parameter, σ_y, is a function of the uncertainties in the independent variables, σ_{x_i}.

The measured parameters were used in some cases to find calculated quantities such as vent flow rates. The uncertainty in these quantities is also found with this equation.

The uncertainties in all reported values, whether measured or calculated, are given in Table D-1.

In the replay data mode an uncertainty of ±5 percent of the measured value is added to the real time uncertainty. The recording and subsequent replay of data at a reduced speed introduces this additional uncertainty. Table D-2 lists the measurements processed under the replay data mode for Run 28.

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*S.J. Kline and F.A. McClintock, "Describing Uncertainties in Single-Sample Experiments," Mech. Eng., January 1953, p. 3.

Table D-1

UNCERTAINTY OF TEST SERIES 5200 REAL TIME PARAMETERS

Measurement Description (DAS Channel)	Uncertainty[a]
A. Pressure[b]	
1. Steam Dome (49)	± 3.0 psi
2. Venturi Throat (50)	± 3.0 psi
3. Drywell Dome (51)	± 0.9 psi
4. Vent Static (52)	± 1.1 psi
5. Wetwell Freespace (53)	± 0.2 psi
6. Drywell Acoustic (79)[c]	± 0.6 psi
7. Downcomer (80 - 84)[c]	± 1.3 psi
8. Wetwell Pool (85 - 96)[c]	± 1.4 psi
9. Drywell-Wetwell Delta Pressure (63)	± 0.1 psi
B. Acceleration[b] and Strain[e]	
1. Wetwell Acceleration (68 - 73)[c]	
a. Vertical	± 0.6 g
b. Radial	± 0.8 g
c. Vent Tangential (74 - 75)	± 1.3 g
2. Wetwell Strains (76 - 78)[c,d]	± 3

[a]The uncertainty for each location was calculated for the instruments used in Run 28. Previous tests may have used different instrument manufacturers or models

[b]Uncertainties were taken from the calibration data worst case

[c]Indicates uncertainty in the dynamic component only, thermal drift effects not included

[d]Percentage of measured value

[e]68% confidence

Table D-1

UNCERTAINTY OF TEST SERIES 5200 REAL TIME PARAMETERS (Continued)

Measurement Description (DAS Channel)	Uncertainty
C. Temperature[a]	
1. Blowdown Line Exit (257)	± 4°F
2. Drywell (258, 259)	± 4°F
3. Vent Flow (260)	± 4°F
4. Wetwell Pool (261 - 271)	± 4°F
5. Wetwell Freespace (272)	± 4°F
D. Drywell Liquid Level (64)[b]	
1. Static Uncertainty	± 0.2 in.
2. Dynamic Uncertainty	± 1.6 in.
E. Air Content[c]	
1. Steam - Air Sample System[d]	
a. Quantities between 5 and 26% air by mass[e]	± 13%
b. Quantities below 5% air by mass	± 0.22% air by mass
2. Oxygen Analyzer (67)	
a. Quantities between 4 and 14% air by mass[e]	± 2.5%
b. Quantities below 4% air by mass	± 0.2% air by mass
F. Calculated Values	
1. Wetwell Liquid Bulk Temperature[f]	+ 5°F/-20°F
2. Venturi Flow Rate[c,e,g]	± 3%
3. Drywell Liquid Mass (static)[b]	± (100 lbm + 1.1%[e])
4. Drywell Liquid Volume (static)[b]	± ($1.7\ ft^3$ + 1.1%[e])

[a] Uncertainty is ± 4°F in 32 to 530°F range and ±0.75% in 530 to 1400°F range

[b] Uncertainties were taken from the calibration data worst case

[c] 68% confidence

[d] Uncertainty in representative sampling time is not included

[e] Percentage of measured value

[f] 95% confidence

[g] Single phase flow only

Table D-2

TEST SERIES 5200 REPLAY PARAMETERS

Measurement Description (Replay Channel)

A. Pressure
   1. Venturi Throat (65)
   2. Drywell Acoustic (74)
   3. Vent (75 - 79)
   4. Wetwell Pool (80 - 91)

B. Acceleration and Strain
   1. Wetwell Acceleration
      a. Vertical (66, 68)
      b. Radial (67)
      c. Vent Tangential (69, 70)
   2. Wetwell Strains (71 - 73)

APPENDIX E
FACILITY STRUCTURAL DATA

This appendix contains strain and acceleration measurements at several locations on the facility structure for Run 7 (L-3.0-93-11-N) and Run 15 (L-2.1-71-11-R). These measurements are made available here as a resource for a possible analysis to assess the magnitude of Fluid Structure Interaction (FSI) effects on pressure data.

Two runs are presented here as representative runs of Test Series 5200. These runs were chosen because both had typical bottom center pressure values, valid data from appropriate transducers, and each run had a different venturi size. A PSD analysis was used to determine the frequency content of strain, acceleration, and pressure signals for both Runs 7 and 15. The time interval selected for the analysis was the 7- to 9-second period for Run 7 and 29 to 31-second period for Run 15.

Run 7 PSD and time history plots for the 7 to 9-second time interval are shown in Figures E-1 through E-12. Included in these plots are the baseplate acceleration, baseplate strain, bottom center pressure, 6-ft elevation wall hoop strain, 12-ft elevation wall hoop strain and the 12-ft elevation wall pressure. The rms values and dominant frequencies of each measurement are summarized in Table E-1.

The PSD and time history plots for Run 15 are shown in Figures E-13 through E-26. Also included for Run 15 are the PSD and time history plots of the wetwell flange vertical acceleration. This measurement monitored the response of the outside of the 4TCO wetwell at the 0-ft elevation. A summary of the dominant frequencies and rms values for Run 15 is included in Table E-2.

The wetwell wall pressure sensor at the 6-ft elevation and the wetwell wall accelerometers at the 6-ft and 12-ft elevations were inoperative for both Runs 7 and 15.

From the results summarized in Tables E-1 and E-2, all measurements in Run 15 consistently showed higher frequencies than observed in other runs of the series. Both the baseplate strain and the bottom center pressure contained the same frequencies. This was also true at the 12-ft elevations.

The baseplate accelerometer in Run 15 experienced frequencies of about 166 Hz and 54 Hz. The baseplate strain showed some response at 54 Hz but very little at 166 Hz. The bottom center pressure showed some response at 54 Hz but not at 166 Hz. The 4T baseplate was analyzed* and found to have a 188.7 Hz single resonant frequency when dry. Therefore, the 166 Hz component observed in the acceleration may be this mode with the frequency modified by the presence of the water.

The outside flange acceleration at the base of the wetwell showed little response as observed in Figure E-14. This shows that the baseplate has minimal response at its circumferential edge.

In evaluating the phase between measurements, it was necessary to define the sign convention used on each instrument. In the baseplate an upward acceleration was positive. A tensile strain in the baseplate was positive. In the wetwell wall a radially outward acceleration was positive. A tensile hoop strain in the wetwell wall was positive.

The PSD analysis of the bottom plate showed the baseplate acceleration and the bottom center pressure to be approximately in phase at their dominant frequencies. Also, the baseplate acceleration and the bottom center pressure were approximately 180° out of phase with the baseplate strain at their dominant frequencies. This can also be interpreted as the acceleration and pressure being approximately in phase with a negative compressive baseplate strain.

The PSD analysis for the wetwell wall showed the wetwell pressure to be approximately in phase with the wetwell hoop strain at their dominant frequencies.

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*"Mark II Containment Program-Summary of 4T Fluid Structure Interaction Studies," NEDE-23710-8, April 1978.

The following Tables are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

Table E-1	Facility Structural Data Summary (7-9 sec) - Run 7
Table E-2	Facility Structural Data Summary (29-31 sec) - Run 15

Figures E-1 through E-26 are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

APPENDIX F

VENT LENGTH EFFECT TIEBACK TESTS BETWEEN TEST SERIES 5200 AND 5101

Seven steam blowdown tieback tests were performed during Test Series 5200 and compared with four steam blowdown tests in Test Series 5101 to determine vent length effects. Test Series 5101 had a vent length of 94 feet from drywell exit to vent exit. Test Series 5200 had a vent length of 45.3 feet not including the 2-ft vent riser.

The tieback test pairings and their test parameters are listed in Table F-1. The steam mass flux for these four pairings are shown in comparison plots Figures F-1 through F-4. The mass flow rate in the vent is assumed to be equal to the venturi flow rate. This assumption is good if the drywell pressure is constant. Since the majority of the drywell pressurization occurs during the first five seconds after blowdown initiation, the assumption is valid in the CO regime. These curves show that the vent mass flux is similar for tests having the same initial conditions.

Comparison plots of the pressure signal rms values and frequency content versus time can be found in Subsection 4.3 for these pairings.

Table F-1

COMPARISON OF TEST SERIES 5200 AND 5101 TIEBACK TESTS

Test Series	Run Number	Suppression Pool Depth (ft)	Venturi Diameter (in)	Vent Submergence (ft)	Average Pool Temperature Initial (°F)	Average Pool Temperature Final (°F)	Long-Term Pressure Drywell (psia)	Long-Term Pressure Wetwell (psia)	CO End (sec)	Vent Mass Flux at CO End (lbm/ft^2-sec)
5200	1	23	3.00	11	69	88	46.2	43.6	21.2	6
5200	16	23	3.00	11	75	98	44.4	40.2	22.4	6
5101	27	23	3.00	11	70	82	47.3	42.2	20.9	6
5200	17	21	3.00	9	71	98	44.3	40.6	21.2	7
5101	31	21	3.00	9	68	85	43.8	39.4	25.9	5
5200	18	25.5	3.00	13.5	71	85	49.6	45.8	18.8	6
5200	19	25.5	3.00	13.5	71	87	47.9	46.1	20.9	6
5101	34	25.5	3.00	13.5	69	80	48.5	42.4	N/A	N/A
5200	20	23	2.50	11	68	87	43.6	42.3	N/A	6
5200	21	23	2.50	11	68	86	47.6	43.6	19.7	7
5101	29	23	2.50	11	70	82	46.5	41.5	24.3	5

Vent Length (ft:
From Drywell exit to Vent Exit
5101 94 ft
5200[a] 45.3 ft

[a]Not including 2-ft vent riser

Common Conditions:

Steam Generator Water Volume (ft^3)	60
Steam Generator Initial Pressure (psia)	1050
Type of Blowdown	Steam
Vent Diameter (in)	24
Initial Drywell Air (%)	100%

Figures F-1 through F-4 are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

APPENDIX G

VENT AIR CONTENT MEASUREMENT

Test Series 5200 had two air sampling systems measuring the vent air content: the Steam-Air Sample System and the Oxygen Analyzer. Both sampling systems use the same sample probe located in the vent approximately four feet below the drywell floor.

The Oxygen Analyzer operates as a continuous sampling device, whereas the Steam-Air Sample System operates at four or five second intervals drawing discrete samples into five evacuated sampling chambers.

Table G-1 lists the results from comparisons between the two systems for each of the chamber's representative sampling time. Also included in Table G-1 is the absolute difference in the measured percent of air by mass for each system and the uncertainty specification set on the Steam-Air Sample System. This uncertainty specification is ±25 percent of the measured quantity for air content values of 20 percent to 5 percent air by mass and ±0.5 percent air by mass for measured values below 5 percent air by mass. Target uncertainty specifications were set at ±10 percent of the measured air fractions for values between 20 percent and 5 percent air by mass and ±0.1 percent air by mass for measured values below 5 percent air by mass. There were no specifications set for measured values above 20 percent air by mass.

A check of these uncertainty specifications can be made by comparing the results from the two systems. However, this check does not measure the true error because both systems contain some uncertainty (see Appendix D). Eighty-nine percent of the data points meet the acceptable uncertainty specifications while eighty-three percent meet the target uncertainty specifications.

The data points with differences exceeding the specifications were all measured during the initial stages of the blowdown when air content was high and was changing rapidly. The large differences are not due to errors caused by measurement techniques or equipment, but by uncertainty in the representative sampling time. The times that were used as representative of the sample are the midpoints of the sample time period for the later sample chambers. During the initial part of the blowdown the air content curves provided by the Oxygen Analyzer were integrated over the sample time period and divided by the sample time to find the average air content. The air content curve was also used to find the time when the average occurred. This method assumes a constant mass flow into the sample chamber.

This method gave average times that were independent of test conditions. For example, fifteen air content curves for liquid blowdowns having all four break sizes, all four initial pool temperatures, 9-ft and 11-ft submergences with and without the vent riser were analyzed and in the 5 to 9 second sampling range the mean average time occurred at 6.7 second. The range given for the fifteen runs was from 6.6 second to 6.9 seconds with a standard deviation of 0.08 seconds.

The mean average time calculated was used as the representative sample time. However, for those chambers in which the flow changed from choked to subsonic, the constant mass flow assumption is violated resulting in a larger sample being collected at the beginning of the sample range. Further analysis could probably give better estimates of representative sample times for these cases.

Figures G-1 through G-18 contain comparison plots of air content versus time for both systems.

The following Table is GENERAL ELECTRIC COMPANY PROPRIETARY and has been removed from this document in its entirety.

Table G-1 Air Sampling Systems Comparison

Figures G-1 through G-18 are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

APPENDIX H
REPEATABILITY OF RESULTS

Four sets of runs with two runs in each set were performed with the same initial conditions (Runs 8 and 23, 9 and 22, 26 and 28, and 18 and 19). The first, three sets were liquid blowdowns with 3.82-in, 3.00-in, and 3.00-in venturi, respectively. Runs 18 and 19 were 3.00-in venturi steam blowdowns.

The pressure signal rms value was plotted versus time in each set for the wet-well bottom center, the wetwell wall at the 12-ft elevation, and the vent exit locations (see Figures H-1 through H-12). These figures show that the rms signal has similar values within each set.

The vent air content versus time for each set was plotted in Figures H-13 through H-16. These plots also show the repeatability of results for tests with the same initial conditions.

The initial and final bulk average pool temperatures, the final drywell and wet-well pressures, and the duration of the CO regime for these runs are given in Table H-1.

The frequency content versus time plots for these runs are given in Appendix B.

The following Table is GENERAL ELECTRIC COMPANY PROPRIETARY and has been removed from this document in its entirety.

Table H-1 CO Parameters Repeatability Comparison

Figures H-1 through H-16 are GENERAL ELECTRIC COMPANY PROPRIETARY and have been removed from this document in their entirety.

APPENDIX I
TEST MATRIX DEVELOPMENT

The analysis that was performed in support of the development of the test matrix for the Mark II 4T Condensation Oscillation (4TCO) Test Program is presented in this Appendix. The analysis is based mainly on results from a computer simulation of the response of Mark II containments and the test facility to LOCA-type blowdowns.

The specific requirements for the 4TCO test matrix that enabled the test program to meet the objectives stated in the Introduction are:

a. Provide for tests at conditions identical to those of previous 4T tests (Test Series 5101) so that the effect of vent length on the CO phenomenon can be established.

b. Provide for tests whose thermodynamic and hydrodynamic conditions bound the thermodynamic and hydrodynamic conditions predicted during a postulated Mark II LOCA blowdown.

c. Provide tests that will enable a parametric study of the effect of important thermodynamic and hydrodynamic conditions on CO.

d. Provide tests that will enable an investigation of the effect on CO of certain plant physical parameters, including vent submergence and the presence of a vent riser in the drywell.

e. Provide some tests that will be run twice with the same initial conditions in order to establish the extent to which test results can be repeated.

The independent test parameters that can be varied in the test matrix are:

a. Blowdown Type (liquid or steam)
b. Venturi Size
c. Initial Pool Temperature
d. Vent Submergence
e. Initial Drywell Air Content
f. Vent Riser (with or without)

The type of blowdown (steam or liquid) was determined by the presence or absence of a "dip-tube" in the steam generator. For a steam blowdown the dip-tube was installed and the vessel filled to the 4-foot level (~2750 lbm water) prior to testing. This was the same steam generator configuration used in the Test Series 5101. For a liquid blowdown the dip-tube was removed and the vessel completely filled (~7340 lbm water).

The initial blowdown flow rate was varied by interchanging the flow restricting venturi in the blowdown line. The four venturi used in the test series had throat diameters of 3.82, 3.00, 2.50, and 2.125-in. A gas heater was used to heat the water in the wetwell.

The thermodynamic response of the 4TCO facility during a blowdown was calculated using an existing computer code. The thermodynamic conditions that were expected to have the strongest influence on CO are:

a. Vent Steam Mass Flux
b. Vent Steam Quality
c. Vent Air Content
d. Pool Temperature

The computer was used to analyze the response of the test facility to liquid blowdowns with venturi diameters of 3.82, 3.00, 2.50 and 2.125-in, and steam blowdowns with venturi diameters of 3.00 and 2.50 in. The results are plotted in Figure I-1. In this figure the vent steam mass flux, vent air fraction and vent quality are plotted as a function of the pool bulk average temperature rise ($T-T_o$). The results were plotted in this way because the initial pool temperature does not effect vent mass flux, vent air content or vent steam quality.

Figure I-1 shows several important characteristics of calculated liquid and steam blowdowns. First, the vent steam quality of liquid blowdowns remains nearly constant at about 35 percent during the entire transient. The steam quality for steam blowdowns is 100 percent. The overall pool temperature rise is about 50°F for liquid blowdowns and 20°F for steam blowdowns. This difference is due to the greater amount of liquid transferred from the steam vessel to the wetwell pool during liquid blowdowns. Finally, the vent steam mass flux of liquid blowdowns is characterized by a rather long period of nearly constant flow, while the steam mass flux of steam blowdowns peaks quickly then steadily decreases.

The thermodynamic response of Mark II plants to both recirculation line and main steam line (MSL) breaks was calculated for the Final Safety Analysis Reports (FSAR) using the same computer code. Data from the FSAR analyses is shown in Figure I-2 and I-3 for recirculation and MSL breaks, respectively. The data is plotted in a manner identical to the test facility data in Figure I-1.

By comparing Figures I-2 and I-3 the characteristics of recirculation line and MSL breaks are shown to be similar. This similarity is due to the method used in making the analysis. In MSL breaks it was assumed that after a short time (∿ one second) the vessel liquid level swells to the height of the break, resulting in two phase flow from the break, as it is for the entire recirculation line break transient. Thus, the vent steam quality during both types of LOCA transients is approximately equal (30 to 40 percent). The total pool temperature rise for the both liquid and steam plant breaks is 30 to 45°F.

In order to satisfy the objective that test conditions bound the expected Mark II range, the results of the pre-test predictions and plant analyses were used. In comparing Figures I-1, I-2, and I-3 the following observations can be made:

a. The total pool temperature rise calculated for Mark II recirculation line and main steam line breaks is 30 to 40°F. The total pool temperature rise calculated for 4TCO liquid blowdowns is 45°F while that of 4TCO steam blowdowns is 20°F.

b. The vent steam quality occurring during Mark II recirculation line and main steam line breaks is 30 to 40 percent. The vent quality of 4TCO liquid blowdowns is about 35 percent while that of steam blowdowns is 100 percent, excluding possible liquid carryover.

Based on these observations it was concluded that 4TCO liquid blowdowns simulate postulated Mark II plant breaks (both recirculation line and main steam line) much better than do 4TCO steam blowdowns. Therefore, liquid blowdowns were selected to be used to bound Mark II condensation oscillation conditions.

A set of seven liquid blowdowns was developed to bound the "3-dimensional space" of vent steam mass flux, vent air content and pool temperature conditions possible in Mark II blowdowns. These tests were Runs 2, 3, 8, 9, 12, 13 and 14 of the test matrix.

In order to show that these tests bound the Mark II conditions, "maps" were prepared which show test and plant vent mass flux versus pool temperature at three different constant air content "planes" of the three dimensional condition space. Figures I-4, I-5, and I-6 show these conditions for plant recirculation and MSL breaks, including predicted test conditions at 10 percent, one percent and 0.10 percent vent air content. In these figures, the test conditions are the points with the number corresponding to the test matrix run number. Considering that plant breaks could occur with the suppression pool at different initial temperatures, the plant conditions could fall within the range shown by the horizontal bars.

Figures I-4, I-5, and I-6 show that the predicted vent mass flux and pool temperature conditions of the tests nearly encircle all the predicted plant conditions at all values of vent air content. At 1.0 percent and 0.1 percent air, Runs 2, 3 and 14 did not quite bound the low temperature end of the Mark II range. The test facility is not equipped with any means to cool the wetwell water. Thus, 70°F is about the coolest possible test condition. The CO loads were expected to be greatest at high pool temperatures and therefore, the possibility of not entirely bounding the Mark II range on the low temperature side was not a serious concern.

Figures I-1 through I-6 are GENERAL ELECTRIC COMPANY PROPRIETARY and ahve been removed from this document in their entirety.