ENCLOSURE 3

MFN 06-127

Reports/Correspondence Related to VB Testing

GE Nuclear Energy

May 2, 1994

MFN NO. 065-94
Docket No. STN 52-004

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Attention: Richard W. Borchardt, Director
Standardization Project Directorate

Subject: NRC Requests for Additional Information (RAIs) on the Simplified Boiling Water Reactor (SBWR) Design

References: Transmittal of Requests for Additional Information (RAI)s Requesting the SBWR Design, Letter from M. Malloy to P. W. Marriott dated February 9, 1994

The Reference letter requested additional information regarding the SBWR wetwell-to-drywell vacuum breaker tests. In fulfillment of this request, GE is submitting Attachment 1 to this letter which transmits the response to RAI 900.62.

Sincerely,

J. E. Leatherman

J. E. Leatherman
Manager, SBWR Design Certification
M/C 781, (408) 925-2023

Attachment 1, "Responses to NRC RAIs"

cc: M. Malloy, Project Manager (w/2 copies of Attachment 1)
F. W. Hasselberg, Project Manager (w/1 copy of Attachment 1)

RAI Number: 900.62

Question:

The staff needs the following information in order to assess the adequacy of the wetwell-to-drywell vacuum breaker test program:

a. Drawings of the vacuum breaker and instrumentation.

b. Purchase Specification No. 25A5388, Revision 1, "Vacuum Breaker (Prototype)."

c. NEBO Engineering Operating Procedure No. 35-3.00, "Engineering Tests."

d. Detailed specification of the conditions, both normal and design basis, under which the vacuum breakers will be required to operate.

e. Detailed test procedures for the tests listed in the test matrix.

f. Any information appropriate to ensuring that the data obtained on the reliable performance of the prototypical valve are applicable to (or will be bounding with respect to) the valves to be incorporated into the certified plant design.

GE Response:

a. The assembly and manufacturing drawings used to fabricate the vacuum breaker valve are attached.

b. The purchase and test specifications 25A5388 Rev. 1 and 25A5445 Rev. 1 are attached.

c. NEBO Engineering Operating Procedure No. 35-3.00, "Engineering Tests," is attached.

d. The detailed specification of the conditions, both normal and design basis, under which the vacuum breakers will be required to operate are contained in Section 4.5 of 25A5388 provided under item b.

e. The following are the detailed test procedures for the vacuum breaker:

  - Radiation Aging Campaign on the Primary Soft Seal of the SBWR Vacuum Breaker Prototype, April 1994. Attached

  - Drywell to Wetwell Vacuum Breaker Dynamic Qualification Test Procedure, Rev. 1, 2/22/94. Attached

GE Response to RAI Number: 900.62
(Continued)

- SBWR Vacuum Breaker (VB) Prototype Experimental Qualification Test Procedure ED45833, Rev. 0. Attached

- Vacuum Breaker Design Basis Accident Simulation Test Procedure PCNVBR00001 (to be provided later following GE approval).

f. Information appropriate to ensuring that the data obtained on the reliable performance of the valve is applicable is contained in, "Bayesian Approach to the SBWR Vacuum Breaker Reliability Demonstration Testing," ECN-CX-93-1355, Rev. 1 (Attached).

GE Nuclear Energy

P. W. Marriott, Manager
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September 26, 1994

MFN No. 113-94
Docket STN 52-004

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington DC 20555

Attention: Richard W. Borchardt, Director
Standardization Project Directorate

Subject: Responses to the Referenced Letters

References:
1) Letter, M. Malloy (NRC) to P. W. Marriott (GE), *SCHEDULE FOR REVIEW OF TEST AND ANALYSIS PROGRAM DESCRIPTION (NEDC-32391P) FOR THE GE NUCLEAR ENERGY (GE) SIMPLIFIED BOILING WATER REACTOR (SBWR) AND INITIAL REQUESTS FOR ADDITIONAL INFORMATION (Q900.65-Q900.81 AND PURDUE UNIVERSITY QUESTIONS - SET 5)*, dated September 12, 1994.

2. Letter, M. Malloy (NRC) to P. W. Marriott (GE), *REQUESTS FOR ADDITIONAL INFORMATION REGARDING THE TEST PROGRAM FOR THE GE NUCLEAR ENERGY (GE) SIMPLIFIED BOILING WATER REACTOR (SBWR) (Q900.82-Q900.95)*, dated September 16, 1994.

The Enclosures to this letter contain responses to Requests for Additional Information (RAIs) 900.65 - 900.81, Purdue University Questions - Set 5 (Questions 1, 2, and 3), and 900.83, 900.87, 900.91, 900.93, and 900.94, which were enclosures to the Referenced letters.

Sincerely,

TR McIntyre

T. R. McIntyre, Acting Manager
Advanced Plant Technologies

Enclosures: 1. Responses to Reference 1.
2. Responses to Reference 2.

cc: P. A. Boehnert (ACRS)
R. W. Hasselberg (NRC)
M. Malloy (NRC)

GE Nuclear Energy

MFN No. 113-94

bcc:	J. A. Beard	
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	GE Master File	M/C 462
	SBWR Project File	M/C 781

RAI Number 300.65

Question:

Resubmit NEDC-32391P, "SBWR Test and Analysis Program Description," with clear identification of the proprietary information on each page sought to be withheld, along with the reasons for withholding the information. Consistent with the staff's April 7, 1994, letter from D. Crutchfield to P. Marriott regarding the quality of the SBWR application, submit a non-proprietary version of the report within a reasonable period of time of the proprietary version, if the versions are not submitted simultaneously. Both versions of the report should be resubmitted as Revision 0 in lieu of a draft.

In the letter(s) transmitting the report, provide a page-by-page summary of any additions and corrections made to the report since the August 10, 1994, version was submitted to the staff for review.

GE Response:

NEDC-32391P, "SBWR Test and Analysis Program Description," Revision A, with clear identification of the proprietary information on each page sought to be withheld was transmitted by MFN 109-94, dated September 15, 1994. The letter transmitting the report provided a page-by-page summary of additions and corrections made to the report. A non-proprietary version entitled "SBWR Test and Analysis Program Description," NEDO-32391, was transmitted by MFN 110-94, dated September 15, 1994.

RAI Number 900.66

Question:

Provide a point-by-point response to the staff's March 7, 1994, letter from D. Crutchfield to P. Marriott regarding concerns about the SBWR testing program. Alternatively, provide a road map that identifies where in NEDC-32391P, "SBWR Test and Analysis Program Description," each of the concerns of the March 7, 1994, letter are explicitly addressed.

GE Response:

Issue
Acceptability of the Gravity Driven Cooling System (GDCS) Integral Systems Test (GIST) program data as the sole integral experimental basis for SBWR in view of the differences in configuration compared to the current SBWR design.

Response
While the physical configuration of GIST is representative of the 1988 SBWR design, GE considers that GIST provides GDCS performance data suitable for TRACG qualification. The basis for this statement is given below.

The principal difference between GIST and the current SBWR design is that the GDCS pool is a separate entity in the drywell instead of being a part of the suppression pool. This difference notwithstanding, the test captures the interactions between multiple regions represented by the reactor vessel, drywell and wetwell. The interactions between RPV depressurization and the GDCS are properly represented. The scaling study in Appendix B of NEDC-32391P demonstrates that the major parameters governing depressurization rate and driving heads for GDCS flow are preserved even though there are differences in the configuration of GIST from the current SBWR design

Testing in GIST is intended to simulate the late blowdown/early GDCS phase of the LOCA transient (Fig. 5.3.1 of NEDC-32391P), and thereby provide data for TRACG qualification of GDCS performance. The parameters of primary interest are: System pressure response which determines the timing of GDCS initiation, GDCS flow and RPV level response.

No scaling distortions have been identified in the significant phenomena which would preclude the use of the GIST data for their intended application

It should also be noted that the GIST data are supplemented by data from other BWR LOCA integral test facilities (TLTA, FIST) for the early part of the blowdown.

Issue
Absence of components/systems that could interact (IC, PCCS)

Response
GIST simulates the limiting LOCA transient without credit for the IC. No credit is taken in LOCA analysis for the IC.

Analysis shows (NEDC-32391P, Appendix C) that the IC increases the minimum water level for the limiting breaks (bottom break and GDCS line break). For the steam line and feedwater line breaks, the minimum water level is lowered due to void collapse. However, for these breaks the minimum water level is several meters above the top of the core and the impact is not significant to safety. Furthermore, postulated interactions between the IC and DPV resulting in flow reversal in the IC and subsequent reduction in the depressurization rate are shown not to be possible (NEDC-32391P, Appendix C). Thus, the overall impact of the IC is to increase the margins for the limiting breaks.

Because a relatively small fraction of the drywell to wetwell flow passes through the PCCS in the blowdown period, the PCCS has a minimal effect on the drywell pressure and GDCS flow(NEDC-32391P, Appendix C). The absence of a PCCS in the GIST tests has little or no effect on the vessel transient.

Interactions between the PCCS and GDCS are important in the containment during the GDCS phase of the transient in that they can result in vacuum breaker opening. This leads to a return of the noncondensibles to the drywell and subsequent recycling through the PCCS. Tests are planned in PANDA Phase 2 to address these interactions.

Issue
Insufficient characterization of GIST facility thermal hydraulic behavior

Response
GE agrees that calibration data on pressure drops and heat losses would be desirable. However, the data are adequate for the intended application.
For the TRACG calculations, the pipes, valves, elbows and orifices were treated as standard hydraulic components. The pressure drops and pressure distributions were calculated based on handbook published loss coefficients (Idelchik, Crane). Based on these assumptions, TRACG calculated the GIST transient response satisfactorily. This confirms the previous good experience with this approach.

Critical flow through the SRVs and the break is based on the minimum flow area. The TRACG model for critical flow, which has been qualified over a wide range of data (NEDC-32391P, Table 5.1-1) was employed for the calculation of critical flow.

Heat losses were calculated based on reasonable analytical values for the natural convection heat transfer coefficient. A sensitivity study on the heat transfer coefficient (variation of heat loss by a factor of 2) showed very little sensitivity to this parameter.

Issue
Lack of a quantitative scaling study

Response
A quantitative scaling study has been performed and is provided in NEDC-32391P, Appendix B, Attachment B1.

Issue
Requirement for additional data from PANDA to be included as part of the testing for design certification. Details of the test matrix and facility scaling to be provided to the NRC.

Response
GE agrees that PANDA data will be used as primary data for TRACG qualification. The test/qualification matrix and facility scaling are provided in NEDC-32391P.

Issue
Requirement for Isolation Condenser performance data from PANTHERS to be included as part of the testing for design certification, if credit is taken for the IC.

Response
GE agrees that PANTHERS thermal hydraulic performance data will be used for TRACG qualification. The test/qualification matrix and facility scaling are provided in NEDC-32391P. While no credit is taken for ICs in LOCA analysis, interaction studies have shown no deleterious effects if ICs were to operate (NEDC-32391P Appendix C).

Issue
Requirement for data demonstrating PCCS performance in the presence of light noncondensible gases in an integral system test.

Response
A combination of tests and analysis addresses the effects of light noncondensibles (hydrogen) on the PCCS performance and containment pressure.

One of the major concerns underlying the light noncondensible gas issue is the capability of the PCCS to restart after the drywell and PCCS have been filled up with noncondensibles. A Noncondensible Blanketing Test (M7) is planned in PANDA Phase 2 to address this issue. Whether the noncondensible gas is lighter or heavier than steam does not make any difference for this demonstration, because it shows that the PCCS can purge the noncondensibles.

At a component level, tests will be performed at PANTHERS to determine the effect of helium buildup in the full scale PCC units. With the vent blocked, the helium will accumulate in the PCCS, and the distribution of helium and the effect on heat removal capacity can be determined.

A helium system response test program in GIRAFFE has been added as described in the response to RAI 900.67.

The effect of the hydrogen resulting from 100% metal-water reaction on the integral system response can be bounded through calculations.

Issue
Availability of experimental and facility data for tests run by others for GE (GIRAFFE, PANDA, PANTHERS).

Response
GE will continue to provide the requested information or provide NRC access to the test facilities and/or test performers.

Issue
Requirement for documentation of testing program in conformance with 10CFR52.47 in Section 1.5 of SSAR.

Response
GE agrees to include a summary of the testing program in SSAR Section 1.5 and/or a reference to NEDO-32391.

Issue
Need for additional test in properly scaled integral test facility.

Response
A systematic study of test and analysis needs has been performed in NEDC-32391P. A need for additional testing has been identified in PANDA for specific interactions between the GDCS and PCCS in the GDCS phase resulting in vacuum breaker openings, for interactions with ICs, and to demonstrate PCCS restart when filled with noncondensible.

(Tests M5 - M9). These tests have been added to PANDA Phase 2 testing. Scaling of PANDA is judged to be adequate for its intended purpose and is addressed in Appendix B of NEDC-32391P.

The GIST tests are adequate for validating vessel performance during the late blowdown/early GDCS phase. Here there are few uncertainties and large margins to core heatup. The overall coverage of the LOCA transient by the integral tests is shown in Figure 5.3-1 of NEDC-32391P.

RAI Number 900.67

Question:

GE's July 1, 1994, letter (MFN No. 087-94) states that GIRAFFE tests were development tests and GE intends to use GIRAFFE data to substantiate the results of PANDA and PANTHERS at another scale. Contrary to this position, NEDC-32391P, "SBWR Test and Analysis Program Description," indicates that the helium test data from GIRAFFE are to be used as part of the TRACG qualification effort. GE needs to clarify the use of helium test data from GIRAFFE vis-à-vis the position on GIRAFFE data stated in MFN No. 087-94, in particular:

(a) Is the GIRAFFE helium test the only one, or are there plans for other helium tests, in GIRAFFE or in another test facility?

(b) If helium test data from GIRAFFE only is to be used, how will GE resolve the quality assurance concerns raised by the staff on other GIRAFFE tests during its June 21-23, 1994, inspection?

(c) The recently conducted GIRAFFE helium test contained only helium. Explain whether future tests will be more typical of post-accident conditions, include a combination of helium and nitrogen. In addition, the test duration should be based on observing at least one purge and transient back to steady state operation of the Passive Containment Cooling System (PCCS).

GE Response:

(a) Since the submittal of NEDC-32319P in mid-August, GE has been pursuing negotiations with Toshiba Corporation regarding additional helium testing in GIRAFFE. These negotiations have recently been concluded. As a result of this agreement, reference to the existing GIRAFFE helium test will be removed from NEDC-32391P, and a new test program will be performed in GIRAFFE specifically to address the staff's concerns relative to lighter-than-steam non-condensable gasses in the SBWR. Facility configuration and instrumentation will be similar to the GIRAFFE Phase 2 Main Steam Line Break tests. The test objectives of the GIRAFFE Helium Test Program are:

1. Provide data that demonstrate the effective operation of the passive containment cooling system with the presence of a lighter-than-steam non-condensable gas, and

2. Provide data for qualification of containment response predictions by TRACG in the presence of lighter-than-steam non-condensable gases.

Four test conditions will be included. Test Condition H1 will be a base case with nominal initial conditions the same as in PANDA tests M3 and M4, e.g., near SBWR SSAR LOCA conditions one hour into the accident scenario. The drywell will contain a mixture of steam and nitrogen at a total pressure of approximately 300 kPa. Test H2 will be a nominal repeat of test H1, but with a helium replacing the total volume of nitrogen in the drywell and PCCS. Test H3 will have the same total initial drywell pressure as tests H1 and H2, but with the initial non-condensable fraction consisting of helium / nitrogen mixture having the same proportions that would result from a 100% SBWR metal water reaction. Test H4 will start with the same initial conditions as test H1, (nitrogen and steam in the drywell), and will have constant helium injection to the drywell. The helium addition rate will be such that the helium is injected over a period of one hour, and the test will be terminated when the total mass of helium added is equal to the initial drywell helium mass in Test H3. The test will be continued to observe the venting of any residual helium from the drywell following termination of helium injection.

System response from the four tests will be compared with each other to establish the effects of lighter than steam, or a mixture of lighter-than-steam and heavier-than-steam non-condensables, on the effectiveness of heat rejection by the PCC heat exchanger. Specific test conditions are currently being finalized. No other helium testing in a facility other than GIRAFFE is planned

(b) The new GIRAFFE HELIUM tests described in response to item (a), above, will be performed by Toshiba in accordance with Japanese National Standard JEAG-4101 (1990 Rev.) GE has reviewed this standard, and concluded that in all important aspects, it meets the intent of 10CFR50 Appendix B and ANSI/ASME NQA-1 (1983). GE requests that the staff review this standard for this application, and concur that tests performed under it are acceptable for the application of this data to the SBWR. GE effort supporting the new GIRAFFE testing will be performed under our own, NRC accepted, QA program.

In addition to the four GIRAFFE Helium tests described in Response (a), Toshiba will also be performing a repeat of the GIRAFFE Phase 2 Main Steam Line Test, one of the two tests described as GIRAFFE Data Group G2 in NEDC-32391P. This test will be performed using the above quality assurance requirements, and will be performed in order to reinforce ("tie-back") the validity of previous GIRAFFE testing with the NRC staff.

(c) We believe the GIRAFFE Helium test program as defined in the response to item (a) is responsive to the staff's comments as elucidated in this item.

RAI Number 900.68

Question:

Both the staff (during a meeting with GE on August 18, 1994) and the ACRS Thermal-Hydraulic Phenomena Subcommittee (during a meeting on August 24, 1994) have expressed concerns regarding test instrumentation. In general, GE seems to place dependence on a limited number of pressure-temperature measurements, and then back-calculate any local conditions of interest. Specifically, the staff is concerned with:

(a) lack of direct local heat fluxes in the PCCS heat exchangers,

(b) lack of direct measurements of the pressure and/or noncondensable gas distribution along the PCCS heat exchanger tubes,

(c) lack of direct measurements of local concentration of noncondensable gases.

Address the above concerns regarding adequacy of test instrumentation for PANDA and PANTHERS.

GE Response:

(a) SIET Document 00157ST92 Rev 1, transmitted to the NRC by MFN No. 086-94 dated June 30, 1994, in response to RAI 950.24, addresses the instrumentation specifically added to the PANTHERS PCC heat exchanger in order to address the ACRS concerns on local heat flux measurement. Figure A.2.1 of the SIET document shows the location and type of instrumentation for local heat flux measurement.

Briefly, 72 thermocouples were added to the PANTHERS test instrumentation to address the ACRS concern. Four PCCS tubes, located at differing locations within the tube bundle, have been instrumented at nine elevations each. Thermocouples are located on the inside and the outside of the tubes, so that local heat fluxes may be calculated from the temperature difference across the tube wall. The algorithm to be used in data analysis is given in SIET document 00098PP91 Rev. 1, transmitted to the NRC by MFN No. 098-95 dated August 16, 1994.

(b) It is true that there are no direct measurements of the pressure or non-condensable gas concentration along the PCC heat exchanger tubes. We have evaluated this situation, and determined that such measurements are not necessary to determine the location within the tubes where condensation is taking place. Temperature measurements along the PCCS tubes were used successfully in GIRAFFE to determine the location of the condensation process within the PCC heat exchanger tubes, and review of initial PANTHERS data likewise has confirmed this capability. Pressure difference measurements between the upper and lower headers of the PANTHERS PCCS have indicated very low pressure drop through the units.

(c) In PANTHERS, which is a steady state experiment, both the air and steam flow to the heat exchangers are measured, and controlled as an independent condition of the experiment. GE has also committed to provide local non-condensable measurements in the PANDA drywell. Our current plan is to determine the non-condensable concentration distribution by use of a combination of temperature measurements and oxygen sensors located at several locations in the PANDA drywell.

RAI Number 900.69

Question:

Adequacy of scaling, phenomena level versus systems interaction: During a meeting regarding the SBWR test and analysis program on August 24, 1994, the ACRS Thermal-Hydraulic Phenomena Subcommittee expressed concerns about whether preserving parameters like gravity head and local friction losses is sufficient to model an integral system behavior. For example, having a "tall and skinny" test facility may affect the 3-dimensional distribution of noncondensable gases. Another example is that inappropriate modeling of global inertia terms may distort the integral system responses, like pressure and water level oscillations. In the scaling analyses, did GE include these "integral" or "global" effects?

GE Response:

GE has included these effects, as noted below:

Scaling of the Global Inertia Terms in the Momentum Equation

In the top-down scaling analysis presented in NEDC-32288 (Section 2.3), the transfers of mass driven by pressure differences were considered using the momentum equation integrated over a segment (piping) length. A rigorous analysis led to Eq. (2.31) of NEDC-32288 where a number of non-dimensional groups appeared. The non-dimensional number multiplying the rate of change of the velocity is Π_{in} (Eq. 2.32 of NEDC-32288),

$$\Pi_{in} = \frac{\rho^o L_I u_r^o / \tau_{tp}^o}{\Delta p^o}$$

which scales the inertial pressure drop with respect to the reference pressure drop. Considering the transit time of the fluid in the piping, P_{in} can be replaced by an alternative form, Eq. (2.37) of NEDC-32288,

$$\Pi_{in} = \frac{\rho^o u_r^{o2}}{\Delta p^o}$$

and the ratio of the equivalent inertia to volume lengths, L_I/L_V, Eq. (2.42).

$$\frac{L_I}{L_V} = \frac{\sum \frac{a_r}{a_n} l_n}{\sum \frac{a_n}{a_r} l_n}$$

The inertia number and the ratio L_I/L_V were considered in Appendix B of NEDC-32391P on Scaling Applicability (Tables B1-9 to B1-11 for GIST; B1-22 to B1-27 for GIRAFFE; B1-39 to B1-46 for PANDA). The L_I/L_V ratios of the prototype and of the various experimental facilities are matched reasonably well. Although the experimental facility components often have different Π_{in} values than the ones of the prototype (due to differences in the flow velocities in these components), this is a very minor scaling distortion, since the relative importance of the inertial pressure drops with respect to the system response is very small. Inertial pressure drops can reach significant magnitudes only during rapid system transients when velocities change abrupty; this is not the case during SBWR transients, except during the very first moments of depressurization. (Rapid velocity changes may take place during certain specific phenomena such as chugging; the scaling of such particular effects is considered in the bottom-up analysis. Inexact scaling of *local* phenomena such as chugging is not expected to affect overall system behavior.)

Moreover, the scaling analysis of NEDC-32288 produced three time scales, (τ^o, τ^o_{in}, and τ^o_{tr}), which scale the rates of volume fill, of inertial effects, and of pipe transfers, respectively (Section 2.4). Clearly, the systems considered here are made of large volumes connected by piping of much lesser volumetric capacity. The inertia and transit times, which are of the same order of magnitude, are much smaller than the volume fill times:

$$\tau^o >> \tau^o_{in} \approx \tau^o_{tr}$$

as shown in the NEDC-32391P tables mentioned above. It was concluded that the time scale that is controlling system behavior and therefore must be considered in scaling the system is τ^o. The other two time scales (controlled by the geometric characteristics L_I and L_V of the piping) are clearly of minor importance.

Three-Dimensional Effects

It is evident that 3D effects cannot be simulated exactly in experiments where the aspect ratio of the system is necessarily distorted (to preserve the important heights) *and* the complex SBWR volume geometries are replaced by cylindrical vessels. Mixing and stratification phenomena in the various SBWR containment volumes are discussed in Section 3.2 of NEDC-32288, where it is shown that appropriate simulation of the discharge areas of components such as vents and vacuum breakers can preserve similarity of the phenomena.

The Grashof numbers of containment volumes controlling natural circulation are considered in Section B1-2.2.2 of NEDC-32391P. For facility components that are full-height, the Grashof numbers calculated with height as the length scale match very well. Examples are shown in Tables B1-12, B1-28, and B1-47 of numbers based on these cannot be matched, but study of 3D effects was not within the scope of these tests. The horizontal dimensions of the PANDA facility approach those of the SBWR. Moreover, representation in PANDA of the Drywell and Suppression Chamber volumes by two large vessels interconnected by very large diameter pipes essentially provides two horizontal reference lengths: for example, the diameter of one SC vessel is close to the width of the annular SBWR SC pool, while the distance between the opposing ends of the two SC vessels approaches that of the SBWR SC perimeter. Thus both length scales will be present in the PANDA model.

RAI Number 900.70

Question:

GE has identified several sources of data that may be included in the SBWR design certification database, e.g., Dodewaard startup, boron mixing tests, and CRIEPI stability tests. For all of these sources (not just those cited here), provide detailed documentation about the tests, such as facility design, scaling, and instrumentation; test specifications and test matrices; and test data and analyses. Also, document specifically how GE will use these data within the test and analysis program.

GE Response:

Section A.3.1.6 of NEDC-32391P "SBWR Test and Analysis Program Description" lists six specific sets of existing test data for which TRACG analyses are being planned. Typically, this is non NQA-1 data, much of it several years old, but that can be used to illustrate TRACG capability to correctly predict a specific parameter; PSTF containment data for as containment main vent clearing during blowdown for example. We intend to use this data to illustrate the breadth of TRACG prediction capability and to corroborate the main body of SBWR data. The specific tests included are:

1/6 Scale Boron Mixing Test
CREIPI Natural Circulation Test
Dodewaard Plant Startup
PSTF Mark III
Mark II - 4T
Suppressions Pool Stratification - Mark III

These data are from tests in SBWR-like, but not necessarily SBWR unique or scaled geometries. Since, in general, these are not SBWR unique tests, specific scaling to the SBWR configuration has not been performed, and were it to be performed, it would result in the obvious; that these are not SBWR scaled tests. We do not plan to perform any additional scaling analyses for these data sets.

Typically, the phenomena addressed are very specific, and were added to the analysis plan for additional confidence in TRACG's predictive capability. In each of the six cases identified, NEDC-32391 is very specific with regard to runs to be analyzed, and the specific purpose of each of the specific comparisons to be made.

References to specific test documentation and the specific data use are given in NEDC-32391P. The following are GE's comments on each of the six addition data sets:

1/6 Scale Boron Mixing:

This data was submitted to the NRC on the ABWR docket. The report includes scaling, facility design, test matrices, and instrumentation used.

Specific runs to be analyzed are still being defined. GE will have a detailed plan for these analyses by December 1, 1994.

CRIEPI Natural Circulation Test:

We recognize that additional information will be required by the staff. GE will prepare a data transmittal on this facility and the results to be used by December 1, 1994.

Dodewaard Plant Startup:

GE will provide the NRC staff with the test reports from the Dodewaard startup, referenced in NEDC-32391P by October 15, 1994. Reactor description and instrumentation is included in the reports. Scaling and test matrix information is not applicable in this situation.

PSTF Mark III:

The test report referenced in NEDC-32391P was submitted to the NRC as part of the GESSAR docket in 1973. Scaling (to the BWR-6 design), test facility design, instrumentation, and test matrices are included in the report.

Mark II-4T:

The test report referenced in NEDC-32391P was provided to the NRC under the Mark II Containment Program in 1976. Scaling (to several Mark II containment configurations), test facility design, instrumentation, and test matrices are included in the report.

Suppression Pool Stratification - PSTF:

The two reports referenced in NEDC-32391P were provided to the staff in 1977 and 1978 under the GESSAR docket. These reports are specifically data analysis reports from PSTF Mark III testing.

RAI Number 900.71

Question:

Explain the rationale for excluding shutdown events and beyond-design-basis events from the SBWR design certification test program. Shutdown events must be evaluated for the SBWR, and presumably will be analyzed using the same computer code(s) used for design-basis analyses. As far as beyond-design-basis accidents are concerned, the staff must determine the robustness of the passive safety systems to deal with events nominally beyond the design basis (e.g., multiple failures) and the possibility of reliance on active, non-safety systems to deal with the consequences of these events. Note: "Beyond-design-basis" in this context is not equivalent to severe accidents.

GE Response:

Beyond-design basis and shutdown events were not explicitly considered for the study that led to the definition of the Test and Analysis Program. In response to this RAI 900.71, these scenarios have been considered and GE concludes that they are covered by the defined programs.

a) Beyond-design basis events:

GE takes this set of events to mean those event and equipment failure combinations which are defined by the PRA success criteria (Attachment 19AA to the SSAR). In these events, core uncovery occurs but cladding temperature remains below 2200 F. The dominant phenomena introduced in these events (beyond the design basis events) relates to core uncovery for a period of time followed by recovery as cooling systems are restored. These phenomena are already included in the PIRT tables (e.g., C11, C13, C14, C15, C24, C25). Tests which cover these phenomena include the TLTA boiloff test, and small and large break tests in TLTA and FIST. All these tests were performed with a simulated full scale BWR fuel bundle and cladding heatup occurred over a range of temperatures and system pressures. TRACG has been qualified against these tests with excellent results (NEDE-32177P). No additional tests or analyses are needed to cover these events.

b) Shutdown events

Plant shutdown to the hot standby condition is accomplished by bypassing steam to the main condenser and through the use of the RWCU/SDC system for decay heat removal. The ICs can also be used for decay heat removal during this phase of the transient. No new phenomena are introduced in this transient, beyond those already considered. Cold shutdown is achieved through decay heat removal by the RWCU/SDC system. If these systems are not available, other core injection systems (e.g. FAPCS), can be used for decay heat removal. One train of the RWCU/SDC system is sufficient to remove the decay heat, but two trains are engaged for the first 8 days to keep the cold leg temperature of the RCCW at 95°F. Again, no new phenomena are introduced.

RAI Number 900.72

Question:

Explain how GE can rely solely upon analysis to resolve the issues of systems interactions during the early phases of transients and accidents, when there are essentially no integral systems test data either existing or planned that cover such conditions during that time. Note that PANDA is not scaled to represent the early phase of SBWR accidents, and is incapable of representing the "worst-case" sequences for the SBWR, that is, bottom drain line and Gravity-Driven Cooling System line breaks.

GE Response:

GE is not relying solely on analysis to resolve systems interaction issues in the early phases of the LOCA transient. Figure 5.3-1 of NEDC-32391P illustrates the coverage of various portions of the transient by different integral systems tests. Section 5.3 of NEDC-32391P discusses this figure. The systems interaction analysis was performed to identify the needs for tests where systems interactions might be important, where possible adverse interactions might occur and where there could be uncertainties in the analysis. This led to the definition of the PANDA Phase 2 tests. It is true that PANDA does not have the power supply capability to simulate the decay power at 10 minutes into the transient, and that the GDCS tanks do not have sufficient capacity to simulate the full capacity in the SBWR. However, test procedures will be developed to minimize the impact of these parameters on the system transient response. This is addressed further in response to RAI 900.73. It should be recognized that the purpose of these tests is to provide representative data for code validation of the key phenomena and interactions. Thus, in the early GDCS period of the transient, the emphasis is on the interactions between the heat removal by the PCCS combined with the effects of steam condensation within the reactor and drywell. The key phenomena related to drywell depressurization, vacuum breaker opening, recycling of noncondensibles, PCCS purging and restoration of PCCS performance will all be maintained even if there are scaling distortions in some of the parameters.

Incidentally, the bottom drain line break and GDCS line break are limiting for the minimum water level in the reactor vessel. In the PANDA tests, the focus is on the containment performance and the large steam line break is the limiting break.

RAI Number 900.73

Question:

Specify as precisely as possible at what time in the accident sequence the PANDA tests that are to represent the "early" phases of main steam line breaks will begin.

GE Response:

Although the detailed procedures for the PANDA Integral Systems Tests with an early start have not been completed, it appears that these tests (M7 and M8) can simulate the SBWR containment response to a steam line break as early as 10 minutes into the transient.

At approximately 10 minutes into a main steam line break accident, the RPV pressure is calculated to have dropped to approximately 300 kPa and is nearly equal to the drywell and wetwell pressures. The PANDA vessels and connecting piping have the capability to model this transient directly from this time on except for the decay heat and the GDCS inventory addition to the RPV.

The PANDA power supply is capable of providing 1.5 MW to the electrical heaters in the RPV. The SBWR scaled decay heat at one hour after scram is approximately 1 MW. The remaining 0.5 MW is available to simulate the RPV structural stored energy for those tests beginning at one hour into the simulated SBWR accident. 1.5 MW matches the scaled SBWR decay heat at approximately 20 minutes following scram.

The PANDA GDCS was designed to provide good simulation of the PCCS condensate drain discharge geometry and discharge conditions after draining of the initial GDCS inventory to the RPV has stopped. Representation of the full GDCS capacity was not an objective for the PANDA design. As a result, the capacity of the GDCS is approximately 40% of the scaled SBWR GDCS volume.

The approach in PANDA for modeling the SBWR transients prior to one hour after scram will take advantage of the fact that a significant fraction of the SBWR decay heat during this period is used to heat the subcooled GDCS water which has drained into the RPV. By running the PANDA tests with a constant power of 1.5 MW for the period simulated prior to one hour and adjusting the initial conditions in the RPV and the GDCS, it is expected that the test start time can correspond closely to 10 minutes into the SBWR main steam line break.

As stated above, the detailed test procedures for M7 and M9, the PANDA Integral Systems Tests with an early start, have not been completed. For test M7, however, the approach described above will provide data to demonstrate the PCC capability to start-up when it is initially filled with air and RPV conditions are representative of SBWR conditions immediately following blowdown. For test M9, the RPV and GDCS conditions will be adjusted to cause vacuum breaker opening and reintroduction of air to the drywell and PCC. Test M9, therefore, will demonstrate the PCC startup capability if air is reintroduced to the drywell via the vacuum breakers early in the transient.

RAI Number 900.74

Question:

PANDA tests will be initiated "on the run", therefore, a transient condition will be established which is intended to simulate a particular reactor transient. How will this be accomplished without significantly affecting the transient under study?

GE Response:

The initial conditions for the PANDA tests will be based on calculated conditions in the SBWR at the time in the transient corresponding to the test start time. For the transients to be simulated, the SBWR pressures, temperatures, liquid levels, and non-condensible gas concentrations which will be the basis for the PANDA initial conditions are not varying rapidly with time. Therefore, establishing initial conditions based on the calculated values for these slowly varying parameters will not affect the test transient.

RAI Number 900.75

Question:

The staff has previously requested detailed test matrices for the PANTHERS Isolation Condenser (IC) tests. These have never been provided and the information in Appendix A of NEDC-32391P, "SBWR Test and Analysis Program Description," is not sufficiently detailed (e.g., noncondensable gas concentrations, test duration, test cycles, etc.). Provide this information for review. In addition, address the concerns raised about instrumentation for PANTHERS PCCS testing (Q900.68 above) for the IC tests.

GE Response:

The PANTHERS Test Requirements and Test Specification were sent to NRC in MFN 119-92, dated May 27, 1992. Rev. 2 of this specification was transmitted by MFN 101-94, dated August 31, 1994.

RAI Number 900.76

Question:

The scaling analysis submitted with NEDC-32391P, "SBWR Test and Analysis Program Description," is an improvement over previous documentation provided by GE; however, additional work is required to demonstrate that for each of the important phenomena identified in the phenomena identification and ranking table (PIRT), the range of thermal-hydraulic conditions expected in the SBWR is covered by one or more tests in the test program.

GE Response:

Data has or will be obtained for all of the phenomena marked 'High' in the phenomena identification and ranking table (PIRT). The data comes from a combination of testing programs and plant data. The type of data used for each phenomena is indicated by the test coverage matrix shown in Figures 5.5-1 and 5.5-2 of the TAPD. Table 1 of this RAI includes the information in those tables along with scaling information on the phenomena. More detailed information showing specifically which test or tests are used to obtain data for each phenomena is also contained in the tables in chapter 5.

Data for some of the parameters have been obtained from operating BWR's. Therefore the data will be over the same ranges as expected in the SBWR. Additionally, data from BWR simulator facilities such as SSTF, TLTA, FIST, PSTF and the Boron Mixing Facility have been used. These facilities were design to simulate operating BWR behavior for accidents and transients which are very similar to those for the SBWR. A description of each of these facilities is included The TRACG Qualification document, NEDE-32177P, Rev 1. Data obtained from this category is marked in the "BWR facility" column of Table 1.

In addition, for those parameters that were considered to be particularly important, a detailed review of the test data and ranges used for coverage was performed. This information is contained in the Qualification Data Base (QDB) that supports the TAPD. Table 1 indicates which PIRT phenomena are reviewed in the QDB. Phenomena that is covered by data from GIST, GIRAFFE, PANDA or PANTHERS has already been scaled in Appendix B of the TAPD. These phenomena are indicated by checks in the "Scaled in App. B" column of Table 1.

Table 1. PIRT phenomena data coverage

PIRT #	Phenomena	Issue	Test Coverage				Scaling		
			Separate Effects Tests	Component Tests	Integral System Tests	Plant Data	Scaled to CQB ?	Scaled to App B ?	Data from BWR Facility ?
A1	LP flashing/redistribution		X	X	X			X	X
A2	LP heat slab stored energy		X	X	X		X	X	X
A3	Inlet orifice uncovery			X	X				X
A4	LP void fraction		X	X	X			X	X
A5	LP void collapse/inlet subc.		X	X	X			X	X
A9	LP stratification		X	X	X			X	X
B1	Bypass flashing		X	X	X			X	X
B2	Bypass level		X	X	X				X
B4	CCFL at bottom of bypass			X	X				X
B5	CCFL at top of bypass			X	X				X
B6	Channel to bypass leakage			X	X	X		X	X
B7	Bypass refill			X	X			X	X
C1AX	Void coefficient					X			
C1BX	Doppler coefficient					X			
C1CX	Scram reactivity					X			
C2AX	Interfacial shear and h.t.		X	X	X	X		X	X
C2BX	Subcooled boiling		X		X	X		X	X
C3AX	Fuel pellet power dist.		X			X			
C3CX	Fuel gap conductance		X			X			
C4	Core flashing		X	X	X			X	X
C5	Inlet orifice uncovery			X	X				X
C6	Inlet orifice CCFL			X	X				X
C7	Upper tieplate CCFL		X	X	X				X
C8	Multibundle flow dist.			X	X	X			X
C8X	Core void collapse			X	X	X			
C10	Core void distribution		X		X	X		X	X
C11	Channel to bypass leakage			X	X	X		X	X
C12	Natural circulation flow		X		X	X		X	X
C13	Dryout/boiling transition		X		X				X
C14	Film boiling (low flow)		X		X				X

Table 1. PIRT phenomena data coverage (cont'd)

PIRT #	Phenomena	Issue	Test Coverage				Scaling		
			Separate Effects Tests	Component Tests	Integral System Tests	Plant Data	Scaled in ODB?	Scaled in App B?	Data from BWR Facility?
C15	Film boiling (disp. drop.)		X		X				X
C23	Core pressure drop		X	X	X	X		X	X
C24	Decay heat				X	X		X	X
C25	Fuel stored energy				X	X		X	X
C26	Critical power for 9 ft core		X				X		
D1	GT flashing		X	X	X			X	X
D2	CCFL at top of GT			X	X				X
D4	Refill of GT			X	X				X
E1	D C break uncovery			X	X		X		X
E2	D C void profile		X		X			X	X
E3	GDCS interaction				X			X	
E5	D C heat slabs			X	X	X		X	X
E6	D C flashing		X		X				X
E7	IC interaction								
E8	D C break flow		X		X			X	X
F1	Chimney void distribution		X	X					X
F2	Chimney flow distribution			X	X				X
F4	Mixing at top of chimney			X		X			
F5	Geysering during startup				X	X			
I1	Separator CU/CO			X		X			
I2	Separator inertia					X			
I3	Separator pressure drop			X		X			
L1X	Steamline pressure drop				X	X			
L2X	Steamline acoustic effects				X	X			
L1	SRV/DPV critical flow		X		X		X	X	X
L2	Droplet entrainment		X		X		X		X
L3	Transition to unchoked flow		X		X		X		X
L5	Multiple choked locations				X			X	
Q1	IC pressure drop			X			X	X	

Table 1. PIRT phenomena data coverage (cont'd).

PIRT #	Phenomena	Issue	Test Coverage: Separate Effects Tests	Test Coverage: Component Tests	Test Coverage: Integral System Tests	Test Coverage: Plant Data	Scaling: Scaled in ODB?	Scaling: Scaled in App B?	Scaling: Data from BWR Facility?
Q2	IC capacity			X			X	X	
Q3	Stratification in IC drums			X			X	X	
Q4	IC pool stratification			X			X	X	
Q5	Secondary side heat transfer			X			X	X	
ST1	Hydrodynamic stability		X						X
ST2	Corewide stability					X	X		
ST3	Regional stability					X	X		
ATW1	Boron mixing in bypass			X					X
ATW2	Boron stratification to LP				X				X
ATW3	Boron delivery to core				X				X
XL1	Interaction between multiple IC modules and units			X	X				
XL3	System interaction – GDCS/System depressurization				X			X	
CONTAINMENT									
BR1	Break mass flow	Critical flow	X	X	X		X		X
		Friction	X	X	X		X		X
		Entrainment	X	X	X		X		X
MV1	Main vent flow				X		X		X
MV3	Vent clearing time				X		X		X
SQ1	SRV flow		X		X			X	X
DW1	Flashing/evaporation in DW				X			X	
DW2	Condensation on DW walls				X		X	X	X
	Degredation of conduction				X		X	X	X
	Wall/Structure conduction				X		X	X	X
DW3	3-D effects	Phase distribution			X		X	X	
		Noncondensables distribution			X		X	X	
		Buoyancy/ natural circulation			X		X	X	

Table 1. PIRT phenomena data coverage (cont'd)

PIRT #	Phenomena	Issue	Test Coverage				Scaling		
			Separate Effects Tests	Component Tests	Integral System Tests	Plant Data	Scaled in CDB?	Scaled in App B?	Data from BWR Facility ?
DW4	Condensation on reactor outflows	Interfacial Heat Transfer			X		X	X	
		Degradation by N/C			X		X	X	
WW1	Condensation/evaporation of main vent discharge	Interfacial Heat Transfer		X	X		X		X
		Degradation by N/C					X		X
WW2	Condensation/evaporation of SRV discharge	Interfacial Heat Transfer		X	X				
WW3	Condensation/evaporation of PCC vent discharge	Interfacial Heat Transfer		X	X		X	X	
WW4	Free surface condensation/ evaporation	Interfacial Heat Transfer			X			X	
		Degradation by N/C			X		X	X	
WW5	Heat sources/sinks	Condensation on WW walls			X		X	X	X
		Conduction through WW walls			X		X	X	X
		Degradation by N/C			X		X	X	X
WW6	Pool mixing and stratification	Bouyancy/ natural circulation		X	X		X	X	X
WW7	3-D effects in gas space	Temperature distribution			X		X	X	
		noncondensable distribution			X		X	X	
		Interfacial shear					X	X	

Table 1. PIRT phenomena data coverage (cont'd)

PIRT #	Phenomena	Issue	Test Coverage: Separate Effects Tests	Test Coverage: Component Tests	Test Coverage: Integral System Tests	Test Coverage: Plant Data	Scaling: Scaled in ODB?	Scaling: Scaled in App B?	Scaling: Data from BWR Facility?
		Mixing, entrainment into jets					X	X	
		Bouyancy/natural circulation					X	X	
		Phase separation					X	X	
WW8	Containment spray condensation	Interfacial Heat Transfer		X	X			X	
		Degradation by N/C			X			X	
WW9	Containment hydrodynamic loads	Pool Swell		X	X		X		
		Condensation oscillation			X		X		
		Chugging			X		X		
		SRV Discharge			X		X		
GD2	GDCS flow				X		X	X	
PC1	PCC flow/pressure drop			X	X		X	X	
PC2	Condensation on primary side	Interfacial H.T.	X	X	X		X	X	
		Degradation by n/c	X	X	X		X	X	
		Shear Enhancement						X	
PC3	Secondary side heat transfer	Pool temp. dist.		X	X		X	X	
		Pool void dist.		X	X		X	X	
		Natural circulation		X	X		X	X	

Table 1. PIRT phenomena data coverage (cont'd)

PIRT #	Phenomena	Issue	Test Coverage				Scaling		
			Separate Effects Tests	Component Tests	Integral System Tests	Plant Data	Scaled in CDB?	Scaled in App B?	Data from BWR Facility?
		Secondary side entrainment		X	X		X	X	
PC4	Parallel PCC tube effects	Friction		X	X		X	X	
		Void fraction		X	X		X	X	
PC5	Parallel PCC unit effects	Friction		X	X		X	X	
		Void fraction		X	X		X	X	
PC6	PCC fan component separation						X		
PC8	PCCS startup with n/c	Purging by presssure diff.			X		X	X	
		Degredation by N/C			X		X	X	
DWB1	Leakage between drywell and wetwell			X	X		X	X	
VB1	Vacuum breaker flow characteristics			X			X		
EQ1	Equalization line flow				X			X	
EQ2	Equalization line sloshing				X			X	
OC1	Heat transfer to safety envelope								
DPV1	Mass flow in DPVs	Critical flow					X		
		Friction					X		
		Entrainment					X		
CW1	Containment liner gap conductance								
CW2	Concrete properties at high temperature			X			X		

Table 1. PIRT phenomena data coverage (cont'd)

PIRT #	Phenomena	Issue	Test Coverage				Scaling		
			Separate Effects Tests	Component Tests	Integral System Tests	Plant Data	Scaled in ODB?	Scaled in App B?	Data from BWR Facility ?
PAR1	Passive Autolitic Recombiners	Operation in hydrogen rich environment		X			X		
PAR2		Added heat load from recombination reaction							
XC1	System interaction	IC/DPV/PCCS			X			X	
XC2	System interaction	IC/DPV/ GDCS/PCCS			X			X	
XC4	System interaction	FAPCS/ PCCS			X			X	
XC5	System interaction	multiple PCC modules and units			X			X	
XC6	System interaction	light noncondensable DW/PCCs/WW			X			X	
XC7	System interaction	containment system response (DW/WW/MV)				X			X

RAI Number 900.77

Question:

Responses to the staff's previous requests for additional information (April 11, 1994) are also needed to determine the adequacy of NEDC-32391P, "SBWR Test and Analysis Program Description." Of particular interest are responses to Q901.23 through Q901.27.

GE Response:

Responses to the referenced RAIs have been sent in to the NRC by letter MFN 096-94, *SUBMITTAL OF ADDITIONAL INFORMATION ON LICENSING TOPICAL REPORT* (NEDE-32177P and NEDE-32178P), dated September 20, 1994.

RAI Number 900.78

Question:

The SBWR is unique from the standpoint of suppression pool thermal capacity. It is designed only for the first hour of decay heat energy, unlike previous designs which could accommodate all of the decay heat energy. Therefore, discuss the interactions expected between the PCCS and the suppression pool during transient periods such as PCCS purging, return to steady state operation, and vacuum breaker opening. Specifically, discuss the potential of opening the main vents for short periods, thereby sending mass and energy to the pool and possible instabilities as seen in the single tube condensation tests at the University of California (Berkeley). This discussion should rely on test data as much as possible.

GE Response:

The statement in this RAI that the SBWR design is unique from the standpoint of suppression pool thermal capacity is incorrect. All BWR pressure suppression pools are sized to accommodate the primary system blowdown energy. None of the suppression pools in existing GE pressure suppression containment types are designed to accommodate all of the decay energy without resort to some other energy removal system. In the absence of such a system, the pool will continue to heat with time as decay energy is added.

In earlier containment designs, the suppression pool temperature is limited by operation of the pool cooling mode of the Residual Heat Removal (RHR) System. The suppression pool absorbs the blowdown energy prior to operator initiation of RHR. Energy addition to the suppression pool continues by flow of drywell steam (generated by decay heat) through the main vents, and energy is removed from the pool by the RHR system to the ultimate heat sink. The peak pool temperature is established by the relative rates of energy addition and extraction. Typically, a maximum pool temperature near 190 degrees F occurs about 6 hours into the accident scenario, when the RHR heat exchanger delta T is sufficient to remove energy at the rate of energy addition to the pool from decay heat. The suppression pool temperature then slowly decreases as the decay energy addition decreases.

In the SBWR the situation is similar. During the blowdown period, the suppression pool absorbs the majority of the primary system energy, although there is some energy extraction by the PCCS. Depending on the break scenario, the blowdown period lasts from about 10 to 30 minutes. Following blowdown, GDCS reflood of the vessel causes subcooling of its fluid contents, and little steaming occurs until about 1 hour into the accident scenario. At this time, the PCCS is capable of rejecting all of the decay heat. In this way, the PCCS is analogous to the RHR system.

A critical element of SBWR design is the PCCS heat exchanger vent configuration. The PCCS vent exits into the suppression pool at a shallower submergence than the top main vent. This geometry is important, because the SBWR pressure suppression containment, like all earlier containments, is a forced flow, pressure driven system, not a temperature driven natural convection system. In all pressure suppression containment systems, mass and energy are added to the drywell from the break in the primary system, and the drywell pressure increases. The pressure will continue to increase, lowering the water level in the vent system, until a flow path is established between the drywell and the wetwell. The wetwell pressure is set by the thermodynamic conditions in the wetwell, including partial pressure of the original wetwell air (or nitrogen in the case of the SBWR), the partial pressure of the air purged over from the drywell to the wetwell air apace, and the vapor pressure of steam corresponding to the suppression pool surface temperature. Once the vents have cleared, the drywell pressure is equal to the wetwell pressure, plus the submergence head of the vents, plus any flow head losses in the vent system. There would be flow from the drywell to the wetwell even if there are only non-condensable gases in the drywell. (In fact, some of the containment testing performed in the 1970's and '80's was performed with only non-condensables.) Once sufficient mass and energy are added to the drywell so that the vent submergence head is overcome, flow will occur. This holds true whether the flow is through the main vents, or through the PCCS heat exchangers

Early in the LOCA scenario, mass and energy addition rates into the drywell from the primary system are larger than the heat removal capacity of the PCCS. During blowdown, the drywell pressure is such that both the PCCS vent and the main vents are cleared, and flow goes to the suppression pool via both paths. As primary system steaming decreases, the drywell pressure will decrease, eventually allowing the top main vents to re-flood and flow to the suppression pool will stop. Flow will still occur, however, through the PCC heat exchanger and PCC vent. It is the difference in submergence between the main vents and PCCS vent that preferentially directs flow through the heat exchanger, and shifts the primary LOCA heat sink from the suppression pool to the PCCS pool.

Table 1 illustrates both the similarities and differences in suppression pool design as containment configurations have evolved. This table gives the ratio of pool volume to core rated thermal power. Both blowdown energy and decay heat are a direct function of core rated power. Thus the ratio of pool volume to core thermal power is a direct indication of the suppression pool's ability to absorb the total primary system accident energy. The value given for the SBWR is the highest of all the containment types listed. The design is very robust. The relatively high value of this parameter for the SBWR is the result of two factors, (1) the potential for thermal stratification in the SBWR suppression pool, which has no safety grade system capable of mixing the pool, and (2) the requirement that the pool absorb both the blowdown energy and that small fraction of the excess decay energy that is released, until the PCCS system is capable of assuming the full load at about one hour.

Table 1
Ratio of Suppression Pool Volume to Core Thermal Power

Containment Type	Ratio (Cubic Feet per MWth)
SBWR	57.58
ABWR	32.20
Mk III (GESSAR)	36.21
Mk III (Grand Gulf)	35.48
Mk II (Nine Mile Point 2)	46.58
Mk I (Browns Ferry)	37.35

In the SBWR, reopening of the main vents is not expected to occur following GDCS reflood of the RPV. If, due to the addition of non-condensables, for example, the PCCS heat rejection capability temporarily drops below the decay energy level, the drywell pressure will increase. However, before the drywell pressure reaches the point where the main vents will reopen, a pressure difference will exist that will clear the PCCS vent, effectively purging the non-condensables and re-establishing PCCS performance.

Even if it is postulated that flow through the main vents is somehow reestablished, the amount of energy added to the pool before an effective PCCS purge of non-condensables causes only a small increase in suppression pool temperature. A bounding calculation of an event of this type was transmitted to the NRC staff by MFN No. 214-93. This calculation was based on the bounding assumption that all the decay heat energy is absorbed by the suppression pool during the time period required to purge all the hydrogen produced by a 100% metal-water reaction from the drywell to the wetwell via the PCCS. The resulting additional pool heatup for this scenario is 3 degrees K.

At one hour into the accident scenario, the steam generated by decay heat in the SBWR is about 12 kg/sec.. The top vent area of the SBWR is 3 square meters, yielding a mass flux of about 4 kg/m^2-sec. The condensation regime has been observed to change from steady to intermittent (chugging) at mass fluxes lower than 10 $lbm/sec\ ft^2$ (48.9 $kg/sec\ m^2$). Therefore, even if main vent flow were to reoccur, it would be within the chugging regime. Cyclic flooding and re-clearing of the main vents that occurs during chugging results in improved suppression pool mixing, and a reduction of pool thermal stratification. The SBWR design uses conservative assumptions for suppression pool stratification, based on limited mixing. While the effect of chugging in reducing thermal stratification is difficult to quantify, it is certainly present, and the effect of the energy addition to the pool would likely be less than the 3 degrees K estimated above.

Instabilities were seen in the first single tube condensation experiments performed at UC Berkeley. This experiment, reported in NEDC-32310, "Single

Tube Condensation Test Program", was performed in a natural circulation loop. Subsequent single tube experiments utilizing forced circulation loops, including two experiments at UC Berkeley and two at the Massachusetts Institute of Technology, have not shown any evidence of flow oscillations or instabilities. Thermocouple instrumentation of the heat exchanger tubes in the PANTHERS experiment (see response to RAI 900.68) make it possible to monitor for instabilities in this prototype heat exchanger test. No evidence of instabilities has been identified in data reviewed to date, which include conditions that span the PCCS flow regime. Given that the SBWR is a forced flow design, and that no instabilities have been seen in forced flow experiments, they are not expected to be a factor in SBWR performance. Also the condensation instabilities seen in the UC Berkeley natural convection experiments were local in nature, and did not greatly effect the overall heat rejection within the tube.

RAI Number 900.79

Question:

Heat loss has proven to be a significant problem in evaluating the GIRAFFE data. Therefore, provide the heat loss evaluation of both the PANTHERS and PANDA facilities and discuss how these losses will be considered in the evaluation of the test data.

GE Response:

Reference: PANTHERS-PCC TEST PLAN AND PROCEDURES, SIET Document No. 00098PP91, Revision 1, July 12, 1994, sent to the NRC in MFN No. 098.94, dated August 16, 1994.

Section 8.1.2.5 of the PANTHERS Test Plan & Procedures (see reference) gives the equation for the global energy balance of the PCC at PANTHERS. The equation includes the heat losses of the inlet and outlet lines. However, these heat losses were measured during the shakedown of the test facility and found to be negligible (i.e., less than 50 kW) compared to the total thermal power (around 1 to 14 MW). Therefore, the condensation thermal power formula will be simplified to that shown at the end of the referenced section.

Quantification of heat losses for PANDA is a planned item in the test facility startup program. The measurements have not yet been performed. PANDA is very heavily insulated, and heat losses are not expected to have a major effect on the results. The design goal is to limit heat losses to 10% of the decay heat at 24 hours into the LOCA scenario. Calculations indicate losses will be substantially less than the target values.

RAI Number 900.80

Question:

Interaction between the ICs and the PCCS may have a profound impact on the performance of the system. Discuss the possibilities of tests considering both units operational. In particular, the early in time test to obtain GIST-type data should be one of the tests considered.

GE Response:

The systems interaction studies performed as part of the SBWR test reassessment and reported in NEDC-32391P indicated that the minimum RPV water level was slightly effected by the presence of the IC and PCC for some postulated break scenarios. However, there was essentially no effect on system performance. The SBWR is a very robust design from the standpoint of core cooling. Minimum accident water levels are calculated to be approximately 1 to 4 meters above the top of the fuel, and peak clad temperatures are essentially unchanged from steady state performance values. Overall system performance would only be effected if the water level dropped below the top of the fuel, and even then there would be very significant margins to 10CFR50.46 and Appendix K temperature limits.

Appendix A of NEDC-32391 defines the tests GE has concluded are technically adequate for SBWR certification. PANDA test M6 was added to the matrix specifically to address IC effects. As a result of staff comments from the meeting on August 18, we are considering adding IC operation to PANDA tests M8 and M9 as well. As noted in the response to RAI 900.73, PANDA tests M7 and M9 will be started approximately 10 minutes into the accident scenario.

RAI Number 900.81

Question:

Transient behavior is of particular concern to the staff, therefore, each PANDA test duration should include at least one purge cycle of the PCCS. Confirm if that is the case.

GE Response:

It is unclear what is meant by a "purge cycle" in this RAI statement. Every PANDA test begins with some air fraction within the drywell. Over time, this air fraction will decline, but there will always be some small residual air content in the drywell. Tests M1 through M4, are of this type. Tests M5 through M9 have test conditions defined to address specific TRACG qualification needs as defined in NEDC-32391P. Some, but not all, of these tests will result in the vacuum breaker opening, and re-enty of non-condensables into the drywell. In these cases, the purge of these non-condensables into the wetwell will be investigated. Again, there can be no assurance that all the air will be purged from the drywell in any given test.

Superimposed on these system purges may be short cycle variations in the non-condensable content with the PCC heat exchanger. These will be investigated, should they occur.

If the staff will be more specific in what they mean by "PCCS purge cycle" we can respond more fully.

Purdue University Questions - Set 5

1. Provide the SBWR drywell spray flow rate and water temperature.

2. Provide the SBWR wetwell spray flow rate and water temperature.

3. What were the droplet size, flow rate, and water temperature of drywell and wetwell sprays that were assumed in TRACG analyses?

GE Response:

1. The maximum allowable differential pressure across the containment liner determines the drywell depressurization rate and consequently the maximum allowed drywell spray flowrate. These parameters have not been finalized yet.

   The Fuel & Auxiliary Pools Cooling System (FAPCS) pumps are variable speed pumps and can provide a flow rate between 257 and 422 m^3/h in the drywell spray mode. If these flow rates are too high, it can be reduced to 150 m^3/h for long term operation without causing problems with the pump. If an even lower flow rate is required, the flow can be partly bypassed by opening the valve in the discharge line to the suppression pool.

   The spray temperature has been calculated to be 55°C with a spray flowrate of 346 m^3/h with the supression pool water (source of drywell spray water being cooled by the FAPCS heat exchanger) at 79°C.

2. The maximum allowed wetwell spray flowrate has not been finalized yet.

   The Fuel & Auxiliary Pools Cooling System (FAPCS) pumps are variable speed pumps and can provide a flow rate between 307 and 445 m^3/h in the wetwell spray mode. If these flow rates are too high, it can be reduced to 150 m^3/h for long term operation without causing problems with the pump. If an even lower flow rate is required, the flow can be partly bypassed by opening the valve in the discharge line to the suppression pool.

   The spray temperature has been calculated to be 55°C with a spray flowrate of 346 m^3/h with the supression pool water (source of wetwell spray water being cooled by the FAPCS heat exchanger) at 79°C.

3. The drywell and wetwell sprays are simulated with the use of a TRACG PUMP component and a component representing the system heat exchanger. The flow rates used for the two spray modes were 321 m^3/hr and 307 m^3/hr for the drywell and wetwell, respectively. The temperature of the spray is not prescribed. The water is circulated through the simulated heat exchanger, characterized by a heat transfer area of 386 m^2, an overall heat transfer coefficient of 1510 Wm^{2}-K, and a sink temperature of 313K. It is expected that the outlet temperature will be only slightly above the sink temperature. Spray droplet size is not prescribed. It is determined by TRACG as the value implied by a critical Weber number of 6.5, based on relative velocity, or 0.2 mm, whichever is larger. As an example, for containment conditions of 300 kPa and 100% steam, the relative velocity is about 5 m/sec, yielding a droplet size in the range of 7 to 8 mm.

RAI Number: 900.83

Question:

Discuss how TRACG models mixtures of steam and non-condensable gases, including mixtures with more than one species of non-condensable gas (e.g., steam, nitrogen, hydrogen).

GE Response:

In addition to steam, TRACG solves the mass conservation equation for a second gas species. In a given computational cell, the two vapor species are perfectly mixed so that they have the same temperature and velocity. Thus the noncondensible gas is transported with the steam to the next cell with the same velocity as the steam. The concentration and partial pressure of the noncondensibles are tracked in every cell. Conventional donor cell techniques are used to calculate the flow of the noncondensibles from one cell to the next. The assumption of perfect mixing within a cell can make the results sensitive to the cell size, and the cell size must be chosen appropriately for the problem being solved. In a three (or two) dimensional grid, buoyancy effects due to larger concentrations of a light gas in certain regions can be properly accounted for within these assumptions.

Currently, TRACG allows for only one gas field other than steam. A mixture of two species would be treated as a gas with averaged properties. For this specific analysis of the containment design basis (100% metal-water reaction) event, a mass conservation model for a second gas field is being implemented in TRACG.

RAI Number: 900.87

Question:

Provide details of the CSAU study related to SBWR containment analysis.

GE Response:

GE intends to follow the CSAU methodology developed by Boyack et al (Quantifying Reactor Safety Margins, NUREG/CR-5249, 12/89). The 14 step methodology developed by this team is outlined in the attached figure from the above reference. Currently, GE is at Step 8 in the process. The test and analysis needs have been defined and the Separate Effects Data analysis is completed. The remaining steps involve the determination of bias and uncertainty in the TRACG calculations (Step 9), establishing whether there is a scale effect (Step 10), and accounting for the effects of uncertainties in the plant operating parameters (Step 11). Under Step 9, all the parameters identified as High in the PIRT tables (e.g., 4.1-2(a)) will be addressed. It is expected that a much smaller subset of this list will show significant effect on the containment pressure and temperature response in the preliminary sensitivity studies. For this reduced set of sensitive parameters, reasonable ranges will be defined for the subsequent statistical analysis in Steps 12 and 13. The model and plant parameters will be perturbed from their nominal values in a set of TRACG calculations. These calculations will serve to define the upper 95th percentile pressure and temperatures, which will be compared with the allowable design limits.

RAI Number: 900.91

Question:

The staff is concerned that assumptions termed as "licensing basis" which are used for calculations of accidents and transients in the SBWR do not represent the actual operation of the plant which would be expected in such cases. These analyses routinely exclude operation of safety systems that would be expected to operate, such as the isolation condenser. It is also possible that selected non-safety systems could operate and change the integral plant behavior. GE should include in its test programs a range of test conditions to ensure that the data will represent a sufficiently broad basis for code assessment assuming both "licensing basis" conditions and realistic plant conditions during accidents.

GE Response:

The "licensing basis" calculations do not take credit for equipment not classified as Engineering Safeguards. Also, single failure assumptions are required in the analysis. However, GE has performed analysis to show that scenarios where such equipment is available improve the accident response, and that the licensing assumptions do in fact provide bounding results.
In NEDC-32391P, calculations have been performed with the ICs available. Cases have also been run with active systems operating (CRD and FAPCS). Based on these calculations (Appendix C), testing needs have been defined. The PANDA tests will include tests where the ICs are operational. The effects of the FAPCS in the drywell spray mode will be simulated by adding cold water to the drywell. The GIST tests included one (A05) in which the CRD system was simulated. The ICs have a beneficial effect on the limiting LOCA transients and were not simulated in GIST.

RAI Number: 900.93

Question:

Provide a discussion of vacuum breaker actions for analyzed transients and accidents, including a Gravity-Driven Cooling System line break and include discussion of assumptions made for both expected and "licensing-basis" scenarios. In addition, detail why failure to close (after actuation) of a drywell-to-wetwell vacuum breaker is not, in GE's view, a credible failure.

GE Response:

Vacuum breaker cycling has been predicted for nearly all LOCAs, following GDCS initiation. The injection of subcooled GDCS water into the vessel reduces the pressure in the vessel and drywell to below the setpoint of the vacuum breakers and they cycle open, returning noncondensible gases to the drywell. Predictions indicate the vacuum breakers remain open for only brief periods, and can cycle several times during the GDCS injection period of the transient. The LOCA transient which is predicted to provide the most vacuum breaker cycles is the GDCS line break. This accident dumps the inventory of one GDCS pool directly into the drywell, which produces vacuum breaker openings. Later, as the GDCS flow from the unbroken lines fills the vessel to the level of the break and spills over into the drywell, additional vacuum breaker openings are predicted. Predictions of this transient indicate that as soon as the decay heat boiloff resumes, the drywell is re-pressurized, flow through the PCCS resumes and the noncondensibles are slowly purged through the PCCS, back to the wetwell.

Differences in the 'licensing basis' and expected LOCA calculations such as those presented to the NRC relate to availability of additional safety systems. As was shown, the use of intermittent drywell spray, while reducing the drywell pressure, also produces additional vacuum breaker cycling. For all cases analyzed to date however, the PCCS was able to return the recycled noncondensibles to the drywell and retain part of the pressure reduction benefit resulting from the use of the spray.

The assumption of the reliability of vacuum breaker operation is based on the design requirement of the vacuum breaker. The vacuum breaker valve design reliability objective is to fail to open or close less than once in every ten thousand demands. To achieve this objective, simplicity of design was used. The design configuration selected is a vertical poppet valve opening with high wetwell pressure and closing by gravity plus drywell pressure. The valve has double sealing surfaces one hard and one soft. The sealing surfaces are designed so that a design basis seal obstruction could be accommodated on one seal without the failure of the second seal. To demonstrate reliability, the prototype valve has undergone extensive testing. Before the valve reliability test was begun, the valve was aged and degraded to simulate sixty years of service. Aging consisted of soft seal irradiation, whole valve thermal aging, whole valve dynamic aging, design basis accident steam aging and ingestion of grit to coat seal and moving surfaces. The valve was then cycled three thousand times without failure. Using a Bayesian statistical approach, three thousand cycles without failure was shown to demonstrate a high probability of meeting the reliability objective of one failure in ten thousand.

RAI Number: 900.94

Question:

Provide a listing of the TRACG code version used for each TRACG run analyzed and presented during the "scaling" part of the August 18, 1994, meeting, including a discussion of any differences in the results obtained with the "preliminary" and the "Level 2 " versions of the TRACG code.

GE Response:

The results discussed at the meeting are contained in Figures B.3-1 to B.3-4 for GIST and Figures B.3-5 to B.3-6 for GIRAFFE. For GIST, TRACG calculations are shown for the test, for the current SBWR design and the 1988 SBWR design. Of these, the test predictions and the calculations for the current SBWR design were made with the Level 2 version of the code, while the calculations for the 1988 SBWR design were old calculations. Calculations made with the preliminary code version and the Level 2 version have shown very little differences for other similar calculations. The GIRAFFE test predictions as well as the corresponding calculations for the SBWR in Figures B. 3-5 and B.3-6 were all made with the Level 2 version of the code.

GE Nuclear Energy

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December 15, 1994

MFN No. 155-94
Docket STN 52-004

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington DC 20555

Attention: Richard W. Borchardt, Director
Standardization Project Directorate

Subject: NRC Requests for Additional Information (RAIs) on the Simplified Boiling Water Reactor (SBWR) Design

References:
1) Transmittal of Requests for Additional Informaton (RAI)s Regarding the SBWR Design, Letter from M. Malloy to P. W. Marriott dated February 9, 1994.
2) NRC Requests for Additional Information (RAIs) on the SBWR Design, Letter from J. E. Leatherman to R. W. Borchardt, dated May 2, 1994.

This letter provides information to supplement that provided by the Reference 2 letter regarding the SBWR wetwell-to-drywell vacuum breaker tests, specifically an additional response to RAI 900.62.

Please note that the information contained in the enclosure is of the type which GE maintains in confidence and withholds from public disclosure. It has been handled and classified as proprietary to GE as indicated in the attached affidavit. We hereby request that this information be withheld from public disclosure in accordance with the provisions of 10CFR2.790.

Sincerely,

P. W. Marriott, Manager
Advanced Plant Technologies

Attachment 1, "Responses to NRC RAIs"

cc: P. A. Boehnert (w/1 copy of Attachment 1)
F. W. Hasselberg (w/1 copy of Attachment 1)
J. H. Wilson (w/2 copies of Attachment 1)

UTE-INITEC/EMPRESARIOS AGRUPADOS
Proyecto Centrales Avanzadas UNESA

PAGES ATTACHED: i-ii, From 1 to 30

SBWR

'STUDY'

VACUUM BREAKER FMCA

UTE I/EA DOC. NO.	PROJECT DOC. NO.	REV. NO.
02 STS-0002-1	T10	1

1	7/94	DESIGN	MPV/	MPF/		MDB/MTA
1P	6/94	INFORMATION AND COMMENTS	MPV/mpv	MPF/mpf		MDB/mdb MTR/mtr
REV. NO	DATE	ISSUING PURPOSE	ORIGINATOR	VERIF./ CHECK.		APPROVAL

SBSTS02A/B/C.R01

SBWR

RECORD OF PRELIMINARY/PENDING DATA

DOCUMENT REFERENCE (*)	PRELIMINARIES/PENDING DESCRIPTION
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(*) Indicate document section, paragraph, figure and/or page.

SBWR

RECORD OF CHANGES

DOCUMENT REVISION NO: 1

DOCUMENT REFERENCE (*)	CHANGE DESCRIPTION AND REASON	CHANGE REFERENCE
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(*) Indicate document section, paragraph, figure and/or page.

TABLE OF CONTENTS

1. PURPOSE

This document describes a Failure Modes and Criticality Analysis (FMCA) for the drywell vacuum breaker valves on the basis of the functional tree constructed for these valves.

2. SCOPE

The scope of this document is the FMCA for the Vacuum Breakers Valves designed for the SBWR project. It is not in the scope of this document the fault tree quantification to obtain failure frequencies. These values could be obtained as a result of the test program.

3. REFERENCES

1. Vacuum Breaker Design Update. SBWR Working Group Meeting. May 10-13, 1993

2. SBWR Vacuum Breaker Valve. General Assembly study and layout. FIAT. 2T137681

3. SBWR Wetwell to Drywell Vacuum Breaker. Test Specification 25A5445

4. SBWR Vacuum Breaker Instrumentation. Test Specification 25A5395

5. NUREG/CR-4692. Operating Experience Review of Failures of Power Operated Relief Valves and Block Valves in Nuclear Power Plants

6. Nuclear Power Experience, vol BWR 2. Relief and Safety Valves

7. Nuclear Power Experience, vol BWR 2. Containment - Miscellaneous

8. SBWR Standard Safety Analysis Report. 25A5113 Rev A

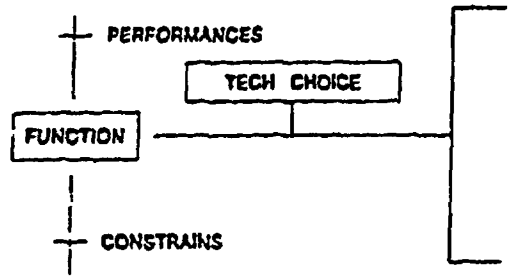
9. FCI-70-2-1991. Fluid Control Institute. Control Valve Seat Leakage

10. Regulatory Guide 1.82, Rev 1. US Nuclear Regulatory Commission, Office of Nuclear Regulatory Research

4. METHODOLOGY

The functional tree of the valve has been constructed on the basis of the valve functions, the modes in which they are performed, and the valve characteristics and conditions.

Each system function may be linked to a series of performances carried out in order to meet a set of needs and also to a list of constraints imposed for execution of the function. The technological choices made are also significant. This is illustrated in the diagram below:



Subsequently, based on the functional tree, a failure modes and effects analysis is carried out on the valve. For this analysis, a table has been prepared, containing the following information for each component:

- Its function or functions
- Its possible failure modes
- Internal or external causes
- Possible effects of these failures on compliance of the valve function
- Detection or location means
- Risk reduction means
- Failure Criticality

The following classification has been performed for each function as regards the failure modes:

- No function. The function is not performed at the desired moment

- Loss of function. The valve functions but then ceases to function

- Degradation of function. The valve functions but the required performances are not achieved

Taking into account the failure modes of each component/s which will carry out the necessary function/s the criticality of the failure on the equipment is hierarchied. This results in:

- Catastrophic equipment failure. The valve is completely incapable of carrying out its function correctly

- Degraded failure, when the valve functions below its specific operating level

- Incipient failure when the valve functions as designed but presents characteristics which, not having been considered, could produce degradations or catastrophic failures

Appendix 40 shows the functional tree constructed for the valves analyzed and appendix 50 contains the tables prepared for the failure modes and effects study.

The equipment description (ref 1 and 2) and the test specifications (ref 3 and 4) were used to perform the analysis.

To identify the mechanisms that could cause the failure of the valves studied herein, information about vacuum breakers and relief and safety valves has been used, taking into account the differences in construction and the operating conditions experienced.

NUREG/CR-4692 (ref 5) task B.1 presents events corresponding to leakage caused mainly by faulty or worn seats, anomalies in the disk and stem, or the presence of foreign matter between the disk and the seat.

Events caused by human error, such as improper installation and misadjustment of the stem causing the valve seat to leak, are mentioned in Table C.1 of the above-mentioned document.

Information on failure mechanisms has also been obtained from "Nuclear Power Experience" (ref 6 and 7). Some of the most representative events referenced are shown in the following table.

Table 4.1

Events / Mechanical Failures

PLANT	EVENT DATE	FAILURE MODE	OBSERVATIONS
Oyster Creek 1	69	Excessive leakage	The seat was lapped, but there was no indication that leakage was caused by a damaged seating surface
Oyster Creek 1	Nov. 71	Leakage	The valve was disassembled; repairs consisted in straightening the stem and lapping the main valve seats. However, the seating surfaces did not seem damaged and did not show uneven wear
Browns Ferry 2	May 79	Leakage	Leakage was caused by irregu-larities on valve seating surfaces and entrapment of debris under the seating surfaces
Arnold	Feb. 83	Leakage	Leakage was caused by wear of the valve seat during operation
Hatch 2	March 80	Excessive leakage	This was due to wear of the seating surfaces. As a result, they were machined and lapped
Hatch 1	July 85	Stem failure	The valve had not been fully backseated, which allowed the stem to vibrate until a fatigue-induced failure occurred
Cooper	May 85	Leakage	The leakage was thought to be the result of a slight misalignment of the valve disk on the valve seat, possibly due to valve mishandling during shipment or to foreign particles trapped on the valve seating surface
Perry 1	Sept. 87	Leakage	Valve leakage was caused by debris caught between the disk and seat

PLANT	EVENT DATE	FAILURE MODE	OBSERVATIONS
Dresden 2	Oct. 87	Problems with tolerances for centering	The tolerances for centering were reduced and centering methods were improved
Limerick 1	May 87	Excessive leakage	Leakage was attributed to minor wear of the valve disk and valve seating surfaces, produced during valve stroking. When the valve disk slid into its seat, small particles of dirt caused light scoring on contact surfaces.
Oyster Creek	July 88	Valve stem was bowed	
Clinton	Jan. 89	Anomalies on seating surface	This was due to seating surface wear
Limerick 1	Feb. 89	Excessive leakage	Leakage was attributed to minor wear of the valve disk and seating surfaces, which occurred when small particles of dirt caused light scoring of the contact surfaces
Oyster Creek	Feb. March 91	Leakage	Leakage was due to damage in the soft-disk seat
Oyster Creek	April 75 Jan. 76	Excessive leakage (vacuum breaker)	
Hatch 2	Aug. 78	Leakage (vacuum breaker)	Leakage was caused by loose retainer ring bolts
Dresden 3	Jan. 82	Leakage (vacuum breaker)	Leakage was caused by a worn seal, which was replaced
Brunswick 2	July 82	Leakage (vacuum breaker)	An accumulation of dirt on the valve seating surfaces prevented proper seating. The valves were cleaned

5. DESCRIPTION OF SYSTEM ANALYZED

The system description covers three aspects:

- System function
- Equipment needed to perform the function
- Operating modes

5.1 System function. The main function performed by the Vacuum Breaker system is to avoid and prevent a high negative differential pressure between the drywell and the wetwell above the suppression pool.

Depressurization in the drywell may be caused by any of the following events:

- Post-LOCA depressurization caused by the Emergency Core Cooling System ECCS flooding the RPV, and cold water spilling out of the broken pipe or of the broken GDCS line directly into the drywell

- Inadvertent actuation of the drywell spray during normal operation

- The heat removed by the combined action of the ICS and PCCS exceeds the decay heat steam production

When depressurization of the drywell as compared to the wetwell reaches the value of 0.5 psi, the vacuum breaker valves open, with subsequent decrease in the pressure difference till a steady state is reached. For more detailed information, see the "SBWR Standard Safety Analysis Report" (Chapter 6 in Ref. 8).

The other function of the system is that of inerting the containment by introducing nitrogen or air into the wetwell and venting it to the drywell through these valves.

Appendix 10 shows the ambient conditions foreseen, during both normal operation and LOCA.

5.2 Equipment needed to perform the function. To deal with depressurization of the drywell, three valves are required, taking into account the single failure criterion (failure on opening of a valve).

To inert the containment, one of the three valves is required to open at 20%.

These valves are mechanical, ie, they open when the pressure difference between the drywell and the wetwell exceeds the weight of the disk and the surface resistance of the bearings, and close with the force of gravity. Each valve consists of a vertical lift disk with an adjustable damper. An EPDM seal and a hard seat ensure that the allowable leak rate is not exceeded. Bearing in mind the maximum allowable rate of leakage through the seat, the valve is considered to be Class IV according to FCI-70-2-1991 (ref 9).

The valves are fitted with instruments which indicate the valve position. Perforated screens protect them against the entry of foreign objects at both the inlet and the four discharge ports.

More information can be obtained from the document "Vacuum Breaker Design Update. SBWR Working Group Meeting" (ref 2).

In view of the foregoing, the main components in each valve are:

- Vertical lift disk with upper and lower bearing
- Hard seat
- Elastomer seal
- Hydraulic damper to avoid disk oscillations (Pend.)
- Screens at inlet and outlets for protection against foreign objects
- Valve position instrumentation (sensors, transducers, power supply)

Appendix 20 contains a diagram of the equipment and Appendix 30 lists the main valve requirements.

5.3 Operating modes

- Valves closed in normal operation
- Valves completely open when $P_{WW}-P_{DW}$ = 0.5 psi after LOCA
- Valve open at 20% in inerting process
- Valves tightness maintained after inerting and after LOCA

6. HYPOTHESES

- Only the main valve components were analyzed during the study.

- During the functional study of the valve, the function referring to indication and alarm on the valve position has been assumed to be a performance function, since its failure presupposes a degraded valve failure. Failure of the instrumentation would imply that the information referring to the prevailing status of the valve was either not received or not issued correctly

- The protective screens serve to prevent the entry of matter which could affect valve operation. The analysis introduces this as a restricting function, affecting both the opening of the valve and the function which ensures isolation between the drywell and the suppression chamber gas space.

- The damper serves to guarantee the valve close/open time and to avoid disk oscillations in the low-flow mode, while ensuring that the valve closes correctly. It also prevents any impact or bouncing that may be produced during opening.

- The function "generate force necessary to maintain surfaces in contact" refers to the system which will be used to attach the EPDM seal and prevent leakage through the seal.

7. CONCLUSIONS

7.1 The position of the sensors could be very important from the point of view of leaks between the drywell and the wetwell through their penetrations. The sensors should be placed in such a way as to eliminate these leak paths.

7.2 Raising the seat could, to some extent, eliminate the possible risk of the elastomer seal behaviour being affected by any debris entering the valve.

7.3 The absence of leaks between the drywell and the suppression chamber is largely dependent on the behaviour of the elastomer seal used. Correct operation of the seal in expected accident environmental conditions should therefore be ensured. Moreover, the allowable force limits for the seal must not be exceeded since excessive compression could lead to the design limits being exceeded, whereas if the minimum force is not used, the required leaktightness level would not be guaranteed.

7.4 In terms of the tests to be conducted on the valve, the damper could be eliminated if the valve behaves correctly; in this way the risk of valve malfunction due to damper defects (incorrect assembly, adjustments, leaks or incorrect behaviour of the fluid in the required environmental conditions) is eliminated. It could also be studied the possibility of replacing the damper by a spring which carries out the same functions of the former but presents a lower risk of failure.

7.5 One of the specifications to be met by the valves is that of supporting dynamic loads produced by earthquakes and jet loads of 10 psi. To ensure correct behaviour of the valve under this type of stress, the tests should be carried out with the same type of anchorage as that used in the final installation.

7.6 In order to avoid, as far as possible, damages to the valve owing to the pipewhip effect or high-speed water or steam jets, it is recommended to physically separate these valves from the high-energy piping systems.

7.7 To avoid incorrect seating of the disk which could cause leaks, a device has been installed a device which prevents the disk from rotating avoiding deformations with certain types of flows. The possible deformations and turns or rotations of the disk will be studied during the functional test on the valve, as mentioned in the document "SBWR Wetwell to Drywell Vacuum Breaker Test Specification" (ref 3). The antirotation key behaviour must be also studied during that test.

7.8 From the construction point of view, the metal used for manufacturing the valve should have good mechanical characteristics, and behave correctly with regard to corrosion and welding.

7.9 Protection against the entry into the valve of foreign matter, such as debris produced by LOCA, is achieved by protective screens at both the inlet and the outlet. These screens should comply with the requirements indicated in Regulatory Guide 1.82 (ref 10), taking into account their location inside the containment where their immersion is highly unlikely. The protection should really act against debris which is generated during the LOCA period and could be transported by blowdown. The installation of a double protective screen could also be recommended, as in the case of the containment heat sinks, where the external screen serves to slow down any possible debris.

The diameter of the perforations in the screen will be obtained after studying pressure losses through them; it will also depend on the need to prevent the entry of objects into the valve.

To ensure correct behaviour of these protective screens during operation, it would be advisable to carry out the valve tests with the screens installed, so as to study the response to external stresses (earthquakes, vibrations, loads, etc) of both the screens and their unions to the valve body.

7.10 The test specification states that the response-to-radiation test will use a 230 Mrad dose. This dose is high, and it is difficult to qualify a material with the characteristics required to ensure valve leaktightness. Therefore, it might be appropriate to perform the test with a lower dose, since regular replacement of the elastomer seal are expected to take place during the operational life of the plant (60 years).

7.11 The "risk reduction means" that appear in the "Failure Modes and Effects Analyse Tables" can be grouped based on the phase in which they are carried out. In this way, the following results appear:

- A first group formed by the qualification and reliability test, which guarantees compliance with the specification requirements in the prototype development and prototype

- During the valve fabrication process controls are necessary in order to assure equipment quality and compliance with design criteria.

- The use of assembly and calibration procedures and the carrying out of preoperational tests (verification of the correct working of valves, opening/closing, and leaktightness) guarantee that the equipment is operative at the time that the reactor starts operation.

- Visual inspections of the accesible parts of the valves should be carried out at each loading to determine and assure that they are free from foreign debris and the disk should be manually tested to assure its freedom of movement and functionability. Also, inspections should be done of those components susceptible to deteriorate with age.

For those components that need substitution every so often (seal, valve position instrumentation, damper), replacement, disassembly and reassembly procedures are necessary. The replacement intervals will be basically designed by the results obtained in the tests carried out on the prototype.

APPENDIX 10

ENVIRONMENTAL CONDITIONS

ENVIRONMENTAL CONDITIONS

- NORMAL OPERATION (60 years)

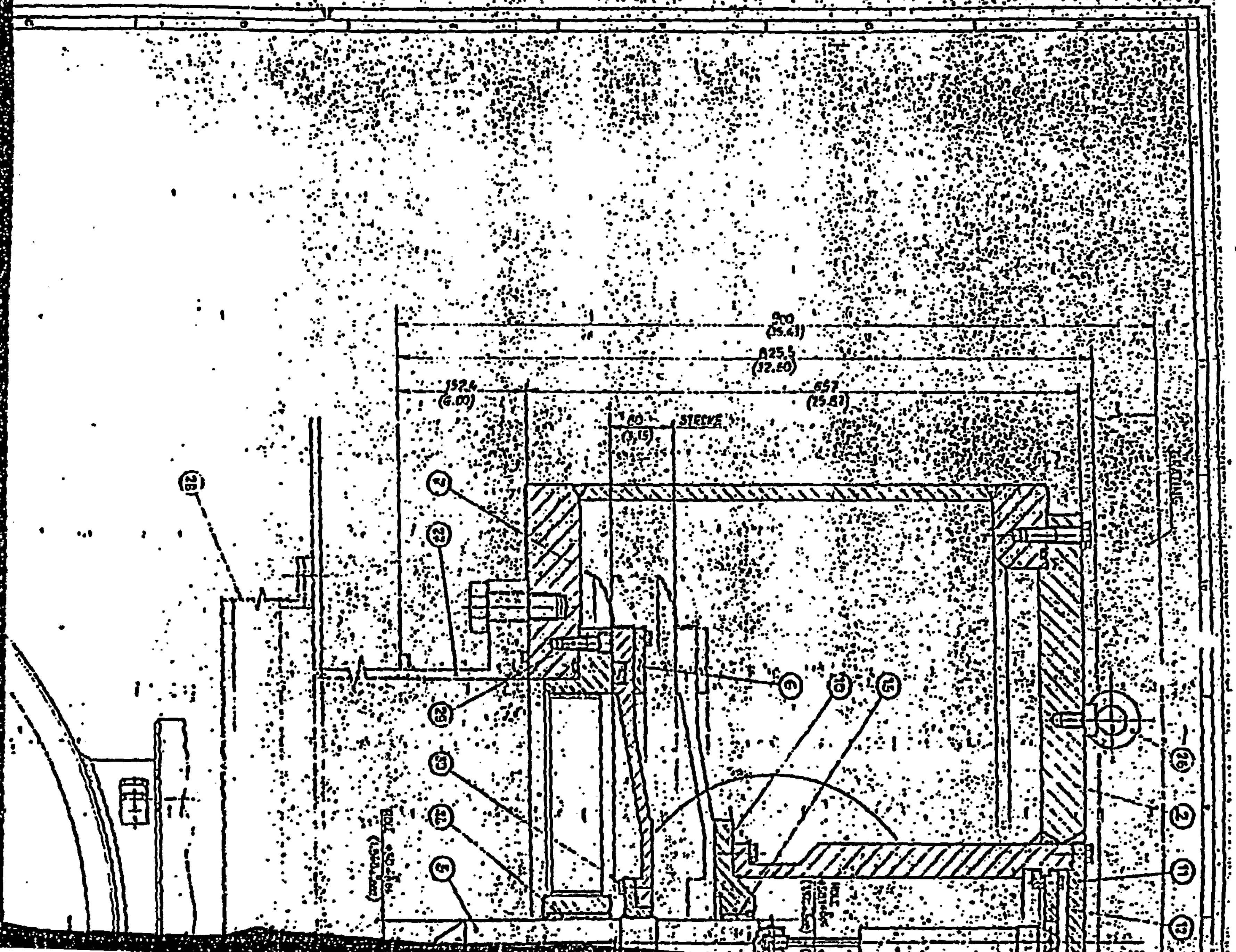
Radiation:	
- Gamma	300 megarads
- Beta	Negligible
- Neutrons	Negligible
Temperature:	135 - 150°F (330-339K)
Humidity:	50%
Fluid:	N_2/Air

- LOCA

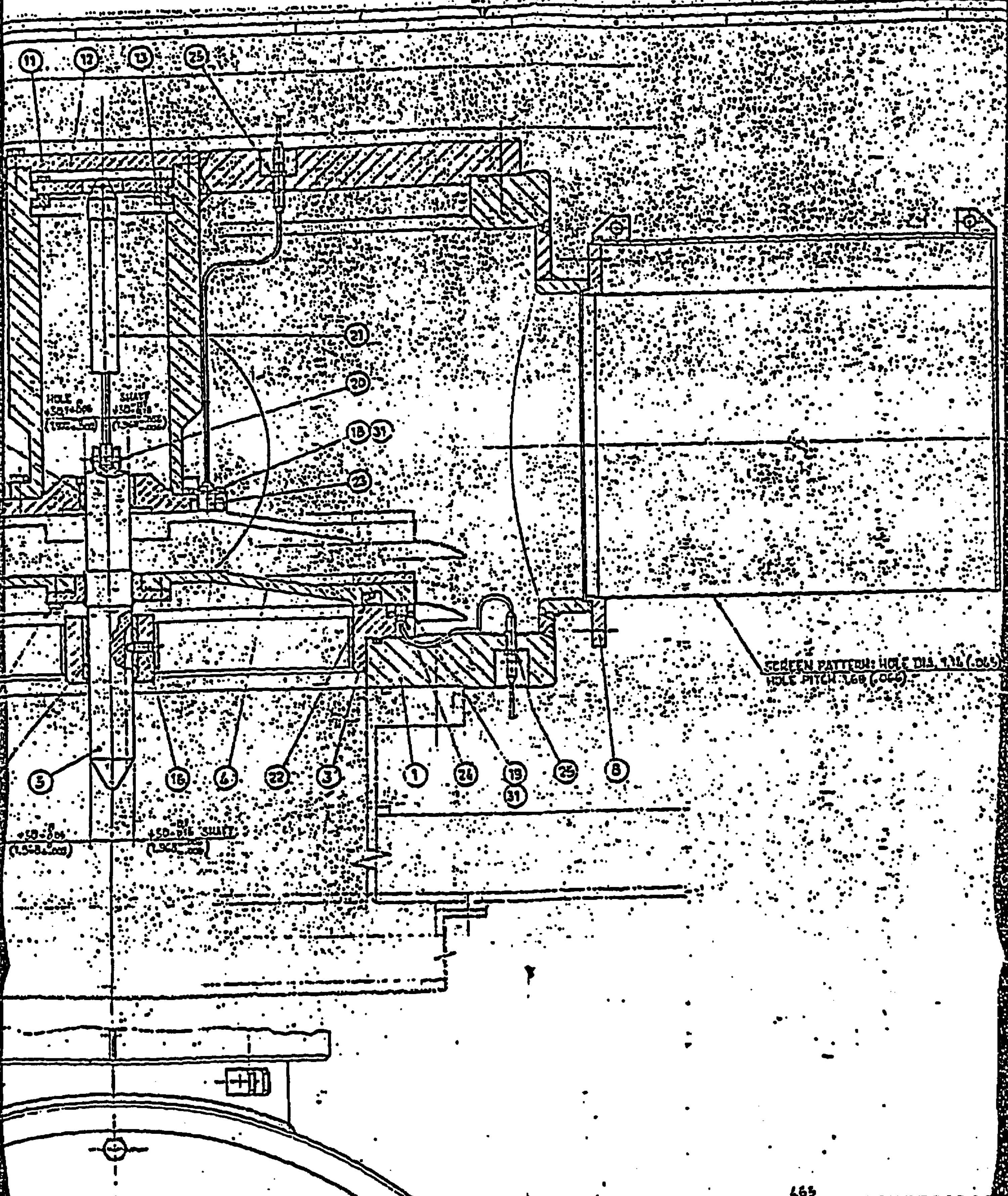
Radiation:	
- Gamma	100 megarads (in 100 days)
- Beta	100 megarads (in 100 days)
- Neutrons	Negligible
Temperature:	303°F (424K) (100 days)
Humidity:	100%
Fluid:	N_2/Air/Saturated Steam

APPENDIX 20

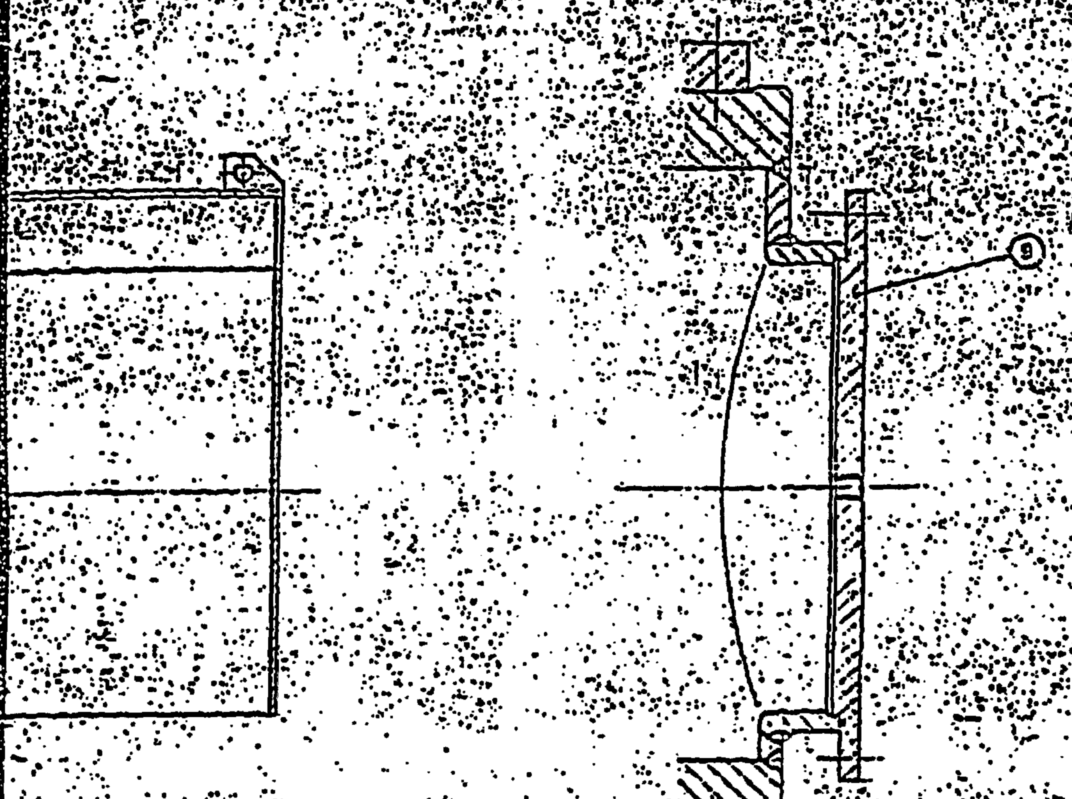
EQUIPMENT DIAGRAM



900
(35.43)
825.5
(32.50)
152.4
(6.00)
657
(25.87)
SLEEVE

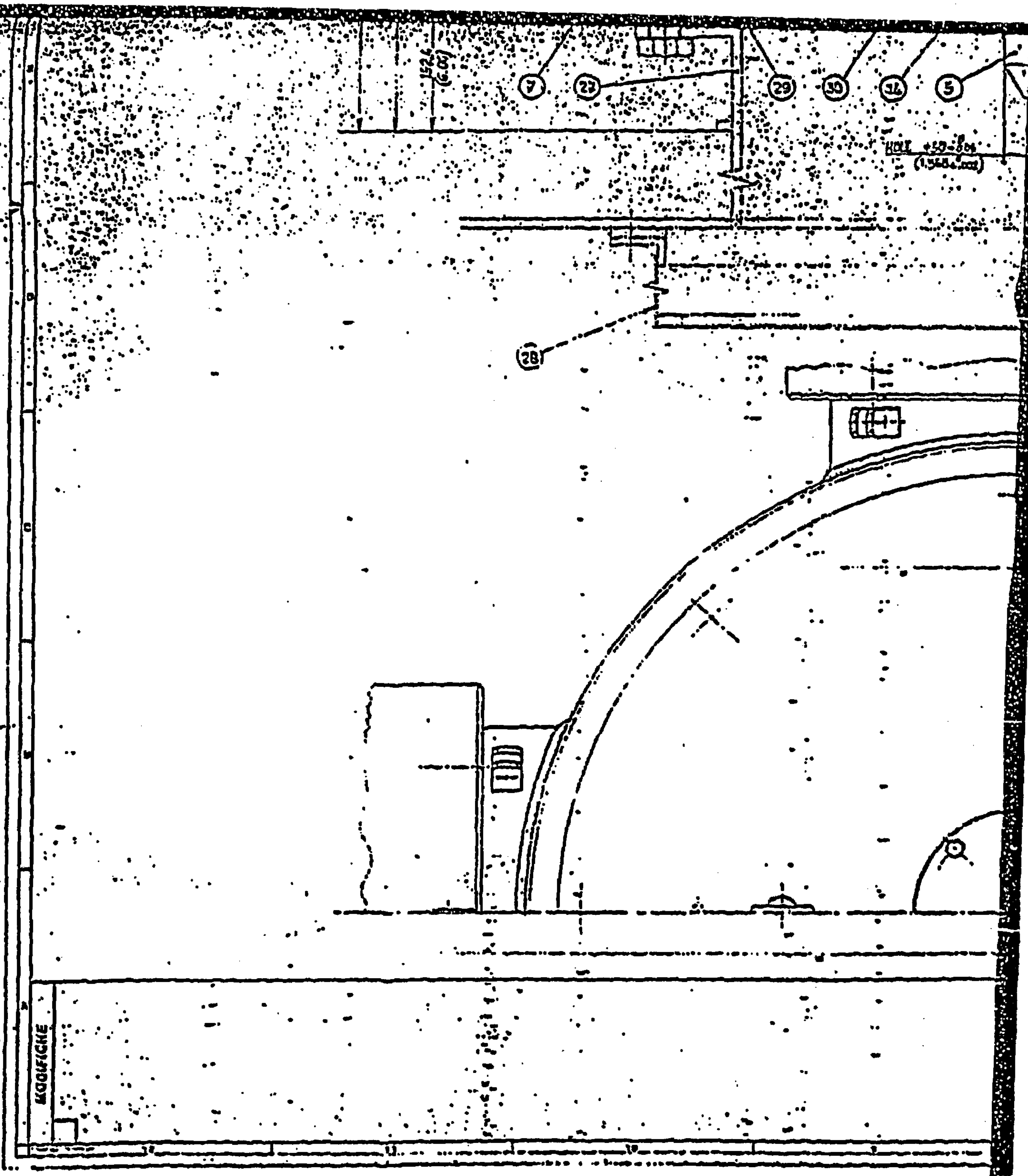

11
12
13
25
21
20
18
31
23
5
16
6
22
3
1
24
19
31
25
8
SCREEN PATTERN: HOLE DIA. 1.14 (.045)
HOLE PITCH 1.68 (.066)

LEAK TEST CONFIGURATION DETAIL

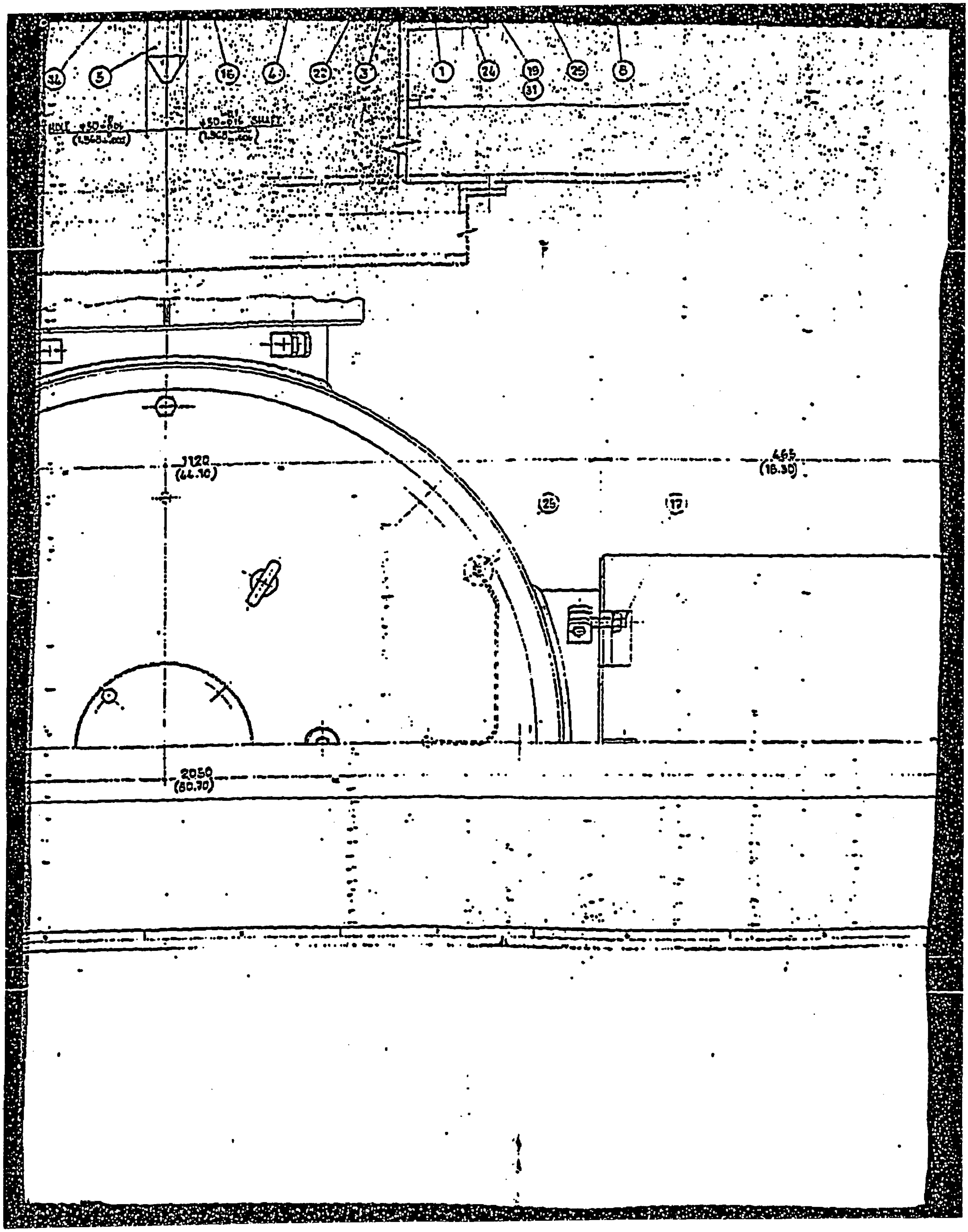


PATTERN: HOLE DIA. 9/16 (.069)
TCH: .68 (.066)

31	10	M4 × 12 HEX HD. SCREW	ASTM A193 G-B8M	COMMERCIAL
30	6	M8 × 22 HEX HD. SCREW	ASTM A193 G-B8M	COMMERCIAL
29	8	M12 × 65 SOCKET HD. CAP SCREW	ASTM A 193 G-B8M	COMMERCIAL
28	1	INLET SCREEN	SEE DWG. 112D6236	G.E. DESIGN
27	1	FLANGED STANDPIPE	24" 150 LB ANSI B16.5 SCH 80	BY OTHERS
26	3	EYEBOLT	CARBON STEEL	COMMERCIAL GR.
25	5	CABLE PENETRATION	# SWH0S303CLLPV	LEMO
24	6	PROXIMITY SENSOR	# KD-2350	BY G.E. - KAMAN
23	1	PROXIMITY SENSOR	# KD-1925	BY G.E. - KAMAN
22	1	DISK SEAL	ELASTOMER	COMMERCIAL
21	1	DAMPER	# ADA 510 M	ENIDINE
20	2	PIN	ASTM A 240 TYPE 316L	
19	6	SENSOR RETAINER	ASTM A 240 TYPE 316L	
18	1	SENSOR RETAINER	ASTM A 240 TYPE 316L	
17	16	HINGE PIN	ASTM A 240 TYPE 316L	
16	1	ANTIROTATION KEY	ASTM A 240 TYPE 316L	
15	1	UPPER BEARING	ASTM B150 No. C63000 OR EQUIVALENT	
14	1	LOWER BEARING	ASTM B150 No. C63000 OR EQUIVALENT	
13	2	SUPPORT DOG	ASTM A 240 TYPE 316L	
12	1	DAMPER THRUST SUPPORT	ASTM A 240 TYPE 316L	
11	1	DAMPER COVER	ASTM A 240 TYPE 316L	
10	1	BEARING SUPPORT	ASTM A 240 TYPE 316L	
9	6	FLANGE (FOR TEST ONLY)	ASTM A 240 TYPE 316L	



7
29
30
5
28
MODIFICHE


32
5
16
4
22
3
1
24
19
31
25
8
1120
(44.10)
465
(18.30)
25
17
2050
(80.70)

ITEM	QTY	NAME	MATERIAL	NOTE
31	10	M 6×12 HEX HD. SCREW	ASTM A193 Gr B8M	COMMERCIAL
30	4	M8×22 HEX HD. SCREW	ASTM A193 Gr B8M	COMMERCIAL
29	8	M12×25 SOCKET HD. CAPSCREW	ASTM A 193 Gr B8M	COMMERCIAL
28	1	INLET SCREEN	SEE DWG 112D6235	G.E. DESIGN
27	1	FLANGED STANDPIPE	24" 150 LB ANSI B16.5 SCH 10	BY OTHERS
26	3	EYEBOLT	CARBON STEEL	COMMERCIAL GR.
25	5	CABLE PENETRATION	# SWHO5303CLLPV	LEMO
24	4	PROXIMITY SENSOR	# KD-1950	BY G.E. / KAMAN
23	1	PROXIMITY SENSOR	# KD-1975	BY G.E. - KAMAN
22	1	DISK SEAL	ELASTOMER	COMMERCIAL
21	1	DAMPER	# ADA 510M	ENIDINE
20	2	PIN	ASTM A 240 TYPE 316L	
19	4	SENSOR RETAINER	ASTM A 240 TYPE 316L	
18	1	SENSOR RETAINER	ASTM A 240 TYPE 316L	
17	16	HINGE PIN	ASTM A 240 TYPE 316L	
16	1	ANTIROTATION KEY	ASTM A 240 TYPE 316L	
15	1	UPPER BEARING	ASTM B150 No. C63000	OR EQUIVALENT
14	1	LOWER BEARING	ASTM B150 No. C63000	OR EQUIVALENT
13	2	SUPPORT DOG	ASTM A240 TYPE 316L	
12	1	DAMPER THRUST SUPPORT	ASTM A240 TYPE 316L	
11	1	DAMPER COVER	ASTM A240 TYPE 316L	
10	1	BEARING SUPPORT	ASTM A240 TYPE 316L	
9	4	FLANGE (FOR TEST ONLY)	ASTM A240 TYPE 316L	
8	4	DISCHARGE SCREEN	ASTM A240 TYPE 316L	
7	1	ANTICHATTERING	ASTM A240 TYPE 316L	
6	1	BALLAST WEIGHT	ASTM A240 TYPE 316L	
5	1	STEM	ASTM A479 TYPE 630	
4	1	DISK	ASTM A240 TYPE 316L	
3	1	SEATING RING	ASTM A240 TYPE 630	
2	1	BONNET	ASTM A240 TYPE 316L ASTM A182 F 316L	
1	1	BODY	ASTM A240 TYPE 316L	

TOTAL DRY WEIGHT 2500 LBS. APPROX.

DIMENSIONS ARE IN MILLIMETERS. DIMENSIONS IN (..) ARE IN INCHES

1:2.5

FIAT

SBWR
VACUUM BREAKER VALVE
GENERAL ASSEMBLY, STUDY AND LAYOUT

336 | 2T137681

APPENDIX 30

MAIN REQUIREMENTS OF EQUIPMENT

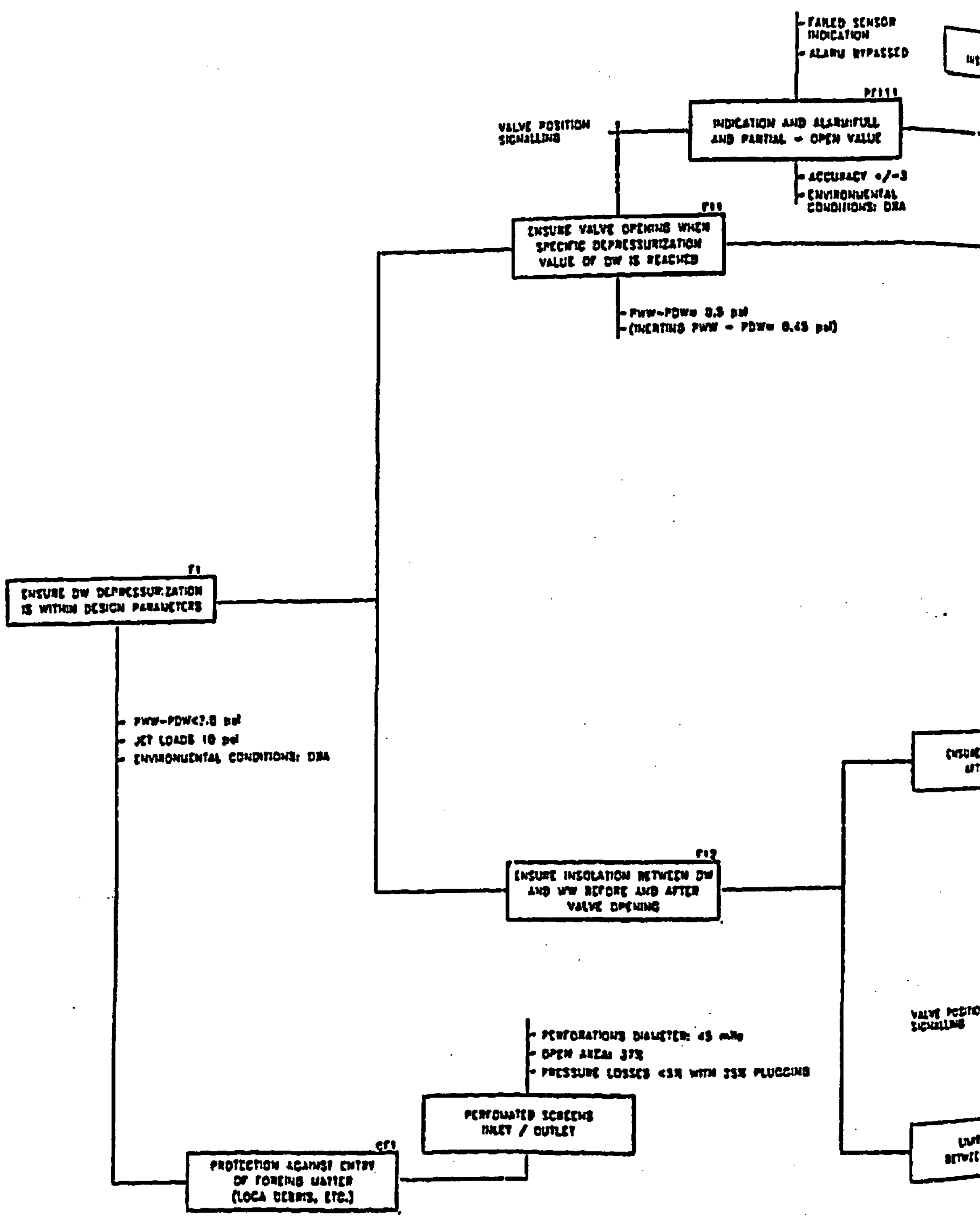
MAIN REQUIREMENTS OF EQUIPMENT

- Flow area $A/\sqrt{K} = 1.04\ ft^2$
- Maximum flow loss coefficient $K = 3$
- Reliability > $3 \cdot 10^{-4}$ failure/demand
- Protection against LOCA debris
- Reliability of instrumentation: Mean Time Between Failures > 6 years
- Design pressure/temperature: 50 psi (338 KPa) / 350°F (151°C)
- Leak rate: $1.0 \cdot 10^{-4}$ cc/s
- Jet loads: 10 psi
- Environmental qualification:

  Radiation
  Thermal
  Dynamic/Seismic
  Design Base Accident (LOCA)

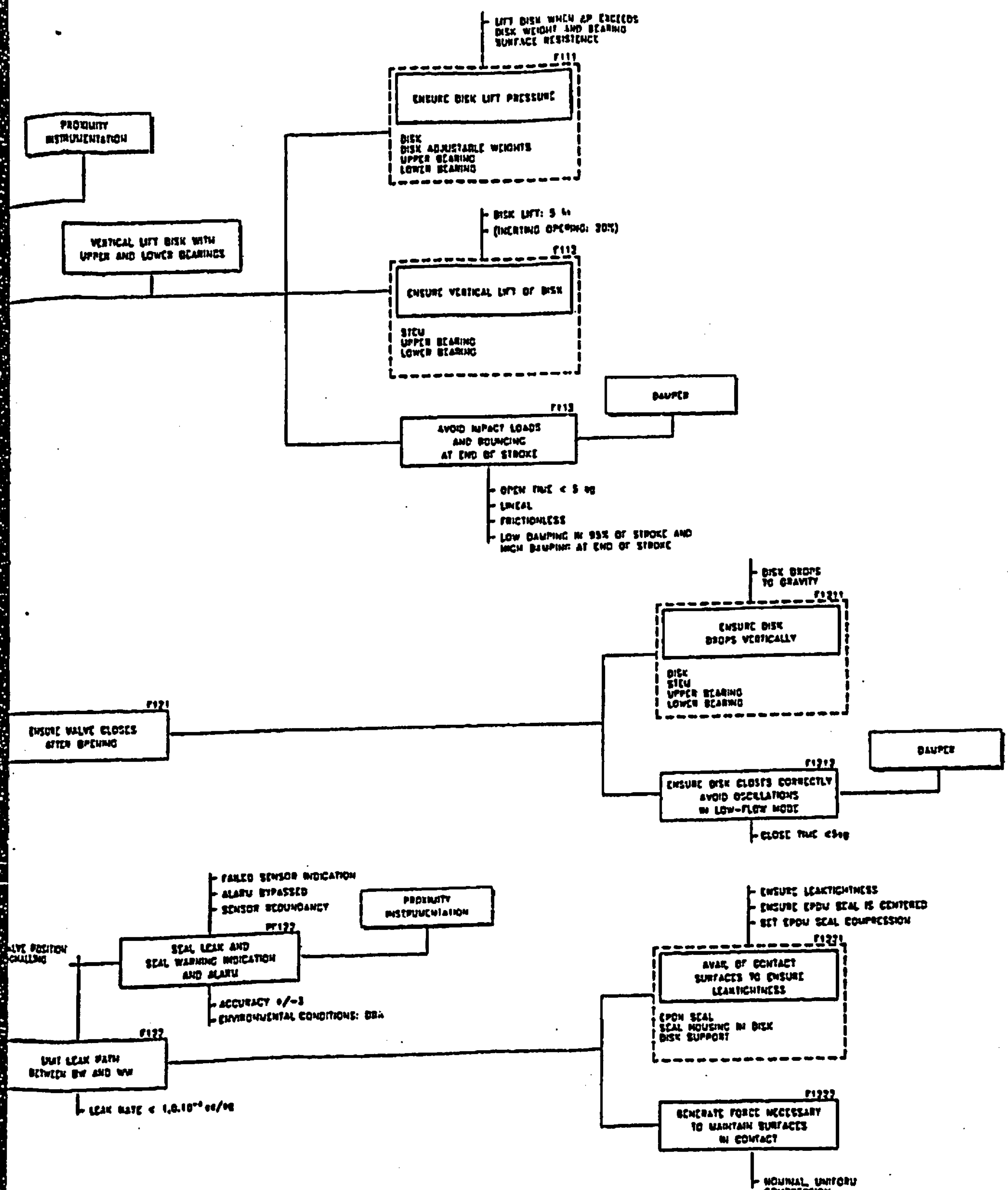
APPENDIX 40

FUNCTIONAL TREE



FAILED SENSOR INDICATION
ALARM BYPASSED
VALVE POSITION SIGNALLING
INDICATION AND ALARM(FULL AND PARTIAL - OPEN VALUE
ACCURACY +/-3
ENVIRONMENTAL CONDITIONS: DBA
ENSURE VALVE OPENING WHEN SPECIFIC DEPRESSURIZATION VALUE OF DW IS REACHED
PWW-PDW= 0.3 psi
(INERTING PWW - PDW= 0.45 psi)
F1
ENSURE DW DEPRESSURIZATION IS WITHIN DESIGN PARAMETERS
PWW-PDW<7.0 psi
JET LOADS 10 psi
ENVIRONMENTAL CONDITIONS: DBA
ENSURE INSOLATION BETWEEN DW AND WW BEFORE AND AFTER VALVE OPENING
PERFORATIONS DIAMETER: 45 mils
OPEN AREA: 37%
PRESSURE LOSSES <3% WITH 35% PLUGGING
PERFORATED SCREENS INLET / OUTLET
PROTECTION AGAINST ENTRY OF FOREING MATTER (LOCA DEBRIS, ETC.)

VACUUM BREA



BREAKER FUNCTIONAL TREE

FIG. 1

APPENDIX 50

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
EPDM Seal. Housing of seal in disk. Disk support (hard seat)	F1221	Avail of necessary contact surfaces to ensure leaktightness - Ensure centering of soft seat - Set compression of soft seat (EPDM seal) - Ensure leaktightness	No function	Geometrical tolerances not respected - Geometrical defects in seal housing - Geometrical defects in seal	Non-nominal compression of seat. Elastomer seat not correctly centered Seal degredation → leaks		Dimensional checks which guarantee that the tolerances are respected	Catastrophic valve failure
				Loss of seal or incomplete seal (<360°)	Absence of leaktightness barrier. Partial or total loss of contact surfaces → leaks		Methods of avoiding human errors during valve erection (Installation instruction) and conduct leaktightness test after erection (Preoperatio-nal checks). Replacement procedures	Catastrophic valve failure

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
EPDM Seal. Housing of seal in disk. Disk support (hard seat)	F1221	Avail of necessary contact surfaces to ensure leaktightness - Ensure centering of soft seat - Set compression of soft seat (EPDM seal) - Ensure leaktightness	No function	Local defects in hard seat - Manufacture - Erection	Uncontrolled leak paths.		Installation instruction. Preoperational checks	Catastrophic valve failure
				Scratches or cracks produced during seal manufacture or assembly	Uncontrolled leak paths		Visual inspection and preoperational checks	Catastrophic valve failure
				Incorrect position of elastomer seal on hard seat	Loss of contact between leaktightness surfaces → leaks	Instrumentation	Installation instruction and preoperational checks(leak test). Replacement procedures	Catastrophic valve failure

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
EPDM Seat. Housing of seal in disk. Disk support (hard seat)	F1221	Avail of necessary contact surfaces to ensure leaktightness - Ensure centering of soft seat - Set compression of soft seat (EPDM seal) - Ensure leaktightness	Loss of function	Evolution of geometrical tolerances during operation	Non-standard leaktightness barrier owing to deterioration of contact surface quality		Determination of impact of environmental conditions in normal operation on evolution of the valve behaviour. Periodical inspections	Catastrophic valve failure
				Wear	Leaks		Qualification for normal operation. Periodical inspection	Incipient valve failure
				Accumulation of dirt in seat	Leaks	Instrumentation	Correct dimensioning of protective screens. Periodical inspections	Incipient valve failure

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
EPDM Seal. Housing of seal in disk. Disk support (hard seat)	F1221	Avail of necessary contact surfaces to ensure leaktightness - Ensure centering of soft seat	Loss of function	Material degradation	Seal degradation and leaks		Seal qualification for normal operaton and accident conditions. Periodical inspections	Catastrophic valve failure
		- Set compression of soft seat (EPDM seal) - Ensure leaktightness		Deformations due to operation and accident loads	Leaks		Qualification for all aspected loads and periodical inspections	Catastrophic valve failure

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
Instrumentation	PF11 PF122	Indication of valve position	No function	Error during assembly	No information or errors regarding valve position		Installation instruction. Replacement procedure. Disassembly and reassembly procedure	Degraded failure of valve
			Loss of function	Failure of position sensors - Ambiente (temperature, humidity, vibrations) - Foreign matter	Idem	Indications of sensor failure	Instrumentation qualification for normal operation and accident conditions. Periodical inspection	Degraded failure of valve

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
Instrumentation	PF11 PF122	Indication of valve position	Loss of function	Loss of power supply	No information regarding valve position	Instrumentation No information	Redundancies in power supply	Degraded failure of valve
				Cable and connection failure	Idem	Instrumentation No information	Installation instruction. Instrumenta-tion qualification. Replacement procedures.	Degraded failure of valve
			3 Degradation of function	Incorrect calibration	Errors information received regarding valve position		Equipment calibration procedures	Degraded failure of valve

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
Damper	F113	Avoid impact loads and bouncing at end of run	No function	Human error during adjustment	Disk oscillations which could produce wear in the seat and deformations		Adjustment procedure	Catastrophic valve failure
	F1212	Guarantee correct closure of disk. Avoid oscillations in low flow mode			Opening and closing time higher than that specified			
			No function	Incorrect assembly	Idem		Installation instruction Replacement procedure Disassembly and reassembly procedure	Catastrophic valve failure

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
Damper	F113	Avoid impact loads and bouncing at end of run	Loss of function	*Maladjustment* during operation	Disk oscillations could produce wear in seat and deformations		Test on damper behaviour during operation conditions	*Catastrophic* valve failure
					Opening and closing time higher than that specified			
	F1212	Guarantee correct closure of *disk*. Avoid oscillations in low flow mode		Damper *fluid leak*	*Idem*			Catastrophic valve failure
				Loss of fluid characteris-tics	*Idem* Blocked valve		Tests on fluid *behaviour* in normal and accident conditions	Catastrophic valve failure

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
Stem Upper bearing Lower bearing	F112	Ensure vertical lift of disk	No function	Geometrical tolerances not respected	Valve movement impossible Excessive friction between stem and bearings	Instrumentation	Dimensional checks Preoperational checks	Catastrophic valve failure
	F1211	Ensure vertical drop of disk						
				Broken or bent stem - Vibrations - Loads - Assembly	Valve movement impossible	Instrumentation	Determination of impact of environmental conditions in normal operation on evolution of the valve operation Periodical inspections Installation procedures	Catastrophic valve failure
				Entry of foreign matter	Idem		Periodical inspections	Catastrophic valve failure

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
Disk Disk adjustable weights Upper bearing Lower bearing	F111	Guarantee disk lift pressure	No function	Incorrect dimensioning of disk and adjustable weights	Opening a depressure value lower than nominal. No opening at nominal pressure		Preoperational checks to guarantee disk lift	Catastrophic valve failure
				Geometrical tolerances not respected	Idem		Dimensional checks	Catastrophic valve failure

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
Perforated screens inlet/outlet	CF1	Protection from foreign matter	Loss of function	Badly finished	Entry of particles into valve → leaks, blockages		Tests on normal operation and pre-accident behaviour to guarantee design criteria - Mechanical resistance to stresses - Pressure losses	Incipient failure
				Unable to bear loads caused by flow modes, vibrations, missile impact, etc.	Strains, loss of screens			
				Plugging	Increase in pressure losses		Periodical checks	Incipient failure

FAILURE MODES AND CRITICALITY ANALYSIS TABLES

COMPONENT	No.	FUNCTION	FAILURE MODE	CAUSES	EFFECTS	DETECTION MEANS	RISK REDUCTION MEANS	CRITICALITY
EPDM seal anchorage system	F1222	Generate the force necessary to maintain the surfaces in contact	Loss of function	Force exerted on seal too strong	Loss of seal characteris-tics		Installation instruction. Replacement disassembly and reassembly procedure	Catastrophic valve failure
			No function	Force on seal insufficient	Leaks		Idem	Catastrophic valve failure
			Loss of function	Defect in anchorage system - Vibrations - Break due to fatigue or corrosion	Leaks		Qualification test. Periodical inspection	Catastrophic valve failure

FIAT - COMPONENTI E IMPIANTI PER L'ENERGIA E L'INDUSTRIA S.p.A. DIVISIONE CIEI		ED45833 Pagn 1

DOCUMENT TYPE: TEST PROCEDURE

INTERNAL CLASSIFICATION: N° 96/93

TITLE : S.B.W.R. VACUUM BREAKER (V.B.) PROTOTYPE
EXPERIMENTAL QUALIFICATION
GENERAL TEST PROCEDURE

JOB N°: C33650

AUTHORS:

- ANSALDO RICERCHE:
- B.P.D. DIFESA E SPAZIO:
  HATU'- ICO:
- FIAT CIEI:

DATE:

1	JULY 1994				ALL SECTIONS AVAILABLE
0	2/15/1994	C. PARTITI	C. PARTITI	B. PARLATORE	ONLY SECTIONS A AND B AVAILABLE
REV.	DATA	EMISSIONE	VERIFICA	APPROVAZIONE	

Mod. CEI 5021 - Ed. 6/90

SUMMARY

B.5.9.) Foreign material seat sensitivity tests (leak tests with particles under the V.B. seal)

B.5.10) Final disassembly and inspection

- SECTION C: TESTS PERTAINING TO HATU'- ICO (ASCOLI PICENO)
  - C.1.) INTRODUCTION
  - C.2.) TEST FACILITY DESCRIPTION
  - C.3.) TEST INSTRUMENTATION
  - C.4.) TEST DATA ACQUISITION AND PROCESSING
  - C.5.) TEST SEQUENCE
    - C.5.1) Radiation ageing

- SECTION D: TESTS PERTAINING TO PERIOLI E GIANOTTI (TORINO)
  - D.1.) INTRODUCTION
  - D.2.) TEST FACILITY DESCRIPTION
  - D.3.) TEST INSTRUMENTATION
  - D.4.) TEST DATA ACQUISITION AND PROCESSING
  - D.5.) TEST SEQUENCE
    - D.5.1.) Thermal ageing

- SECTION E: TESTS PERTAINING TO ANSALDO RICERCHE (GENOVA)
  - E.1.) INTRODUCTION
  - E.2.) TEST ARRANGEMENT DESCRIPTION
  - E.3.) TEST INSTRUMENTATION
  - E.4.) TEST DATA ACQUISITION AND PROCESSING
  - E.5.) TEST SEQUENCE (Resonance search, Fragility test (with leakage monitoring), Seismic test (S.S.E. time histories application))
  - E.6.) ACCEPTANCE CRITERIA
  - E.7.) TEST REPORT
  - E.8.) QUALITY ASSURANCE REQUIREMENTS
  - E.9.) MANAGEMENT OF TEST NON CONFORMANCES

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D) FERIOLI E GIANOTTI TEST PROCEDURE, DOC. N° ED45894

D.1.) THERMAL AGEING FURNACE SKETCH

D.2.) FURNACE INSTRUMENTATION CERTIFICATES

D.3.) TEMPERATURE RECORDER CERTIFICATE

E) ANSALDO RICERCHE TEST PROCEDURE, DOC. N° TCE.MII.S.1001

F) BPD DIFESA E SPAZIO TEST PROCEDURE, DOC. N° PCNVBR00001

F.1.) VACUUM BREAKER FACILITY P.I.D.

F.2.) NITROGEN SUPPLY SYSTEM FOR LEAK TESTS

F.3.) SIMULATED SERVICE CONDITION TEST PROFILE

GENERAL ABSTRACTS

The WET WELL to DRY WELL VACUUM BREAKER (V.B.) is one of the safety related components of the GENERAL ELECTRIC nuclear power plant with increased inherent safety S.B.W.R.
Owing to its new conceptual design, V.B. safety functions must be warranted by means of an experimental qualification campaign performed on a prototype unit, as per IEEE standards n°323, 1984.
Qualification standards suggest the following sequence of tests/operations be performed on the prototype:

- Baseline performance identification in normal conditions
- Accelerated radiation ageing on sensitive subcomponents
- Accelerated thermal ageing of the complete unit
- Application of service mechanical vibration on the complete unit, taking into account also seismic vibration
- Simulation of the DESIGN BASIS ACCIDENT (D.B.A.) on the unit
- Reliability confirmation by means of iterative functional cycles on the unit
- Final detailed analysis of the sub components

This general procedure refers to the above-mentioned campaign planned for the V.B. prototype manufactured by FIAT COMPONENTI ED IMPIANTI PER L'ENERGIA E L'INDUSTRIA, CIEI DIVISION, Torino, ITALY.
The articulation of the qualification campaign implies the utilization of different test facilities, hence the collaboration of several firms, in details:

- the test hall of FIAT COMPONENTI ED IMPIANTI PER L'ENERGIA E L'INDUSTRIA, CIEI DIVISION, Torino, for V.B. flow tests
- the irradiation device of HATU' - ICO, Ascoli Piceno for radiation ageing
- the furnace of FERIOLI E GIANOTTI - TRATTAMENTI TERMICI, TORINO for thermal ageing

- the shaking table of ANSALDO RICERCHE, Genova, for mechanical vibrations application
- the steam chamber of BPD-DIFESA E SPAZIO, Colleferro (ROMA) for D B.A. simulation.

Therefore the present document is composed of several sections relating to:

- General references (Section A), as:
  * reference technical documents
  * descriptions of the test item
  * identification of the general qualification program, also specifying operative competences
  * general organization of individual test procedures

- Detailed operative test procedures (Sections B÷F), represented by specific documents written by the individual cooperating firms on a uniform structural format.

SECTION A: GENERAL REFERENCES AND ORGANIZATION

A.1) REFERENCE DOCUMENTS

- G.E. Doc. N° 25A5445, Rev. 1, "Wet well to dry well vacuum breaker - Test specification".
- G.E. Doc. N° 25A5388, Rev. 1, "Vacuum breaker prototype - Purchase specification".
- G.E. Doc. N° 25A5395, Rev. 0, "Vacuum breaker instrumentation - Test specification".
- G.E. Doc. N° 25A5489, "Seismic responses of SBWR Reactor building".
- ASME 1989, Sect. III, Division 1, paragraph NE-6220.
- FCI-70-2-1991, Fluid controls institute, control valve seat leakage.
- MIL-STD-810 E, July 14, 1989.
- FIAT CIEI Drawing N° 2T137684, Rev. 1, and 2S137714, Rev. 1, "Vacuum breaker general assembly and outline".
- G.E. side letter of July 12, 93: leak rate testing suggested conditions.
- G.E. side letter of Sept.21, 93: DBA test technical detailed conditions.
- G.E. side letter of Dec.1, 93: V.B. radiation environment definition.

A.2) TEST SAMPLE DESCRIPTION

The V.B. is a low pressure opening and gravity assisted closing check valve, which vents the wet well to the dry well of the SBWR. A general sketch of the V.B. prototype is shown in Attachment A: its principal features are:

- a cylindrical body, provided with four discharge nozzles
- a vertically guided sealing disk, equipped with the primary elastomer soft seal
- a metallic hard seat, facing to the sealing disk and acting as a secondary seal.
- a double acting damping device, optionally mounted in line with the stem of the sealing disk.

Additional provisions of the V.B. shown in Attachment A are:

- a set of proximity sensors, to detect any displacement of the sealing disk.
- a ballast weight, placed on the sealing disk to adjust the operative lift pressure.
- a flanged stand-pipe, supporting the V.B. and simulating the real air flow duct of the V.B. installation arrangement in the SBWR building.
- outlet and inlet screens, acting as anti-missile devices in the SBWR plant; they are assembled on the V.B. during the flow tests of the qualification campaign to reproduce the total head loss of the nominal V.B. system.

Reference technical data for the V.B. are the following:

- materials:
  * V.B. body : 316L stainless steel
  * Sealing disk: 316L " "
  * Hard seat: 400 series stainless steel

- V.B. total weight: 1280 da N (2800 Lbs)
- operating temperature range: 277°÷444°K (40°÷340°F)
- operating pressure:
  * Max differential pressure in the closing direction (dry well to wet well): 241.3 KPa (35 psid)
  * Max differential pressure in the opening direction (wet well to dry well): 20.7 KPa (3 psid)

- process fluid: nitrogen, air, steam
- V.B. minimum expected equivalent relief/flow area: $9.67.10^{-2}$ m^2 (1.04 $foot^2$)
- V.B. expected opening set point: 3.45 KPa (0.5 psid) differential pressure (wet well to dry well)

- V.B. expected operating response time:
  * opening time with 3.45 KPa (0.5 psid) differential pressure: 5 sec
  * closing time with 0 KPa (0 psid) differential pressure: 5 sec.

A.3) GENERAL QUALIFICATION PROGRAM

Table 1 shows the detailed V.B. prototype general qualification program in terms of:

- tests/activities identification
- tests/activities attribution to the individual cooperating firm
- reference to the specific paragraphs of the general test procedure.

FIAT - COMPONENTI E IMPIANTI PER L'ENERGIA E L'INDUSTRIA S.p.A. DIVISIONE CIEI		ED45833 Page 12

TABLE 1 : S.B.W.R. VACUUM BREAKER PROTOTYPE

GENERAL QUALIFICATION PROGRAM

Tests + Activities	Pertaining to: FIAT CIEI	HAW-LCO	TERNOLI GAVOTTI	DWALCO	GE	See paragraph N°
1) Hydrotest	•					B.5.1
2) Proximity instrumentation calibration	•					B.5.2
3) Baseline leak test (hard seat and disk seal)	•					B.5.3
4) Baseline low flow tests (lift pressure, stroke/speed adjustements, flow stability with/without damper)	•					B.5.4
5) Full flow tests (V.B. head + flow curve)	•					B.5.5.
6) Radiation ageing (on the disk seal)		•				C.5.1.
7) Systematic checks (leak rate)	•					B.5.6
8) Thermal ageing (complete V.B.)			•			D.5.1
9) Systematic checks (leak rate, lift force proximity probes functional tests).	•					B.5.6

Mod. CIEI 9/21 - To. CARO

Tests + Activities	Pertaining to: FATICA	[illegible]	TENUTA [illegible]	[illegible]	BPD	See paragraph Nº
10) Resonance search (Complete V.B.)				•		E.5
11) Fragility test (with leakage monitoring)				•		E.5
12) Seismic test (S.S.E. time histories application)				•		E.5
13) Systematic checks (leak rate, lift force, proximity probes functional tests)	•					B.5.6
14) Design basic accident simulation (complete V.B., with leakage monitoring)					•	F.5.1
15) Systematic checks (leak rate, lift force, proximity probes functional tests)	•					B.5.6
16) Grit ingestion test (silicon flour blow)	•					B.5.7
17) Systematic checks (leak rate, lift force, proximity probes functional tests).	•					B.5.6

Tests + Activities	Pertaining to FIAT CIEI	FIAT-ICO	FERRIOLI GIANOTTI	ANSALDO	BPD	See paragraph N°
18) Reliability test (3000 strokes)	*					B.5.8
19) Systematic checks (leak rate, proximity probes functional tests)	*					B.5.6
20) Foreign material seat sensitivity tests (leak tests with particles under the V.B. seal; <u>for information only</u>)	*					B.5.9
21) Final disassembly and inspection	*					B.5.10

A.4) DOCUMENT ORGANIZATION

Operative procedures for the different kinds of tests/activities of the V.B. prototype qualification program are defined in the specific documents written by the cooperating firms, attached to the present general procedure.

Each specific test procedure has the following structure:

- a general introduction on the operative background dealing with the performance of the tests.
- a description of the test facility arrangement, fitted with reference sketches.
- a description of the test instrumentation, explained by means of a flow diagram.
- a description of the data acquisition and processing system, helped by simplified block-diagrams.
- the identification of the test sequence, with following details explored for each test:
  * test set-up prerequisites
  * test performance operative procedures
  * test data recording requirements
  * test standard records to be utilized
  * test results acceptance criteria

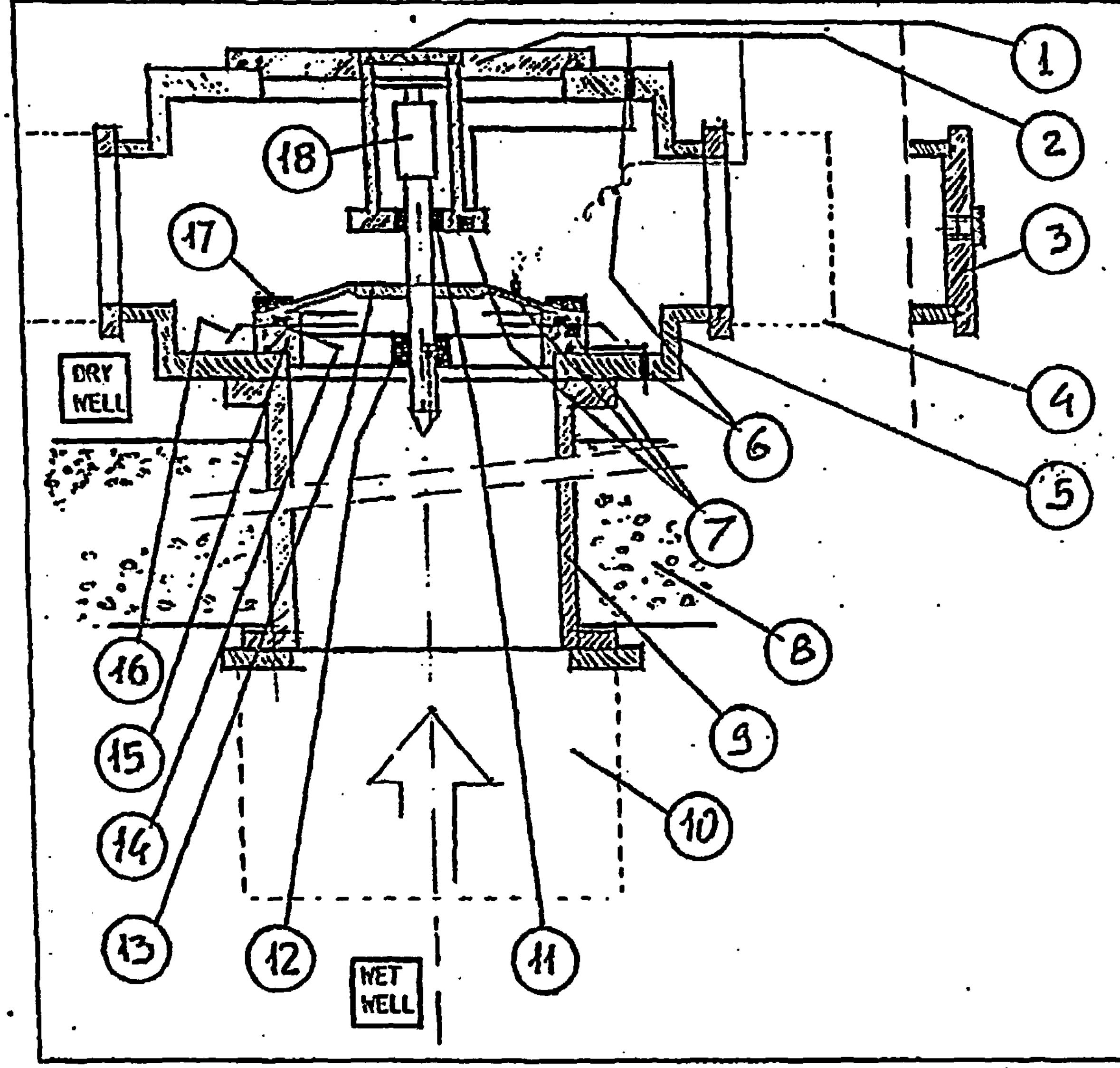
- SECTION B : <u>TESTS PERTAINING TO FIAT CIEI (TORINO)</u>
  (See Doc. FIAT CIEI n° ED 45834, Attachm. B)

- SECTION C : <u>TESTS PERTAINING TO HATU'-ICO (ASCOLI PICENO)</u>
  (See Doc. HATU'-ICO n° 06494 Attachm. C)

- SECTION D : <u>TESTS PERTAINING TO FERIOLI E GIANOTTI (TORINO)</u>
  (See Doc. FIAT CIEI n° ED45894, Attachm. D)

- SECTION E : <u>TESTS PERTAINING TO ANSALDO RICERCHE (GENOVA)</u>
  (See Doc. Ansaldo n° TCE.MII.S.1001, Attachm. E)

- SECTION F : <u>TESTS PERTAINING TO B.P.D.- DIFESA E SPAZIO (COLLEFERRO - ROMA)</u>
  (See Doc. B.P.D. n° PCNVBR00001, Attachm. F)



LEGENDA

1. DAMPER COVER
2. V.B. BONNET
3. LEAK TIGHT TEST FLANGE
4. OUTLET SCREEN
5. V.B. BODY (4 NOZZLES)
6. CABLE PENETRATIONS.
7. PROXIMITY PROBES (5 ITEMS) AND ACCELEROMETER
8. REACTOR BUILDING FLOOR
9. V.B. SUPPORTING STAND PIPE
10. INLET SCREEN
11. DISK STEM UPPER BEARING
12. LOWER BEARING WITH ANTIROTATION DEVICE
13. V.B. SEALING DISK
14. SOFT SEAL
15. HARD SEAT
16. ANTICHATTERING DISK
17. BALLAST WEIGHT
18. DAMPER

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ATTACHMENT A
V.B. PROTOTYPE QUALIFICATION TESTS
TEST SAMPLE SKETCH

ED 45833
Page 17

ATTACHMENT B

FIAT CIEI DOCUMENT, N° ED 45834

FIAT CIEI TESTS PROCEDURE

DOCUMENT TYPE: TEST PROCEDURE

INTERNAL CLASSIFICATION: Nº 97/93

TITLE : S.B.W.R. VACUUM BREAKER (V.B.) PROTOTYPE
EXPERIMENTAL QUALIFICATION
FIAT CIEI TEST PROCEDURE

JOB Nº: C33650

AUTHORS:
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The present document is the Section B of the vacuum breaker prototype general test procedure, FIAT CIEI Doc. n. ED45833

1	APRIL 1994	[signature]	[signature]	[signature]	G.E. COMMENTS INSERTED
0	2/15/1994	C. PARTITI	C. PARTITI	B. PARLATORE	
REV.	DATA	EMISSIONE	VERIFICA	APPROVAZIONE	

SUMMARY

ATTACHMENTS:

B.1.) FIAT CIEI TEST HALL PERSPECTIVE VIEW
B.2.) V.B. FLOW TEST FACILITY INSTALLATION PLAN VIEW
B.3.) FLOW TEST STAND LAYOUTS
B.4.) LEAK TEST STATION LAYOUT
B.5.) FLOW TEST STAND INSTRUMENTATION
B.6.) LEAK TEST STATION INSTRUMENTATION
B.7.) FLOW TEST DATA ACQUIS./PROCESS. DIAGRAM
B.8.) HYDROTEST CERTIFICATE
B.9.) PROXIMITY PROBES CALIBRATION CERTIFICATE
B.10) LEAK TEST CERTIFICATE
B.11) LOW FLOW TEST CERTIFICATE
B.12) FULL FLOW TEST CERTIFICATE
B.13) RELIABILITY TEST SUMMARY CERTIFICATE
B.14) FINAL INSPECTION CERTIFICATE

B.1.) INTRODUCTION

V.B. prototype "FLOWTEST", "Systematic Functional Controls" and "Reliability Test" planned in its experimental qualification campaign will be run at ENEA/FIAT CIEI test hall "A. Pogagnolo" in Torino. The test hall was built on the beginning of the eighties with the financial participation of ENEA in order to supply test devices to the italian firms involved in the late national nuclear power program.
The test hall perspective view of Attachment B.1. shows following principal facilities:

- the Primary Pumps Test Loop, for P.W.R. and B.W.R. primary R.C.P. functional testing in full nominal conditions [16 MPa (2250 psi), 563° K (552° F), 8m³/sec. (130.000 GPm), 10 MW]

- the Auxiliary Pumps Test Loop, for nuclear and conventional service pumps testing in operating conditions and in severe upset conditions (thermal shock) [2MPa (280 psi), 473°K (392°F), 0,8 m³/sec. (13.000 GPm), 10 MW]

- the Mechanisms and Valves Test Loop, for functional and endurance testing of P.W.R. control rod drive mechanism and nuclear and conventional auxiliary valves [16 MPa (2250 psi) 563°K (552° F), $8 \cdot 10^{-2}$ m³/sec (1300 GPm) maximum simulated flow].

Attachment B.2. shows a plan view of the test hall where the installation of the two test devices is indicated, the "flow tests stand", and the "leak tests station". Following auxiliary systems/items of the test hall are utilized during V.B. tests:
- low-voltage (380 V) power supply system
- nitrogen central supply system

- test data central acquisition and processing system
- instruments calibration laboratory
- the Primary Pumps Test Loop anti-noise structure, built for P.W.R. R.C.P. testing
- general lifting devices.

Assembling and disassembling operations on the V.B. prototype will be performed by CIEI specialists coming from the nuclear components assembling hall, who usually act in collaboration with test hall personnel.

B.2.) TEST FACILITY DESCRIPTION

B.2.1) Flow Test Stand

Attachment B.3. shows different views of the stand with its over all dimensions and its principal structural features.

The general stand arrangement includes:

- A fan, supplying the air flow to the V.B. prototype, whose technical data are:
  * Type : centrifugal, reverse blades impeller, single suction
  * Nominal flow: 80.000 m^3/hr ($2.84.10^6$ ft^3/hr)
  * Nominal head: 800 mm H_2O (31.5 inches of water)
  * Speed: about 1490 rpm
  * Power: 220 KW

- A fan suction regulating valve, to totally intercept air flow during fan start-ups, and to perform a gross flow regulation during the test.

- A flexible joint, for vibration decoupling of the stand piping.

- A discharge flow modulating bypass with several purposes:
  * to avoid unstable fan performances in the low flow region
  * to allow continuous fan operation during V.B. repeated functional cycling (reliability tests)
  * to increase flow regulation sensitivity
  * to allow a precise identification of the V.B. opening differential pressure (lift pressure)

The by pass includes:

- a flow regulating shutter type valve
- a fixed flow calibration gate, set to obtain a low static pressure under the V.B. disk while the fan discharges its full flow through the by-pass, across the fully open shutter valve.

- A flow veins straightener, to increase flow measurements precision
- A pipe connection with section varying from rectangular to circular shape
- A horizontal duct made of circular thin walled pipe of 1 m (3.2 feet) diameter, 2.5 x 10^{-3}m (0,1 inch) thickness, 15 m (48 feet) length, required for standard flow measurements
- A bend and a vertical pipe segment of the same dimensions
- A V.B. "stand pipe" mock-up 0,6 m (24 inches) diameter, 0,660 m (26 inches) length showing
  - at the top end, a 150 LB ANSI B16.5 SCH.20 flange supporting the V.B. prototype
  - at the bottom end, a sructural flange carrying the inlet screen and bolted to the vertical pipe segment

- A V.B. supporting structure, partially made of welded beams and showing a detachable section to facilitate disassembling.
  The structure rests on the frame of the antinoise cage and on the massive pump casing utilized during the P.W.R. R.C.P. tests.
- A anti-noise structure, made of sound absorbing panels and equipped with doors, operative floors and an openable roof allowing items handling operations.

The flow stand arrangement includes also a low performances auxiliary fan installed on the primary fan casing as a possible back-up for lift pressure-low flow tests. Indicative technical data for the auxiliary fan are:

- nominal flow : 500 m^3/hr (17700 ft^3/hr)
- nominal head : 525 mmH_2O (21 inches of water)

the utilization of the auxiliary fan might be required by a possible lack of sensitivity in the identification of V.B. characteristic parameters at low flows. The primary fan suction valve will be full closed and the flow modulating bypass will be plugged during auxiliary fan operation.

B.2.2) Leak Test Station

Attachment B.4 shows this multi-purpose station, identified by means of its prevailing function. The station really acts as:

- a generic V.B. prototype support for any service operation
- a V.B. support and pressurized water supply during hydrotest
- a handy V.B. support during proximity instrumentation calibration
- a fully equipped station for V.B. systematic leak tests.

Main features of the leak test station are:

- the V.B. supporting seat, tailored for easy assembling and disassembling of the test item
- the demineralized water supply system, equipped with a tank, a pneumatic charging pump, isolating valves and a pressure measurement section
- the nitrogen supply system, equipped with a pressure reducer, a safety valve, isolating valves and a pressure measurement section, and connected to the test hall general nitrogen supply system (racks of nitrogen bottles with a sequence of pressure reducers)
- the leak conveyer cover, to be assembled to the V.B. bottom in order to detect primary seal leaks by means of a small diameter tube submerged in water (see. ANSI/FCI 70-2-1991, note to table 2, pag. 7).

Complementary features of the leak tests station are:

- the atmospheric pressure high precision monitoring system available in the instruments calibration laboratory of the test hall

- the ambient temperature monitoring devices available for generic test hall services
- the 4 leak tight test flanges supplied with the V.B. for discharge nozzles closure during leak tests, equipped with a fast joint for water and nitrogen supply.

B.3.) TEST INSTRUMENTATION

B.3.1) Flow Test Stand Instrumentation

A schematic instrumented flow diagram of the flow tests stand is shown in Attachment B.5.

Following instrumentation is foreseen:

- Air flow measurement and recording: techn. data:
  * Flow sensor:
    . type multiple "Pitot" tube
    . flow range: 0÷80.000 m^3/hr (0÷2.84.10^6 ft^3/hr)
    . operative temperature: ambient
    . air speed : 29 m/sec $_{max}$ (95 feet/sec)
    . precision: 1% of instant flow, over the full flow range

  * Differential pressure transducer and square root operator:
    . power supply : 24 VDC
    . output signal: 4÷20 mA (proportional to the flow)
    . precision: ± 0.5% full scale

  * Digital indicator:
    . led type
    . 4 digits
    . power supply: 220V - 50 hz
    . precision : ± 0.25% full scale

- V.B. differential pressure measurement and recording techn. data:
  * Relative pressure transducer:
    . pressure range: 0÷1000 mmH_2O (0÷40 inches of water)

. power supply: 24 VDC
. output signal: 4÷20 mA
. precision: ± 0,2% full scale

* Digital indicator:
 . LED type
 . 3 ½ digits
 . power supply: 220V - 50 hz
 . precision: ± 0.25% full scale

- V.B. disk acceleration measurement and recording: techn. data:
 * Acceleration transducer:
  . type: PCB 308804
  . measurement range: ± 50 g
  . operative temperature: ambient
  . resolution: 0.003 g

- Air temperature measurement: techn. data:
 * Temperature sensor:
  . type: THERMORESISTANCE, PT 100
  . temperat. range: 0 ÷ 200°C (32° ÷ 392°F)
  . precision: ± 0.25% full scale

 * Power supply:
  . CONVERTER ohm/mA, 24 V DC
  . output signal: 4 ÷ 20 mA
  . precision: ± 0.25% full scale

 * Digital indicator:
  . LED type
  . 3 digits
  . power supply: 220 V - 50 Hz
  . precision: ± 0.25% full scale.

- V.B. disk displacement measurement and recording (instrumentation and electronics supplied by G.E.); techn. data:
  * Proximity sensors:
    . n° 4 "Kaman" KD1950 extreme environment probes
    . n° 1 "Kaman" KD1975 " " " "

  * Signal amplifier
    . n° 5 "Kaman" KDM-8200 electronics modules
    . output signal: 0÷2V

  * Power supply:
    . n° 1 3V/42HP half-rack enclosure, 220 V - 50÷60 hz

Attachment B.5 indicates also power supply and control devices for the motors of the primary and auxiliary fans of the flow tests stand.

B.3.2) Leak Test Station Instrumentation

Attachment B.6 shows a schematic diagram of the instrumentation equipping the multi-purpose leak tests station and including:

- Hydrotest pressure measurement:
  * instrument: BOURDON pressure-gauge
  * pressure range: 0÷1 MPa (0÷140 psi)
  * precision: ± 1% full scale

- Leak test pressure measurement:
  * instrument: BOUDON pressure-gauges
  * pressure range: 0 ÷ 160 KPa (0 ÷ 23.2 psi), and
    0 ÷ 300 KPa (0 ÷ 43.5 psi)
  * precision: ± 1% full scale

- Time measurement:
  * instrument: JAQUET
  * resolution: 0.2 sec

Leak tests station instrumentation complementary items are:

- Atmospheric pressure measurement:
  * instrument: FORTIN BAROMETER
  * precision: 1 mmHg

- Ambient temperature measurement:
  * instrument: GIUSSANI, MOD. DP4, DIGITAL
  * precision: ± 0.1°C (± 0.18°F).

B.4.) TESTS DATA ACQUISITION AND PROCESSING

B.4.1) Flow Test Data Acquis./Process.
The complete flow tests data travel is simplified in Attachment B.7.
The indicated stations have following functions:

- FLOW TESTS STAND : experimental data production

- ANALOGIC AND DIGITAL TRANSDUCERS : data monitoring and transmission

- DATA ACQUISITION SYSTEM (D.A.S.) :
  . data reception
  . data engineering identif.
  . data arrangement
  . data packaging

- DATA PROCESSING SYSTEM (D.P.S.) ("DIGITAL" PDP11-34 double unit computer and auxiliary personal computers) :
  . dialogue with D.A.S.
  . data mathematical processing
  . data recording ("DIGITAL" standard disks)
  . data supply organization

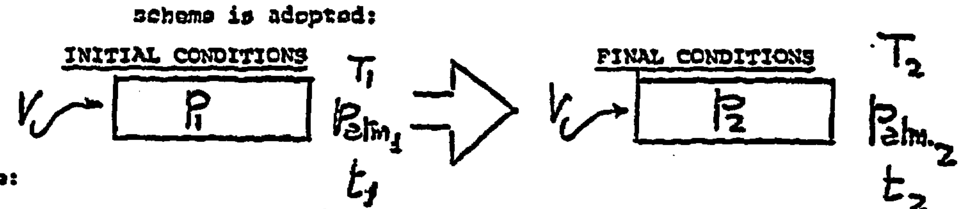
- DATA SUPPLY SYSTEM :
  . dialogue with D.P.S.
  . data final presentation:
    # monitors
    # printers
    # plotter
    # p.c. floppy disks (3" ½)

B.4.2) Leak Tests Data Acquis./Process.

During V.B. primary/secondary seals leak tests no automatic data recording/processing is foreseen. All tests data will be visually acquired and manually recorded on certification standard modules. Following general philosophy applies to the planned leak tests:

- 1st step: Attempt to perform the leak test by means of a "bubbles count" (as per ANSI/FCI 70-2-1991, note to Tab. 2, with possible different levels of seal pressurization) including:
  * test equipment set up
  * V.B. seal differential pressurization
  * leak stabilization wait
  * direct bubbles count during a measured time (bubbles/min)
  * transformation of the bubbles count rate into a standard leak rate (stcc/sec)

- 2nd step: Leak test performance by means of a "pressure loss" measurement, if bubbles count results are not reliable (too high bubbles production rate); following operative scheme is adopted:



Where:

V = controlled pressurized volume (cc), constant in time
t1 = initial test time (sec)
p1 = initial relative pressure in volume V (Pa)
T1 = initial ambient temperature (°K)
$Patm_1$ = initial atmospheric pressure (Pa)
t2 = final test time (sec)

P2 = final relative pressure in Volume V (Pa)

T2 = final ambient temperature (°K)

$Patm_2$ = final atmospheric pressure (Pa)

Being moreover by convention:

$Patm_o$ = "standard" atmospheric pressure (Pa)

T0 = "standard" ambient temperature (°K)

a "mean leak rate" Qm in the time interval t1 ÷ t2, expressed in (st.cc/sec), is given by:

$$Qm = \frac{V}{(t2-t1)\ Patm_o} \times \left[(P1+Patm_1)\frac{To}{T1} - (P2+ Patm_2)\frac{T0}{T2} \right]$$

The abovementioned mean value of the leak rate is finally put in correlation with the mean value of the pressurization of volume V, pm = ½ (p1+ p2).

B.5.) TESTS SEQUENCE

B.5.1) Hydrotest

B.5.1.1.) Pre-requisites

a) V.B. nominal primary seal replaced by a conventional commercial seal, envisaged as a test tool only for hydrotest performance
b) Proximity probes absent, cable penetrations replaced by plugs.
c) Leak tight test flanges assembled on the V.B. discharge nozzles.
d) V.B. prototype placed on the supporting seat of the leak test station and connected to the demineralized water feed line.
e) Demineralized water tanks filled with water at room temperature. Water chemistry certificate available.
f) All isolation valves closed.

B.5.1.2.) Operative procedure

a) Open filling valves and fill the V.B. prototype venting by the plug of the cable penetration on the bonnet, and by the damper cover. Close vents.
b) Isolate the filling line, open the water feed valve and start up the charging pump with V.B. internal pressure control.
c) Stop V.B. pressurization at p = 325 KPa (47.25 psi).
Shut down the charging pump and close feed water valve.
Maintain this pressurization a minimum of 10 minutes: if necessary restore pressure with the charging pump.

d) Open feed water valve and reduce V.B. internal pressure to 245 KPa (35.5 psi) by means of the discharge valve. Close feed water valve.
Maintain this pressure during examination for leakage of the V.B. structure. If necessary restore pressure with the charging pump.

N.B. Direct away from the surface of the V.B. any leakage from temporary seals utilized for the test, to avoid masking leaks from other joints.

e) Open feed water valve and depressurize the V.B. by means of the discharge valve. Open the venting plug on the bonnet and unscrew the damper cover. Open the drain valve and one of the bottom cable penetration plugs and empty the V.B. Close all isolation valves and disconnect the V.B. from the water supply system.

B.5.1.3.) Data recording

a) During the top pressurization phase record
- top pressure
- pressurization time

b) During the leakage examination phase record
- reduced pressure
- pressurization time
- any leakage from welded joints, connections, regions of high stress, thickness transition sections.

B.5.1.4.) Standard records

Test data will be recorded on standard form shown in Attachment B.8.

B.5.1.5.) Acceptance criteria

No leakage is acceptable from welded joints and structural parts of the V.B. prototype body.

Leakage of temporary seals, installed for the purpose of hydrotest performance, may be permitted unless the leakage exceeds the capacity to maintain system test pressure for the required amount of time.

B.5.2) Proximity Instrumentation Calibration

B.5.2.1) Pre-requisites

a) Proximity probes installed on the V.B. prototype, equipped with nominal cable penetrations, and connected to their electronics modules by prototypical cable lengths.

b) V.B. prototype placed on the supporting seat of the leak test station.

c) Test flanges and discharge screens absent (free discharge nozzles)

d) V.B. bonnet unscrewed and equipped for frequent handling.

e) V.B. disk stem equipped for frequent liftings and lowerings

f) V.B. disk nominal primary seal absent

g) Calibrated shims and feeler gauges available.

h) Probes electronics power supply available

i) Disk and seating ring mating surfaces cleanness inspected.

B.5.2.2.) Operative procedure

B.5.2.2.1) System accuracy/repeatability demonstration

a) Verify probes behaviour at varying disk/seat distances placing sets of calibrated shims (3 shims each time at 120°) under the disk of 0.76, 1.018, 2.036, 2.54, $3.8 \cdot 10^{-3}$m (30,40,80,100,150 mils) thickness and back for lower probes testing and of (S-1.26), (S-1.764), (S-2.782), (S-3.04), (S-3.8)10^{-3}m thickness and back for upper probe testing, where "S" is the disk stroke measured during V.B. assembling.

Gap tolerances shall be ± $2.5.10^{-6}$m (±0.1 mils): feeler gauges will be used between the seat and disk to assure the required gap.

b) Repeat twice the verifications of point B.5.2.2.1.a)

c) Return to zero gap between the seat and disk

B.5.2.2.2) Particle test

a) Verify probes behaviour by inserting a feeler gauge of $1.52.10^{-3}$m (60 mils) thickness between the seat and the disk at 45° from one proximity probe. Gap tolerance shall be ± $2.5.10^{-6}$m (±0.1 mils).

b) Repeat the verification of point B.5.2.2.2.a) with a feeler gauge of $2.036.10^{-3}$m (80 mils)

c) Return to zero gap between the seat and disk.

B.5.2.3.) <u>Data recording</u>

B.5.2.3.1) System accuracy/repeatability demonstration

Record all probes readings at each step of variation of the disk/seat gap from zero to the max foreseen in the cycles required at point B.5.2.2.1.

B.5.2.3.2) Particle test

Record the disk/seat gap indications of each proximity probe following the feelers insertions required at point B.5.2.2.2.

B.5.2.4.) Standard records

Tests data will be recorded on standard form shown in Attachment B.9.

B.5.2.5.) Acceptance criteria

B.5.2.5.1) System accuracy/repeatability demonstration

Proximity probes readings shall match the actual gaps indicated at point B.5.2.2.1 within ± $7.5 \cdot 10^{-5}$m (±3 mils)

B.5.2.5.2) Particle test

At least two of the proximity probes shall indicate values greater than $0.76 \cdot 10^{-3}$m (30 mils) for $1.52 \cdot 10^{-3}$m (60 mils) feeler insertion, required at point B.5.2.2.2., and greater than $1.018 \cdot 10^{-3}$m (40 mils) for $2.036 \cdot 10^{-3}$m (80 mils) feeler insertion.

GENERAL NOTE

Paragraph B.5.2. meets the requirements of ref. G.E. Spec. 25A5395 Rev. 0 and the first calibration shall be carried out at FIAT premises by G.E. technical responsable personnel with FIAT CIEI assistance and training.

B.5.3) Baseline Leak Tests (Hard seat and disk seal)

B.5.3.1) Hard seat leak test

B.5.3.1.1) Pre-requisites

a) Proximity instrumentation nominally installed on the V.B. prototype.

b) V.B. disk nominal primary seal absent, disk directly in contact with the hard seat.

c) Leak tight test flanges assembled on the discharge nozzles

d) V.B. placed on the supporting seat of the leak test station, connected to the nitrogen supply line.

e) Test hall general nitrogen supply system available.

f) All nitrogen isolation valves closed.

B.5.3.1.2) Operative procedure

a) Open nitrogen feed valves and pressurize the V.B. body up to 100 KPa (14 psi) acting on the pressure reducer. Reach a stable pressurization condition.

b) Close nitrogen feed valve and follow the depressurization of the V.B. body by a timer pointing out 90,80,70,60,50 KPa (12.6,11.2, 9.8,8.4, 7 psi) steps.

c) Repeat twice the abovementioned pressurization and controlled depressurization sequence.

d) Let the V.B. body depressurize completely.

e) Disconnect the V.B. from the nitrogen supply system, depressurize the nitrogen feed line and close all isolating valves.

B.5.3.1.3) Data recording

Record during each test sequence:

a) The initial stable pressurization of the V.B.

b) Initial ambient temperature and atmospheric pressure

c) Time at the five depressurization steps.

d) Final ambient temperature and atmospheric pressure.

B.5.3.1.4) Standard records

Test data will be recorded on standard form shown in Attachment B 10-1.

The form structure foresees for each test sequence:

- mean leak rate calculation at each depressurization step
- correlation of the mean leak rate to the mean value of V.B. body pressurization at each step.
- hard seat leak mean equivalent area (A/√K) calculation at each depressurization step.

- resulting hard seat leak mean equivalent area calculation (averaged over the five depressurization steps).

A final hard seat leak mean equivalent area is obtainable averaging over the three test sequences.

B.5.3.1.5) <u>Acceptance criteria</u>

The final hard seat leak mean equivalent area ($A/\sqrt{K}$), averaged over the required test sequences, must be less than $2.10^{-5} m^2$ ($2.16x10^{-4} ft^2$).

B.5.3.2) Disk seal base line leak test

B.5.3.2.1) Pre-requisites

a) Proximity instrumentation nominally installed on the V.B. prototype.

b) V.B. disk nominal primary seal installed

c) Leak tight test flanges assembled on the discharge nozzles.

d) Seal leak conveyor cover installed, with bubble monitoring tube placed in a transparent water container.

e) V.B. placed on the supporting seat of the leak test station, connected to the nitrogen supply line.

f) Test hall general nitrogen supply system available.

g) All nitrogen isolation valves closed.

B.5.3.2.2) Operative procedure

a) Open nitrogen feed valves and pressurize V.B. body up to 245 KPa (35 psi) acting on the pressure reducer.

b) Close the nitrogen feed valve and wait for stabilization of possible leak from the primary seal, conveyed by the collecting cover to the water container (pressure under the collecting cover must grow over the water head of the monitoring tube immersion, to give rise to bubbles).

Expected stabilization time with maximum acceptable seal leak = 20 min.

c) Count bubbles rising from the monitoring tube during a minimum period of 50 min.

d) Open nitrogen feed valve and depressurize V.B. body. Close nitrogen feed valves.

e) Repeat twice operations from a) to d).

f) Depressurize nitrogen feed line and close all isolation valves.

B.5.3.2.3) Data recording

Record for each test sequence:

a) V.B. body pressurization level
b) leak stabilization wait time
c) bubbles counting period
d) N° of bubbles counted

B.5.3.2.4) Standard records

Tests data will be recorded on standard form shown in Attachment B.10-2.

The form indicates also the transformation of the "bubble count rate" into a standard "leak rate" in accord with ANSI/FCI 70-2-1991, note to TAB. 2 (1 bubble = 0.15 cc).

B.5.3.2.5) Acceptance criteria

V.B. leakage across the disk seal must be less than 10^{-4}cc/sec = 1 bubble / 25 min.

B.5.4) Baseline Low Flow Tests (Lift pressure, stroke/speed adjustements, flow stability with/without damper)

B.5.4.1) <u>Tests without anti chattering disk and without damper</u>

B.5.4.1.1) <u>Pre-requisites</u>

a) V.B.prototype nominally assembled with the exception of the antichattering device on the sealing disk, of the damper on the disk stem, and of the damper cover

b) proximity instrumentation nominally installed on the V.B. and connected to power supply and amplification electronics

c) accelerometer placed on the sealing disk (vertical direction) and connected to its power supply and amplification system

d) V.B. prototype installed on the supporting structure of the flow test stand

e) main V.B. feeding fan in line on the flow test stand

f) V.B. prototype and flow tests stand instrumentation connected to data acquisition and processing systems

g) main fan suction regulating valve closed

h) by-pass flow regulating valve fully open

i) auxiliary V.B. feeding fan available with its pertaining tools.

j) 200 daN (450 lb) dynamometer available. (better than 5% precision)

k) main and auxiliary fans power supply available.

B.5.4.1.2) Operative procedure

a) Lift three times the V.B. sealing disk by means of service lifting devices, to identify a "baseline lift force" on the dynamometer. Install the damper cover on the V.B. bonnet.

b) Start-up the main fan and, slowly, partially open the suction regulating valve: the fan flow is totally diverted to the by-pass, and the pressure under the V.B. sealing disk is lower than the expected lift pressure, owing to a previous adequate calibration of the by-pass flow calibration gate. Check instrumentation readings and recordings.

c) Slowly close the by-pass flow regulating shutter valve, in order to increase the pressure under the V.B. sealing disk, until the disk lift pressure is reached and disk displacements are noticed. Go on closing the by-pass shutter valve until the V.B. is completely open, then slowly re-open the shutter valvo, in order to reduce the V.B. feed pressure, until the sealing disk leans on the seat. Finally fully re-open the by-pass shutter valve.

d) Repeat four times operations of point C.

e) Shut down the main fan and close its suction regulating valve.
Stop recording.

NOTE:

In case of lack of adequate sensitivity in the identification of V.B. characteristic parameters at low flows (disk lift pressure, V.B. opening time, V.B. closing pressure, V.B. closing time), install the auxiliary fan, plug the flow diverter by-pass, close the main fan suction regulating valve and perform above-mentioned test points. Make use of the auxiliary fan suction regulating valve to modify pressure under the V.B. sealing disk and flow across the V.B. during opening/closing phases.

B.5.4.1.3) Data recording

Following data must be recorded during the test:

a) V.B. sealing disk assembly "baseline" lift force
b) time history of the differential pressure across the disk: particular attention must be paid to the identification of the disk "lift pressure" and of the V.B. closing pressure. Adjustements may be made by ballast weight calibrations.
c) time histories of the disk displacements indicated by the 5 proximity probes: particularly important is the behaviour of the signals in the "opening start" and "closing end" periods. Instability phenomena ought to be detected by means of signals oscillations.
d) time history of the vertical acceleration of the disk, in order to confirm and possibly amplify detection capabilities of above - mentioned instability phenomena.
e) time history of the air flow behaviour during V.B. opening and closing phases.
f) V.B. opening and closing strokes time lenghts, derived from proximity probes signals time histories

g) annotations coming from visual inspections of the disk behaviour: one or more outlet screens may be disassembled from the V.B. if considerable instabilities are detected on proximity probes signals time histories
h) reference air temperature and atmospheric pressure during the test.

B.5.4.1.4) Standard records

Lift force test data will be recorded on or attached to standard form shown in Attachment B.11-1.
Low flow tests data will be recorded on or attached to standard form shown in Attachment B.11-2.

B.5.4.1.5) Acceptance criteria

Test results are evaluated by means of following criteria:
a) V.B. sealing disk "lift pressure " shall be 3.45 KPa (0,5 psid) ± 5%
b) V.B. opening and closing times shall be 5 sec or less
c) under low flow conditions the valve disk shall not chatter

NOTE:

- If point b) and c) criteria are not fulfilled tests of paragraph B.5.4.2 must necessarily be performed
- If point b) and c) criteria are fulfilled G.E. and FIAT CIEI might agree either to stop V.B. LOW FLOW TESTS at paragraph B.5.4.1, or to go on to paragraph B.5.4.2 tests to explore V.B. improvable performance capabilities.

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B.5.4.2) Tests with anti chattering disk and without damper

B.5.4.2.1) Pre-requisites
As per B.5.4.1.1 wich the exception of the antichattering device nominally assembled on the V.B. sealing disk.

B.5.4.2.2) Operative procedure
As per B.5.4.1.2.

B.5.4.2.3) Data recording
As per B.5.4.1.3. V.B. sealing disk "lift pressure" may be adjusted by ballast weight calibration. The disk behaviour in the "opening start" and "closing end" periods may be corrected by means of antichattering disk calibrations.

B.5.4.2.4) Standard records
As per B.5.4.1.4

B.5.4.2.5) Acceptance criteria
As per B.5.4.1.5.

NOTE:
- If points b) and c) criteria are not fulfilled tests of paragraph B.5.4.3 must necessarily be performed.
- If point b) and c) criteria are fulfilled G.E. and FIAT CIEI might agree either to stop V.B. LOW FLOW TESTS at paragraph B.5.4.2. or to go on to paragraph B.5.4.3 tests to explore V.B. improvable performance capabilities.

B.5.4.3) Tests with anti chattering disk and with damper

B.5.4.3.1) Pre-requisites

As per B.5.4.1.1 with the exception of the antichattering device and the damper both assembled on the V.B.

B.5.4.3.2) Operative procedure

As per B.4.5.1.2.

B.5.4.3.3) Data recording

As per B.5.4.1.3. V.B. sealing disk "lift pressure" may be adjusted by ballast weight calibration. The disk behaviour in the "opening start" and "closing end" periods may be corrected by means of antichattering disk calibrations. V.B. opening and closing times may be modified acting parametrically on the damping coefficient trigger.

B.5.4.3.4) Standard records

As per B.5.4.1.4

B.5.4.3.5) Acceptance criteria

As per B.5.4.1.5.

B.5.5) Full Flow Tests (V.B. head/flow curve)

B.5.5.1) Pre-requisites

a) V.B. prototype assembled in the configuration identified by the results of paragraph B.5.4 tests (Low Flow tests).
b) Proximity instrumentation nominally installed on the V.B. and connected to power supply and amplification electronics.
c) Accelerometer placed on the sealing disk (vertical direction) and connected to its power supply and amplification system.
d) V.B. prototype installed on the supporting structure of the flow test stand.
e) Main V.B. feeding fan in line on the flow tests stand.
f) V.B. prototype and flow test stand instrumentation connected to data acquisition and processing systems.
g) Main fan suction regulating valve closed.
h) By-pass flow regulating valve fully open.
i) Main fan power supply available.

B.5.5.2) Operative procedure

a) Start-up the main fan and, slowly, partially open the suction regulating valve: the fan flow is totally diverted to the by pass, and the pressure under the V.B. sealing disk is lower than the expected lift pressure, owing to a previous adequate calibration of the by-pass flow calibration gate. Check instrumentation readings and recordings.

b) Slowly close the by-pass flow regulating shutter valve, in order to increase the pressure under the V.B. sealing disk, until the disk lift pressure is reached and disk displacements are noticed. Go on closing the by-pass shutter valve until the V.B. is completely open, and then go on closing the shutter valve to increase flow across the V.B.

c) Stabilize flow with increasing differential pressure at 400, 450, 500, 550, 600, 650, 700 mm H_2O steps (0.57, 0.64, 0.71, 0.79, 0.86, 0.93, 1 psid): when necessary (by-pass shutter valve completely closed) open the fan suction regulating valve to increase flow across the V.B.

d) Partially close fan suction regulating valve and then re-open by-pass shutter valve to decrease flow across the V.B., and stabilize flow with decreasing differential pressure at same steps as point c).

e) Repeat twice operations of points c) and d)

f) Slowly go on reopening the shutter valve until the V.B. closes, then fully reopen the shutter.

g) Shut down the main fan, and close its suction regulating valve. Stop recording.

B.5.5.3) **Data recording**

Following data must be recorded during the test:

a) Time history of the differential pressure across the V.B.

b) Time histories of the V.B. sealing disk displacements (proximity probes signals)

c) Time history of the vertical acceleration of the disk

d) Time history of the air flow across the V.B.

e) V.B. opening and closing times

f) Reference air temperature and atmospheric pressure during the test.

B.5.5.4) **Standard records**

Test data will be recorded on or attached to standard form shown in Attachment B.12-1.

B.5.5.5) **Acceptance criteria**

Flow rate across the V.B. shall exceed values provided in Attachment B.12-2 from the "lift pressure" up to at least 6.9 KPa (1 psid)

B.5.6) Systematic checks (Leak rate, lift force, proximity probes functional tests))

B.5.6.1) Disk seal systematic leak test

B.5.6.1.1) 1st step bubble test

B.5.6.1.1.1) Pre-requisites

a) V.B. prototype nominally assembled, with the exception of the outlet screens replaced by the leak tight test flanges on the discharge nozzles.
b) Seal leak conveyer cover installed, with bubble monitoring tube placed in a transparent water container.
c) V.B. placed on the supporting seat of the leak test station, connected to the nitrogen supply line.
d) Test hall general nitrogen supply system available
e) All nitrogen isolation valves closed.

B.5.6.1.1.2) Operative procedure

a) Open nitrogen feed valves and pressurize V.B. body up to 20.5 KPa (3psi) acting on the pressure reducer.
b) Close the nitrogen feed valve and wait for stabilization of possible leak from the primary seal, conveyed by the collecting cover to the water container (pressure under the collecting cover must grow over the water head of the monitoring tube immersion to produce bubbles).

Suggested stabilization time: some seconds.

c) Count bubbles rising from the monitoring tube during a minimum period of 1 minute.

NOTE

If bubbles count is unreliable (too many bubbles per second) open nitrogen feed valve, depressurize V.B. body and set-up paragraph B.5.6.1.2 test performance

d) Open nitrogen feed valve and depressurize V.B. body. Close nitrogen feed valve.

e) Repeat twice operations from a) to d)

f) Repeat operations from a) to e) at 41, 69 and 103 KPa (6,10,15 psi) of V.B. body pressurization.

g) Depressurize nitrogen feed line and close all isolation valves.

B.5.6.1.1.3) Data recording

Record for each test sequence:

a) V.B. body pressurization level

b) leak stabilization wait time

c) bubbles counting period

d) N° of bubbles counted

B.5.6.1.1.4) Standards records

Tests data will be recorded on standard form shown in Attachment B.10-2.
The form indicates also the transformation of the "bubbles count rate" into a standard "leak rate" in accord with ANSI/FCI 70-2-1991, note to Tab. 2 (1 bubble = 0,15 CC).

B.5.6.1.1.5) Acceptance criteria

Leak rate shall not exceed values provided in Attachment B.10-4 at test pressure.

NOTE: Failure of elastomers doesn't constitute V.B. failure. The time and manner of failure will be the basis for conservatively defining the replacement intervals.

B.5.6.1.2) 2nd step Pressure Loss test

B.5.6.1.2.1) Pre-requisites

As per B.5.6.1.1.1 with the exception of the absence of the seal leak conveyer cover.

B.5.6.1.2.2) Operative procedure

a) open nitrogen feed valves and pressurize V.B. body up to 20.5 KPa (3 psi) acting on the pressure reducer
b) close nitrogen feed valve and wait for 10 minutes to allow V.B. internal pressure decrease

c) open nitrogen feed valve and depressurize V.B. body. Close nitrogen feed valve

d) repeat twice operations from a) to c)

e) repeat operations from a) to d) at 41, 69 and 103 KPa (6, 10, 15 psi) of V.B. body pressurization

f) depressurize nitrogen feed line and close all isolation valves.

B.5.6.1.2.3) Data recording

Record during each pressure loss test:

a) initial pressurization of the V.B. body

b) initial ambient temperature and atmospheric pressure

c) wait time for V.B. body depressurization

d) final pressurization of V.B. body

e) final ambient temperature and atmospheric pressure

B.5.6.1.2.4) Standard records

Test data will be recorded on standard form shown in Attachment B.10-3.

The form structure foresees for each pressure loss test:

- mean leak rate calculation
- correlation of the mean leak rate to the mean value of the V.B. body pressurization during the test.

Resulting mean leak rates for each V.B. pressurization level are obtained by averaging over single pressure loss tests.

B.5.6.1.2.5) Acceptance criteria

Leak rate shall not exceed values provided in Attachment B.10-4 at test pressure.

NOTE: Failure of elastomers doesn't constitute V.B. failure. The time and manner of failure will be the basis for conservatively defining the replacement intervals.

B.5.6.2) Disk assembly lift force systematic checks

B.5.6.2.1) Pre-requisites

a) V.B. prototype nominally assembled, with the exception of the damper cover
b) V.B. placed on the supporting seat of the leak test station
c) proximity instrumentation connected to power supply, amplification and recording systems
d) 200 daN (450 lb) dynanometer available (better than 5% precision)
e) probes electronics power supply available

B.5.6.2.2) Operative procedure

a) lift three times the V.B. sealing disk assembly by means of service lifting devices, controlling lift force behaviour on the dynamometer. Stop proximity probes recording.

B.5.6.2.3) Data recording

Record during the test:

a) disk assembly lift force readings
b) annotations on possible disk lifting anomalies (discontinuities, force oscillations, jerkily motion,....)

B.5.6.2.4) Standards records

Data will be recorded on standard form of Attachment B.11-1.

B.5.6.2.5) Acceptance criteria

Max acceptable force variation 5% of "baseline lift force"

B.5.6.3) <u>Proximity probes calibration systematic checks</u>

B.5.6.3.1) <u>Pre-requisites</u>

a) V.B. prototype nominally assembled, and placed on the supporting seat of the leak test station
b) proximity probes connected to power supply, amplification and recording systems
c) V.B discharge nozzles free from flanges or screens
d) V.B. bonnet unscrewed and equipped for frequent handling
e) V.B. disk stem equipped for frequent liftings and lowerings
f) calibrated shims and feeler gauges available
g) probes electronics power supply available

B.5.6.3.2) <u>Operative procedure</u>
As per B.5.2.2.1

B.5.6.3.3) <u>Data recording</u>
As per B.5.2.3.1

B.5.6.3.4) <u>Standard records</u>
As per B.5.2.4

B.5.6.3.5) <u>Acceptance criteria</u>
As per B.5.2.5.1

B.5.7) Grit Ingestion test (Silicon flour blow)

B.5.7.1) Pre-requisites

a) V.B. prototype nominally assembled, with inside surfaces covered with a thin coat of mineral oil.

b) V.B. prototype installed on the supporting structure of the flow test stand.

c) Proximity instrumentation connected to power supply, amplification electronics and recording system.

d) Flow, temperature and pressure transducers disassembled from the flow tests stand, and replaced by plugging devices.

e) Main V.B. feeding fan in line on the flow test stand.

f) Main fan suction regulating valve closed.

g) By-pass flow regulating valve fully open.

h) Dust abating curtains placed around the V.B., to limit anti-noise structure contamination.

i) 0,454 Kg (1 lb) of silicon flour available.

j) Proximity probes power supply available.

k) Main fan power supply available.

B.5.7.2) Operative procedure

a) Start-up the main fan and, slowly, partially open the suction regulating valve: the fan flow is totally diverted to the by-pass, and the pressure under the V.B. sealing disk is lower than the lift pressure owing to the calibration of the by-pass gate.

Check proximity probes recordings.

b) Slowly close the by-pass flow regulating shutter valve to increase the pressure under the V.B. disk, until the lift pressure is reached and disk displacements are noticed. Go on closing the shutter valve until the V.B. is completely open. Completely close the shutter valve.

c) Slowly empty the silicon flour container in the air flow at the main fan suction, to blow it trough the V.B.. Maintain flow for at least 1 minute.

d) Re-open the by pass shutter valve to reduce flow across the V.B. and then to close it. Fully open the shutter valve.

e) Shut-down the main fan, and close its suction regulating valve. Stop recording.

B.5.7.3) Data recording

Record proximity probes signals during test operations, and possible annotations on their behaviour.

B.5.7.4) Standard records

Test data will be recorded on or attached to standard form shown in Attachment B.11-2.

B.5.7.5) Acceptance criteria

Silicon flour composition in accordance with MIL-STD-810 E (July 1989), method 510.3, section I-3.2.d (1) (b).

NOTE

Silicon flour captured by the oil film on the inside surfaces of the V.B. must not be removed before subsequent tests ("RELIABILITY TEST" and "SEAT SENSITIVITY TEST")

B.5.8) Reliability test (3000 strokes)

B.5.8.1) Pre-requisites

a) V.B. prototype nominally assembled (same configuration as per "Full Flow tests" paragraph B.5.5).

b) V.B. inside surfaces contaminated by silicon flour blown through the V.B. during "Grit Ingestion test", paragraph B.5.7.

c) Proximity instrumentation connected to power supply and amplification electronics.

d) V.B. prototype installed on the supporting structure of the flow test stand.

e) Main V.B. feeding fan in line on the flow tests stand.

f) Flow tests stand nominally equipped with pressure, temperature and flow transducers.

g) V.B. prototype and flow test stand instrumentation connected to data acquisition and elaboration systems.

h) Main fan suction regulating valve closed.

i) By-pass flow regulating valve fully open.

j) Main fan power supply available.

B.5.8.2) Operative procedure

a) Start-up the main fan and, slowly, partially open the suction regulating valve: the fan flow is totally diverted to the by-pass and the pressure under the V.B. disk is lower than the lift pressure owing to the by-pass calibration gate. Check instrumentation readings and recordings.

b) Slowly close the by-pass flow regulating shutter valve in order to completely open the V.B. and stabilize a differential pressure of 520 mm H_2O (0.74 psid): maintain flow for at least 40 sec.

c) Slowly completely re-open the shutter valve in order to close the V.B. and divert the fan full flow to the by-pass.

d) Repeat 3000 times operations of point b) and c).

NOTE:

Presently 8÷9 hours a day of testing are planned, 3000 strokes being the integral performance to be reached. At the end of each daily phase operations of point e) will be performed.

e) Shut-down the main fan, and close its suction regulating valve. Stop recording.

B.5.8.3) Data recording

Following data must be recorded during the test:

a) Time history of the differential pressure across the V.B.

b) Time histories of the V.B. sealing disk displacements (proximity probes signals)

c) Time history of the air flow across the V.B.

d) Reference air temperature and atmospheric pressure during the test.

B.5.8.4) <u>Standard records</u>

Test data will be summarized on or attached to standard form shown in Attachment B.13 Sample records of V.B. "lift pressure", "opening time", "stabilized differential pressure", "stabilized flow", "closing time" are foreseen every 100 strokes.

B.5.8.5) <u>Acceptance criteria</u>

No failure in V.B. lift on demand over 3000 operations.

B.5.9) Foreign Material Seat Sensitivity test (Leak tests with particles under the V.B. seal)

B.5.9.1) Pre-requisites

a) V.B. prototype nominally assembled, with the exception of the damper cover and of the outlet screens on the discharge nozzles.

NOTE :

V.B. prototype general conditions must be those resulting from the "RELIABILITY TEST" of paragraph B.5.8.

b) V.B. placed on the supporting seat of the leak test station.

c) Rough metallic or ceramic particles (or scraps, or grains) of different average dimensions available.

d) Test hall general nitrogen supply system available

e) All nitrogen isolation valves closed.

B.5.9.2) Operative procedure

a) Place one particle of average dimensions of about 0,38 x 10^{-3}m (15 mils) under the soft seal of the V.B. disk. Replace and nominally close the damper cover, and assemble the leak tight test flanges.

b) Connect the V.B. to the nitrogen supply system, open nitrogen feed valves and pressurize V.B. body up to 20,5 KPa (3psi) acting on the pressure reducer.

c) Close nitrogen feed valve and wait for 10 minutes to allow V.B. internal pressure decrease.

NOTE:

If the depressurization rate is too high to allow a wait time of 10 minutes, stop the wait time when one half of initial pressurization is reached.

d) Open nitrogen feed valve and depressurize V.B. body.
Close nitrogen feed valve.

e) Repeat twice operations from b) to d).

f) Repeat operations from b) to e) at 41, 69, and 103 KPa (6,10,15 psi) of V.B. body pressurization.

g) Disconnect the V.B. from the nitrogen supply system, disassemble leak tight test flanges and damper cover.

h) Repeat operations from a) to g) with particles of 0,76 $\times 10^{-3}$ and 1.27 $\times 10^{-3}$m (30 and 50 mils) average dimensions placed under the soft seal of the V.B. disk.

i) Depressurize nitrogen feed line and close all isolation valves.

B.5.9.3) Data recording

Record during each pressure loss test:

a) Average dimensions of the particle placed under the soft seal of the V.B. disk.

b) Initial pressurization of the V.B. body.

c) Initial ambient temperature and atmospheric pressure.

d) Wait time for V.B. body depressurization.

e) Final pressurization of the V.B. body.

f) Final ambient temperature and atmospheric pressure.

B.5.9.4) Standard records

Test data will be recorded on standard form shown in Attachment B.10-3.

The form structure foresees for each pressure loss test:

- Mean leak rate calculation
- Correlation of the mean leak rate to the mean value of the V.B. body pressurization during the test.

Resulting mean leak rates for each V.B. pressurization level are obtained by averaging over single pressure loss tests.

B.5.9.5) Acceptance Criteria

Leak rates will be compared to values provided in Attachment B.10-4 at test pressure:
Results are for G.E. information only, out of the V.B. prototype qualification test campaign.

B.5.10) Final Disassembly and Inspection

B.5.10.1) Pre-requisites

a) All tests of the V.B. qualification campaign performed

b) V.B. prototype completely assembled in the final test conditions

c) V.B. prototype placed in the final inspection hall of the shop (including inlet screen)

d) Shop drawings, inspection/measurement tools and camera available.

B.5.10.2) Operative procedure

a) Completely disassemble the V.B. prototype, with the exception of the proximity probes clamped cables.

NOTE:

Try not to alter items surface conditions during disassembling (e.g. grit presence, oil presence, oxidations, corrosions,...)

b) Perform visual inspection on each V.B. item, and immediately take pictures of any possible anomaly.

c) Perform dimensional and surface roughness checks as required at point B.5.10.3.

d) Individually package V.B. items with identifying devices, for planned subsequent shop operations.

B.5.10.3) Data recording

a) Take annotations (and if necessary pictures) of V.B. items surface conditions, with particular attention for:

- Disk soft seal
- Hard seat
- Disk stem
- Disk stem bearings
- Proximity pobes
- Proximity probes connectors, cables and penetrations
- Inlet and oulet screens

NOTE:

Important features are:

- Structural deformations
- Wear marks
- Local grit accumulation
- Possible oxidation traces
- Initial corrosion indications

b) Make dimensional checks (and if necessary surface roughness checks) on:

- Disk
- Disk stem
- Lower and upper bearings
- Hard seat
- Disk soft seal

B.5.10.4) Standard records

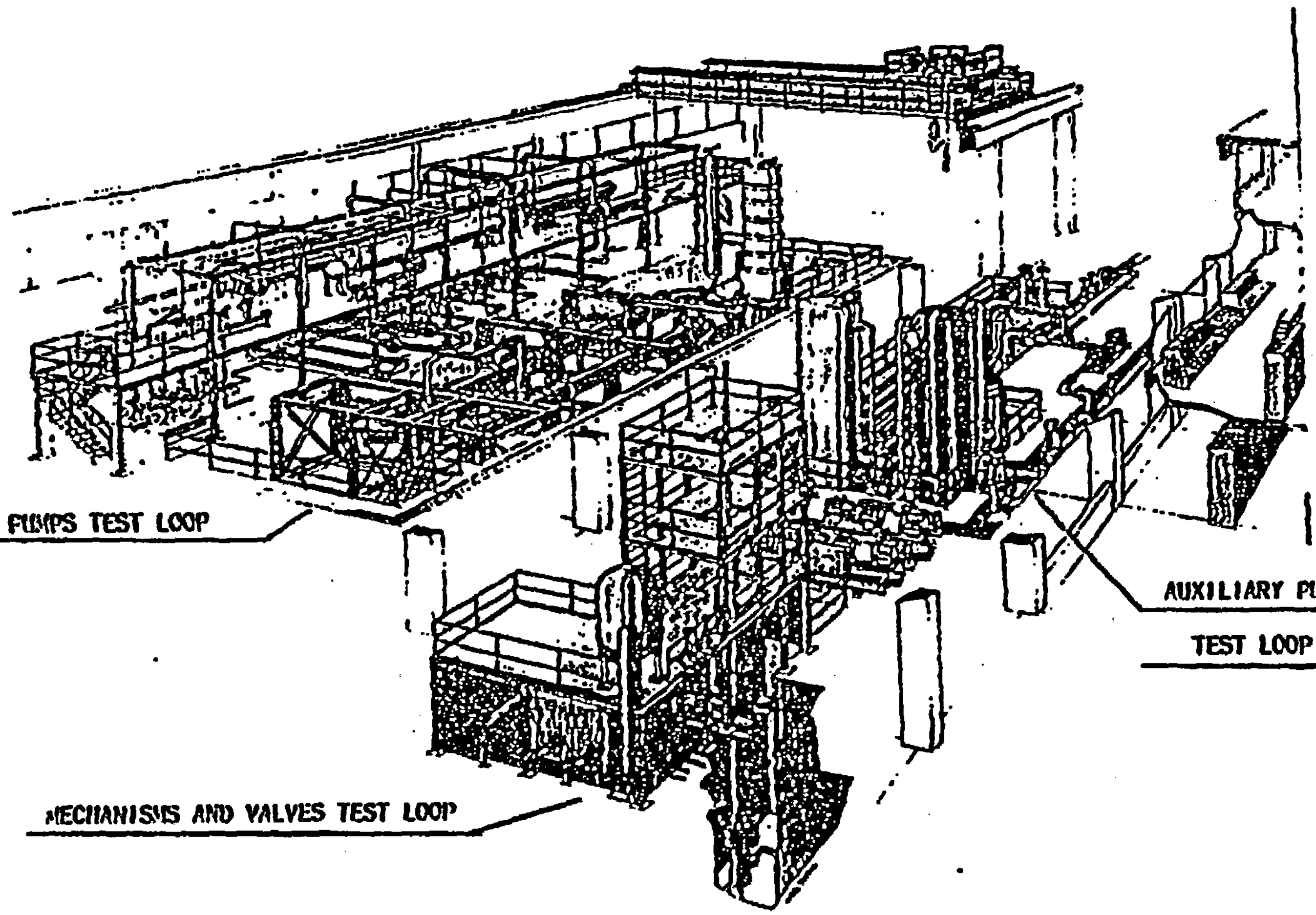
Record/attach final inspection results on/to standard form shown in Attachment B.14.

B.5.10.5) Acceptance criteria

Not applicable. FINAL INSPECTION WILL BE PART OF THE FINAL QUALIFICATION TEST REPORT.

NOTE:

Failure of elastomers in the course of the test campaign does not constitute V.B. failure.
The time and manner of failure will be the basis for conservatively defining the replacement intervals.



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DIVISIONE CIEI

ATTACHMENT B.1.

V.B. PROTOTYPE QUALIFICATION TESTS

FIAT CIEI TEST HALL PERSPECTIVE VIEW

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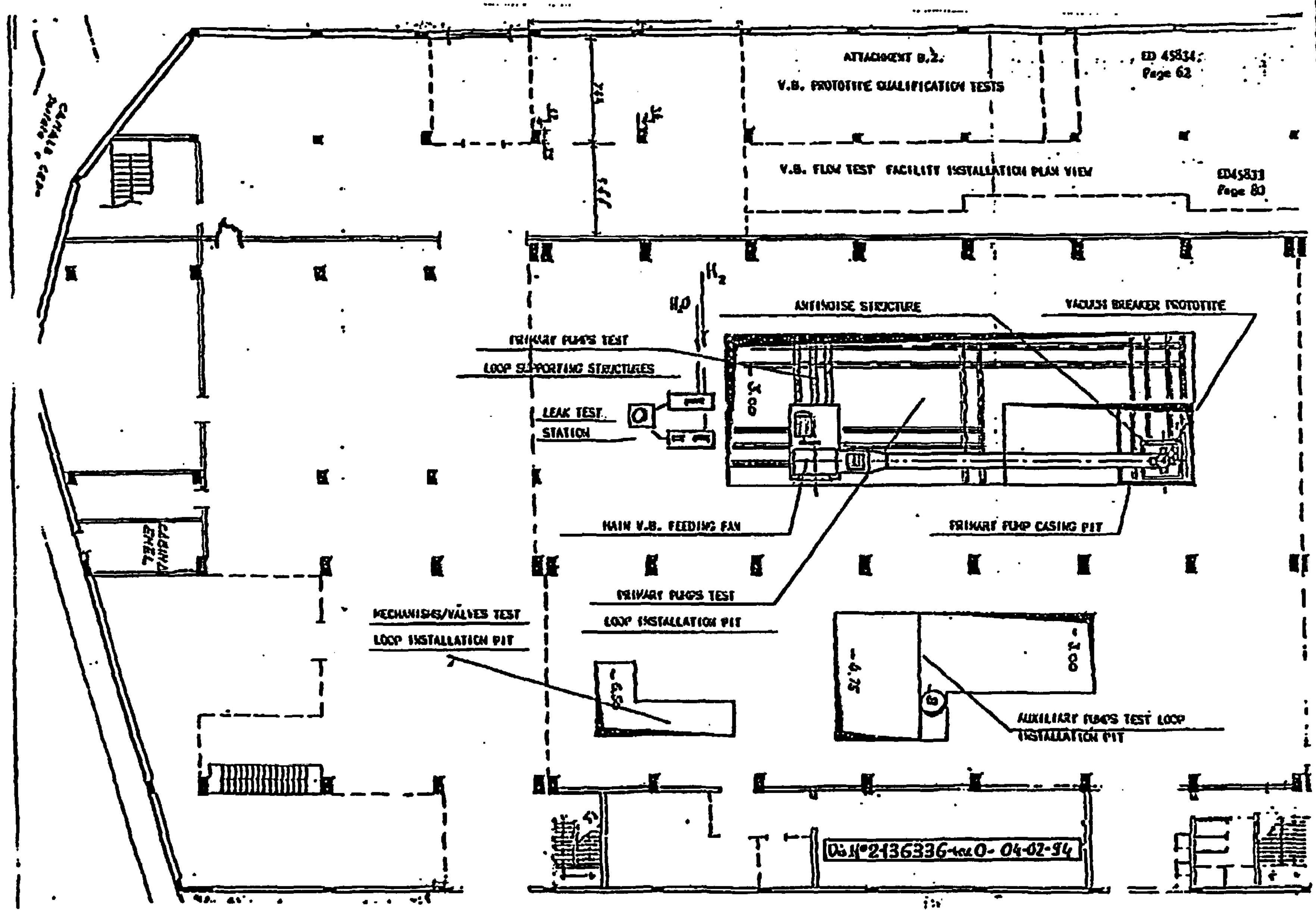
ATTACHMENT B.2.
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V.B. PROTOTYPE QUALIFICATION TESTS
V.B. FLOW TEST FACILITY INSTALLATION PLAN VIEW
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ANTINOISE STRUCTURE
VACUUM BREAKER PROTOTYPE
PRIMARY PUMPS TEST
LOOP SUPPORTING STRUCTURES
LEAK TEST
STATION
MAIN V.B. FEEDING FAN
PRIMARY PUMP CASING PIT
PRIMARY PUMPS TEST
LOOP INSTALLATION PIT
MECHANISMS/VALVES TEST
LOOP INSTALLATION PIT
AUXILIARY PUMPS TEST LOOP
INSTALLATION PIT
-3.00
-4.75
-3.00
-6.00
Dis N°2136336-rev.0- 04-02-94

S.B.W.R. VACUUM BREAKER (V.B.) PROTOTYPE

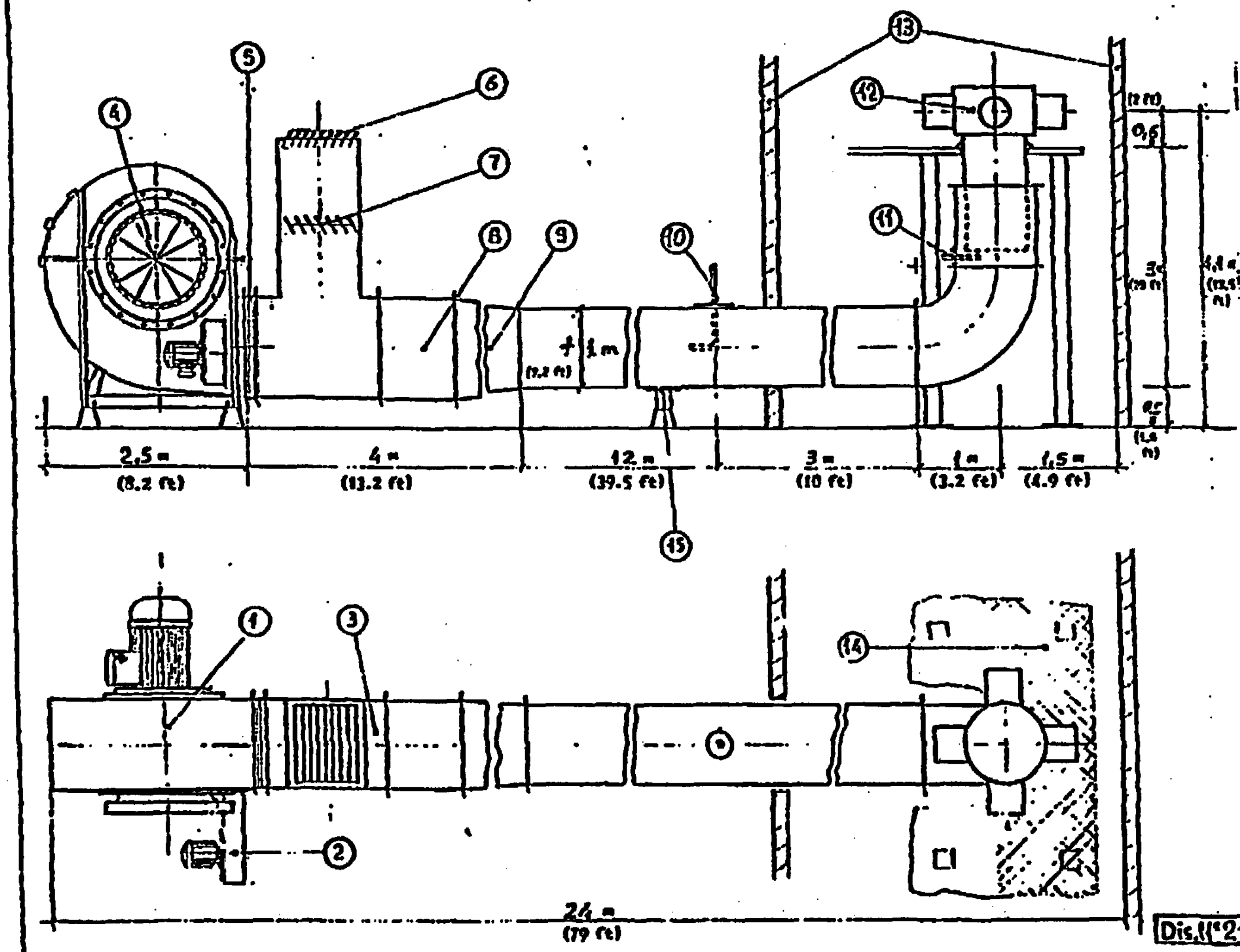
QUALIFICATION TESTS

PERFORMANCE AND RELIABILITY TESTS STAND

(FIAT CIEI TEST HALL)

ATTACHMENT B.3.

SHEET 1/2



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LEGENDA

1) Main V.B. feeding fan
(Nominal performances
- Flow: 80.000 m^3/hr
(2.84×10^6 ft^3/hr)
- Head: 800 mm H_2O
(31.5 inches of water)
- Speed: 1.490 rpm
- Power: 220 KW)

2) Auxiliary V.B. feeding fan, for "lift pressure" and "low flow" tests
(Flow: 500 m^3/hr (17700 ft^3/hr);
Head: 525 mm H_2O (21 inches of water))

3) Main fan flow diverter by-pass

4) Main fan suction regulating valve

5) Antivibration joint

6) By-pass flow calibration gate

7) By-pass flow regulation valve

8) Flow veins straightener

9) Pipe connection (rectangular ÷ circular)

10) Flow meter ("PITOT" tube)
(from 0 to 80.000 m^3/hr)

11) Pressure transducer (from 0 to 1.000 mm H_2O (40 inches of water)

12) V.B. prototype

13) Anti-noise structure

14) V.B. supporting structure operative floor

15) Pipe support

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SHEET 2/2

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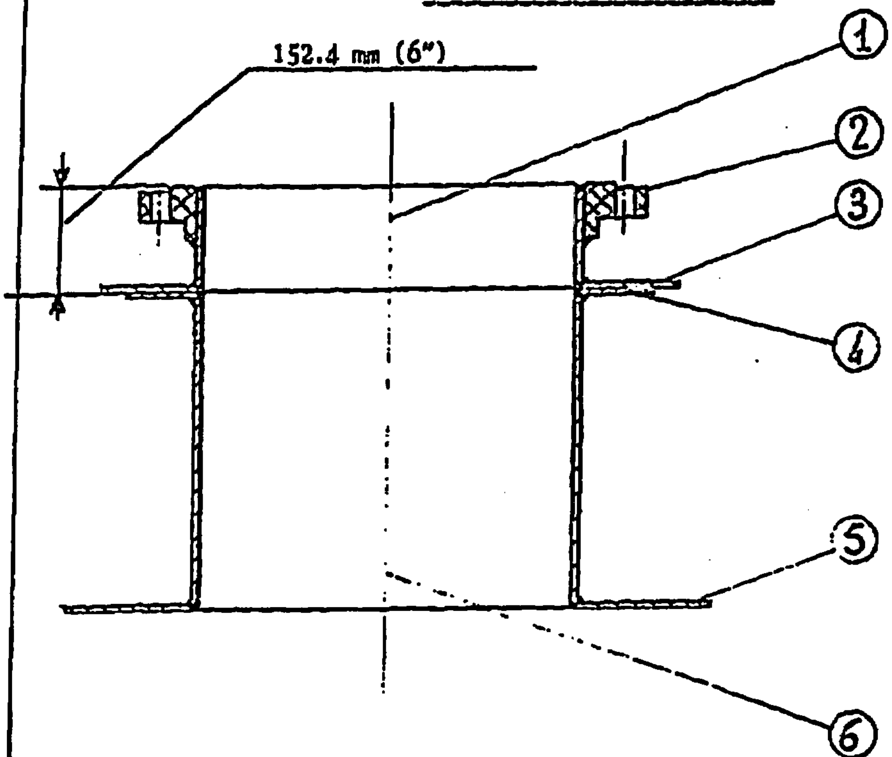
V.B. SUPPORTING STAND PIPE



1	UPPER DRUM 24" SCH. 20
2	24" ANSI - 150 SERIES FLANGE
3	INTERMEDIATE ASSEMBLING FLANGE (*)
4	FLOW TEST STAND ASSEMBLING FLANGE
5	INLET SCREEN AND PIPING ASSEMBLING FLANGE
6	LOWER DRUM 24" SCH. 20

NOTE:

(*) FITTING EITHER WITH FIAT CIEI FLOW TEST STAND, OR WITH ANSALDO RICERCHE SHAKING TABLE

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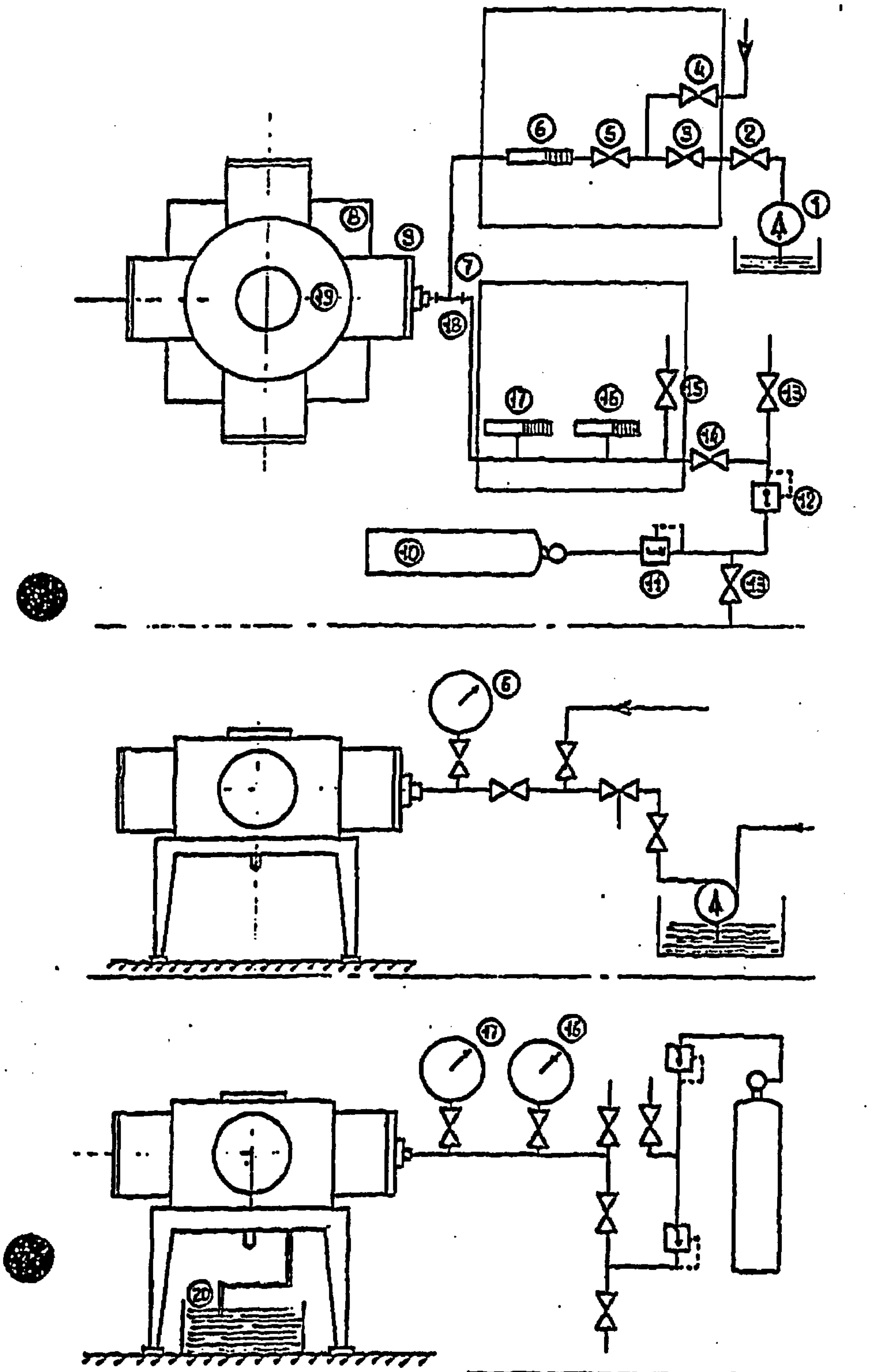

LEGENDA

1. DEMINERALIZED WATER CHARGING PUMP
2. CHARGING PUMP ISOLATION VALVE
3. DISCHARGE VALVE
4. DEMINERALIZED WATER FEED VALVE
5. V.B. ISOLATION VALVE
6. HYDROTEST PRESSURE MEASUREMENT
7. WATER LINE CONNECTION
8. V.B. SUPPORTING SEAT
9. LEAK TIGHT TEST FLANGE
10. NITROGEN BOTTLE
11. PRESSURE REDUCER
12. PRESSURE REDUCER
13. DISCHARGE VALVE
14. V.B. ISOLATION VALVE
15. SAFETY VALVE
16. PRESSURE MEASUREMENT (HIGH LEVEL)
17. PRESSURE MEASUREMENT (LOW LEVEL)
18. NITROGEN LINE CONNECTION
19. V.B. PROTOTYPE
20. BUBBLES COUNTING DEVICE

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ATTACHMENT 8.4.

V.B. PROTOTYPE QUALIFICATION TESTS

LEAK TEST STATION LAYOUT

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BUBBLES COUNTING DEVICE

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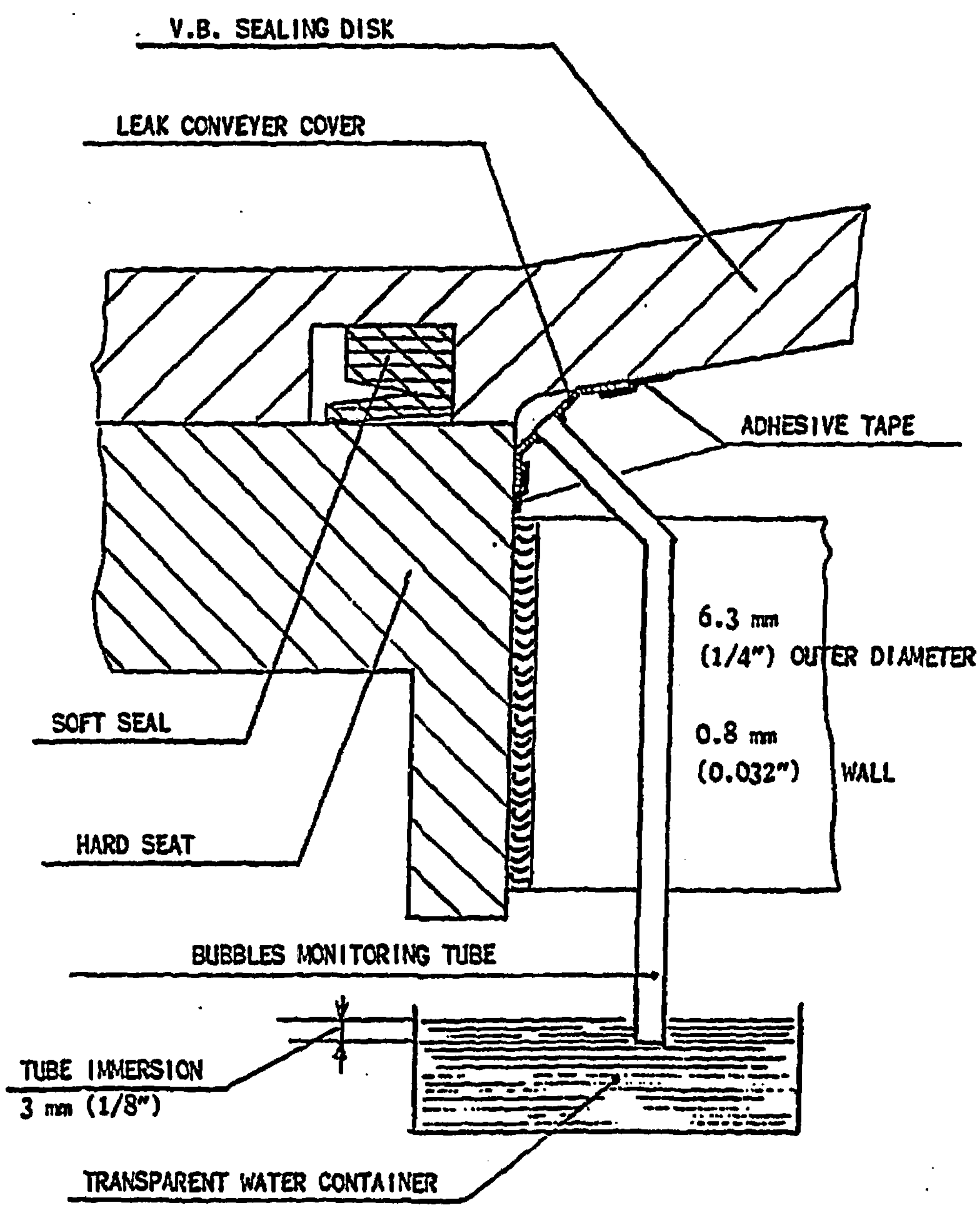
SHEET 2/2



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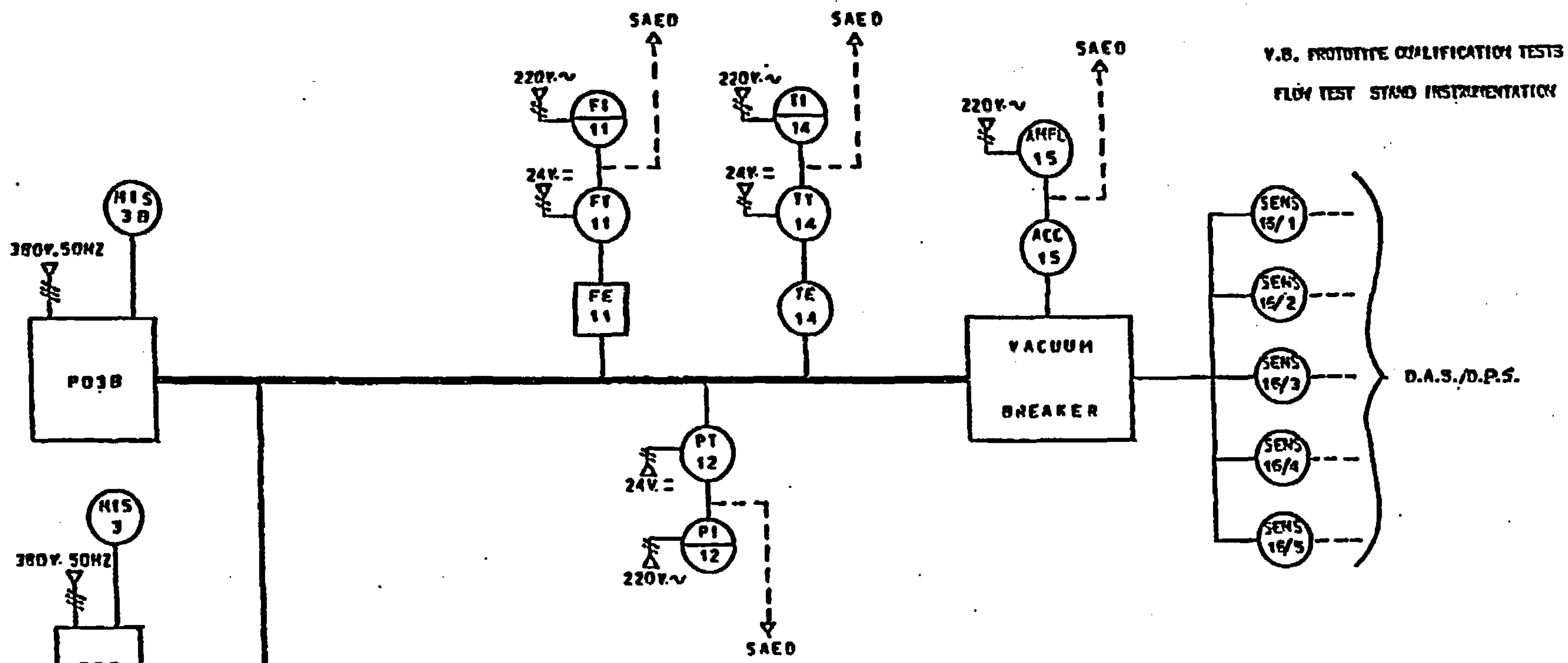
V.B. PROTOTYPE QUALIFICATION TESTS

FLOW TEST STAND INSTRUMENTATION



PO 3 B	= MAIN FAN POWER SUPPLY	P 12	= PRESSURE MEASUREMENT CHAIN
PO 3	= AUXILIARY FAN POWER SUPPLY	T 14	= TEMPERATURE MEASUREMENT CHAIN
HIS 3 B	= MAIN FAN START + STOP	ACC 15	= ACCELERATION MEASUREMENT CHAIN
HIS 3	= AUXILIARY FAN START + STOP	SENS 16/1÷5	= DISK DISPLACEMENTS MEASUREMENTS
F 11	= FLOW MEASUREMENT CHAIN	D.A.S./D.E.S.	= DATA ACQUISITION/ELABORATION SYSTEM

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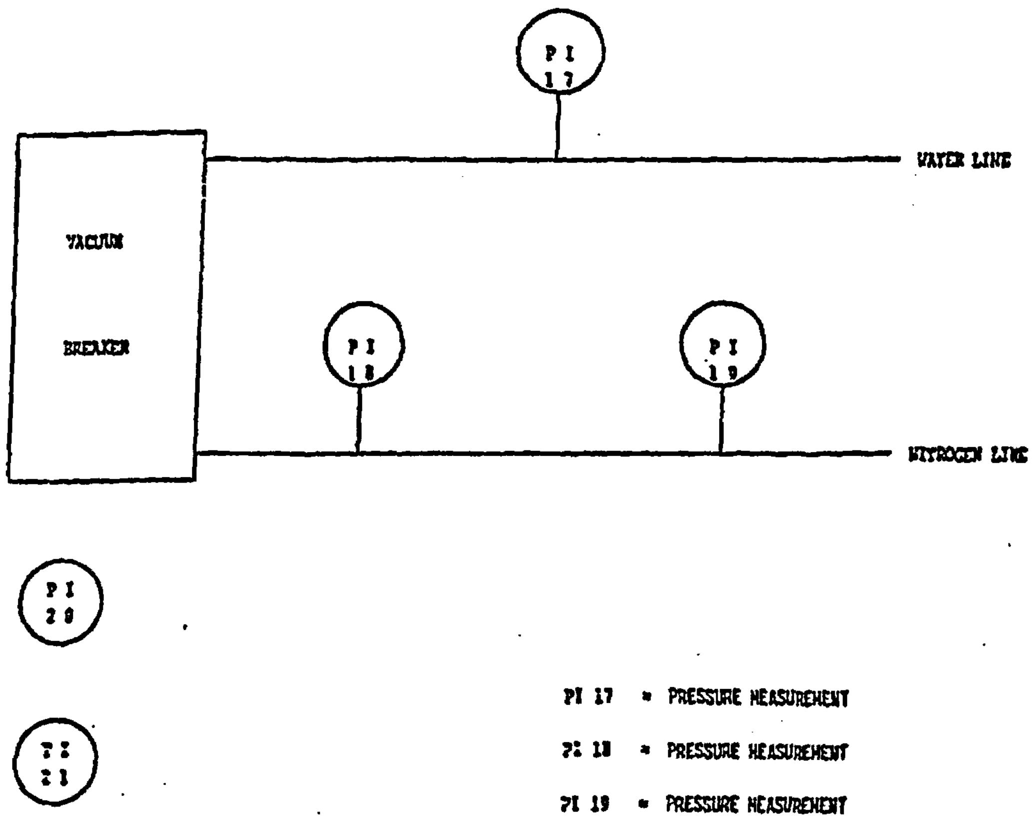


PI 17 = PRESSURE MEASUREMENT

PI 18 = PRESSURE MEASUREMENT

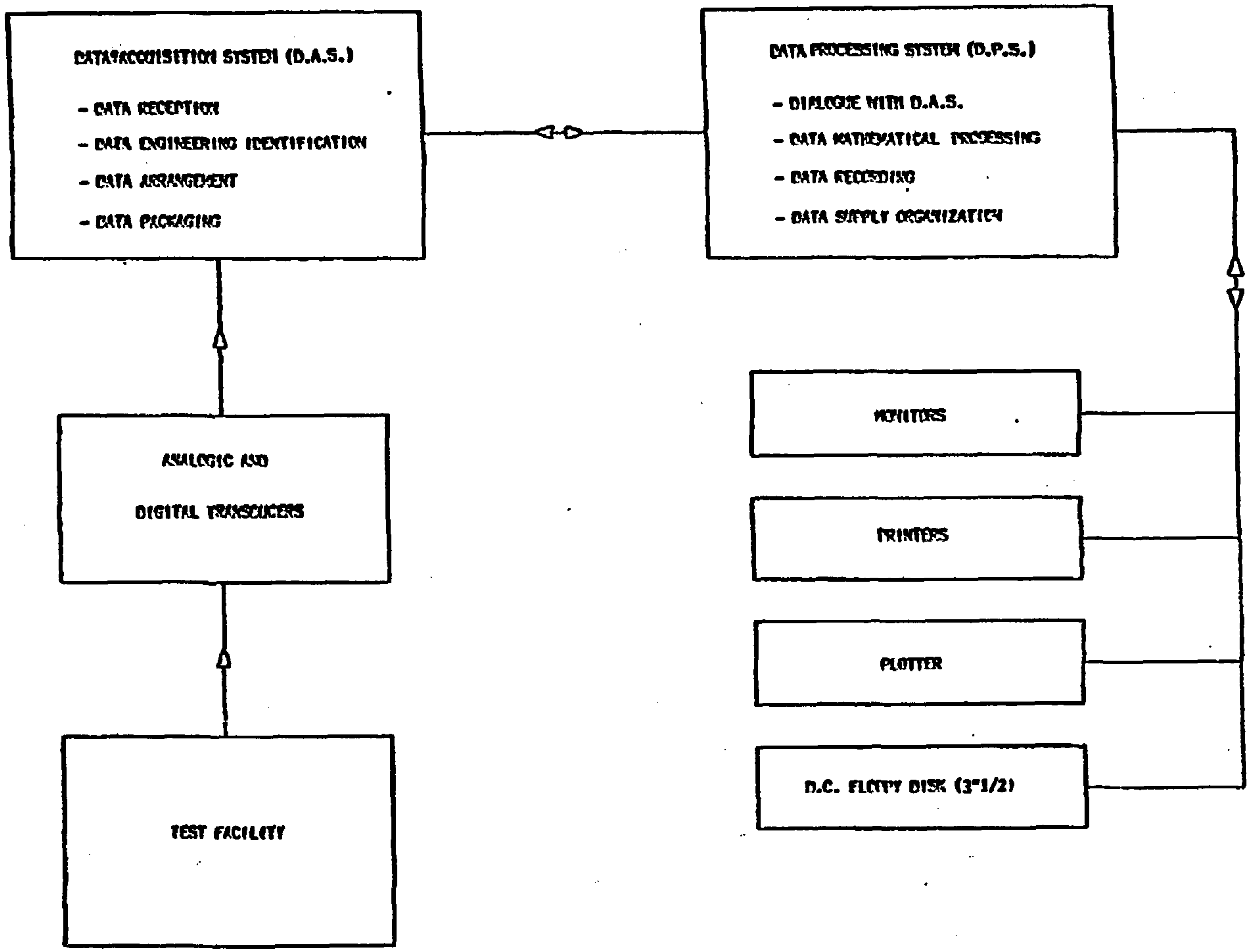
PI 19 = PRESSURE MEASUREMENT

PI 20 = ATMOSPH. PRESS. MEASUR.

TI 21 = AMBIENT TEMPERAT. MEASUR.

V.B. PROTOTYPE QUALIFICATION TESTS

FLOW TEST DATA ACQUIS./PROCESS.DIAGRAM



- TESTING FIRM: .... CERTIFICATE N°: ....
  DATE: ....

- TEST FACILITY: LEAK TEST STATION

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- TEST PROCEDURE: DOC. N° ED45834, REV. ......

- TEST MEDIUM: DEMINERALIZED WATER

- TOP PRESSURIZATION PHASE DATA:

Nominal top pressure	Real top pressure	Pressurization time
325 KPa	...... KPa	.... min
(47.25 psi)	(...... psi)	

- LEAKAGE EXAMINATION PHASE DATA:

Nominal pressure	Real pressure	Pressurization time
245 KPa	...... KPa	.... min
(35.5 psi)	(...... psi)	

ANNOTATIONS: ....
....
....
....
....
....

- TEST RESULT: ....

- TEST CONDUCTOR: .... G.E REPRESENTATIVE: ....

- TESTING FIRM: .... CERTIFICATE N°: ....
  DATE: ....
- TEST FACILITY: LEAK TEST STATION PAGE: 1/3
- TEST PROCEDURE: DOC. N° ED45834, REV. ......

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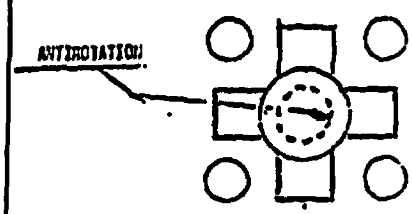
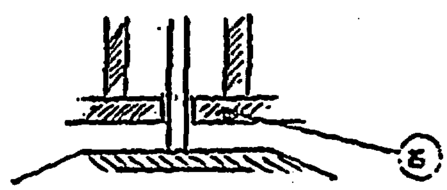
- TEST : BASELINE SYSTEMATIC
- PRECEDING OPERATIONS ON THE V.B.: ....
- PROBES IDENTIFICATION:

Lower Probes



Upper Probe



NOTES :

- ACCURACY/REPEATABILITY TESTS DATA: Page 2/3

PROBE READINGS

PROBE N°		1			2			3			4			5		
TEST N		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
SHIMS THICKNESS Probes 1,2,3,4	Probe 5															
0	S															
0.76 mm (30 mils)	(S-1.26) mm															
1.018 mm (40 mils)	(S-1.764) mm															
2.036 mm (80 mils)	(S-2.782) mm															
2.54 mm (100 mils)	(S-3.04) mm															
3.8 mm 150 mils)	(S-3.8) mm															
2.54 mm	(S-3.04) mm															
2.036 mm	(S-2.782) mm															
1.018 mm	(S-1.764) mm															
0.76 mm	(S-1.26) mm															
0	S															

NOTE: "S" = V.B. sealing disk stroke, measured during assembling [mm]

CERTIFICATE N°: ....

DATE: ....

PAGE: 3/3

- PARTICLE TEST DATA:

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PROBE READINGS

PROBE N° / FEELER GAUGE	1	2	3	4	5
1.52 mm (60 mils)					
2.036 mm (80 mils)					

- ANNOTATIONS:

  . Accuracy/Repeatability Tests: ....
....
....
....
....
....
....
....

  . Particle Test: ....
....
....
....
....

- TEST RESULT: ....

- TEST CONDUCTOR: .... G.E. REPRESENTATIVE ....

HARDSEAT BASELINE LEAK TEST

- TESTING FIRM: .... CERTIFICATE N°: ....
  DATE: ....
  PAGE: 1/5
- TEST FACILITY: LEAK TEST STATION
- TEST PROCEDURE: DOC. N° ED45834, REV. ....
- TEST MEDIUM: NITROGEN
- V.B. BODY DEPRESSURIZATION TESTS DATA:
  . Initial ambient temperature: .... °C (.......°F)
  . Initial atmospheric pressure: ...... KPa (..... psi)
  . Depressurization history:

V.B. BODY PRESSURE | TIME

V.B. BODY PRESSURE	1st Test	2nd Test	3rd Test
100 KPa (14 psi)	0.00 sec	0.00 sec	0.00 sec
90 KPa (12.6 psi)			
80 KPa (11.2 psi)			
70 KPa (9.8 psi)			
60 KPa (8.4 psi)			
50 KPa (7 psi)			

. Final Ambient Temperature: .... °C (....... °F)
. Final Atmospheric Pressure: .... KPa (....... psi)

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HARDSEAT BASELINE LEAK TEST

- MEAN LEAK RATES CALCULATION:..
  (SEE NOTE 1)

CERTIFICATE N°: ....
DATE: ....
PAGE: 2/5

V.B. BODY PRESSURE — MEAN LEAK RATES st.m³/sec (st.ft³/sec)

	100÷ 90 KPa	90÷80 KPa	80÷70 KPa	70÷60 KPa	60÷50 KPa
	14÷12.6psi	12.6÷11.2psi	11.2÷9.8psi	9.8÷8.4psi	8.4÷7 psi
1st TEST	.... (........)	.... (........)	.... (.......)	.... (........)	.... (........)
2nd TEST	.... (........)	.... (........)	.... (.......)	.... (........)	.... (........)
3rd TEST	.... (........)	.... (........)	.... (.......)	.... (........)	.... (........)

- HARD SEAT LEAK MEAN EQUIVALENT AREAS (A/√K) CALCULATION (AT EACH DEPRESSURIZATION STEP):
  (SEE NOTE 2)

V.B. BODY MEAN PRESSURES — MEAN EQUIVALENT AREAS m² (ft²)

	95 KPa	85 KPa	75 KPa	65 KPa	55 KPa
	(13.3 psi)	(11.9 psi)	(10.5 psi)	(9.1 psi)	(7.7 psi)
1st TEST	.... (........)	.... (........)	.... (.......)	.... (........)	.... (........)
2nd TEST	.... (........)	.... (........)	.... (.......)	.... (........)	.... (........)
3rd TEST	.... (........)	.... (........)	.... (.......)	.... (........)	.... (........)

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HARDSEAT BASELINE LEAK TEST

- RESULTING HARDSEAT LEAK MEAN EQUIVALENT AREA CALCULATION (AT EACH TEST): (SEE NOTE 3)

CERTIFICATE N°: ....
DATE: ....
PAGE: 3/5

RESULTING MEAN EQUIVALENT AREA m^2 (ft^2)

1st TEST	....	(..................)
2nd TEST	....	(..................)
3rd TEST	....	(..................)

- FINAL HARDSEAT LEAK MEAN EQUIVALENT AREA CALCULATION: (SEE NOTE 4)

$(A/\sqrt{K})_{HARDSEAT\ (FINAL)}$ = ... m^2 (........... ft^2)

- TEST RESULT: ....

- TEST CONDUCTOR: .... G.E. REPRESENTATIVE ....

HARDSEAT BASELINE LEAK TEST

NOTES:

CERTIFICATE N°: ....
DATE: ....
PAGE: 4/5

NOTE 1 : MEAN LEAK RATE CALCULATION (Q_{MEAN}) AT EACH DEPRESSURIZATION STEP (BEING AMBIENT TEMPERATURE AND ATMOSPHERIC PRESSURE PRACTICALLY CONSTANT DURING THE TESTS A SIMPLIFIED EXPRESSION FOR Q_{MEAN} IS USED)

$$Q_{MEAN} = \frac{V \cdot (P_1 - P_2)}{(t_2 - t_1) \cdot P_{atm_0}} \cdot \frac{T_0}{T_{amb.}} \qquad (st.m^3/sec)$$

WHERE:

V = V.B. INTERNAL VOLUME = ... m^3 (......... ft^3)
P_1 = INITIAL V.B. INTERNAL RELATIVE PRESSURE (Pa)
P_2 = FINAL V.B. INTERNAL RELATIVE PRESSURE (Pa)
t_1 = DEPRESSURIZATION STEP INITIAL TIME (sec)
t_2 = DEPRESSURIZATION STEP FINAL TIME (sec)
P_{atmo} = "STANDARD" ATMOSPHERIC PRESSURE = 760 mmHg = 1.01×10^5 Pa = 14.6 psi
To = "STANDARD" AMBIENT TEMPERATURE = 20°C = = 293°K = 68°F
T_{amb} = TEST AMBIENT TEMPERATURE (°K)

HARDSEAT BASELINE LEAK TEST

CERTIFICATE N°: ....
DATE: ....
PAGE: 5/5

NOTE 2 : MEAN EQUIVALENT AREA $(A/\sqrt{K})_{MEAN}$ CALCULATION AT EACH DEPRESSURIZATION STEP:

$$(A/\sqrt{K})_{MEAN} = Q_{MEAN} \cdot \sqrt{\frac{\rho_0}{2 \cdot P_{mean}}} \qquad (m^2)$$

WHERE:

Q_{MEAN} = MEAN LEAK RATE (SEE NOTE 1) (st.m³/sec)

ρ_0 = "STANDARD" AIR DENSITY, AT 760 mmHg ATMOSPHERIC PRESSURE AND 293°K AMBIENT TEMPERATURE = = 1.205 kg/m³ = 7.55 x 10^{-2} lb/ft³

P_{MEAN} = MEAN V.B. INTERNALL RELATIVE PRESSURE DURING THE STEP (Pa)

NOTE 3 : RESULTING MEAN EQUIVALENT AREA CALCULATION AT EACH TEST:

$$\left(\frac{A}{\sqrt{K}}\right)_{\substack{MEAN \\ RES.}} = \frac{1}{5} \cdot \sum_{1}^{5} \left(\frac{A}{\sqrt{K}}\right)_{MEAN}$$

NOTE 4 : FINAL MEAN EQUIVALENT AREA CALCULATION:

$$\left(\frac{A}{\sqrt{K}}\right)_{\substack{HARDSEAT \\ FINAL}} = \frac{1}{3} \cdot \sum_{1}^{3} \left(\frac{A}{\sqrt{K}}\right)_{\substack{MEAN \\ RES.}}$$

DISK SEAL BUBBLE LEAK TEST

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- TESTING FIRM: .... CERTIFICATE N°: ....

DATE: ....

- TEST FACILITY: LEAK TEST STATION PAGE: 1/2

- TEST PROCEDURE: DOC. N° ED45834, REV. ......

- TEST MEDIUM: NITROGEN

- TEST KIND : BASELINE SYSTEMATIC

- PRECEDING OPERATIONS ON THE V.B.: ....

- BASELINE TEST DATA:

	1st TEST	2nd TEST	3rd TEST
V.B. BODY PRESSURIZATION (NOMINAL)	245 KPa (35 psi)	245 KPa (35 psi)	245 KPa (35 psi)
V.B. BODY PRESSURIZATION (REAL)	... KPa (... psi)	... KPa (... psi)	... KPa (... psi)
LEAK STABILIZATION WAIT TIME	....	....	....
BUBBLES COUNTING PERIOD	....	....	....
N° OF BUBBLES COUNTED	....	....	....
RESULTING LEAK RATE (1 BUBBLE = 0.15 cc)	.... cc/sec	.... cc/sec	.... cc/sec

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DISK SEAL BUBBLE LEAK TEST

- SYSTEMATIC TEST DATA:

CERTIFICATE N°: ....
DATE: ....
PAGE: 2/2

V.B. BODY PRESSURIZATION	TEST N°	LEAK STABILIZ. WAIT TIME	BUBBLES COUNTING PERIOD	N° OF BUBBLES COUNTED	RESULTING LEAK RATE (1 bubble = = 0.15 cc
20.5 KPa (3 psi)	1				cc/sec
	2				cc/sec
	3				cc/sec
41 KPa (6 psi)	1				cc/sec
	2				cc/sec
	3				cc/sec
69 KPa (10 psi)	1				cc/sec
	2				cc/sec
	3				cc/sec
103 KPa (15 psi)	1				cc/sec
	2				cc/sec
	3				cc/sec

- TEST RESULT: ....

- TEST CONDUCTOR: .... G.E. REPRESENTATIVE ....

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DISK SEAL PRESSURE LOSS LEAK TEST

- TESTING FIRM: .... CERTIFICATE N°: ....
  DATE: ....
- TEST FACILITY: LEAK TEST STATION PAGE: 1/5
- TEST PROCEDURE: DOC. N° ED45834, REV. ......
- TEST MEDIUM: NITROGEN
- PRECEDING OPERATIONS ON THE V.B.: ....
  . Particles under soft seal:

  PRESENT ABSENT

  . Particles diameter: .... mm (........... mils)
- TEST DATA:

INITIAL V.B. BODY PRESSURIZATION (RELATIVE)

DATA	TEST N°	20.5 KPa (3 psi)	41 KPa (6 psi)	69 KPa (10 psi)	103 KPa (15 psi)
INITIAL AMBIENT TEMPERATURE (°K)	1				
	2				
	3				
INITIAL ATMOSPH. PRESSURE (Pa)	1				
	2				
	3				
DEPRESSURIZATION WAIT TIME (sec)	1				
	2				
	3				
FINAL V.B. BODY PRESSURIZATION (Pa rel)	1				
	2				
	3				
FINAL AMBIENT TEMPERATURE (°K)	1				
	2				
	3				
FINAL ATMOSPH. PRESSURE (Pa)	1				
	2				
	3				

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DISK SEAL PRESSURE LOSS LEAK TEST

- MEAN V.B. BODY PRESSURIZATIONS (P_{MEAN}) CERTIFICATE N°: ....
  AND MEAN LEAK RATES (Q_{MEAN}) DATE: ....
  IDENTIFICATION: PAGE: 2/5
  (SEE NOTES 1 and 2)

V.B. BODY INITIAL PRESSURIZATION	TEST N°	MEAN V.B. BODY PRESSURIZATION	MEAN LEAK RATE
20.5 KPa (3 psi)	1		stcc/sec
	2		stcc/sec
	3		stcc/sec
41 KPa (6 psi)	1		stcc/sec
	2		stcc/sec
	3		stcc/sec
69 KPa (10 psi)	1		stcc/sec
	2		stcc/sec
	3		stcc/sec
103 KPa (15 psi)	1		stcc/sec
	2		stcc/sec
	3		stcc/sec

DISK SEAL PRESSURE LOSS LEAK TEST

- RESULTING MEAN V.B. BODY PRESSURIZATIONS ($P_{MEAN\ RES.}$) AND MEAN LEAK RATES ($Q_{MEAN\ RES.}$) CALCULATION: (SEE NOTE 3)

CERTIFICATE N°: ....
DATE: ....
PAGE: 3/5

V.B. BODY INITIAL PRESSURIZATION	RESULTING MEAN V.B. BODY PRESSURIZATION	RESULTING MEAN LEAK RATE
20.5 KPa (3 psi)	...... KPa (...... psi)	.... stcc/sec
41 KPa (6 psi)	...... KPa (...... psi)	.... stcc/sec
69 KPa (10 psi)	...... KPa (...... psi)	.... stcc/sec
103 KPa (15 psi)	...... KPa (...... psi)	.... stcc/sec

- TEST RESULT: ....
(COMPARISON WITH ATTACHMENT B.10-4 OF DOC. N° ED 45834)

- TEST CONDUCTOR: .... G.E. REPRESENTATIVE: ....

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DISK SEAL PRESSURE LOSS LEAK TEST

NOTES:

CERTIFICATE N°: ....

DATE: ....

PAGE: 4/5

NOTE 1 : MEAN V.B. BODY
PRESSURIZATION CALCULATION AT EACH TEST:

$$P_{MEAN} = 1/2 \; (P_{INITIAL} + P_{FINAL})$$

NOTE 2 : MEAN LEAK RATE
CALCULATION AT EACH TEST:

$$Q_{MEAN} = \frac{V}{(t_2 - t_1) \cdot P_{atm_0}} \cdot \left[\left(P_1 + P_{atm_1}\right) \cdot \frac{T_0}{T_1} - \left(P_2 + P_{atm_2}\right) \frac{T_0}{T_2} \right]$$

(stcc/sec)

WHERE:

V = V.B. INTERNAL VOLUME (cc)
t_1 = INITIAL TEST TIME (sec)
t_2 = FINAL TEST TIME (sec)
P_1 = INITIAL V.B. BODY PRESSURIZATION (Pa relative)
P_2 = FINAL V.B. BODY PRESSURIZATION (Pa relative)
T_1 = INITIAL AMBIENT TEMPERATURE (°K)
T_2 = FINAL AMBIENT TEMPERATURE (°K)
P_{atm1} = INITIAL ATMOSPHERIC PRESSURE (Pa)
P_{atm2} = FINAL ATMOSPHERIC PRESSURE (Pa)

DISK SEAL PRESSURE LOSS LEAK TEST

CERTIFICATE N°: ....
DATE: ....
PAGE: 5/5

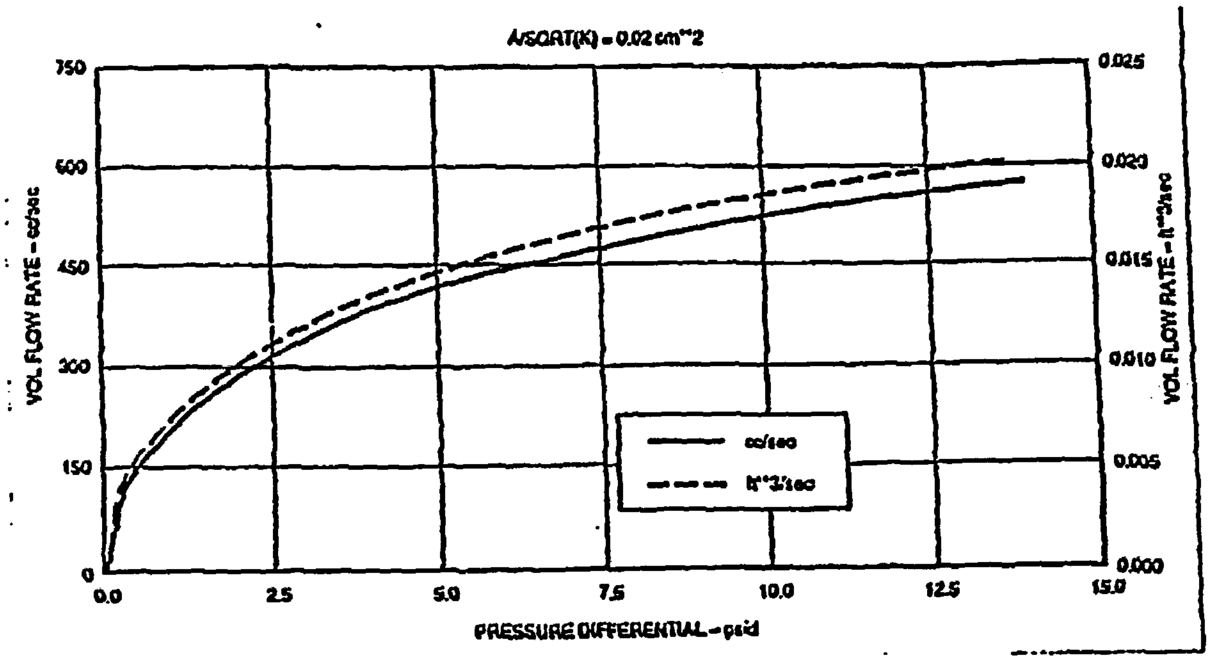
$P_{atmo.}$ = "STANDARD" ATMOSPHERIC PRESSURE = 760 mmHg =
= 1.01×10^5 Pa = 14.6 psi

To = "STANDARD" AMBIENT TEMPERATURE = 20°C =
= 293°K = 68°F

NOTE 3 : RESULTING MEAN V.B. BODY PRESSURIZATION AND MEAN LEAK RATE CALCULATION:
(AT EACH INITIAL PRESSURIZATION LEVEL)

$$\left(P_{\substack{MEAN\\RES.}}\right) = \frac{1}{3} \cdot \sum_{1}^{3} \left(P_{MEAN}\right)$$

$$\left(Q_{\substack{MEAN\\RES.}}\right) = \frac{1}{3} \cdot \sum_{1}^{3} \left(Q_{MEAN}\right)$$



MAXIMUM ACCEPTABLE LEAK RATES

FROM V.B. DISK SEAL

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FIAT - COMPONENTI E IMPIANTI PER L'ENERGIA E L'INDUSTRIA S.p.A.
DIVISIONE CIEI

ATTACHMENT B.10-4
V.B. PROTOTYPE QUALIFICATION TESTS
LEAK TEST CERTIFICATE

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DISK ASSEMBLY LIFT FORCE

- TESTING FIRM: .... CERTIFICATE N°: ....
  DATE: ....
- TEST FACILITY: ....
- TEST PROCEDURE: DOC. N° ED45834, REV. ......
- TEST KIND: BASELINE SYSTEMATIC
- PRECEDING OPERATIONS ON THE V.B.: ....
- TEST DATA:

READING N°	LIFT FORCE N (lb)
1	.... (...............)
2	.... (...............)
3	.... (...............)

ANNOTATIONS: ....
....
....
....
....
....

- TEST RESULT: ....
- TEST CONDUCTOR: .... G.E REPRESENTATIVE: ....

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LOW FLOW V.B. PERFORMANCES

- TESTING FIRM: .... CERTIFICATE N°: ....
  DATE: ....
- TEST FACILITY: FLOW TEST STAND PAGE: 1/2
- TEST PROCEDURE: DOC. N° ED45834, REV. ......
- TEST MEDIUM: AIR
- TEST DATA SUMMARY:
  . ANTICHATTERING DEVICE: PRESENT ABSENT
  . DAMPER: PRESENT ABSENT

DATA	TEST N°				
	1	2	3	4	5
AIR TEMPERATURE (°K)	......	......	......	......	......
ATMOSPH. PRESSURE (Pa)	......	......	......	......	......
INITIAL PROBES READINGS					
- PROBE 1	......	......	......	......	......
- PROBE 2	......	......	......	......	......
- PROBE 3	......	......	......	......	......
- PROBE 4	......	......	......	......	......
- PROBE 5	......	......	......	......	......
LIFT PRESSURE (KPa)	...... (......)	...... (......)	...... (......)	...... (......)	...... (......)
OPENING TIME (sec)	......	......	......	......	......
CHATTERING	YES NO	YES NO	YES NO	YES NO	YES NO
V.B. OPEN PROBES READINGS					
- PROBE 1	......	......	......	......	......
- PROBE 2	......	......	......	......	......
- PROBE 3	......	......	......	......	......
- PROBE 4	......	......	......	......	......
- PROBE 5	......	......	......	......	......

LOW FLOW V.B. PERFORMANCES

- TEST DATA SUMMARY: (CONTINUED)

CERTIFICATE N°: ....
DATE: ....
PAGE: 2/2

DATA	TEST N°				
	1	2	3	4	5
MAX ESTABLISHED AIR FLOW (m^3/sec)	......	......	......	......	......
	(...... ft^3/sec)	(...... ft^3/sec)	(...... ft^3/sec)	(...... ft^3/sec)	(...... ft^3/sec)
CLOSING PRESSURE (KPa)	......	......	......	......	......
	(...psi)	(...psi)	(...psi)	(...psi)	(...psi)
CLOSING TIME (sec)	......	......	......	......	......
CHATTERING	YES NO	YES NO	YES NO	YES NO	YES NO
V.B. CLOSED PROBES READINGS					
- PROBE 1	......	......	......	......	......
- PROBE 2	......	......	......	......	......
- PROBE 3	......	......	......	......	......
- PROBE 4	......	......	......	......	......
- PROBE 5	......	......	......	......	......

ANNOTATIONS: ....
....
....
....
....
....

- TEST RESULT: ....
- TEST CONDUCTORS: .... G.E REPRESENTATIVE: ....

FULL FLOW V.B. PERFORMANCES

- TESTING FIRM: .... CERTIFICATE N°: ....
  DATE: ....
- TEST FACILITY: FLOW TEST STAND PAGE: 1/2
- TEST PROCEDURE: DOC. N° ED45834, REV. ......
- TEST MEDIUM: AIR
- TEST DATA SUMMARY:
  . Air temperature: .... °K
  . Atmospheric pressure: .... Pa
  . V.B. lift pressure : .... KPa (........... psi)
  . V.B. opening time : .... sec

  . V.B. full flows data:

DIFFERENTIAL PRESSURE	FLOWS M^3/SEC (FT^3/SEC)		
	1st TEST	2nd TEST	3rd TEST
400 mm H_2O (0.57 psid)			
450 mm H_2O (0.64 psid)			
500 mm H_2O (0.71 psid)			
550 mm H_2O (0.79 psid)			
600 mm H_2O (0.86 psid)			
650 mm H_2O (0.93 psid)			
700 mm H_2O (1 psid)			

FULL FLOW V.B. PERFORMANCES

- V.B. FULL FLOWS DATA: CERTIFICATE N°: ....

(CONTINUED) DATE: ....

PAGE: 2/2

DIFFERENTIAL PRESSURE	FLOWS M^3/SEC (FT^3/SEC)		
	1st TEST	2nd TEST	3rd TEST
650 mm H_2O (0.93 psid)			
600 mm H_2O (0.86 psid)			
550 mm H_2O (0.79 psid)			
500 mm H_2O (0.71 psid)			
450 mm H_2O (0.64 psid)			
400 mm H_2O (0.57 psid)			

- V.B. CLOSING PRESSURE: .... KPa (......... psi)
- V.B. CLOSING TIME: .... sec.
- TEST RESULT: ....

  (COMPARISON WITH ATTACHMENT B.12-2 OF DOC. N° ED 45834)

- TEST CONDUCTORS: .... G.E REPRESENTATIVE: ....

Mod CIEI 1032 - Tip. CASO

FIAT - COMPONENTI E
IMPIANTI PER L'ENERGIA E
L'INDUSTRIA S.p.A.
DIVISIONE CIEI

ATTACHMENT B.12-2

V.B. PROTOTYPE QUALIFICATION TESTS

FULL FLOW TEST CERTIFICATE

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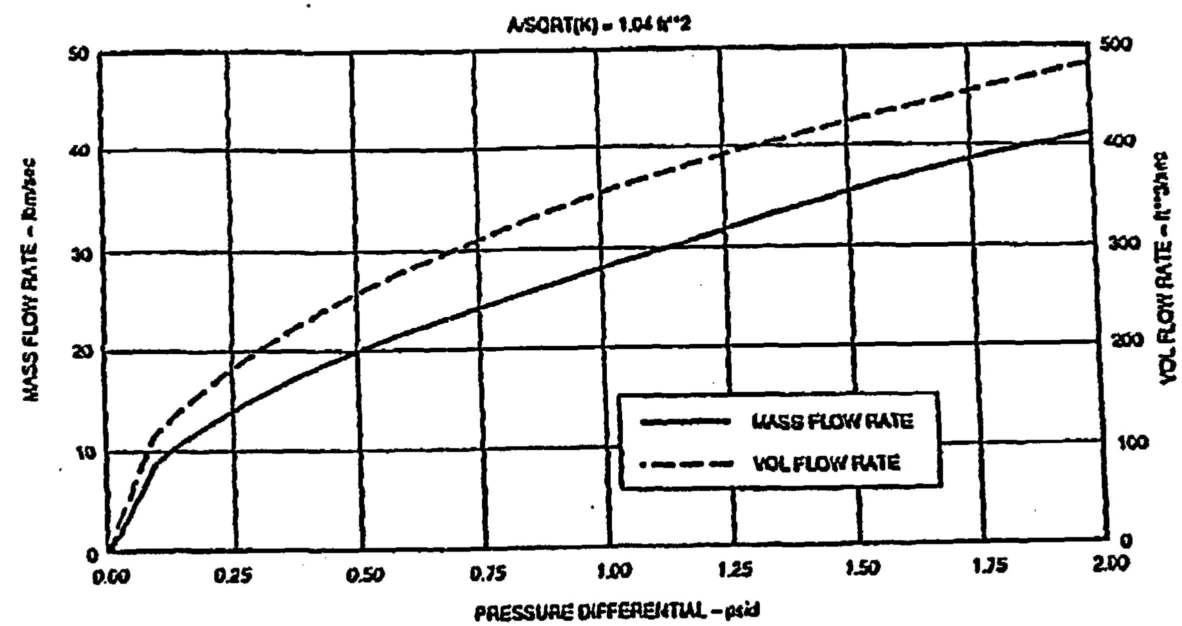
MINIMUM ACCEPTABLE FLOW RATES

ACROSS THE V.B.



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FIAT - COMPONENTI E IMPIANTI PER L'ENERGIA E L'INDUSTRIA S.p.A. CIEI	ATTACHMENT B.13 V.B. PROTOTYPE QUALIFICATION TESTS RELIABILITY TEST SUMMARY CERTIFICATE	ED45834 Page 43

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TESTING FIRM: .... CERTIFICATE N°: ....

DATE: ....

- TEST FACILITY: FLOW TEST STAND PAGE: 1/2

- TEST PROCEDURE: DOC. N° ED45834, REV. ......

- TEST MEDIUM: AIR

- SAMPLE TEST DATA:

DATE	STROKE N°	LIFT PRESSURE	OPENING TIME	STABILIZED DIFFERENT. PRESSURE	STABILIZED FLOW	CLOSING TIME
	1					
	100					
	200					
	300					
	400					
	500					
	600					
	700					
	800					
	900					
	1000					
	1100					
	1200					
	1300					
	1400					

Mod. CII 8322 - To.GA80

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- SAMPLE TEST DATA: (CONTINUED)

CERTIFICATE N°: ....
DATE: ....
PAGE: 2/2

DATE	STROKE N°	LIFT PRESSURE	OPENING TIME	STABILIZED DIFFERENT. PRESSURE	STABILIZED FLOW	CLOSING TIME
	1500					
	1600					
	1700					
	1800					
	1900					
	2000					
	2100					
	2200					
	2300					
	2400					
	2500					
	2600					
	2700					
	2800					
	2900					
	3000					

ANNOTATIONS: ....
....
....
....
....
....

- TEST RESULT: ....
- TEST CONDUCTORS: .... G.E REPRESENTATIVE: ....

FIAT COMPONENTI E IMPIANTI PER L'ENERGIA E L'INDUSTRIA S.p.A.
DIVISIONE CIEI

CERTIFICATO DI CONTROLLO

INSPECTION CERTIFICATE

CC N. ________

Foglio / sheet ________

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Fabbricazione / Manufacturing ________

Cliente / Customer ________ Fornitura / Order ________

Oggetto / Object ________ Disegno / Drawing ________

Materiale / Material ________ Manufatto / Manufactured ________

Piano di Controllo / Control plan ________ Fase / Phase ________ Pagina / Page ________

Specifica di controllo / Control specification ________ Livello di accettazione / Acceptance standard ________

CARATTERISTICHE DELL'ESAME
DATA EXAMINATION

Zone esaminate: / Control extension: ________

Risultato: / Result: [1] Accettabile / Acceptable [2] Non accettabile / Unacceptable

Note / Remarks

1
2
3 DOC. ED45834
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5
6
7 ATTACHMENT N° 8.14
8
9
10 V.E. PROTOTYPE QUALIFICATION TESTS
11
12 FINAL INSPECTION CERTIFICATE
13
14
15
16
17
18
19
20

Data / Date	Eseguito da: / Performed by:		Ispettore FIAT		Ispettore Cliente / Customer Inspector	Enti collaudatori / Surveyors
		Liv.-Lev.		Liv.-Lev.		

Mod. CIEI 14047

ATTACHMENT C

HATU'-ICO DOCUMENT N° 06494

HATU-ICO TESTS PROCEDURE

HATÙ-ICO

HATÙ-ICO S.p.A. ARTICOLI DI GOMMA PER USO SANITARIO
SIRINGHE, AGHI, TERMOMETRI - LINEE INFANZIA, IGIENE, SALUTE E BELLEZZA
CAPITALE INT. VERSATO L. 10.000.000.000 - REG. SOC. N. 48042

Tel. (051) 61.20.111 centralino unico

SEDE E STABILIMENTO
40033 CASALECCHIO DI RENO (BO) - VIA RONZANI 47
C.P. N° 134 - CASALECCHIO DI RENO
C/C POSTALE
TELEFAX (051) 61.38.410

DEPOSITO
AREA 7 - INTERPORTO
40010 BENTIVOGLIO (BOLOGNA)

STABILIMENTO ASCOLI PICENO
Zona Industriale - Marino del Tronto
TELEFAX (0736) 402.361

HATU
ICO
mister BABY
SAUBER

CASALECCHIO DI RENO

ns. rif.:

RADIATION AGEING CAMPAIGN ON THE PRIMARY SOFT SEAL OF THE S.B.W.R. VACUUM BREAKER PROTOTYPE

The present document is the Section C of the vacuum breaker prototype general test procedure, FIAT CIEI Doc. n. ED45833

Prepared by: Francesco Pollei
April, 1994

SUMMARY

Attachments:

C.1) INTRODUCTION

The procedure shows operations to be performed on the primary elastomeric soft seal of the S.B.W.R. Vacuum Breaker Prototype (V.B.), FIAT CIEI drawing n° 2T137684, to simulate environmental radiation ageing.
The target of the campaign is the exposure of the item to a gamma-radiation field able to give the required TOTAL INTEGRATED DOSE of 20 Megarads (200 KGy) in a reasonable time.

C.2) TEST FACILITY DESCRIPTION

The irradiation chamber is a concrete structure with walls of 1.8m (6ft) thickness, equipped with a labyrinth for the inlet/oulet of the exposed product.
Inside the chamber, the radiating Cobalt 60 rods are arranged in an adequate rack, made up with 8 modules, each of them containing 42 Cobalt rods, for a global charge of 336 rods (See. Attachment C.1).
During facility stand-by the radiative source rests in a pool of demineralized water.
The facility is equipped with an automatic handling system for the irradiation of industrial products placed in standard card-board boxes and remotely operated when the radiative source is out of the water pool.
For irradiation of items larger and heavier than standard set up operations are performed by hands (with source under water) or by means of a hoist, to lift the concrete plug on the roof of the chamber and place items inside.

Possible movements of irradiated items are obtainable by means of dedicated trailers.

Main features of the chamber are the following:

- Source: stainless steel rectangular rack, lift by a pneumatic hoist, laterally guided by two stainless steel ropes.
- Internal capacity: 133 m^3 (4700 ft^3).
- Ventilation system performance: 14 air interchanges per hour (air flow 1870 m^3/hr, 66000 ft^3/hr).

In Attachment C.2 real iso-dose values of the test environment are tabulated.

C.3) TEST INSTRUMENTATION

The irradiation facility is equipped with following instrumentation:

- Dosimeters specific absorption measurements:
  - instrument: spectrophotometer for UV/V.I.S.
  - made by: BAUSCH-LOMB
  - model: SPECTRONIC 501
  - series n°: 01830314

- Dosimeters thickness measurements:
  - instrument: micrometer (10^{-6}m precision)
  - made by: MITUTOYO
  - model : 7301
  - series n°: 2046-08

- Gamma-dose measurements:
  - instrument: dosimeters RED PERSPEX
  - made by: HARWELL LABORATORY
  - model: 4034CD (measurem. field 5/50 K Gy)
  - supply: BATCH "AN" lot, october 1992
  - readings: performed with reference to air and bymeans of a calibration curve pertaining to the dosimeters used (see Attachment C.3).

- Environmental conditions measurements:

  NOTE

  Temperature inside the irradiation chamber doesn't influence the test, anyway readings of chamber temperature and item temperature are possible, and will be made at the beginning and at the end of the campaign.

  - Chamber temperature:
    * instrument: valve thermometer
    * made by: FILOTECNICA

  - Item temperature:
    * instrument: thermocouple
    * made by: KANE-MAY LIMITED
    * model: series 03-704-708/A

C.4) TEST DATA ACQUISITION AND PROCESSING SYSTEM

The method used to identify the "dose-rate" obtainable in the irradiation facility is shown in the following sequence:

a) on February, 7th, 1994, at 11 a.m., 30 dosimeters were placed inside the chamber, as shown in Attachment C.2: all dosimeters certified as per Attachment C.4. Dosimeters were fixed by means of adhesive tape to a cable placed parallel to the source at a distance of 2.03m (6.7 ft), and 1.3 m (4.3 ft) high from the ground

b) on February 7th, 1994, at 11.30 a.m., the irradiation was started (planned irradiation period: 21 hrs)

c) on February 8th, 1994, at 8.30 a.m., the irradiation was stopped to allow dosimeters take-up after a real irradiation period of 21 hrs

d) on February 9th, 1994, at 9.00 a.m., absorbed doses were read on all dosimeters and dose-rates were calculated (see Attachment C.5). From dose-rate calculations the position of the V.B. primary seal to be irradiated was identified (see Attachment C.5), corresponding approximately to dosimeters positions from 5A to 12A and from 5B to 12B.
The general result of the calculations was an average dose - rate" from the radiating source of 0.90 KGy/hr ($9x10^{-2}$ Mrad/hr).

C.5) TEST SEQUENCE

C.5.1) Radiation Ageing

The V.B. primary seal irradiation campaign should last 222 hrs: possible stops will be certified. The seal will be assembled in the test tool shown in Attachment C.7 (FIAT CIEI DRAWING n. 2R137732), to simulate its nominal configuration during V.B. normal operation in the S.B.W.R. plant; the arrangement will be periodically rotated to obtain maximum exposition uniformity.

The TOTAL INTEGRATED DOSE of 20 Mrads will show a tolerance of +5%.

The T.I.D. evaluation will be performed by means of dosimeters placed on both sides of the irradiated arrangement.

Dosimeters readings will be certified at the end of the campaign.

Attachment C.1: Radiating source structural sketch

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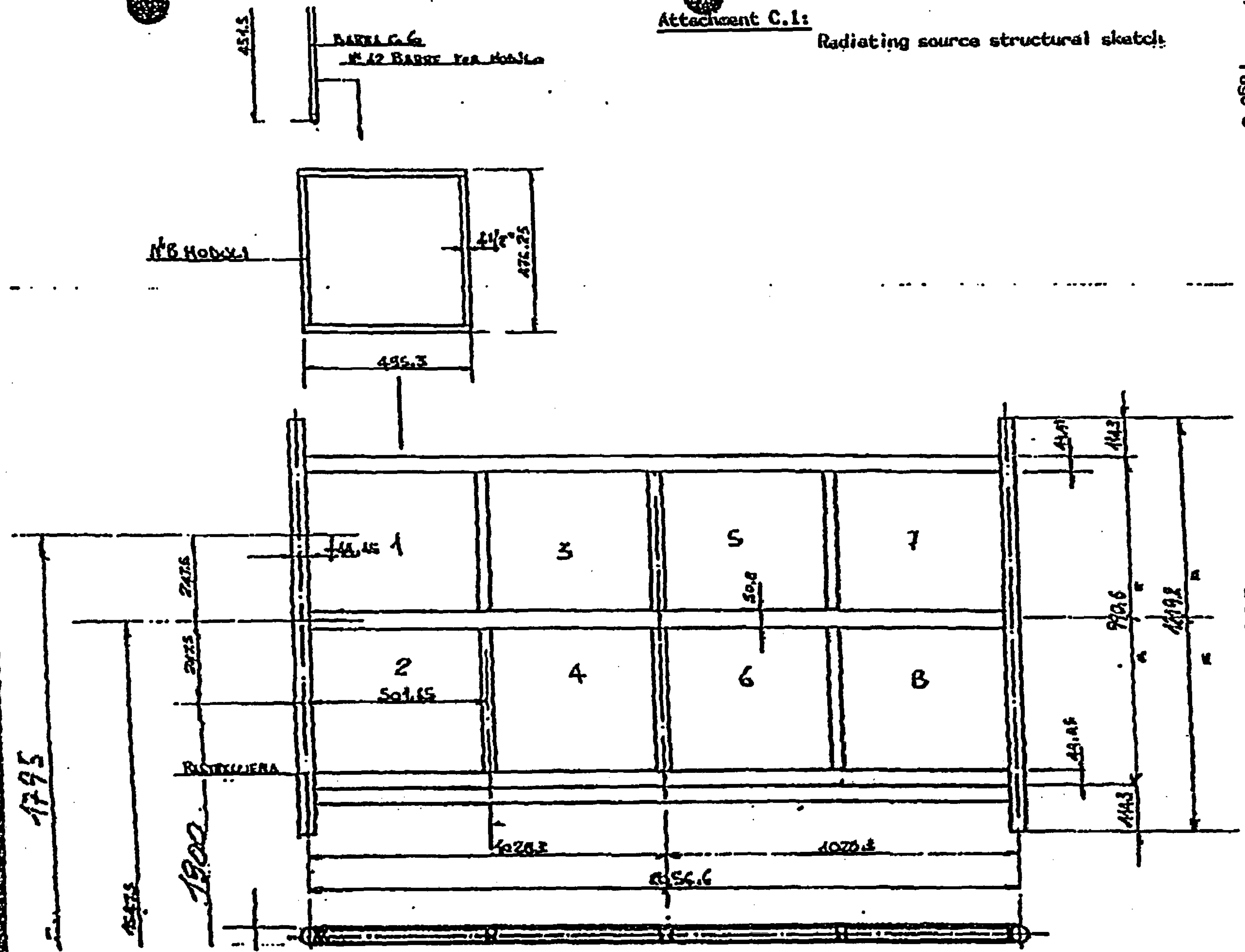

HATU-ICO
CASALECCHIO DI RENO

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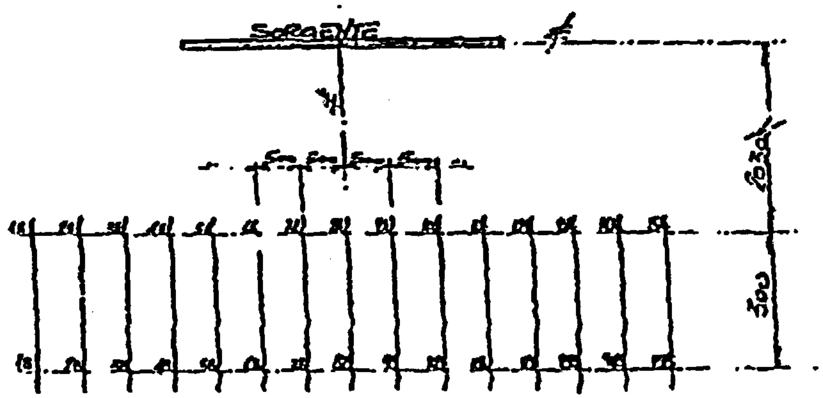
HATÙ-ICO
CASALECCHIO DI RENO



Il PAVIMENTO = 13cm

DOSIMETERS	1A	2A	3A	4A	5A	6A	7A	8A	9A	10A	11A	12A	13A	14A	15A
DOSE Gy/h	[illegible]	0,780	0,444	0,566	0,713	0,887	1,078	1,314	1,323	1,294	0,942	0,541	0,330	0,342	0,264
DOSIMETERS	1B	2B	3B	4B	5B	6B	7B	8B	9B	10B	11B	12B	13B	14B	15B
DOSE Gy/h	0,282	0,304	0,423	0,533	0,436	0,785	0,957	1,066	1,083	0,955	0,883	0,558	0,401	0,323	0,233

Attachment C.2: Test environment ISO-DOSE values (dosimeters, arrangement configuration)

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Attachment C.3

Gamma dosimeters calibration curve
(sheet 1/3)

RED 4034 BATCH CD. SPECIFIC ABSORBANCE (640 nm) VERSUS DOSE TABLE.

Abs. cm-1	Dose kGy	Abs. cm-1	Dose kGy	Abs. cm-1	Dose kGy	Abs. cm-1	Dose kGy
0.71	5.0	0.72	5.1	0.73	5.2	0.74	5.3
0.75	5.3	0.76	5.4	0.77	5.5	0.78	5.6
0.79	5.7	0.80	5.7	0.81	5.8	0.82	5.9
0.83	6.0	0.84	6.1	0.85	6.2	0.86	6.3
0.87	6.4	0.88	6.5	0.89	6.5	0.90	6.6
0.91	6.7	0.92	6.8	0.93	6.9	0.94	7.0
0.95	7.1	0.96	7.2	0.97	7.3	0.98	7.4
0.99	7.5	1.00	7.6	1.01	7.7	1.02	7.8
1.03	7.9	1.04	8.0	1.05	8.1	1.06	8.2
1.07	8.3	1.08	8.4	1.09	8.6	1.10	8.7
1.11	8.8	1.12	8.9	1.13	9.0	1.14	9.1
1.15	9.2	1.16	9.3	1.17	9.4	1.18	9.5
1.19	9.7	1.20	9.8	1.21	9.9	1.22	10.0
1.23	10.1	1.24	10.2	1.25	10.4	1.26	10.5
1.27	10.6	1.28	10.7	1.29	10.8	1.30	10.9
1.31	11.1	1.32	11.2	1.33	11.3	1.34	11.4
1.35	11.5	1.36	11.7	1.37	11.8	1.38	11.9
1.39	12.0	1.40	12.2	1.41	12.3	1.42	12.4
1.43	12.5	1.44	12.7	1.45	12.8	1.46	12.9
1.47	13.0	1.48	13.2	1.49	13.3	1.50	13.4
1.51	13.6	1.52	13.7	1.53	13.8	1.54	14.0
1.55	14.1	1.56	14.2	1.57	14.3	1.58	14.5
1.59	14.6	1.60	14.7	1.61	14.9	1.62	15.0
1.63	15.1	1.64	15.3	1.65	15.4	1.66	15.5
1.67	15.7	1.68	15.8	1.69	16.0	1.70	16.1
1.71	16.2	1.72	16.4	1.73	16.5	1.74	16.6
1.75	16.8	1.76	16.9	1.77	17.1	1.78	17.2
1.79	17.3	1.80	17.5	1.81	17.6	1.82	17.8
1.83	17.9	1.84	18.1	1.85	18.2	1.86	18.3
1.87	18.5	1.88	18.6	1.89	18.8	1.90	18.9
1.91	19.1	1.92	19.2	1.93	19.4	1.94	19.5
1.95	19.7	1.96	19.8	1.97	20.0	1.98	20.1
1.99	20.3	2.00	20.4	2.01	20.6	2.02	20.7

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Attachment C.3

(sheet 2/3)

CASALECCHIO DI RENO

RED 4034 BATCH CD. SPECIFIC ABSORBANCE (640 nm) VERSUS DOSE TABLE.

Abs. cm-1	Dose kGy	Abs. cm-1	Dose kGy	Abs. cm-1	Dose kGy	Abs. cm-1	Dose kGy
2.03	20.9	2.04	21.0	2.05	21.2	2.06	21.3
2.07	21.5	2.08	21.7	2.09	21.8	2.10	22.0
2.11	22.1	2.12	22.3	2.13	22.4	2.14	22.6
2.15	22.8	2.16	22.9	2.17	23.1	2.18	23.2
2.19	23.4	2.20	23.6	2.21	23.7	2.22	23.9
2.23	24.1	2.24	24.2	2.25	24.4	2.26	24.6
2.27	24.7	2.28	24.9	2.29	25.1	2.30	25.3
2.31	25.4	2.32	25.6	2.33	25.8	2.34	26.0
2.35	26.1	2.36	26.3	2.37	26.5	2.38	26.7
2.39	26.8	2.40	27.0	2.41	27.2	2.42	27.4
2.43	27.6	2.44	27.8	2.45	27.9	2.46	28.1
2.47	28.3	2.48	28.5	2.49	28.7	2.50	28.9
2.51	29.1	2.52	29.3	2.53	29.5	2.54	29.7
2.55	29.9	2.56	30.1	2.57	30.2	2.58	30.4
2.59	30.7	2.60	30.9	2.61	31.1	2.62	31.3
2.63	31.5	2.64	31.7	2.65	31.9	2.66	32.1
2.67	32.3	2.68	32.5	2.69	32.7	2.70	32.9
2.71	33.2	2.72	33.4	2.73	33.6	2.74	33.8
2.75	34.0	2.76	34.3	2.77	34.5	2.78	34.7
2.79	35.0	2.80	35.2	2.81	35.4	2.82	35.7
2.83	35.9	2.84	36.1	2.85	36.4	2.86	36.6
2.87	36.8	2.88	37.1	2.89	37.3	2.90	37.6
2.91	37.8	2.92	38.1	2.93	38.3	2.94	38.6
2.95	38.9	2.96	39.1	2.97	39.4	2.98	39.6
2.99	39.9	3.00	40.2	3.01	40.4	3.02	40.7
3.03	41.0	3.04	41.3	3.05	41.5	3.06	41.8
3.07	42.1	3.08	42.4	3.09	42.7	3.10	43.0
3.11	43.2	3.12	43.5	3.13	43.8	3.14	44.1
3.15	44.4	3.16	44.7	3.17	45.0	3.18	45.4
3.19	45.7	3.20	46.0	3.21	46.3	3.22	46.6
3.23	46.9	3.24	47.3	3.25	47.6	3.26	47.9
3.27	48.2	3.28	48.6	3.29	48.9	3.30	49.2
3.31	49.6	3.32	49.9	3.33	50.3		

Attachment C.3 (sheet 3/3)

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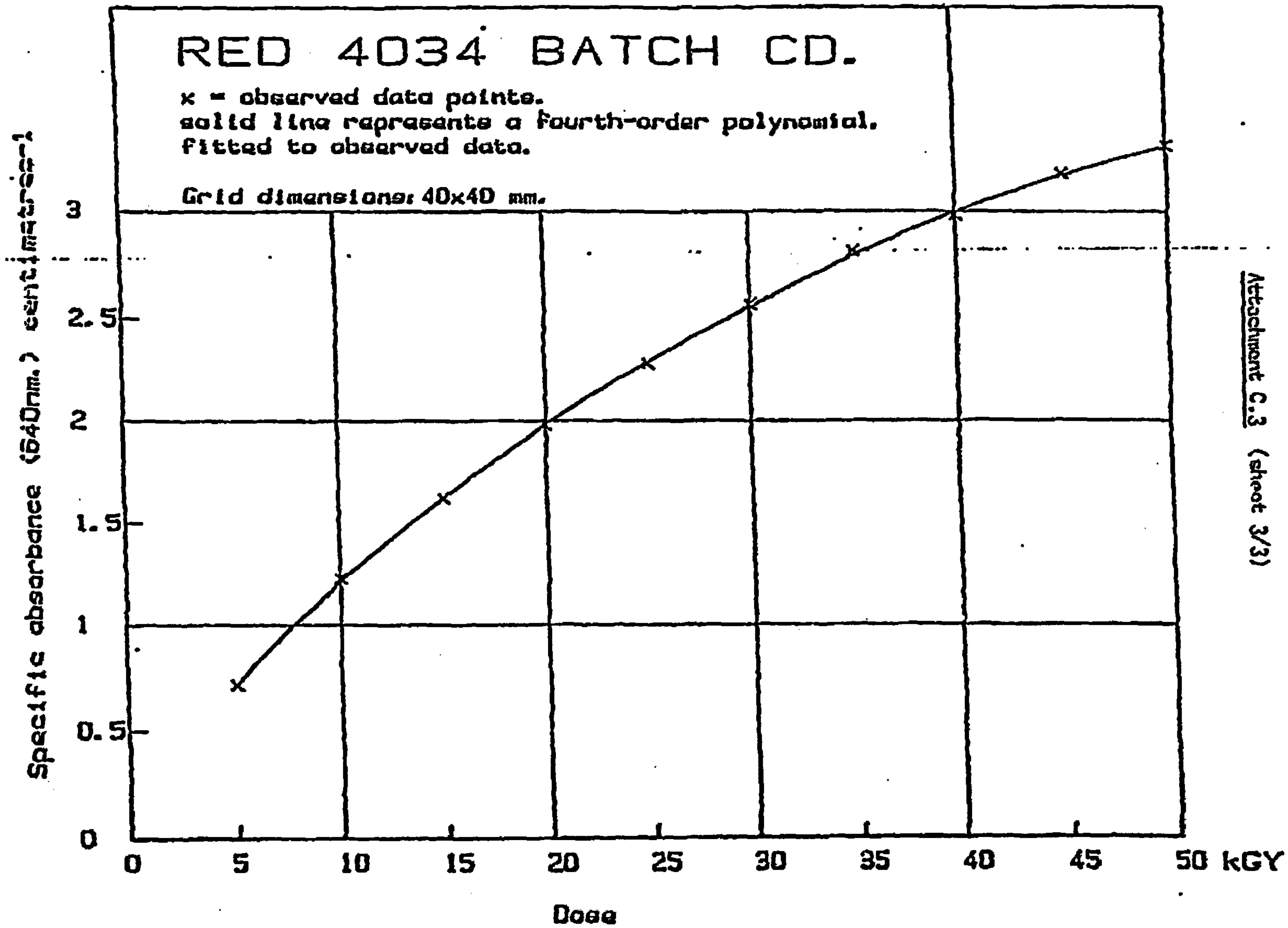

Attachment C.4

Dosimeters certification
(sheet 1/2)

CASALECCHIO DI RENO

HARWELL

AEA TECHNOLOGY

High Dose Dosimetry Service
Building 10.30

Harwell Laboratory
Oxfordshire OX11 ORA
Telephone: 0235-24141
Fax: 0235-432916/832591
Telex: 83135 ATOMHA G
FAX NO. (0235) 43 6314

HARWELL PERSPEX (PMMA) DOSIMETERS

The following dyed-polymethylmethacrylate (PMMA) dosimeters have been developed at Harwell for the measurement of high doses of gamma radiation in industrial radiation processing.

Type	Recommended Dose Range	Recommended Read-out Wavelength
Red 4034	5 to 50 kilograys (kGy)	640 nanometres
Amber 3042	3 to 15 kGy	603 nm.
GAMMACHROME YR	100 Gy to 3kGy	530 nm.

The dosimeters are 30 x 11 mm. optically clear rectangular pieces of material, individually pre-packed in labelled polyester/aluminium foil/polyethylene laminate sachets. On irradiation the dosimeters visibly darken and the degree of darkening, accurately measureable by spectrophotometry is related to absorbed (water-equivalent) dose.

The dosimeters are produced in batches. The batch reference numbers or letters are displayed on the dosimeter labels. (For example 4034 AX is Red 4034 batch AX). Each batch of dosimeters is subjected to rigorous quality-control, and finally calibrated using a standardised cobalt-60 irradiator and PU8800 spectrophotometer before sale. The standardisation of the irradiator, and the final dosimeter calibrations are directly traceable to U.K. National Standards.

Instrumentation Required

Good quality spectrophotometer. Micrometer or dial gauge. It is recommended that these instruments are regularly tested for accuracy by means of standardised glass filters and hardened-steel gauge blocks.

Method

1) The dosimeters must remain sealed before, during and after irradiation, until the time of reading. (The packaging material is specially selected to protect the PMMA from the effects of extremes of atmospheric humidity).

2) Preferably, the dosimeters should be read within 1-2 days after irradiation.

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RED 4034 PERSPEX CALIBRATION DATA

Irradiation

7kCi Co-60 "Cell 2", Harwell

Four dosimeters simultaneously irradiated to each of ten doses.

Measurements

Pye-Unicam PU8800 spectrophotometer. Wavelength scale accuracy checked by deuterium arc lines. Absorbance-scale accuracy by measurement of standard filters certified by UK Standards Laboratory (NPL).

Absorbance versus air (640nm wavelength) divided by dosimeter thickness = 'specific absorbance'. In the sp. absorbance vs. dose response curve supplied each data point represents the main sp. absorbance of four dosimeters.

Traceability

Irradiation via Fricke and dichromate dosimetry to UK Standards Laboratory.

Spectrophotometry: via standard filters/D-emission lines.

Curve-Fitting/Generation of Tables

$$Y = A + B.x + C.x^2 + D.x^3 - E.x^4$$

Y = dose (or sp. absorbance)
x = sp. absorbance (or dose)

Users are advised to use the supplied calibration data as a guide and to establish calibration-curves for their own instruments by measuring sets of accurately irradiated dosimeters.

Sets of irradiated dosimeters are available from Harvell. A charge is made for the service.

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Attachment C.5

Dose rates read during facility capability definition

(sheet 1/2)

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laboratorio Chimico Fisico
Ascoli Piceno

Dosimetria per assorbimento a 640 nm

Data esposizione	Lotto Produzione	Posizione Dosimetro	Assorbanza (A)	Spessore (S)	A/S	Dose Tot. Assorbita (kGy)	Dose Assorb. Tot(kGy) Valore medio/h	Data controllo
07-02-94	X 21/4	1A	0,237	0,303	0,78	5,6	0,266	9/2/94
"	"	2A	0,275	0,305	0,90	6,6	0,314	"
"	"	3A	0,333	0,302	1,10	8,7	0,414	"
"	"	4A	0,405	0,293	1,38	11,9	0,566	"
"	"	5A	0,519	0,318	1,63	15,1	0,719	"
"	"	6A	0,560	0,300	1,87	18,5	0,880	"
"	"	7A	0,724	0,327	2,21	23,7	1,128	"
"	"	8A	0,675	0,278	2,43	27,6	1,314	"
"	"	9A	0,739	0,303	2,44	27,8	1,323	"
"	"	10A	0,735	0,320	2,30	25,3	1,204	"
"	"	11A	0,611	0,312	1,96	19,8	0,942	"
"	"	12A	0,420	0,303	1,37	11,8	0,561	"
"	"	13A	0,327	0,309	1,06	8,2	0,390	"
"	"	14A	0,280	0,292	0,96	7,2	0,342	"
"	"	15A	0,196	0,316	0,62	4,3	0,204	"

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CASALECCHIO DI RENO

HATÙ-ICO

Laboratorio Chimico Fisico
Ascoli Piceno

Dosimetria per assorbimento a 640 nm

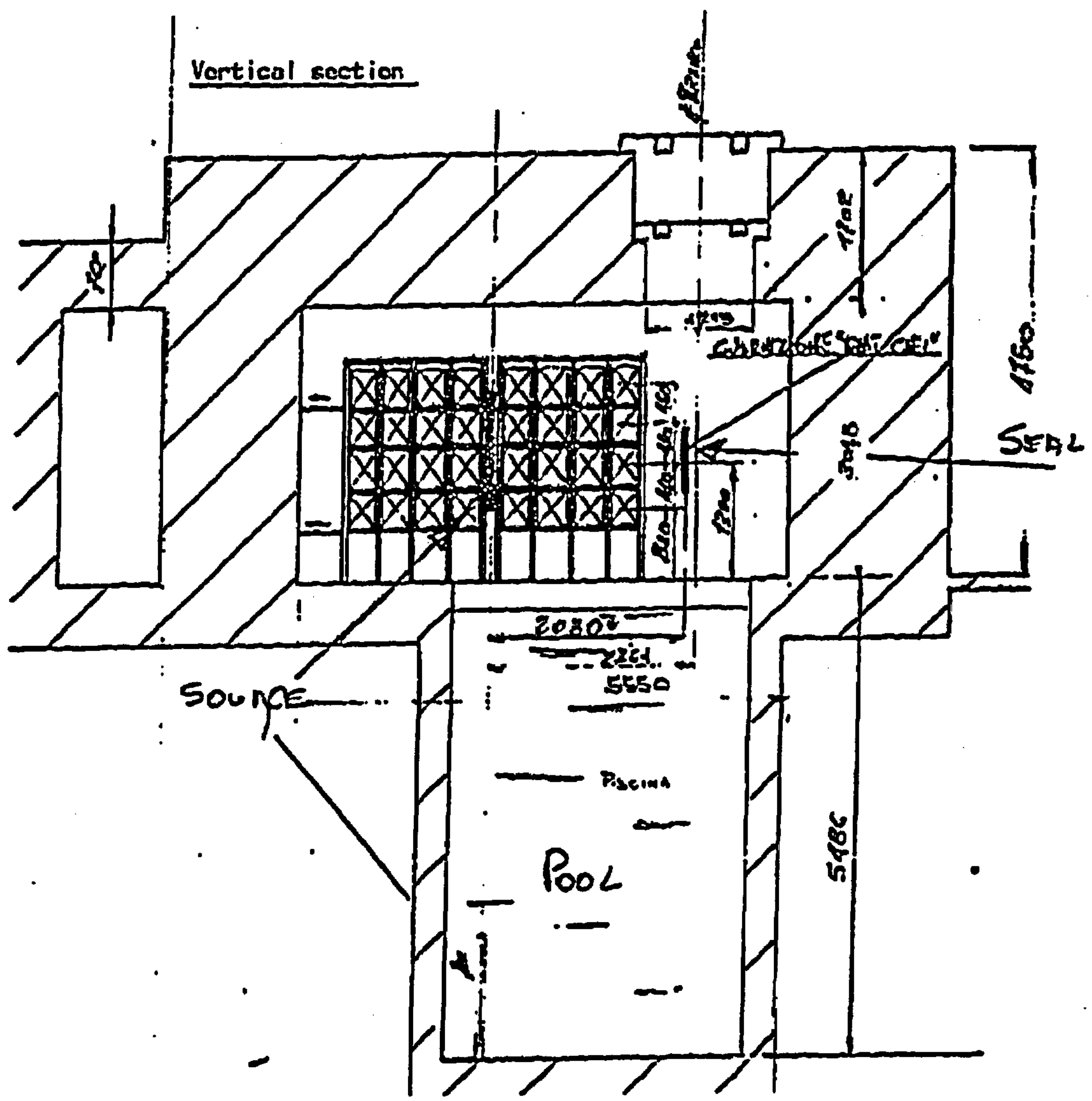
Data esposizione	Lotto Produzione	Posizione Dosimetro	Assorbanza (A)	Spessore (S)	A/S	Dose Assorbita (kGy)	Dose Assorbita (kGy) Valore medio/h	Data controllo
07-02-94	Y 21/4	1B	0,251	0,324	0,77	5,5	0,262	9-02-94
"	"	2B	0,277	0,310	0,89	6,5	0,309	"
"	"	3B	0,370	0,330	1,12	8,9	0,423	"
"	"	4B	0,411	0,310	1,32	11,2	0,533	"
"	"	5B	0,419	0,279	1,50	13,4	0,638	"
"	"	6B	0,540	0,312	1,73	16,5	0,785	"
"	"	7B	0,581	0,293	1,98	20,1	0,957	"
"	"	8B	0,623	0,292	2,13	22,4	1,066	"
"	"	9B	0,644	0,299	2,15	22,8	1,085	"
"	"	10B	0,631	0,310	2,03	20,9	0,995	"
"	"	11B	0,540	0,300	1,80	17,5	0,833	"
"	"	12B	0,443	0,316	1,40	12,2	0,581	"
"	"	13B	0,325	0,298	1,09	8,6	0,409	"
"	"	14B	0,268	0,292	0,92	6,8	0,323	"
"	"	15B	0,206	0,295	0,70	4,9	0,233	"

HATÙ-ICO

Attachment C.6

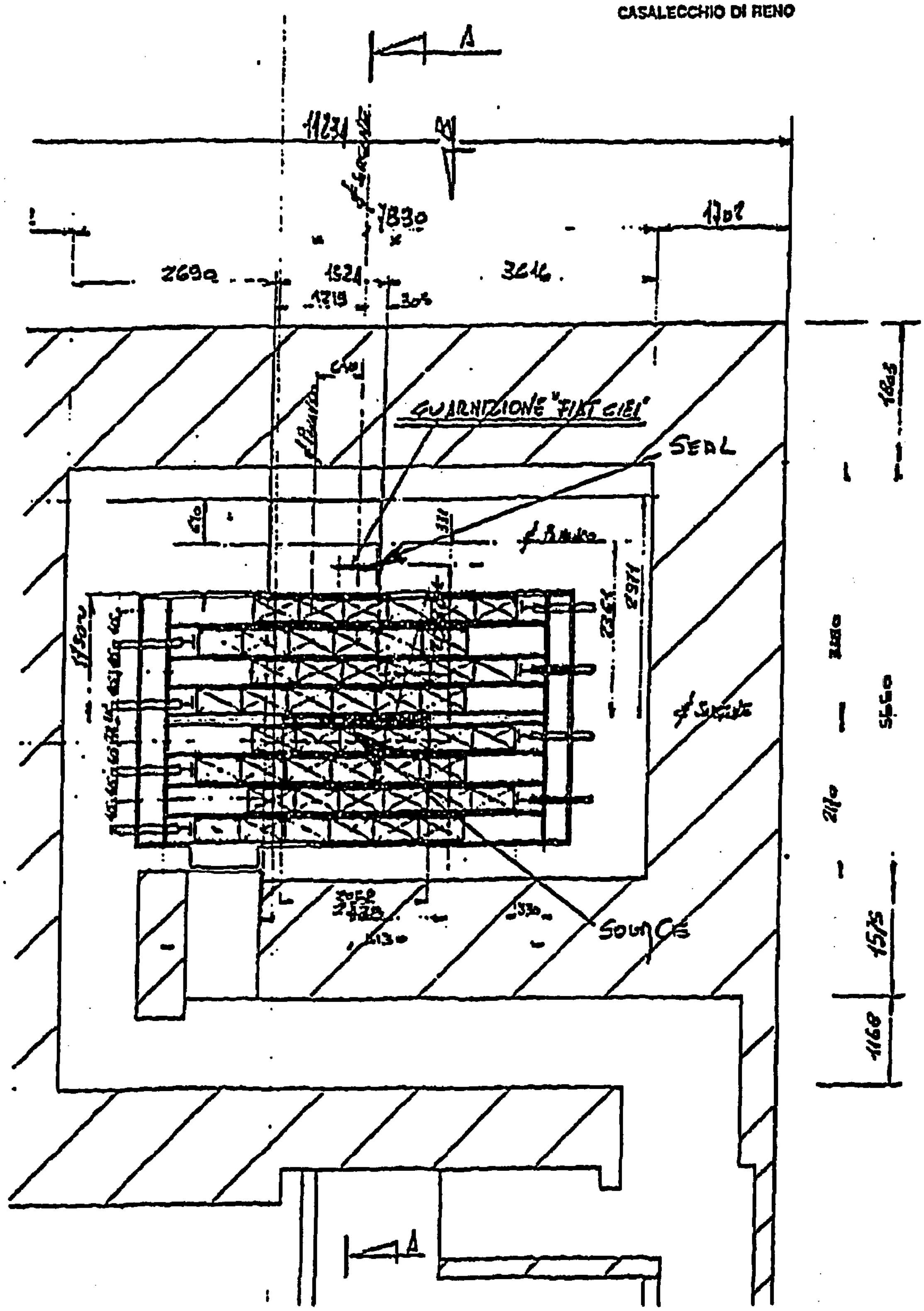
V.B. primary seal installation in the irradiation facility (sheet 1/2)

CASALECCHIO DI RENO

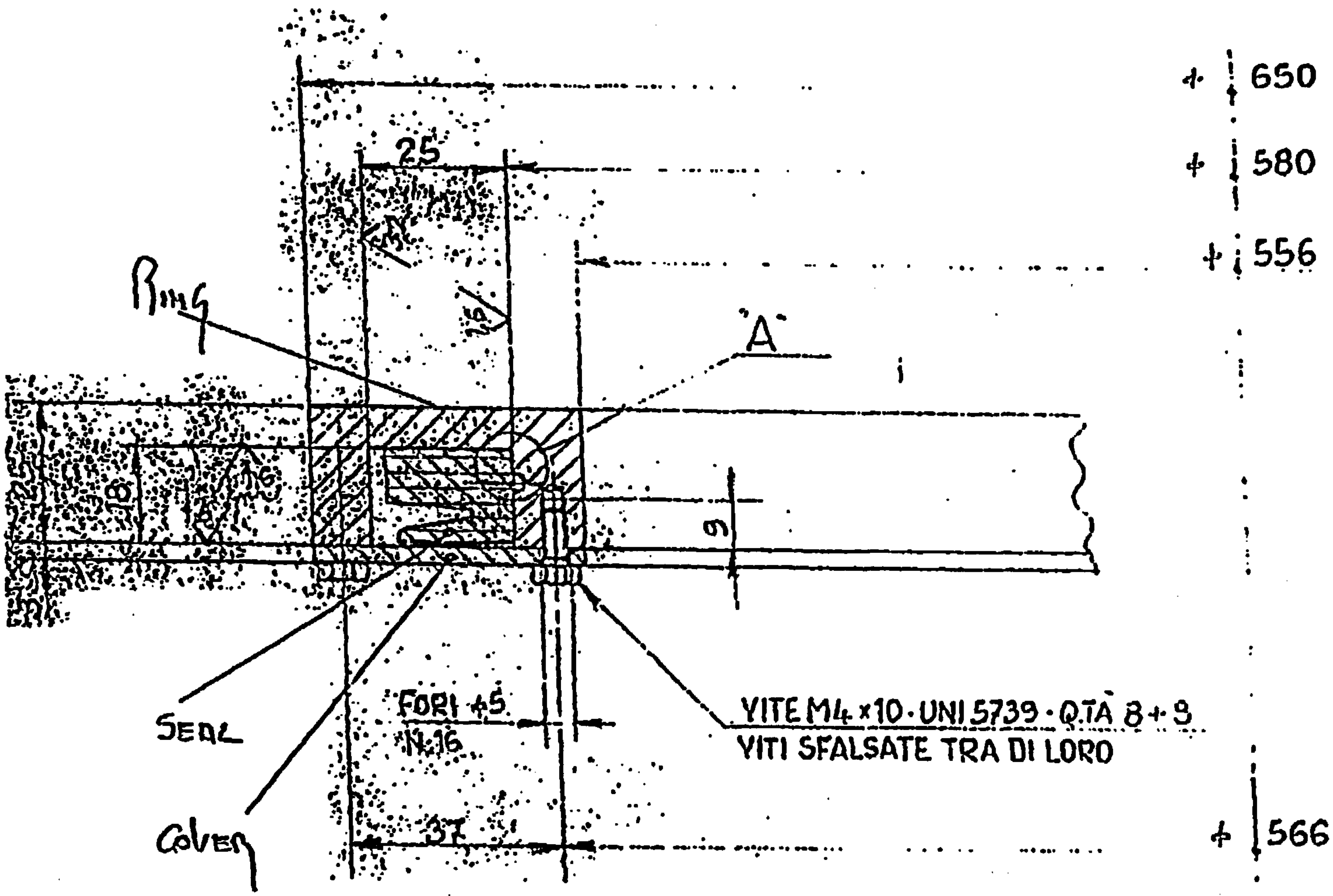


HATÙ-ICO

CASALECCHIO DI RENO



Attachment C.6 (sheet 2/2) Plan view



Attachment C.7 Test tool for primary seal irradiation

ATTACHMENT D

FIAT CIEI DOCUMENT, N° ED45894

FERIOLI E GIANOTTI TESTS PROCEDURE

DOCUMENT TYPE: TEST PROCEDURE

INTERNAL CLASSIFICATION: N° 98/94

TITLE : S.B.W.R. VACUUM BREAKER (V.B.) PROTOTYPE EXPERIMENTAL QUALIFICATION THERMAL AGEING PROCEDURE

JOB N°: C33650

AUTHORS:

- FERIOLI E GIANOTTI
- FIAT CIEI

The present document is the SECTION D of the vacuum breaker prototype general test procedure ED45833

0	April 94	C. Partiti	C. Partiti	B. Parlatore	
REV.	DATA	EMISSIONE	VERIFICA	APPROVAZIONE	

Mod. CIEI 9721 - Fo. 6/80

SUMMARY

Attachments:

D.1) INTRODUCTION

The procedure refers to the thermal ageing campaign to be performed on the S.B.W.R. VACUUM BREAKER (V.B.) PROTOTYPE, as a part of its experimental qualification program.
The campaign will simulate the cumulative effects due to environmental temperature of the reactor building during a V.B. mean life time of 6 years.
The whole V.B. will be subjected to the campaign, which might however cause measurable effects primarily on the sealing disk displacements monitoring instrumentation and on the elastomeric soft seal.

D.2) FACILITY DESCRIPTION

The thermal ageing campaign will be performed by means of the furnace of "FERIOLI E GIANOTTI - HEAT TREATMENTS", Turin, Italy. The furnace is a "hot air recirculation" facility and its principal features are sketched in Attachment D.1., where also test item installation and thermal monitoring devices are indicated.

The upper portion of the stand-pipe mock-up used for flow tests performance (see procedure FIAT CIEI n° ED45834 Attachment B.3, sheet 2/2) will be utilized as a V.B. supporting device, to make its installation inside the furnace easier.

D.3) INSTRUMENTATION

The furnace is equipped with following instrumentation:

- Safety monitoring:
  - instrument: pyrometer
  - made by: CHINO
  - range: 0°\1000° C (32°\1832° F)
  - precision: between 0,5 and 1%
  - serial number: 4376131

- Control monitoring:
  - instrument: pyrometer
  - made by: CHINO
  - range: 0°\400° C (32°\752° F)
  - precision: better than 0.5%
  - serial number: 1163974

- Recording
  - instruments: thermocouples (n° 3 units)
  - made by: TERMOTECNICA
  - range: 200°\1000°C (392°\1832°F)
  - precision: better than 0,5%
  - serial number: D2, D3, D4

Certification sheets of furnace instrumentation are shown in Attachment D.2.

D.4) DATA ACQUISITION AND PROCESSING

Furnace temperatures time histories will be paper recorded during the V.D. thermal ageing campaign by means of following device:

- multitracks recorder
- made by: SICEST
- range: 0°\1200°C (32°\2192° F)
- precision: better than 0.5%

The device certification sheet is shown in Attachment D.3

D.5) OPERATIVE SEQUENCE

D.5.1) Thermal ageing
Following phases are planned:

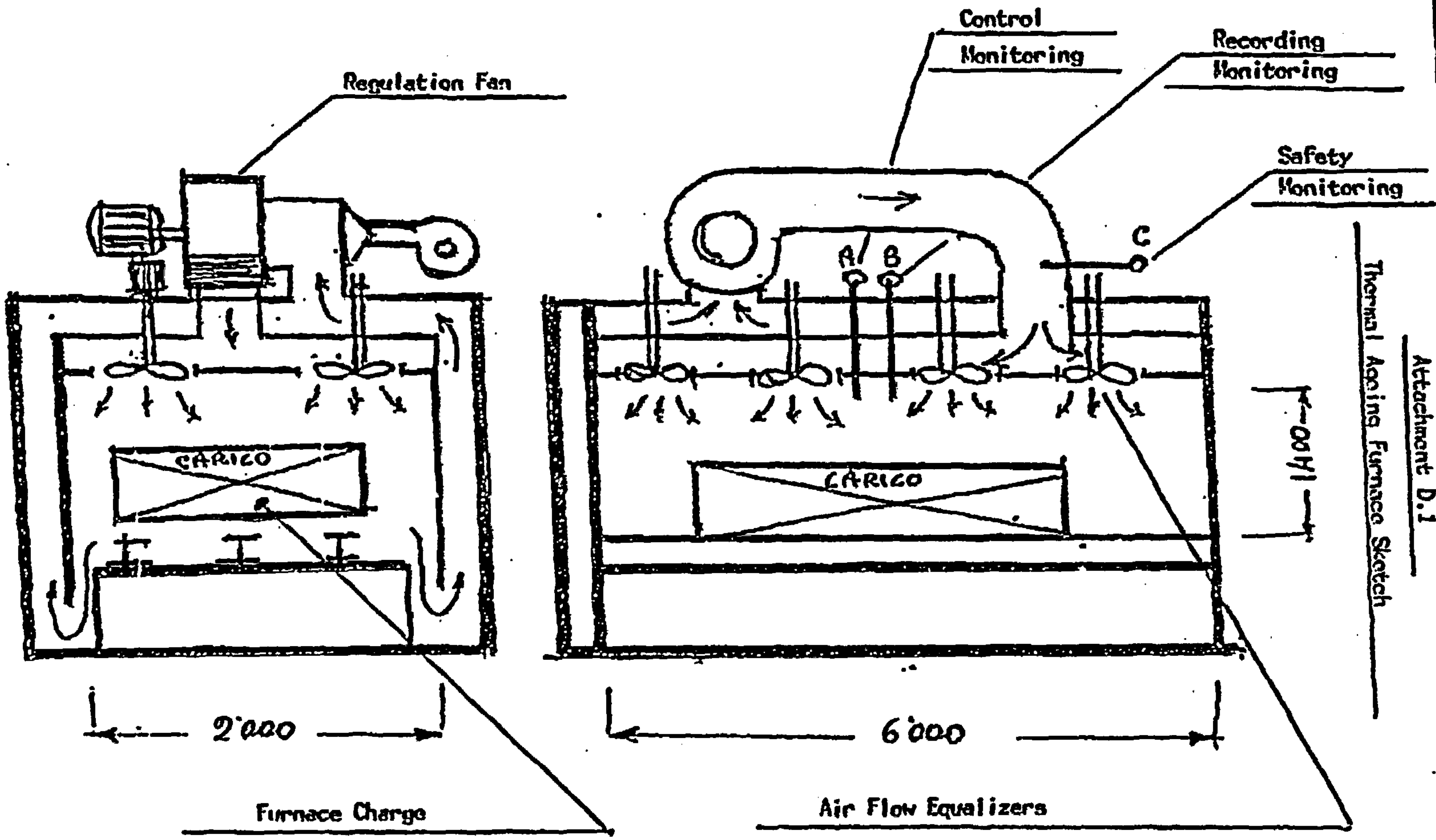
a) Heat-up
The V.B. will be installed inside the furnace equipped with its disk displacements monitoring instrumentation (n°5 probes) and with a radiation - aged primary soft seal.
The temperature of the furnace will be increased at low rate (30°\40°C per hour, 54°\72°F per hour) to 121°C (250°F), and its time history will be paper recorded.

b) Steady phase
The V.B. will be maintained at a constant temperature of 121°C (250°F) for 8 days (192 hours).
Furnace temperature will be paper recorded during the whole period.

c) Cool down
The temperature of the furnace will be lowered to ambient value at low rate (30°\40°C per hour, 54°\72°F per hour), with continuous recording.

Paper records coming from the three phases will certify the execution of the thermal ageing campaign.

Mod. CIEI 9022 - Ta. 6/80



Attachment D.1

Thermal Ageing Furnace Sketch

FIAT - COMPONENTI E IMPIANTI PER L'ENERGIA E L'INDUSTRIA S.p.A.

DIVISIONE CIEI

ED15833

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SAFETY PYROMETER CERTIFICATE

FERIOLI & GIANOTTI S.p.A. Mod. LAB 002	SCHEDA TARATURA STRUMENTI CONTROLLO E GESTIONE TEMPERATURA	Data 8-12-1993 Firma [signature]

CONTROLLO IN ACCETTAZIONE ☐ **CONTROLLO IN PRODUZIONE** ☒

Tipo strumento PIROMETRO
Matricola 4376131
Costruttore CHINO
N° XAB -- Data --
N° certificato conformità --
Anno di fabbricazione 1979
Scala 0-1000° Risoluzione ±5°
Tipo di termocoppia K
Campo di temperatura utile 0-1000
Destinato a impianto FL2
Utilizzato su impianto N° FL2
Periodo utilizzo --
Data rottamazione

Forno N° FL2 Reparto AREZZO
Data 8-12-93 Firma [signature]
PIROMETRO DI SICUREZZA

Interventi di manutenzione

° C MEMOCAL	° C STRUMENTO	° C MEMOCAL	° C STRUMENTO
100	105	100	
200	205	200	
300	300	300	
400	400	400	
500	495	500	
600	595	600	
700	695	700	
800	800	800	
900	900	900	
1000		1000	
1100		1100	
1200		1200	
ΔT ammesso ±0,5%	ΔT riscontrato	ΔT ammesso ±0,5%	ΔT riscontrato

Note: Idoneo [signature]

Note:

CONTROL PYROMETER CERTIFICATE

FERIOLI & GIANOTTI S.p.A.
Mod. LAB 002

SCHEDA TARATURA STRUMENTI CONTROLLO E GESTIONE TEMPERATURA

Data 8.12.1993
Firma Gianotti

CONTROLLO IN ACCETTAZIONE ☐

Tipo strumento PIROMETRO
Matricola 11639?4
Costruttore CHINO
N° XAB – Data –
N° certificato conformità –
Anno di fabbricazione 1979
Scala 0-400° Risoluzione ±1°
Tipo di termocoppia K
Campo di temperatura utile 0-400
Destinato a impianto FL2
Utilizzato su impianto N° FL2
Periodo utilizzo –
Data rottamazione –

CONTROLLO IN PRODUZIONE ☒

Forno N° FL2 Reparto Arrezzo
Data 8.12.93 Firma Gianotti

PIROMETRO DI REGOLAZIONE

Interventi di manutenzione

°C MEMOCAL	°C STRUMENTO	°C MEMOCAL	°C STRUMENTO
100	100	100	
200	200	200	
300	301	300	
400	401	400	
500		500	
600		600	
700		700	
800		800	
900		900	
1000		1000	
1100		1100	
1200		1200	
ΔT ammesso ± 0,5%	ΔT riscontrato	ΔT ammesso ± 0,5%	ΔT riscontrato

Note: Idoneo Ef.

Note:

Mod. C418012 - Tp 0480

1st RECORDING THERMOCOUPLE CERTIFICATE

FERIOLI & GIANOTTI S.p.A.
Mod. LAB 001

SCHEDA TARATURA TERMOCOPPIE

Data 2 [illegible]
Firma [illegible]

Matricola termocoppia D2 Fornitore TERMOTECNICA

N° XAB .... Data .... N° dichiarazione conformità ....

Tipo termocoppia K Campo di temperatura .... ΔT ....

Tipo di impianto a cui è destinata FORNO LOTTI 2, (INVECCHIAM. AL)

N° forno utilizzatore .... Periodo .... Rottamatura ....

DATI DI PROVA

N°	Temperatura di prova °C	Temperatura Memocal °C	Temperatura termocoppia °C	ΔT °C
1	200	201	201	-
2	400	400	401	+1
3	600	601	600	-1
4	700	699	700	+1
5	800	801	803	+2
6	900	899	901	+2
7	1000	1003	1005	+2

NOTE:

GIUDIZIO: Adatta

[illegible]

FIAT - COMPONENTI E IMPIANTI PER L'ENERGIA E L'INDUSTRIA S.p.A. DIVISIONE CIEI	ATTACHMENT D.2 FURNACE INSTRUM. CERTIFICATION SHEETS	ED45833 Page 146

2nd RECORDING THERMOCOUPLE CERTIFICATE

FERIOLI & GIANOTTI S.p.A. Mod. LAB 001	SCHEDA TARATURA TERMOCOPPIE	Data 26/11/93 Firma [illegible]

Matricola termocoppia Δ3 Fornitore TERMOTECNICA.

N° XAB .... Data .... N° dichiarazione conformità ....

Tipo termocoppia .... Campo di temperatura .... ΔT ....

Tipo di impianto a cui è destinata FORNO LOTTI 2 (INVECCHIAM. ALLUM.)

N° forno utilizzatore .... Periodo .... Rottamatura ....

DATI DI PROVA

N°	Temperatura di prova °C	Temperatura Memocal °C	Temperatura termocoppia °C	ΔT °C
1	200	201	201	-
2	400	400	400	-
3	600	601	602	+1
4	700	699	699	-
5	800	801	803	+2
6	900	899	900	+1
7	1000	1003	1004	+1

NOTE:

GIUDIZIO: Adatta

[illegible]

Vol. 0613322 - Tp G430

3rd RECORDING THERMOCOUPLE CERTIFICATE

FERIOLI & GIANOTTI S.p.A. Mod. LAB 001	SCHEDA TARATURA TERMOCOPPIE	Data 22/4/03 Firma Grandi

Matricola termocoppia ...L 4... Fornitore ...TERMOTECNICA...

N° XAB .... Data .... N° dichiarazione conformità ....

Tipo termocoppia .... Campo di temperatura .... ΔT ....

Tipo di impianto a cui è destinata ...FORNO A LOTTI 2 (INVECCHIAM. AL.)

N° forno utilizzatore .... Periodo .... Rottamatura ....

DATI DI PROVA

N°	Temperatura di prova °C	Temperatura Memocal °C	Temperatura termocoppia °C	ΔT °C
1	200	201	201	-
2	400	400	400	-
3	600	604	604	-
4	700	699	700	+1
5	800	801	802	+1
6	900	899	898	-1
7	1000	1003	1001	-2

NOTE:

GIUDIZIO: Idonea

Mod. C41322 - To. 0250

ATTACHMENT D.3 – TEMPERATURE RECORDER CERTIFICATION SHEET

FERIOLI & GIANOTTI S.p.A. Mod. LAB 002	SCHEDA TARATURA STRUMENTI CONTROLLO E GESTIONE TEMPERATURA	Data 6.12.1993 Firma Grandi

CONTROLLO IN ACCETTAZIONE ☐	CONTROLLO IN PRODUZIONE ☑
Tipo strumento REGISTRATORE 6 PISTE Matricola 9LL ф.u. — SEI PISTE Costruttore SICEST N° XAB — Data — N° certificato conformità — Anno di fabbricazione 1993 Scala 0-1200 Risoluzione ±1 Tipo di termocoppia K Campo di temperatura utile 0-1200 Destinato a impianto FLN2 Utilizzato su impianto N° Periodo utilizzo — Data rottamazione —	Forno N° FL2 Reparto GAZZO Data 6.12.93 Firma Grandi REGISTRATORE 6 PISTE Interventi di manutenzione

°C MEMOCAL	°C STRUMENTO	°C MEMOCAL	°C STRUMENTO
100	101	100	
200	201	200	
300	301	300	
400	400	400	
500	500	500	
600	600	600	
700	699	700	
800	799	800	
900	898	900	
1000	998	1000	
1100	1098	1100	
1200	—	1200	
ΔT ammesso ±0,5%	ΔT riscontrato	ΔT ammesso ±0,5%	ΔT riscontrato

Note: Idoneo SF	Note:

Mod. CEI 3032 - 1a GASO

ATTACHMENT E

ANSALDO RICERCHE DOCUMENT, N° TCE MII.S.1001

ANSALDO RICERCHE TESTS PROCEDURE

ANSALDO
Ricerche

Progetto	Identificativo document no. TCE.MII.S.1001			
Cliente client FIAT CIEI	Comm.-s/comm. job. no. TQ8000	Emittente issued by ARI.TCE	Pagina page 1	Di of 23

Rag. doc. doc. code	Rif. str. prod. prod. str. no.	Identificativo componente equipment identification code	Tipo doc. doc.type	Cl. ris. class	Allegati enclosures

Titolo title
DRYWELL TO WETWELL VACUUM BREAKER DYNAMIC QUALIFICATION. TEST PROCEDURE.

Derivato da derived from

Sostituisce substitutes

Rev. rev. 0 Data date 22/02/94 Descrizione: description Stato valid.: rev. scope

Redazione: prepared by A. BOTTINO Bottino

Controllo/approvazione: checked by/approved by C. MAZZIERI

Autorizzazione emissione: issue authorization C. MAZZIERI

ATTACHMENT "E" TO FIAT CIEI GENERAL PROCEDURE

CED

Rev. rev.	Data date	Descrizione description	Stato Valid. rev. scope	Redazione prepared by	Controllo/ approvazione checked by/ approved by	Autorizzazione emissione issue authorization
1	27.04.94	Revision due to modification of response spectra contained in the test specification		A. Bottino	C. Mazzieri	C. Mazzieri

Progetto project	Identificativo document no. TCE.MII.S.1001	Rev. rev. 1	Pagina page 2

INDEX

E.1 Introduction

E.1.1 Scope

This document has the scope to define the procedure that will be used to perform resonance, fragility and seismic tests on the **DRYWELL TO WETWELL VACUUM BREAKER** described at ref. E.1.2.1.1 and E.1.2.1.2 .

E.1.2 Reference documents

E.1.2.1 FIAT CIEI and G.E documents

E.1.2.1.1 25A5445 rev. 1 " Drywell to wetwell vacuum breaker . Test specification "
E.1.2.1.2 2T137684 rev. 1 " SBWR . Vacuum breaker valve . General assembly "
E.1.2.1.3 Letter FIAT CIEI S/CP/1/0048/94 dated 15.04.94 containing modification of acceleration response spectra
E.1.2.1.4 Drawings NO. 2136331 , 2136332 , 2136337 and notes contained in letter Fiat CIEI S/CP/1/0013/34
E.1.2.1.5 2S137714 rev. 1 " SBWR . Vacuum breaker valve . Outline "
E.1.2.1.6 Fax FIAT CIEI S/CP/1/0052/94 dated 19.04.94 containing precisation about applicable acceleration response spectra .

E.1.2.2 Ansaldo Ricerche documents

E.1.2.2.1 MTS Operation manual - JOB 932.89
E.1.2.2.2 MTS Seismic simulation software manual - JOB 921.78
E.1.2.2.3 LAQ.RP.003 rev. 0 " Rapporto di qualificazione programmi di simulazione sismica"
E.1.2.2.4 LAQ.RP.016 rev. 0 " Impianto di simulazione sismica biassiale . Rapporto delle prove di qualificazione "
E.1.2.2.5 LAQ.PT.384 rev. 0 " Sistema di monitoraggio contact chatters . Concetti e istruzioni operative del software ".

E.2 Test arrangement description

E.2.1 Vacuum valve and test facility identification and description

E.2.1.1 Vacuum valve identification and description

The vacuum valve is described in ref. E.1.2.1.1 and E.1.2.1.2. The device will be shipped to Ansaldo Ricerche assembled in test configuration, that is with the test flanges (item 25 of reference E.1.2.1.2) mounted on the outlets, and the valve itself mounted on the supporting flanges of ref. E.1.2.1.4.
The mass of the valve is equal to 1245 kg. The mass of the supporting flange (see ref. E.1.2.1.4) is equal to 210 Kg..
The device will be identified by the serial number written on the nameplate.
The nameplate will be tack welded to the outer surface of the valve (see ref. E.1.2.1.2).

E.2.1.2 Test facility identification and description

For the dynamic tests described in this procedure the " SCORPIUS " shaking table of Ansaldo Ricerche will be used. A description of this test facility is contained in ref. E.1.2.2.1 and E.1.2.2.4.

E.2.2 Environmental conditions simulation

E.2.2.1 Fragility test conditions

The fragility qualification will be performed by subjecting the device (at the basis of the supporting flange : see ref. E.1.2.1.4) to uniaxial sinusoidal excitation along each of the principal axis until the malfunction of the valve (see para. E.2.3 and E.6). The characteristics of the sinusoidal motion will be the following (see ref. E.1.2.1.1):

a) Sine sweep test integrated with sine dwell test

- acceleration peak value : 1g and 2g (this value could be lower depending on the shaking table maximum capability)
- frequency range : from 10 to 100 Hz for each acceleration peak value
- sweep rate : ≤ 2 oct/min

The frequency range from 4 Hz to 10 Hz will be covered by sine dwells at 4 Hz and 7 Hz with the acceleration peak values indicated above. The duration of each dwell will be 30 s.

Progetto project	Identificativo document no. TCE.MII.S.1001	Rev. rev. 1	Pagina page 5

In case the above said accelerations values were not able to provoke the malfunction of the valve (see para. E.2.3 and E.6) the fragility test will be performed with the method of the sine dwell as indicated below:

- acceleration : two value, with peak acceleration >2g, up to the limits of the shaking table, with step of 1g or less (consistent with the table capability, see fig. 4)
- frequency : see fig. 4
- duration : 30 s for each peak value

b) Resonance frequency dwell

- acceleration peak value : from 1g up to the limits of the shaking table (see fig. 4) with step of 1g (consistent with the table capability, see fig. 4)
- frequency : first resonance frequency identified during resonance search test (see paragraph E.4.3)
- duration : 30 s for each peak value

E.2.2.2 Seismic conditions

The seismic qualification will be performed by subjecting the device (at the basis of the supporting flange ; see ref. E.1.2.1.4) to a biaxial vibratory motion defined by the SSE response spectra (RRS) of fig. 1, 2 and 3.
These spectra are obtained as envelope of the two vertical and horizontal spectra contained in ref. E.1.2.1.3.
The tests simulating the SSE vibratory motion will consist of the application of:

- 10 acceleration time histories (the duration of each test shall be 30 s)

The result of the test will be presented in terms of test response spectra (TRS) at 2% damping for comparision to the corresponding RRS of fig. 1, 2 and 3.
The processed TRS will envelope the RRS of fig. 1, 2 and 3.
The frequency distribution of the significative components of the seismic motion will be limited to 36 Hz.

E.2.3 Functional condition simulation

The tested vacuum valve will be equipped with 5 proximity probes, 1 pressure transducer and related electronic equipments for feeding and conditioning (supplied by FIAT CIEI).
The output of these probes will be recorded during the dynamic tests. Before the starts of the tests the inlet volume of the vacuum valve will be pressurized with nitrogen or air.

The pressure value will be about 100÷150 mm of water .The necessary equipment will be supplied by FIAT CIEI .
The output signals will have the following characteristics :

- type of signals : DC voltage
- range : 0÷2 V for proximity sensors
- range : 1÷5 V for the pressure transducer ; obtained by the flowing of the pressure transducer output current (4÷20 mA) through a 250 ohm resistor (precision 1 %) placed in the pressure transducer circuit

The above instruments will be switched on and switched off some seconds before and after the start and stop (respectively) of each dynamic tests .
The computerized system used for the acquisition and recording of the above signals is described in ref. E.1.2.2.5 (see also para. E.3.2) . An equivalent system could be used alternatively .
These systems grant a resolution of ±5 mV .

E.2.4 Interfaces

The device tested will be mounted on a supporting flange supplied by FIAT CIEI (see ref. E.1.2.1.4) . This fixture will be fixed to the shaking table (vacuum valve stem in vertical position and horizontal axes of the discharge outlets coincident with those of the shaking table) and will permit to rotate the device 90 degrees with respect to the shaking table .

E.3 Test instrumentation

E.3.1 Measuring devices locations

E.3.1.1 Accelerometers locations

The shaking table motion will be controlled by means of two accelerometers mounted in the position of fig. 5.
Response accelerations of the vacuum valve will be recorded by means of three accelerometers mounted on each principal axis of the device (see fig. 6).
Response accelerations will be recorded only during the resonance search test.

E.3.1.2 Proximity probes and pressure transducer locations

The proximity probes (no. 5) and the pressure transducer (see paragraph E.2.3) will be installed by FIAT CIEI.
The proximity probes locations are indicated at ref. E.1.2.1.2. The pressure transducer location will be indicated by FIAT CIEI and will not be affected by vacuum breaker vibrations.

E.3.2 Control and measurement equipment

E.3.2.1 Equipments

A) Control and measurement equipment for Scorpius shaking table

1. digital programming and data acquisition consoles (with DEC PDP 11/34)
2. control analog console MTS 443.11
3. accelerometers ENDEVCO 2262.25 used to control the shaking table
4. amplifiers DC-MTS 440.21
5. oscillator mod. SD104A/5 for fragility tests (sine dwell)
6. LING analogical system for acceleration control (for sine sweep fragility and resonance search tests)

A schematic diagram of the control and measuring equipment is shown in fig. 7.

B) Measurement equipment for acceleration signals

1. accelerometers ENDEVCO 2262C-25/2262-25 and/or Bruel & Kjaer 4438
2. amplifiers VISHAY 3120 or Validine PA89 equipped with impedance converters COLUMBIA mod. 5673 (or equivalent)

3. converters A/D MTS-12 bits-1231.0
4. computer DEC-PDP 11/34
5. computer acquisition system Masscomp SLS-5450-01 (see ref. E.1.2.2.5) or equivalent for sine sweep fragility test and sine dwell (fragility) test at resonance frequency .

C) Measurement equipment for proximity probes and pressure transducer

The measurement equipment indicated at previous point B) 5 or equivalent will be used to measure and record the signals indicated at paragraph E.2.3 .

E.3.2.2 Measuring errors

a) The global measuring errors of the acceleration measuring devices is equal to :

$$\varepsilon < 2.3\ \% \qquad 0 \div 200\ \text{Hz}$$

b) The measuring resolution of the output voltages from proximity sensors and pressure transducer is :

$$\pm 5\ \text{mV}$$

E.4 Test data acquisition and processing systems

E.4.1 System software

The software used during dynamic tests will be the following (see ref. E.1.2.2.1 ÷ E.1.2.2.3) :

- MTS frequency response function analysis
- MTS random data analysis
- MTS earthquake simulation testing software
- Time data shock response spectrum syntesis and analysis program

E.4.2 Synthetization of the accelerograms simulating the seismic SSE events

The accelerograms will be generated by computer in order to obtain 30 s simulated seismic events .

The synthetized accelerograms will be random motions with the following characteristics :

- block size : 4096
- output rate : 409.6 Hz
- time duration : 10 s

The time duration of 30 s will be obtained sending the same signal to the shaking table for three times without interruption .

E.4.3 Resonance search test

A resonance search test for the different measuring locations on the device (see paragraph E.3.1) will be performed before the application of seismic and fragility tests.

The test will consist in the application of a sine sweep uniaxial motion for each of the three principal axis .

The characteristic of the motion will be the following :

- type of motion : sine sweep
- frequency range : from 4 to 100 Hz and back
- acceleration peak value : 0.2 g
- sweep rate : ≤ 2 oct/min

E.4.4 Signals acquisition and processing

E.4.4.1 Signals from accelerometers

E.4.4.1.1 Acquisition

The characteristics of sampling acquisition are :

- low pass filter cut off frequency : 200 HZ
- sampling rate : 409.6 Hz for resonance and seimic tests
- sampling rate : 200 Hz for sine sweep fragility test and sine dwell fragility test at resonance frequency

E.4.4.1.2 Processing

E.4.4.1.2.1 Resonance search test

The data from the accelerometers on the device and those from the accelerometers on the shaking table will be recorded and processed as transfer function of the measuring points on the device to the table accelerations .
Any amplification exceeding ratio of 4 to 1 will be defined as resonance .

E.4.4.1.2.2 Fragility test

a) Sine sweep test

The table accelerations will be recorded and processed in order to obtain :

- Accelerograms defining the table motion

b) Dwell test in the range 4÷100 Hz

The peak acceleration of each dwell will be controlled by the shaking table operators through the display of the LING system (see paragraph E.3.2.1 A point 6) . Each performed test value will be registered in special tables by the operator .

c) Dwell test (at resonance frequency)

The 30 s table accelerations will be recorded and processed in order to obtain :

- Accelerograms defining the table motion

E.4.4.1.2.3 Seismic test (SSE)

The last 10 s of table accelerations will be recorded and processed in order to obtain :

- accelerograms defining the table motion
- response spectra (TRS) with the following characteristics :
  - absolute value
  - frequency range : 1÷100 Hz
  - resolution : 1/3 octave
  - damping : 2 %

E.4.4.2 Signals from proximity sensors and from pressure transducer

Voltage signals from proximity sensors and pressure tranducer will be recorded and processed in order to obtain (see also paragraph E.3.2.1 C) :

- diagrams of voltage versus time

E.5 Test sequence

The tests will be performed according to the following sequence :

a. identification of the device (see paragraph E.2.1)
b. mounting of the device on the shaking table (see para. E.2.4) , preparation of the map of the signals to acquire during tests (see para. E.3.2) .
c. connection of the feeding cables of the proximity sensors and pressure transducer electronic systems to the electric net . Connection of the measuring instruments to data acquisition systems and checking of the correct operating of the acquisition systems (see para. E.2.3 and E.3.2) .
d. perform uniaxial resonance search test (see para. E.4.3) in the following directions :

- z (vertical direction)
- x (first horizontal direction)

e. rotate the device 90 degrees in the horizontal plane
f. repeat point d. in the y direction
g. pressurization of the internal volume of the vacuum valve with nitrogen or air (see paragraph E.2.3)
h. perform uniaxial fragility tests by sine sweep and eventually by sine dwell (see para. E.2.2.1 a)) in the directions z and y
i. perform uniaxial fragility tests (see para E.2.2.1 b)) by sine dwell at the first resonance frequency (if existing) in the directions z and y
l. rotate the device 90 degrees in the horizontal plane
m. repeat point h. in the x direction
n. repeat point i. in the x direction
o. perform 10 bidirectional SSE tests of 30 s duration (see paragrapphs E.2.2.2 and E.4.2) in the directions z/x
p. rotate the device 90 degrees in the horizontal plane
q. perform point o. in the z/y directions

The proximity sensors and pressure transducer measuring systems (see para. E.2.3) will be switched on and switched off some seconds before and after the starting and stopping (respect.) of each dynamic tests .
At the end of each SSE and fragility event a visual inspection of the device will be performed .
Any significative visible failure or modification of the device will be registered in the laboratory log-book (see paragraph E.8) .

E.6 Acceptance criteria

E.6.1 Dynamic tests acceptance criteria

E.6.1.1 Resonance search acceptance criteria

As stated in ref. E.1.2.1.1 any amplification exceeding ratio of 4 to 1 will be defined as resonance .

E.6.1.2 Fragility test

The only acceptance criteria applied to these tests are those related to the performance of the vacuum valve . They are indicated at paragraph E.6.2 .

E.6.1.3 SSE seismic test

During tests it will be controlled that :

- the test response spectra (TRS) related to the table motion, will envelope the required response spectra (RRS of fig. 1 , 2 and 3) .
- the peak value of the imposed acceleration will be equal or greater than the Z.P.A taken through the RRS og fig. 1 , 2 and 3 .

It will be acceptable that the TRS is lower than RRS in the frequency field under 4 Hz .
In case of test non conformances the repetition of the SSE event is allowed with a maximum of 4 SSE events on a total of 10 SSE .

E.6.2 Functional tests acceptance criteria (by FIAT CIEI)

The acceptance criteria related to the performance of the device during dynamic tests, based on proximity sensors and pressure transducer outputs, will be defined and maneged by FIAT CIEI . Ansaldo Ricerche will only acquire and process the output of the above probes (as indicated at paragraph E.2.3 and E.4.4.2) .

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E.7 Test report

The test report will contain :

- test device identification
- test facility description
- results of resonance research tests (see paragraph E.4.4.1.2.1)
- results of fragility tests (see paragraph 4.4.1.2.2)
- results of SSE tests (see paragraph 4.4.1.2.3)
- results of the acquired outputs of proximity sensors and pressure transducer (see paragraph E.4.4.2)
- informations about possible visual failures of the device during the dynamic tests
- indication of possible deviation with respect to the test procedure
- indication and description of possible non conformances (about dynamic test)

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E.8 Quality assurance requirements

E.8.1 Documents to be issued

For the present activity the following documents will be issued :

- present test procedure
- quality control plan
- test report

Moreover the test activity will be recorded in the laboratory log book

E.8.2 Calibration status of accelerometer chains

Ansaldo Ricerche calibration laboratory has implemented an instrumentation management system that permit to control the calibration status of the accelerometers chains (accelerometers and amplifiers) used .

E.9 Management of test non conformances

Any type of non conformances occurring during any phase of the dynamic tests comprising those indicated at paragraph E.6 (acceptance criteria) , regardless the dynamic simulator performances or the test specimen performances , will be addressed in the following manner :

- complete identification , and documentation of the non conformance
- determination of the cause of the non conformance
- determination of the impact of the non conformance on the present phase of testing
- implementation of corrective measures to prevent reoccurrence of the non conformance

It shall be responsibility of the Ansaldo Ricerche laboratory :

- timely notifiy to FIAT CIEI that a test non conformance related to his test facility has occurred
- perform the activities listed above related to all the aspects of the non conformance inherent his test facility

It shall be responsibility of FIAT CIEI :

- perform the activity listed above related to all the test specimen functional aspects and their test equipments involved in the non conformance occurred .

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FIG. 1 RRS FOR HORIZONTAL X DIRECTION - 2% DAMPING

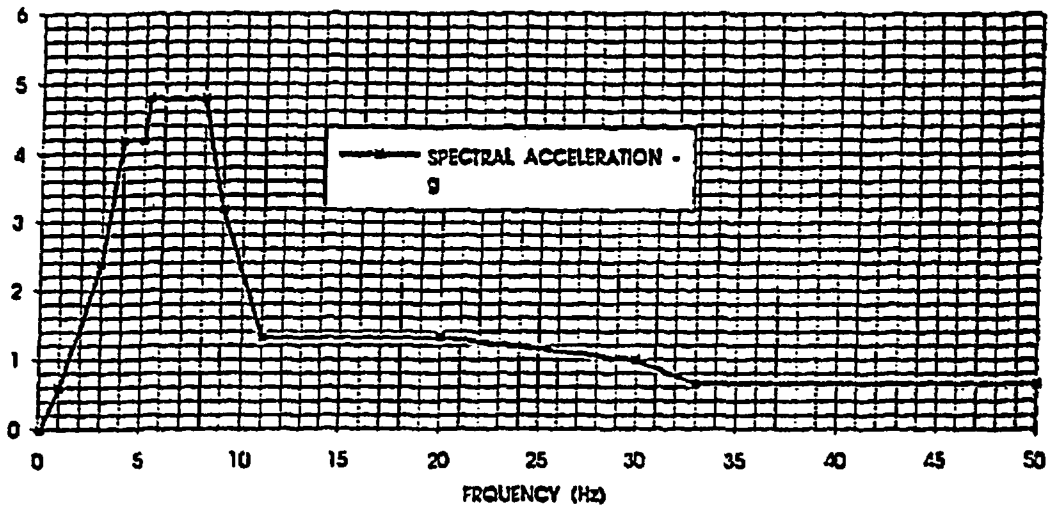

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FIG. 2 RRS FOR HORIZONTAL Y DIRECTION - 2% DAMPING

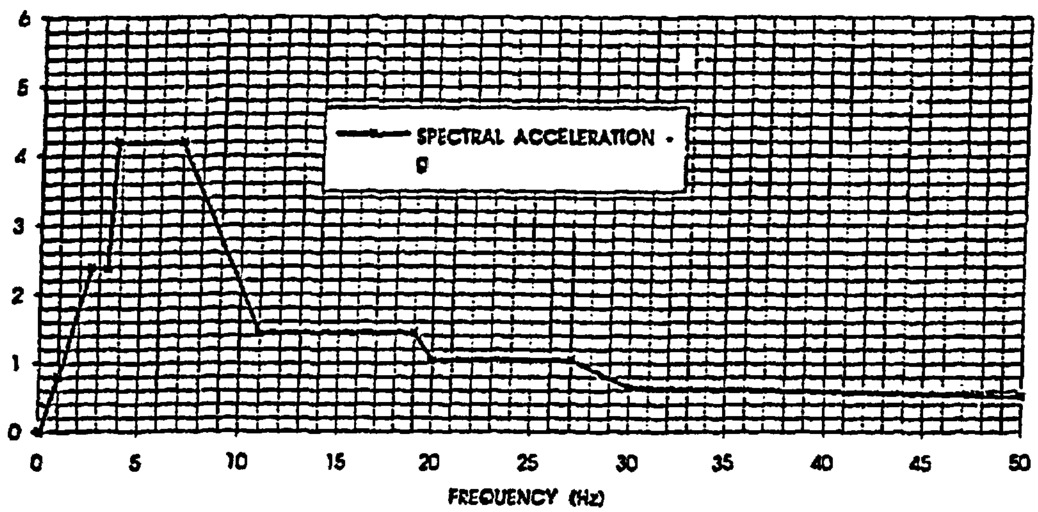

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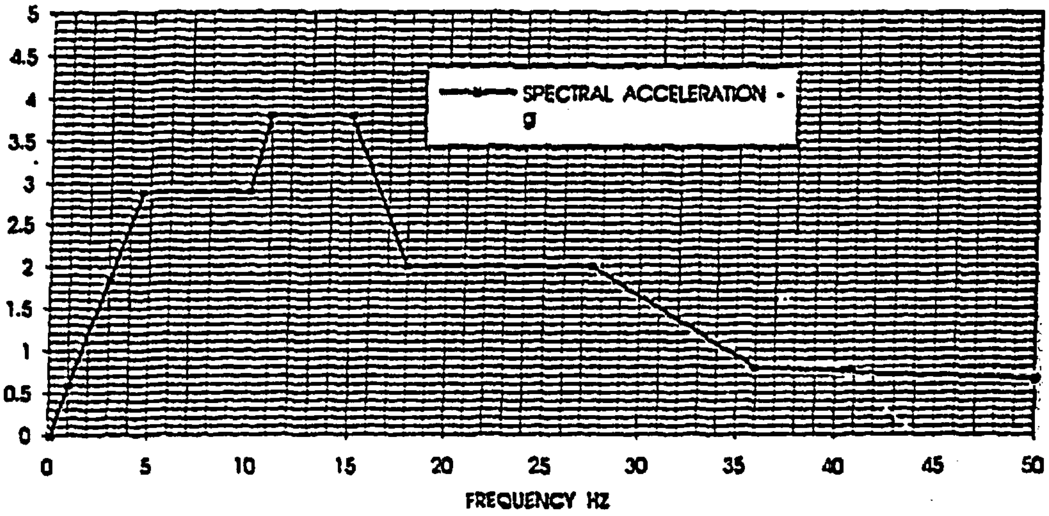
FIG. 3 RRS FOR VERTICAL Z DIRECTION - 2 % DAMPING



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MAXIMUM TABLE ACCELERATIONS WITH AN ADDED MASS OF 1400 Kg		
FREQUENCY (Hz)	ACCELERATION (g peak) VERTICAL AXIS	ACCELERATION (g peak) HORIZONTAL AXIS
4	3	2.5
7	4	4
10	4	4
16	4	4
22	4	4
28	4	4
34	4	4
40	3.5	4
46	3.5	4
50	4	4
58	3	4
64	4	4
70	4	4
76	3.5	4
82	2.5	4
88	2.5	4
94	2.5	4
100	3	4

FIG. 4 Shaking table maximum estimated performances (tested device mass 1400 Kg)

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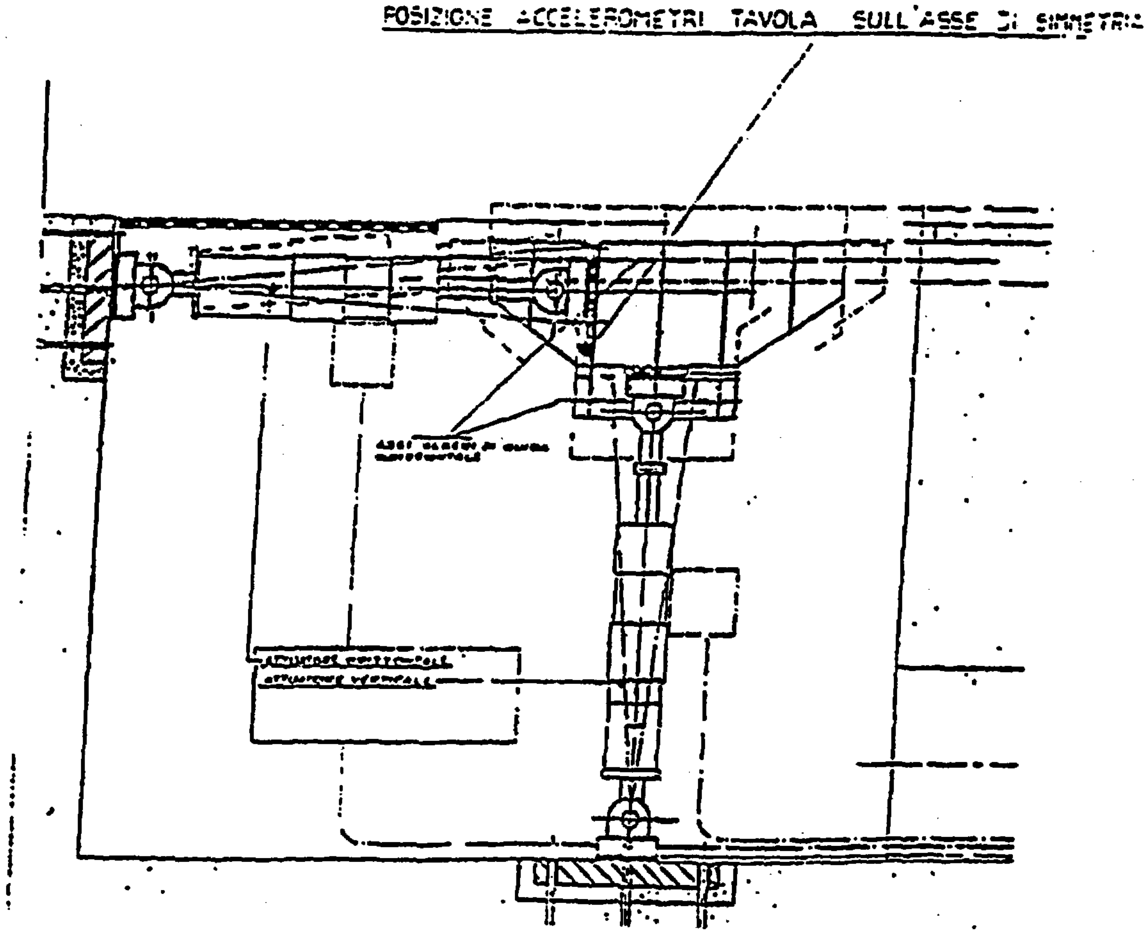

FIG. 5 Accelerometers locations on shaking table

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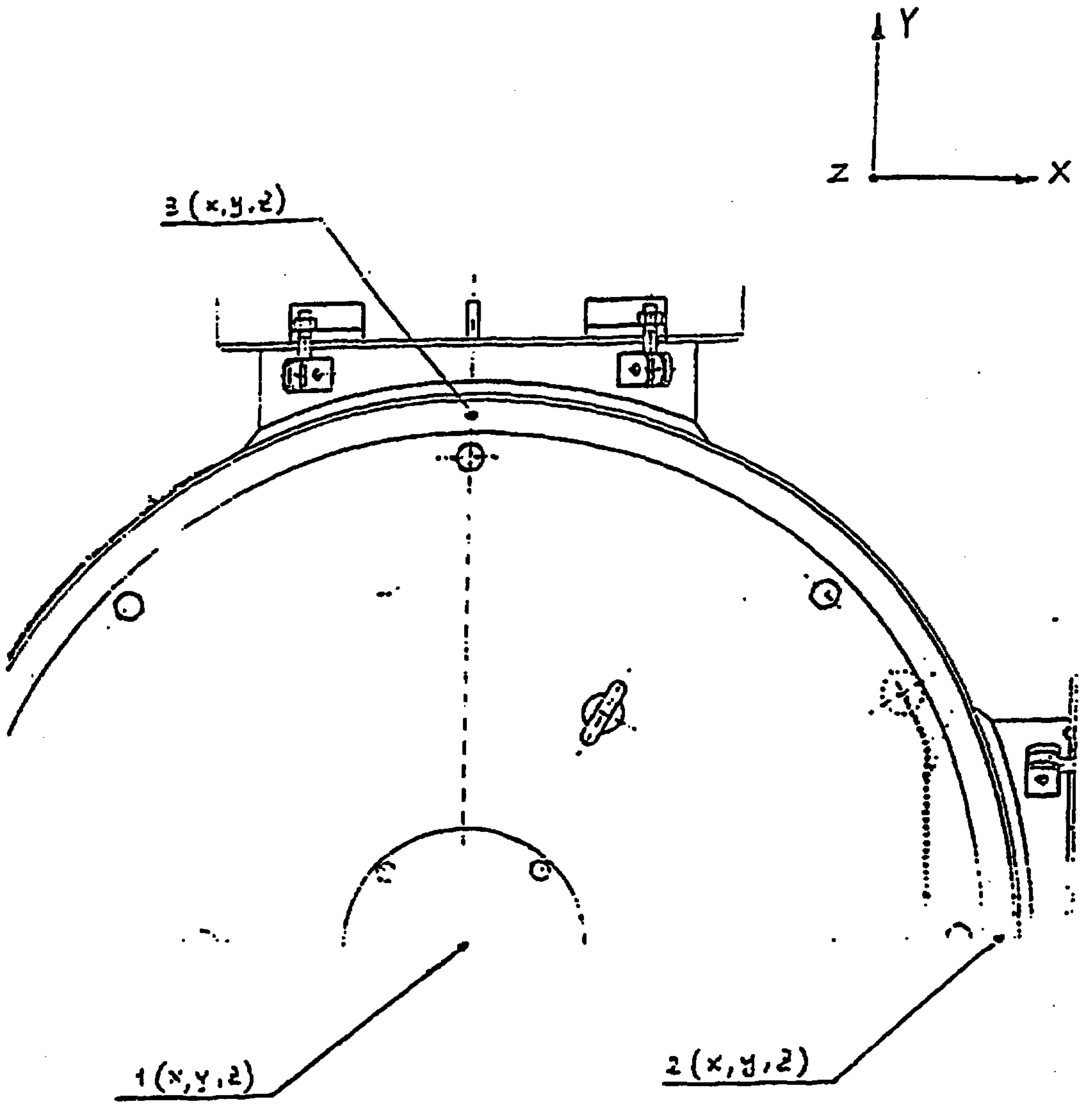

FIG. 6 Accelerometers locations on tested device (plant view)

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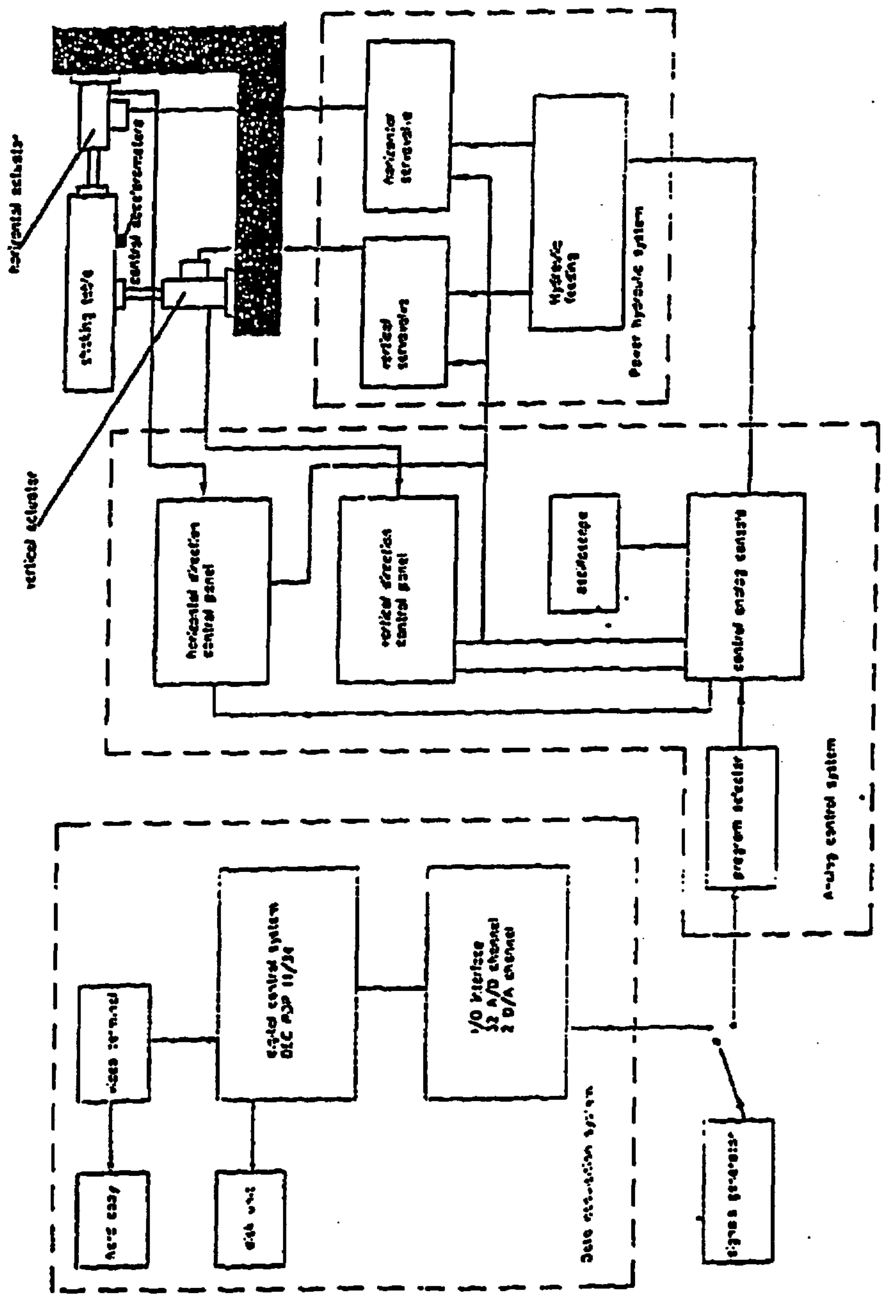

FIG. 7 Shaking table control scheme

ATTACHMENT F

B.P.D. DIFESA E SPAZIO DOCUMENT, N° PCNVBR00001

B.P.D. DIFESA E SPAZIO TESTS PROCEDURE

BPD DIFESA E SPAZIO

BPD

VACUUM BREAKER

DESIGN BASIS ACCIDENT SIMULATION
TEST PROCEDURE

THE PRESENT DOCUMENT IS THE SECTION F
OF THE VACUUM BREAKER PROTOTYPE
GENERAL TEST PROCEDURE. FIAT CIEI DOC. N° ED 45833

PREPARATO DA:	PRO/SP/INT	C.B. CARNEVALE	
CONTROLLATO DA:	PRO/SP/INT	V. MANTINI	
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PCNVBR00001 Is.: 1 Rev.: 1
Pag.: 2

BPD

BPD DIFESA E SPAZIO

ISSUED BY:	DOCUMENT CONFIGURATED	CLASSIFICATION
BPD DIFESA E SPAZIO	( ) Yes ( ) Not	IND
AUTHOR (S) : C.B. CARNEVALE	IF THE DOCUMENT IS ISSUED FOR A PROGRAM	
	Contractual	Program VACUUM BREAKER
Typist: /	(X) Yes ( )Not	N/A ( ) General ( )
DISKETTE IDENTIFICATION	Contract Number	Customer
	/	FIAT CIEI

TITLE:
~~VACUUM BREAKER~~
DRYWEL TO WETWELL VACUUM BREAKER DESIGN BASIS ACCIDENT SIMULATION TEST PROCEDURE

Pages: Annexes: Total Pages: 78

AUTOR ABSTRACT:

~~THIS DOCUMENT DESCRIBE HOW TO PERFORM THE DESIGN BASIS ACCIDENT SIMULATION TEST FOR~~
THE S.W..B.R. VACUUM BREAKER VALVE.

DEPT.: PRO/SP/INT NAME: V. MANTINI DATE: 21-07-94

KEY WORDS

- S.B.W.R.
- VACUUM BREAKER
- DESIGN BASIS
- ACCIDENT SIMULATION

Distributed by:

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VISA by CID: Date:

STATO DELLE EDIZIONI
ISSUE STATUS

Data Date	Ediz. Issue N.	Breve Descrizione della Modifica Brief Description of Change	Mod. N. (se rich.)	RAD N.	Config. Control Approval
21-07-94	1	FIRSTH ISSUE	/	/	

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NOTE: THIS DOCUMENT IS A PART OF THE S.B.W.R. VACUUM BREAKER (V.B.) PROTOTYPE EXPERIMENTAL QUALIFICATION GENERAL TEST PROCEDURE "ED 45833", AND CONSTITUTE THE SECTION "F" OF THAT DOCUMENT.

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CONTENTS

F.1 INTRODUCTION

F1.1 SCOPE

~~This procedure describes all the operations necessary to carry out~~ the DESIGN BASIS ACCIDENT (DBA) SIMULATION test for the VACUUM BREAKER valve. All the activities shall be performed at COLLEFERRO (Roma) in the 3C-TEST CENTER.

National and center safety regulation shall be considered as applicable.

~~F1.2~~ APPLICABLE DOCUMENTS:

25A5388	VACUUM BREAKER (PROTOTYPE)	PURCHASE SPEC.
25A5445	DRYWELL TO WETWELL V. BREAKER	TEST SPEC.
DWG 818.PC.01A.003.00		NITROGEN SUPPLY S. FOR LEAK TEST.
DWG 313.00.A.001		VACUUM BREAKER FACILITY P&ID

F.2 Test Facility Description

The DBA simulation facility, is designed and manufactured conform ~~with the VACUUM BREAKER VALVE DBA test specification GE 25A5445.~~

The facility is mainly constituted by the followings:

- Test chamber.
- Fluids (Steam, water & Nitrogen) supply system.
- Test data acquisition.
- Test data monitoring.
- Test facility control system.
- Test Volume pressurization, Nitrogen supply control system.

F.2.1 Test chamber:

The test chamber ref. DWG 313.00.e.001 having a diameter of 2700 mm and a length of 5200 mm, with an internal volume of about 27 cubic meter, is capable to be pressurized at 9 BarG, and shall be submitted to validation by ISPESL according to ANCC requirements.

F.2.2 Steam supply system:

The steam supply system is constituted by a 47.5 BarG pressure steam generator, used to pressurize up to 15 bar a 60 cubic meters steam accumulator, a demineralized water supply facility, to be used also for the WATER SPRAY.

F.2.3 Test data acquisition and data monitoring:

The data acquisition is based on a General Automation computer, having a capability up to 128 channel multiplexer NEF-300 and stored on a 80 Mb hard disk, monitors, plotter, data cartridge, printer etc. are available.

The test data shall be supplied :

- Chart table print out of "ALL" parameter.
- Magnetic tape, to be stored and available for a maximum of 1 year.
- Floppy Disk ASCII format up to 24 channel each disk on request.

F.2.4 Test data monitoring:

The test conductor shall follow the test activities by a monitor able to display up to 24 parameters in the same time, the test data to be shown on data screen shall be selected by test conductor; the test conductor shall inform the computer operator prior to start of test activity.

F.2.5 Test control system:

The test control system is based on a PLC controller, capable to drive the test main parameters (pressure & temperature) automatically. The test PLC and relative lamps and selector switches are located on CONTROL RACK.

The test conductor shall actuate the controls and relative commands manually or automatically by automatic/on/off selector switch (for example for the WATER SPRAY).

The physical parameters (pressure, temperature, water level etc.) shall be monitored by DATA MONITOR of DATA ACQUISITION SYSTEM.

The leak test shall be performed by actuating (manually) the test volume nitrogen supply and purging system by NITROGEN CONTROL PANEL refer to dwg. n° 818.FC.01A.003.00.

F.2.6 Test volume Nitrogen supply system:

The Test Volume, located in the wetwell side of the Vacuum Breaker shall be pressurized in order to maintain the maximum allowable delta pressure of 20 PSI during the Test Chamber pressurizations.

A cracking diaphragm at 2 Bar shall be installed in order to avoid a reverse pressurization between DRYWELL and WETWELL.

F.3 <u>TEST FACILITY ITEM LIST</u>

~~XV-04~~	~~DN 200~~	~~VENT~~
PV-04C	DN 15	VENT
XV-03	DN 40	VENT TEST CHAMBER "HIGH PRESSION"
XV-09	DN 80	CONDENSE DISCHARGER "ATMOSPHERIC PRESSURE"
PT-04	10 BAR	TEST CHAMBER
PTD-02	1 BAR	DELTA PRESSURE TEST CHAMBER / TEST VOLUME
TE-04A	TC	TEST CHAMBER TEMPERATURE
TE-04B	TC	TEST CHAMBER TEMPERATURE
TE-04C	TC	TEST CHAMBER TEMPERATURE
FG-02	DN 32	FLOWMETER "DE-OVERHEATER" (VISUAL MONITOR)
PI-08		PRESSURE GAUGE WATER PUMP "DE-OVERHEATER"
~~HS-01~~		~~HAND SWITCH WATER PUMP "DE-OVERHEATER"~~
LG-01		LEVEL WATER TANK "DE-OVERHEATER"
~~TV-04~~		~~STEAM VALVE "E-1" (PRERISC. 57°C)~~
~~TI-03~~		~~"E-1" OUTPUT TEMPERATURE INDICATOR~~
ZSL-01		HAND VALVE "OPEN" INDICATOR SWITCH "E-1"
PI-10		NITROGEN SUPPLY PRESSURE GAUGE
PI-07		STEAM ACCUMULATOR PRESSURE GAUGE
PI-13		"E-1" SUPPLY STEAM PRESSURE INDICATOR
TI-05		TEST CHAMBER SUPPLY STEAM TEMPERATURE INDICATOR
TI-02		WATER SPRAY TEMPERATURE INDICATOR
PI-09		P-2 WATER SPRAY PUMP PRESSURE INDICATOR
~~FIQT-01~~	~~DN 40~~	~~WATER SPRAY FLOW TRANSMITTER (4-20mA) 0-15mc/h~~
FY-01A		WATER SPRAY FLOW (CONVERTER I-V)
WTL-1		T-1 TANK WATER SPRAY LEVEL
WTA-1		T-1 WATER SPRAY LOW LEVEL ALARM

STRUMENTATION:

PT-04	TEST CHAMBER PRESSURE (CONTROL PROCESS)
PTD-02	DELTA PRESSURE (CONTROL PROCESS)
PT-1	WATER SPRAY TANK LEVEL
PT-3	TEST CHAMBER PRESSURE
PT-2	NITROGEN INLET PRESSURE (TEST VOLUME)
PT-4	NITROGEN INLET PRESSURE (TEST VOLUME)
TC-2	TEST VOLUME TEMPERATURE
TC-3	TEST VOLUME TEMPERATURE
TC-10	TEST VOLUME NITROGEN OUTLET TEMPERATURE
TC-11	TEST VOLUME BOTTOM DRAIN NITROGEN OUTLET TEMPERATURE
TC-12	COOL TRAP BODY TEMPERATURE
TC-8	WATER SPRAY TANK TEMPERATURE (43°C)

F.4 TEST DATA ACQUISITION SYSTEM

The data acquisition system shall be capable to measure and record one sample (channel) each 30 microseconds, during test activities shall be used the sampling time of 100 microseconds.

The maximum channel number is 128, during tests shall be used a maximum of 64 channel.

~~The data shall be recorded as value after application of calibration factors.~~

The data print-out may be performed at equal or lower (than acquisition) frequency

The measuremont instruments are:

PT-1	WATER SPRAY TANK LEVEL
~~PT-3~~	~~TEST CHAMBER PRESSURE~~
PT-2	NITROGEN INLET PRESSURE (TEST VOLUME)
PT-4	NITROGEN INLET PRESSURE (TEST VOLUME)
TC-2	TEST VOLUME TEMPERATURE
TC-3	TEST VOLUME TEMPERATURE
TC-10	TEST VOLUME NITROGEN OUTLET TEMPERATURE
TC-11	TEST VOLUME BOTTOM DRAIN NITROGEN OUTLET TEMPERATURE
TC-12	COOL TRAP BODY TEMPERATURE
TC-8	WATER SPRAY TANK TEMPERATURE (43°C)

For the pressure transducer the accuracy is 3% fs.

TERMOCOUPLE FE-CO J acc 3% qty 12

Pressure & temperature transducer calibration data sheets shall be available, in accordance AQAP.

The calibration of the flow-meter shall be supplied by manufacturer, during test the output shall be compared to the T-1 tank level variation value.

F.5 TEST SEQUENCE

NOTE: THE TEST DIRECTOR OR THE TEST CONDUCTOR CAN DECIDE TO MODIFY THE TEST SEQUENCE, OR THE TEST DURATION ACCORDING TO THE TEST DATA.

"TO" INITIAL 135 °F (57°C) CONDITIONING.

PRE-REQUISITES:

- Vacuum Breaker inside test chamber.
- Test Volume connected to Vacuum Breaker.
- Test Volume connected to pressurization system.
- Test Volume connected to steam condensed measuring system.
- Test Volume Termocouples installed and functioning.
- Test Volume pressure transducers functioning.
- Test Volume delta pressure transducers functioning.
- Test chamber closed.
- Steam generator pressure 14 Bar minimum.

OPERATIVE PROCEDURE:

NOTE: ALL WATER COMING OUT OF THE COOLD TRAP MUST BE COLLECTED AND MEASURED. THE TABLE BELOW MUST BE USED TO RECORD THE FOLLOWING PARAMETERS:

TABLE DATA LOG :

DATE	TIME	COOL TR. TEMP °C	N2 INLET FLOWRATE l/min	N2 OUT T. n.10 °C	N2 BOTT.DRA. OUT. n.11 °C	CONDENSATE VOL. COLL. ml

TABLE DATA LOG :

DATE	TIME	COOL TR. TEMP	N2 INLET FLOWRATE	N2 OUT T. n.10 °C	N2 BOTT.DRA. OUT. n.11 °C	CONDENSATE VOL. COLL.

- Verify that the 4 instruments on facility control rack have the MANUAL lamp OFF.
- Verify that the PC04 controller on facility control rack is in REMOTE mode.
- Verify that ALL selector switches are in AUTO position.
- Verify that PD INSTRUMENT CONTROLLER is 0.6 Bar, if not set the controller to this value, by pressing the up/down arrows on the front of instrument.
- ~~Open the hand valve G-01 and verify ZAL-01 LAMP VALVE CLOSE IS "OFF"~~ (on facility control rack).
- Verify manual valve from cold trap are to test volume are OPEN
- Open the hand valve G-01 and verify ZAL-01 LAMP VALVE CLOSE IS "OFF".
- Give the start for T-0 sequence command by PLC (start hot air supply to TEST VOLUME) by pressing the "57° C" press push-button located on facility control rack.
- Verify K-1 fan lamp ON.
- Verify temperature increasing on facility control rack.
- Wait until Test Chamber temperature sensors are stabilized, if necessary adjust TIC-04 located on CONTROL RACK to obtain the required temperature of 57°C.:

Record value :

TC-1	____°C	TC-6	____°C	A4	____°C
TC-2	____°C	TC-7	____°C	A5	____°C
TC-3	____°C	TC-9	____°C	A6	____°C
TC-4	____°C	TC-10	____°C	(process rec.)	
TC-5	____°C	TC-11	____°C		

DATA RECORDING T-0 STATUS:

- Give the computer operator the STATUS ACQUISITION command for data acquisition of 60 seconds.

ACCEPTANCE CRITERIA T-0 STATUS:

- Perform a quick-look on data-print-out to verify measuring system is functioning,

- Verify that following parameters are :

PTD02(Diff) 0 BAR ± 0.1 BAR, record value __________BAR

PT-04(vess) 101KpaA± 10KpaA, record value __________BAR

TO-T1-T2 THERMAL SHOCK TO FROM 135 °F (57°C) TO 340 °F (171 °C).

PRE-TEST CONDITION:

- Vacuum Breaker inside test chamber at the "T-0" condition (57°C).
- Test Volume connected to nitrogen supply system.
- Nitrogen supply valve OPEN.
- Test Volume connected to condensed steam measuring system.
- Test Volume Termocouples installed and functioning.
- Test Chamber pressure transducers functioning.
- Test Volume pressure transducers functioning.
- Steam generator pressure 15 Bar minimum.
- Hot water accumulator DH-1 to 1/2 of tank minimum.
- DH1 water injection pump P-1 operating and the flowrate 15 m^3/min on FG-02, (if necessary operate on V-02 (by pass) and V-01) to adjust flowrate.

OPERATIVE PROCEDURE:

NOTE: ALL CONDENSATE WATER COMING OUT OF THE COLD TRAP MUST BE COLLECTED AND MEASURED. THE FOLLOWING TABLE MUST BE COMPLETED TO DOCUMENT CONDENSATE COLLECTION:

TABLE DATA LOG :

DATE	TIME	COOL TR. TEMP °C	N_2 INLET FLOWRATE l/min.	N_2 OUT T. n.10 °C	N_2 OUT T. n.11 °C	CONDENSATE VOL. COLL. mliters

TABLE DATA LOG :

DATE	TIME	COOL TR. TEMP °C	N2 INLET FLOWRATE l/min.	N2 OUT T. n.10 °C	N2 OUT T. n.11 °C	CONDENSATE VOL. COLL. mliters.
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- Verify that the delta pressure controller on facility control rack is set to 0.6 bar.
- Start water flowrate to maintain low temperature in cool trap.
- By leak test control panel set the nitrogen valve in the following position:

  V1 OPEN

  V2 OPEN

  V3 OPEN

  V5 OPEN

  V6 OPEN
- By leak test control panel set the nitrogen valve V8 OPEN and by visual inspection on the test volume draining output verify that the test volume do not contain water, if necessary adjust the nitrogen purge by-pass to a flowrate of 12 l/minutes, and wait until the test volume shall be drains.
- Leave the nitrogen by-pass flowrate control valve in this position.
- Switch OFF the K1 fan by selector switch on facility control rack.
- Close valve C-01 at the output of the heater (manually) fully clockwise position.
- Verify K-1 fan lamp (on control rack) OFF.
- Verify C-01 lamp CLOSE is ON (on the control rack).
- Verify Open V-6 and V8 valve by Nitrogen control panel to connect the test volume to the cold trap.
- Verify water flow to the cold trap.
- Adjust the nitrogen flow-rate to 20 l/min
- Open the hand valve on the test valve nitrogen outlet

- Adjust the hand valve on the test volume bottom drain in order to observe the nitrogen outlet control valve working at regular interval of 1 to 6 seconds.
- Verify that the Nitrogen supply system is ready to pressurize (facility main control valve on nitrogen tank n°4 OPEN, and ball valve before pressure regulator OPEN) and a nitrogen supply to the test volume low flow rate is maintained.

NOTE: THE VACUUM BREAKER VALVE MAY BE DAMAGED IF THE PRESSURE OF THE TEST CHAMBER OVERCAME THE TEST VOLUME PRESSURE FOR A VALUE GREATER THAN 35 PSI (ABOUT 2 BAR). FOR THIS REASON THE NITROGEN SUPPLY SYSTEM SHALL BE MAINTAINED FREE TO PRESSURIZE, AND THE VENTING SYSTEM SHALL BE ISOLATED BY CLOSING THE V-5 VALVE ON NITROGEN SYSTEM CONTROL PANEL.

- Remove the water (if present) from water bucket.
- Verify that the computer is ready to start the T0-T1-T2 data acquisition.
- Verify that the operator on the test field is ready to insert an empty bucket below the cool trap outlet at the T0 start command.
- Give to the computer operator the T0-T1-T2 acquisition start command at - (minus) 10 seconds.
- When the count-down reach "0 TIME" Give the start T0-T1-T2 command by a selector to activate the automatic sequence controlled by PLC.
- Verify temperature on control rack rising.

- Wait until Test Chamber pressure & temperature sensors are ~~stabilized, (the expected rising time is 4 minutes).~~
- Replace bucket when T2 condition is reached (when the pressure reaches 810 Kpa on Facility control rack panel.
- Measure condensed water, record value.
- Adjust, if necessary, the nitrogen flowrate to 7.5 l/minutes (anticlockwise to increase flow, clockwise to reduce flow).
- Monitor continuosly the bucket to prevent overflow.
- Continue record 6 minutes after stabilization time (about 10 minutes from the starting sequence. At the discretion of the test conductor, instruct the computer operator to stop data acquisition (if necessary adjust PIC-04 located on CONTROL RACK to obtain the required pressure of 810 KpaA (temperature of 171°C).
- Adjust, if necessary, nitrogen flowrate to 7.5 l/minutes
- Drain, measure, and record the quantity of condensed water if present.

T2-T3 LEAK TEST DURING THERMAL STEADY STATUS AT 340 °F (171 °C).

- Starting with an empty bucket, begin 1 hour test duration. bucket , to prevent overflow.
- After 1 hour verify the level of bucket, remove condensate (measure and record value).

T3-T4 WATER SPRAY TEST FROM 171°C (340 °F).

- Verify water spray temperature is 43 °C.
- Verify computer ready to start data aquisition.
- Remove condensate, mesure and record value.

- Begin the count-down for the water spray test from -10 seconds.

  At -5 give the computer aquisition start command. At 0 rotate the NEXT SEQUENCE selector switch to start the water spray, start stop watch and after 65 seconds rotate the water spray selector switch to 0 to stop water flow.- Measure condensate, record value.

- ~~Continue depressurization by placing in MANUAL the PV04AC and by controller PT04 in MANUAL and the set-point to 0.~~

- Wait until pressure decrease is below 350 PaA, than actuate the XV04 by placing the selector switch to MANUAL.
- RESET SEQUENCE by selector switch on control rack.
- Place the selector switch to T5 position on control rack.

"T5" INITIAL 135 °F (57°C) CONDITIONING.

- Verify that the 4 instruments on facility control rack have the MANUAL lamp OFF.
- Verify that the PC04 controller on facility control rack is in REMOTE mode.
- Verify that ALL selector switches are in AUTO position.
- Verify that PD INSTRUMENT CONTROLLER is set to 0.6 Bar; if not, set the controller to this value by pressing the up/down arrows on the front of instrument.
- Open the hand valve G-01 and verify ZAL-01 LAMP VALVE CLOSE IS "OFF" (on facility control rack).
- Give the start for T-0 sequence command by PLC (start airsupply to TEST VOLUME) by pressing the "57° C" press push-buttonlocated on facility control rack.

- Verify K-1 fan lamp ON.

- ~~Verify temperature increasing on facility control rack.~~

- Wait until Test Chamber temperature sensors are stabilized, if necessary adjust TIC-04 located on CONTROL RACK to obtain the required temperature of 57°C.:

Record value :

TC-1	____°C	TC-6	____°C	A4	____°C
TC-2	____°C	TC-7	____°C	A5	____°C
~~TC-3~~	~~____°C~~	~~TC-9~~	~~____°C~~	~~A6~~	~~____°C~~
TC-4	____°C	TC-10	____°C	(process rec.)	
~~TC-5~~	~~____°C~~	TC-11	____°C		

DATA RECORDING T-5 STATUS:

- Give the computer operator the STATUS ACQUISITION command for data acquisition of 60 seconds.

~~ACCEPTANCE CRITERIA T-5 STATUS:~~

- Perform a quick-look on data-print-out to verify measuring system is functioning,

- Verify that following parameters are :

PTD02(Diff) 0 BAR ± 0.1 BAR, record value __________BAR

PT-04(vessel) 101KpaA± 10KpaA, record value __________BAR

T6-T7-T8 THERMAL SHOCK TO FROM 135 °F (57°C) TO 340 °F (171 °C).

PRE-TEST CONDITION:

- Vacuum Breaker inside test chamber at the "T-5" condition (57°C).
- Test Volume connected to Nitrogen supply system.
- Nitrogen supply valve OPEN.
- Test Volume connected to condensed steam measuring system.
- Test Volume Termocouples installed and functioning.
- Test Chamber pressure transducers functioning.
- Test Volume pressure transducers functioning.
- Steam generator pressure 15 Bar minimum.
- Hot water accumulator DH-1 to 1/2 of tank level by site glass.
- DH1 water injection pump P-1 operating and the flowrate 15 l/min on FC-02, (if necessary operate on V-02 (by pass) and V-01) to adjust flowrate.

OPERATIVE PROCEDURE:

NOTE: ALL CONDENSATE COMING OUT OF THE COLD TRAP MUST BE COLLECTED AND MEASURED. THE FOLLOWING TABLE MUST BE USED TO DOCUMENT CONDENSATE COLLECTION:

TABLE DATA LOG :

DATE	TIME	COOL TR. TEMP	N2 INLET FLOWRATE	N2 OUT T. n.10 °C	N2 OUT T. n.11 °C	CONDENSATE VOL. COLL.
.....	......	...°C....	...l/min..	....	....	...mliters..

TABLE DATA LOG :

DATE	TIME	COOL TR. TEMP °C	N2 INLET FLOWRATE l/min	N2 OUT T. n.10 °C	N2 OUT T. n.11 °C	CONDENSATE VOL. COLL. mliters

- Verify that the delta pressure controller on facility control rack is set to 0.6 bar.
- Start water flow rate to maintain low temperature on cool trap.
- By leak test control panel set the nitrogen valve in the following position:

  V1 OPEN

  V2 OPEN

  V3 OPEN

  V5 OPEN

  V6 OPEN
- By leak test control panel set the nitrogen valve V8 OPEN and by visual inspection the test volume draining output verify that the test volume does not contain water, if necessary adjust the nitrogen purge by-pass to a flowrate of 12 l/minutes, and wait untill the test volume shall be drained.
- Leave the nitrogen by-pass flowrate control valve in position.
- Switch OFF the K1 fan by selector switch on facility control rack.
- Close valve G-01 at the output of the heater (manually) fully clockwise position.
- Verify K-1 fan lamp (on control rack) OFF.
- Verify G-01 lamp CLOSE is ON (on the control rack).
- Verify Open V-6 and V8 valve by Nitrogen control panel to connect the test volume to the cold trap.
- Verify water flow to cold trap.
- Adjust the nitrogen flow-rate to 20 l/min
- Open the hand valve on the test valve nitrogen outlet

- Adjust the hand valve on the test volume bottom drain in order to observe the nitrogen outlet control valve working at regular interval of 1 to 6 seconds.
- Verify that the Nitrogen supply system is ready to pressurize (facility main control valve on nitrogen tank n°4 OPEN, and ball valve before pressure regulator OPEN) and a nitrogen flow to the test volume is maintained.

NOTE: THE VACUUM BREAKER VALVE MAY BE DAMAGED IF THE PRESSURE OF THE TEST CHAMBER COMES THE TEST VOLUME PRESSURE BY MORE THAN 35 PSI (ABOUT 2.5 BAR). THEREFORE THE NITROGEN SUPPLY SYSTEM SHALL BE MAINTAINED FREE TO PRESSURIZE, AND THE VENTING SYSTEM SHALL BE ISOLATED BY CLOSING THE V-5 VALVE ON THE NITROGEN SYSTEM CONTROL PANEL.

- Remove the water (if present) from water bucket.
- Verify that the computer is ready to start the T6-T7-T8 data acquisition.
- Verify that the operator at the test facility is ready to insert an empty bucket below the cool trap outlet at the T6 start command.
- Give the computer operator the T6-T7-T8 acquisition start command at - (minus) 5 seconds.
- When the count-down reaches "0 TIME", give the start T6-T7-T8 command by a selector to activate the automatic sequence controlled by PLC.
- Verify temperature on control rack rising.

- Stabilize Test Chamber pressure & temperature sensors are stabilized, (the expected rising time is 4 minutes), - Replace bucket when T7 condition is reached (i.e when the pressure reaches 810 KPa on Facility control rack).
- Measure condensed water, record value.
- Adjust if necessary the nitrogen flowrate to 7.5 l/minutes (anticlockwise to increase flow, clockwise to reduce flow).
- Monitor continuosly the bucket to prevent overflow.
- Continue to record 6 minutes after stabilization time (about 10 minutes from the starting sequence. At the discretion of the test conductor, instruct the computer operator to stop data acquisition. If necessary, adjust PIC-04 located on CONTROL RACK to obtain the required pressure of 810 KpaA (temperature of 160°C).
- Adjust if necessary nitrogen flowrate to 7.5 l/minutes
- Drain, measure, and record the quantity of condensed water if present.

<u>T7-T8 LEAK TEST DURING THERMAL STEADY STATUS AT 340 °F (171 °C).</u>

- Start 1 hour test with an empty bucket duration controlling buchet continuosly, to prevent overfolw.
- After 1 hour remove condensate measure and record value.

T8-T9 DEPRESSURIZZATION TO 150 °C.

- Remove condensate, measure and record value.
- Start the falling slope by actuating the NEXT SEQUENCE SELECTOR SWITCH.
- After 35 minutes remove condensate and record value.

NOTE : TEST CONDITION TO REMAIN AT THIS VALUE FOR 80 HOUR CONTI- ~~NUOSLY, IF A FACILITY FAILURE OCCURS IT IS NOT REQUIRED TO START FROM T0, RECOVERY WILL BE MADE TO 150 °C AND 80HR RUN~~ WILL BE COMPLETED.

- Verify delta pressure controller is adjusted to 0.6.
- Adjust nitrogen flowrate to 7.5 l/minutes if necessary.
- Wait untill pressure, temperature, delta pressure and water is stabilized.
- Remove condensate, measure and record amount.
- Start 1 hour test while monitoring condensate water.
- Remove condensate, measure and record value.
- Verify delta pressure controller is adjusted to 0.7.
- Adjust nitrogen flowrate to 7.5 l/minutes if necessary.
- Wait until pressure, temperature, delta pressure and water is stabilized.
- Remove condensate, measure and record amount.
- Start 1 hour test while monitoring condensate water.
- Remove condensate, measure and record value.

- Verify delta pressure controller is adjusted to 0.8.
- ~~Adjust nitrogen flowrate to 7.5 l/minutes if necessary.~~
- Wait until pressure, temperature, delta pressure and water is stabilized.
- Remove condensate, measure and record amount.
- Start for 1 hour test duration while monitoring condensate water.
- Remove condensate, measure and record value.
- Verify delta pressure controller is adjusted to 0.9 or the ~~maximum that the controller can obtain.~~
- Adjust nitrogen flowrate to 7.5 l/minutes if necessary.
- Wait until pressure, temperature, delta pressure and water is stabilized.
- Remove condensate, measure and record value.
- Start 1 hour test while monitoring condensate water.
- Remove condensate, measure and record value.

T9-T10 WATER SPRAY TEST FROM 150°C.

- ~~Verify water spray temperature is 43 °C.~~
- Verify computer ready to start data aquisition.
- Remove condensate, measure and record value.
- Give the count-down for the water spray test from -10 seconds at -5 give computer aquisition start command; at 0 rotate the NEXT SEQUENCE selector switch to start the water spray. Start stop switch and after 65 seconds rotate the water spray selector switch to 0 to stop water flow.- Measure condensate, record value.
- Continue depressurization by placing in MANUAL the PV04AC and by controlliar PT04 in MANUAL place the set-point to 0.
- Wait until pressure decrease below 350 KPaA, than actuate the XV04 by placing the selector switch to MANUAL.

Note: Refer to test director for instructions.

FIGURE COLLECTION :

ANNEX F.1:

DWG 313.00.A.001 VACUUM BREAKER FACILITY P&ID

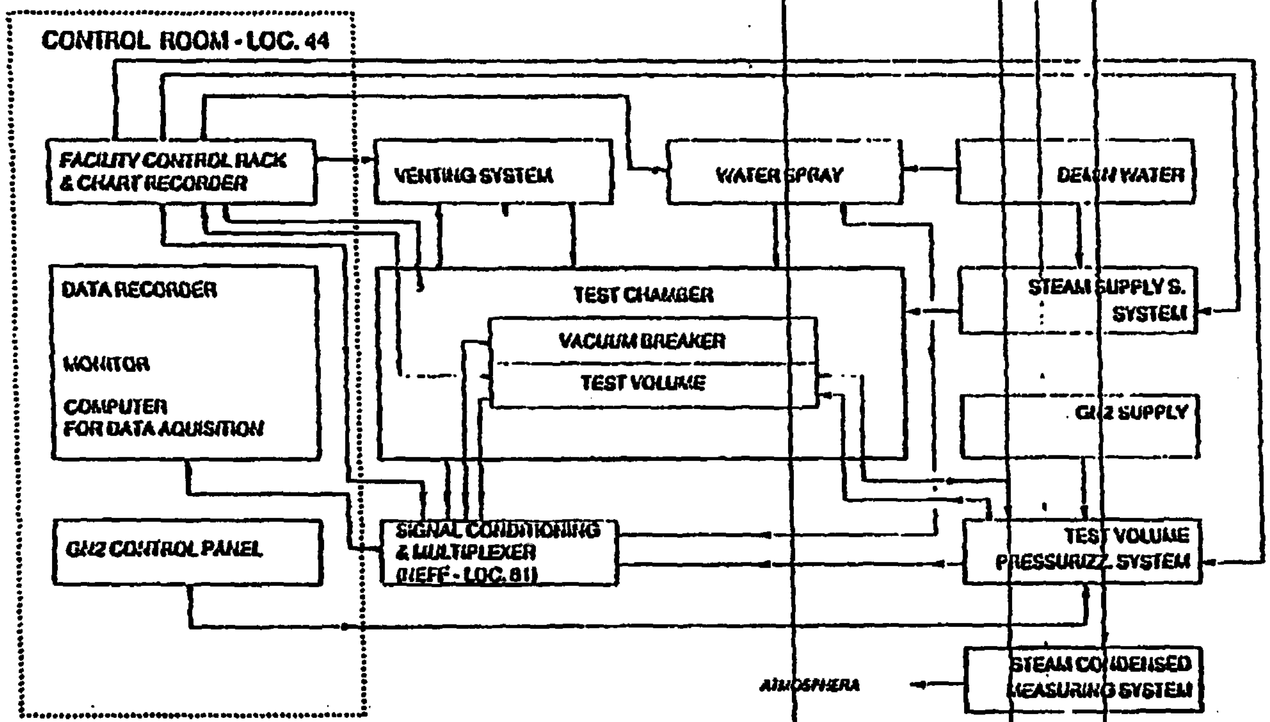
ANNEX F.2:

DWG 818.FC.01A.003.00 NITROGEN SUPPLY S. FOR LEAK T.

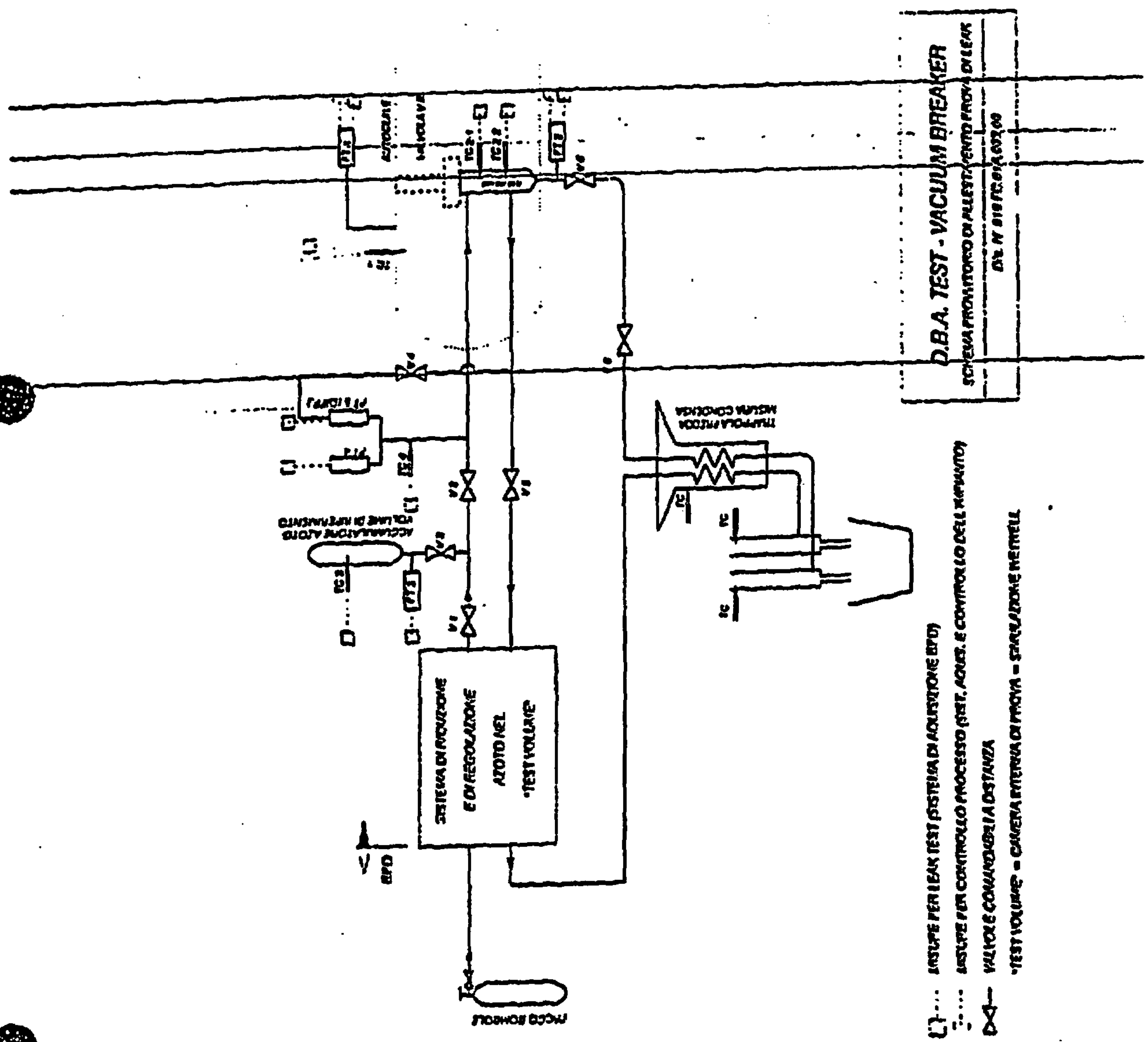
ANNEX F.3:

SPEC 25A5445 FIGURE 1 SIMULATED SERVICE CONDITION TEST PROFILE

VACUUM BREAKER VALVE - DBA TEST P&I BLOCK DIAGRAM



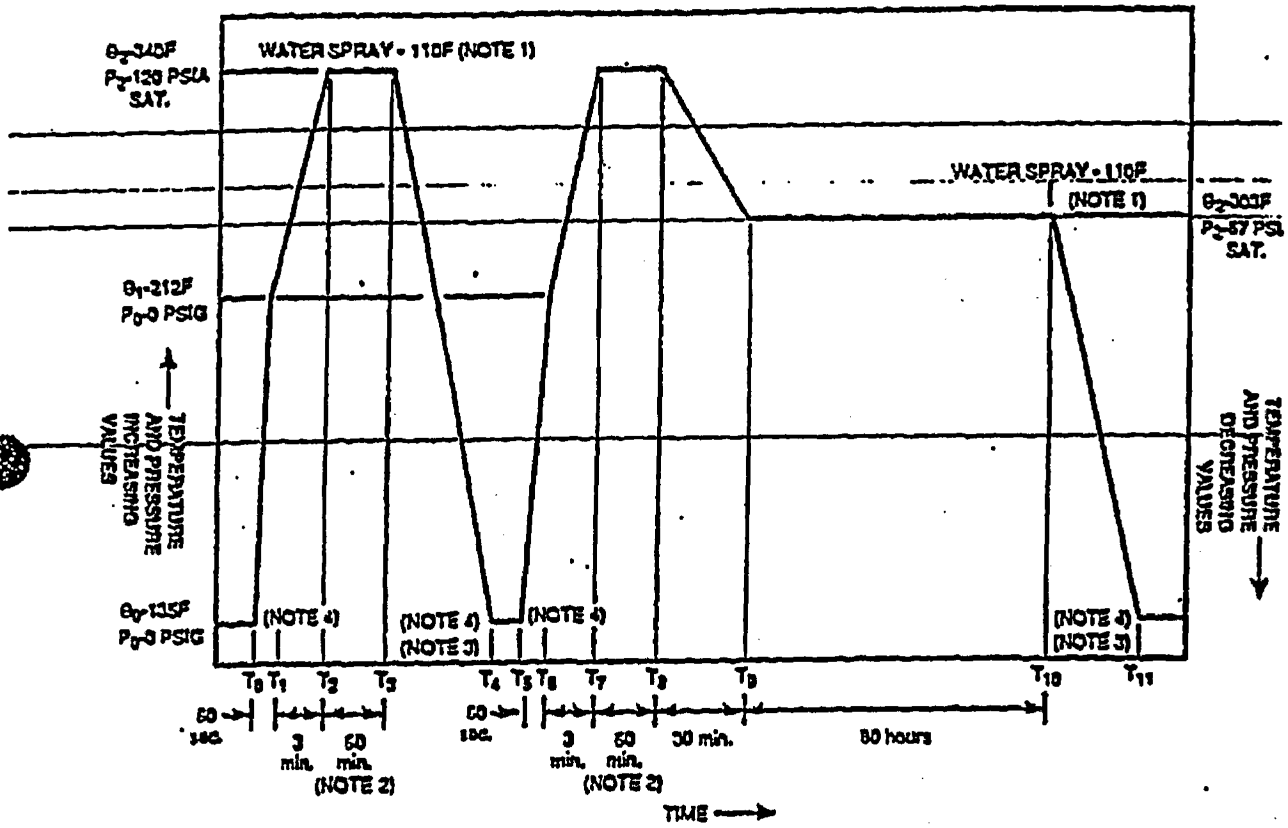
ANNEX F.2 NITROGEN SUPPLY SYSTEM FOR LEAK TEST



ANNEX F.3 SIMULATED SERVICE CONDITION TEST PROFILE

GE Nuclear Energy

25A5445	SH NO. 13
REV 1	



NOTES:

1. SPRAY RATE IS 3 GPM PER MINUTE PER SQUARE METER OF TEST VOLUME PLAN VIEW AREA. SPRAY PERIOD SHALL BE NOT LESS THAN ONE MINUTE.
2. HOLD TEMPERATURE AND PRESSURE FOR A MINIMUM OF 60 MINUTES OR LONG ENOUGH TO MEASURE LEAK RATE BETWEEN CHAMBER AND TEST VOLUME.
3. RATE OF COOLDOWN AND PERIOD OF HOLD BETWEEN COLD CONDITION AND HEATUP ARE AT THE OPTION OF THE TESTER.
4. MEASURE AND RECORD NET LEAKAGE BETWEEN T_0 AND T_2, T_3 AND T_4, T_5 AND T_9, T_{10} AND T_{11}.

Figure 1. Simulated Service Condition Test Profile

GE Nuclear Energy

J. E. Quinn, Projects Manager
LMR and SBWR Programs

General Electric Company
175 Curtner Avenue, M/C 165 San Jose, CA 95125-1014
408 925-1005 (phone) 408 925-3991 (facsimile)

February 16, 1995

MFN No. 021-95
Docket STN 52-004

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington DC 20555

Attention: Richard W. Borchardt, Director
Standardization Project Directorate

Subject: Request for Exemption of the SBWR Drywell to Wetwell Vacuum Breaker from the Single Failure Criteria

Reference:

1. *GE letter MFN No. 018-95, J. E. Quinn (GE) to R. W. Borchardt (NRC), "Approach to Achieve Closure of Items Related to the GE SBWR TAPD," dated February 14, 1995.*
2. *Letter, T. R. McIntyre (GE) to Richard W. Borchardt (NRC), Responses to the Referenced Letters, GE MFN No. 113-94, dated September 26, 1994.*
3. *Letter, J. E. Leatherman (GE) to Richard W. Borchardt (NRC), NRC Requests for Additional Information (RAIs) on the Simplified Boiling Water Reactor (SBWR) Design, GE MFN No. 065-94, dated May 2, 1994.*

The "SBWR Drywell to Wetwell Vacuum Breaker Valve White Paper" Attachment to this letter is the GE response to item No. 42 in Attachment 2 to the Reference 1 letter. The purpose of this paper is to present additional information regarding exemption of the SBWR vacuum breakers from the single failure criteria based on demonstrated reliability. The paper describes the design features of this special vacuum breaker valve which significantly improve its leak tightness and reliability performance. The paper also presents the rigorous leak tightness, performance, Design Basis Accident (DBA), and reliability testing which the valve has successfully undergone in substantiating this exemption from the single failure criteria.

In the GE Response to RAI Number 900.68 (Reference 2), a discussion of vacuum breaker actions for analyses, transients and accidents, including a Gravity Driven Cooling System (GDCS) line break and discussion of assumptions made for both expected and "licensing basis" scenarios was presented. Reference 2 also included detail as to why failure to close (after actuation) of a drywell to wetwell vacuum breaker is not, in GE's view, a credible failure.

In the GE Response to RAI Number 900.62 (Reference 3), information was presented to enable the staff to access the adequacy of the wetwell-to-drywell vacuum breaker test program including: drawings of the vacuum breaker and instrumentation; the vacuum breaker Purchase Specifications; a copy of the Engineering Operating Procedure; detailed specification of the conditions, both normal and design basis, under which the vacuum breakers will be required to operate; the detailed test procedures for the vacuum breaker; and information appropriate to ensuring that the data obtained on the reliable performance of the valve is applicable to the valves to be incorporated into the certified plant design.

We hereby request your review of this letter along with the references and approval of this request for exemption of the subject vacuum breaker from having to meet the single failure criteria for application to the SBWR.

Sincerely,

James E. Quinn, Projects Manager
LMR and SBWR Programs

Enclosure: SBWR Drywell to Wetwell Vacuum Breaker Valve White Paper

cc: P. A. Boehnert (NRC/ACRS)
I. Catton (ACRS)
S. Q. Ninh (NRC)
J. H. Wilson (NRC)

@

GE Nuclear Energy

General Electric Company
175 Curtner Avenue, San Jose, CA 95125

February 14, 1995

MFN No. 018-95
Docket STN 52-004 (GE SBWR)

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Attention: Richard W. Borchardt, Director
Standardization Project Directorate

SUBJECT: APPROACH TO ACHIEVE CLOSURE OF ITEMS RELATED TO THE GE SBWR TAPD

Refs:

1. NEDC/0-32391 Rev. A, "SBWR Test and Analysis Program Description" (TAPD), dated September, 1994.
2. Memorandum to John T. Larkins (ACRS) from Dennis M. Crutchfield (NRC), "Draft Safety Evaluation Report (SER) on the adequacy of the Technical Approach to the Testing and Analysis Program (TAP) for the Simplified Boiling Water Reactor (SBWR) Design", dated Nov. 25, 1994.
3. ACRS Thermal Hydraulic Phenomena Subcommittee meetings December 15 & 16, 1994, and January 10, 1995.
4. NRC Meeting January 9, 1995.
5. ACRS 417th Meeting, January 12, 1995.

Dear Mr. Borchardt:

GE has submitted a Testing and Analysis Program Document (Ref. 1) defining details of how we would complete these key areas in support of the SBWR certification effort. The NRC has reviewed this document and formally provided its comments in Ref. 2. In addition, there have been several meetings (Ref 3-5) with the NRC Staff and the ACRS to explore the comments/questions. These have been supplemented by informal interactions (faxes, E-mails, telecons, working meetings) to clarify the positions such that appropriate responses could be prepared by GE that would satisfy the NRC and ACRS reviewers. A pathway to this is shown in Att. 1 and the timing and location of each response, along with a brief statement of the comment/question being addressed, is shown in Att. 2.

We have started the process of developing responses, and the first compilation in Rev. B of the TAPD will be issued for review on April 17, 1995.

GE expects that completion of SBWR Testing and Analysis Program (TAP) as described in NEDC/0-32391, "SBWR Test and Analysis Program Description" (TAPD) and completion of the work outlined in the Attachments to this letter will constitute an acceptable technology basis for Certification of the SBWR.

We appreciate the constructive dialogue that has led to this approach and trust you will find this an acceptable path and plan.

Sincerely yours,

J.E. Quinn, Projects Manger
LMR and SBWR Programs

Attachment 1: NRC/ACRS Issue Closure Process
Attachment 2: List of Additional Work From the NRC 12/94 - 1/95

cc: w/attachments:

P.A. Boehnert	-	NRC/ACRS
I. Catton	-	ACRS
S.Q. Ninh	-	NRC
J.H. Wilson	-	NRC

MFN No. 018-95

bcc:	J.A. Beard		
	P.F. Billig		
	R.H. Buchholz		
	R.W. Burke	(EPRI)	(w/2 copies of atts)
	T. Cook	(DOE)	(w/atts)
	J.D. Duncan		
	T. Fernandez	(EPRI)	(w/atts)
	J.R. Fitch		
	L.S. Gifford		
	F.E. Hatch		
	J.E. Leatherman		
	J.E. Quinn		
	T.R. McIntyre		
	F.A. Ross	(DOE)	
	K.T. Schaefer		
	R. Srinvasan	(EPRI)	
	GE Master File	(M/C 747)	(w/atts)
	SBWR Project File	(w/atts)	

Attachment 2 to MFN 018-95

List of Additional Work
From The NRC 12/94 - 1/95

No.	Item Description	Where To Be Documented
1	MSLB outside containment - TRACG analysis. Perform TRACG analysis for this accident with focus on containment response and PCCS purging.	SSAR
2	BDB outside containment - TRACG analysis Perform TRACG analysis of accident. For RPV, clarify timing of events leading to isolation of system. For containment, focus on PCCS purging.	SSAR
3	Document TRACG time step determination logic. (Part of Item 53)	MODEL
4	Document chimney technical basis. Document supporting data for void fraction in large diameter pipes and capability of TRACG to analyze flow distribution in parallel channels.	QDB
5	Develop description on chimney technical basis developed in Item 4 in TAPD	TAPD Rev. C
6	Develop figure of SBWR/SBWR nodalization similar to Figure 2.1 of NEDE-32178 for reactor vessel and containment	MODEL
7	Derivation of TRACG conservation equations w/ assumptions. (Part of Item 53)	MODEL
8	Details of assumptions and range of applicability for correlations in TRACG (Part of Item 53)	MODEL
9	Provide report on separator modeling in TRACG (Sections 4&5 of NUREG/CR-2574, "BWR Refill-Reflood Program Task 4.7 - Model Development TRAC-BWR Component Models")	LETTER
10	Document range of separator data vs. range of SBWR conditions during normal operation and transients	QDB
11	Comparison of TRACG decay heat model (used in transients in conjunction with neutronics model) vs. ANS standard (1979)	MODEL
12	Describe SBWR TRACG BOP model used in transient analysis. Justify representation of dynamic components such as pumps by control system elements.	APP
13	Provide scaling study of CRIEPI tests to demonstrate that appropriate SBWR parameters are properly scaled	TAPD Rev. B
14a	Expand scaling study to include global scaling of entire system. This should include detailed scaling of interactions between loops and components.	TAPD Rev. C
14b	Extend GIRAFFE scaling study to the late blowdown phase (starting at~10 bar)	TAPD Rev. B
15	Develop scaling groups for individual PIRT parameters (ranked High, Medium) and compare values of these parameters for SBWR and test facilities	TAPD Rev. C
16	Add description of Main Steam line break to TAPD Section 2.2.1	TAPD Rev. B
17	Consideration of medium and low phenomena - Include medium ranked phenomena in assessment matrix; low ranked phenomena only in checks for existence of models in TRACG	TAPD Rev. C
18	Review best estimate LOCA scenario accounting for equipment availability and operator actions. Determine if any additional items need to be added to PIRT.	TAPD Rev. B
19	Clarify interaction studies discussed in Sections 4.2 and Appendix C of TAPD to address specific questions in DSER	TAPD Rev. C
20	Include vessel/containment interactions as specific highly ranked phenomena in PIRT	TAPD Rev. C
21	Discuss PCCS purge/vent process from phenomenological point of view	TAPD Rev. C
22	Separate out SRV air clearing loads as an item in PIRT for containment	TAPD Rev. C
23	Add description of ATWS scenario in Section 2.2.3 and expand Table 2.3-4. For stability, expand Table 2.3-5 PIRT format. Include consideration of bouyancy-driven oscillations during startup at low pressure and power, but with large subcooling.	TAPD Rev. C
24	Include discussion of PAR interactions. Add description of performance characteristics and flow patterns induced by PARs.	TAPD Rev. C

List of Additional Work
From The NRC 12/94 - 1/95

No.	Item Description	Where To Be Documented
25	Expand discussion of PIRT tables. Add new Appendix E which will include a brief discussion of each parameter and the basis for its ranking.	TAPD Rev. C
26	Address phases of the transient in Section 3. Add column to Table 3.2-1 to indicate for what transient the phenomena are ranked and for what phase. Clarify discussion of what is meant by SBWR unique features and phenomena.	TAPD Rev. C
27	Prepare Qualification Data Base (QDB) report for external distribution. Review for completeness, consistency and quality and upgrade as necessary. Add purpose and a brief summary of the process.	QDB
28	Quantification of data uncertainties. Quantify measurement uncertainties in major test parameters. (Included in plan for Test Reports)	TEST
29	Quantification of correlation uncertainties. Quantify uncertainties in the correlations used in TRACG with reference to application to SBWR. (Included in Item 53)	MODEL
30	Update detailed test objectives in Appendix A to be consistent with discussions with NRC Staff.	TAPD Rev. B
31	Expand test conditions description.	TAPD Rev. B
32	Justification of test initial conditions and range. Compare the range of parameters in the test to those expected in SBWR. Develop basis for how the test is picked up "on the fly"; i.e. how rate of change of parameters is treated.	TAPD Rev. B & Rev. C
33	Test facility design details. (Included in individual test reports on the various test programs)	TEST
34	Test instrumentation details - types of instruments, locations and accuracy. (Included in test reports)	TEST
35	Test procedure details - details of test loop preconditioning and initiation of test. (Included in test reports)	TEST
36	QA plans - included as part of test documentation.	TEST
37	Use of GIRAFFE data. Role of GIRAFFE data in validation of TRACG.	TAPD Rev. B
38	Use of GIST data. Role of GIST data in validation of TRACG.	TAPD Rev. C
39	Determination of TRACG biases and uncertainties. Delineation of sources of data for quantifying bias and uncertainty in specific models. Roles of separate effects and integral tests in determination of overall uncertainty. (Included in plan for Qual. LTR	QUAL
40	TRACG model ranges vs. SBWR range. Quantify range of parameters over which TRACG models have been assessed vs. range of parametrs expected in SBWR transients and LOCAs. Comparisons will be made for scaling groups identified for high and medium ranked PIRT	QUAL
41	Scope and range of sensitivity studies. Quantify the range of sensitivity studies planned for the high ranked PIRT parameters as part of CSAU application.	APP
42	Provide vacuum breaker white paper. Justify exemption from single failure criteria based on demonstrated reliability.	LETTER
43	Debris resistant design. General concept to screen PCCS inlet from debris resulting from blowdown. (Detailed design features not part of this program.)	SSAR
44	Justify PCCS test data range (at LOCA vs 1 hr). Compare maximum credible PCCS flow (limited by main vent uncovery) with PANTHERS test data range.	TAPD Rev. B
45	PANTHERS IC additional tests (LOW PRESSURE, He). Include additional test and new test matrix in , TAPD Appendix A.	TAPD Rev. B
46	Definition of PANDA tests M5,M7, M9. Define test conditions for PANDA tests based on TRACG results and engineering judgment.	TAPD Rev. C
47	GIRAFFE/Helium test objectives. Add to TAPD, Appendix A.	TAPD Rev. B

List of Additional Work
From The NRC 12/94 - 1/95

No.	Item Description	Where To Be Documented
48	Define additional GIRAFFE integral system tests. Develop test matrix and initial conditions. Add to TAPD, Appendix A.	TAPD Rev. B
49	Additional GIRAFFE analysis. Perform TRACG analysis of additional tests defined in Item 48.	QUAL
50	Additional PANTHERS analysis. Perform TRACG analysis of additional tests defined in Item 45.	QUAL
51	Justification of UCB correlation for Hydrogen. Define appropriate correlation to use for condensation in the presence of Hydrogen.	MODEL
52	Reconcile SBWR nodalization vs. tests. Review TRACG nodalization used for individual test comparisons with the corresponding regions in SBWR. Perform sensitivity studies to establish appropriate SBWR nodalization, if significantly different from tests.(In	QUAL
53	Models and Correlations Report- Technical content. Modify TRACG Model LTR (32176) to include Items 3, 6, 7, 8, 11 and 29.	MODEL
54	Models and Correlations Report- Production	MODEL
55a	Presentation on startup process. Prepare discussion of Dodewaard startup procedure and SBWR startup procedure, showing trajectory of power, pressure, flow and inlet subcooling.	Presentation
55b	Discussion of startup process. Prepare presentation based on Item 55a.	TAPD Rev. C
56a	Treatment of noncondensible distribution-TRACG. Develop plan for validation and application of TRACG for noncondensible distribution.	TAPD Rev. B
56b	Treatment of noncondensible distribution-measurement. Add capability for measurements of noncondensible distributions in the containment regions of the SBWR test facilities.	TAPD Rev. B
57	Dryer data range. Tabulate the range of data over which TRACG model is applicable.	QDB
58	Develop TRACG documentation plan. Prepare a detailed plan and table of contents for the modified TRACG Model LTR for discussion with NRC Staff.	LETTER
59	Develop outline for test reports. List proposed test reports. Review proposed content with NRC Staff.	TAPD Rev. B
60	Develop outlines for validation reports. List proposed validation reports. Review proposed content with NRC Staff.	TAPD Rev. B
61	Add "roadmap" to introduction section. Include list of reports and tables of contents as an appendix.	TAPD Rev. B

November 7, 1995

MFN 216-95
Docket STN 52-004

Document Control Desk
U.S. Nuclear Regulatory Commission
Washington DC 20555

Attention: T. E. Quay, Director
Standardization Project Directorate

Subject: **SBWR - Vacuum Breaker Single Failure Exemption**

References

1. Letter, J. H. Wilson (NRC) to J.E. Quinn (GE), Staff Review of GE Request for Exception to Single-Failure Criterion for Drywell-to-Wetwell Vacuum Breakers, dated August 22, 1995.

2. Letter MFN 021-95, J.E. Quinn (GE) to R.W. Borchardt (NRC), Request for Exemption of the SBWR Drywell to Wetwell Vacuum Breaker from the Single Failure Criteria, dated February 16, 1995.

3. Letter MFN 113-94, T.R. McIntyre (GE) to R.W. Borchardt (NRC) Responses to the Referenced Letters, dated September 26, 1994.

4. Letter MFN 065-94, J.E. Leatherman (GE) to R.W. Borchardt (NRC), NRC Requests for Additional Information (RAIs) on the Simplified Boiling Water Reactor (SBWR) Design, dated May 1994.

This letter is written in response to the Reference 1 letter, which was in response to the Reference 2 letter.

We will respond to Reference 1 in two parts: the vacuum breaker testing program and the request for single failure exemption. With regard to the former, there has been a significant investment by NRC and the GE team in the testing program. We request that you provide a letter stating that the program results are valid and acceptable for use in licensing and meet the defined testing program objectives. This would in no way relate to the exemption question.

J.M. Quinn

We need NRC's closure regarding the testing performed on the SBWR vacuum breaker since the test facility will soon be dismantled due to a relocation of the testing agency, and GE needs to disposition the test article. As indicated by References 3 and 4, and several NRC visits to the test facility in Europe, both the staff and GE have made a substantial investment in developing and reviewing the SBWR vacuum breaker design, test performance, and test results. We need closure on this part of the technology program while the people who participated in the program are available to address questions. Deferring action will likely make it difficult for the NRC to recreate the familiarity that presently exists from the close association with the test program, in addition to the inefficiency and expense required to restart the effort later.
Your cooperation in completing the review of the vacuum breaker test data is needed so that GE has confidence that the vacuum breaker testing conducted was adequate and sufficient.

Concerning the Vacuum Breaker Single Failure Exemption Request, GE understands the NRC position that the SBWR PRA needs updating and that the TRACG review needs to be more mature before coming to a decision. The PRA update and completion of the design will come after completion of the Technology Program. GE agrees to delay further action on the exemption request decision until resumption of the Design Phase. However, GE firmly believes that the SBWR can meet all of the requirements noted in the attachment to Reference 1:

- Parametric studies of the SBWR behavior with a qualified TRACG code will adequately demonstrate that the duty required of the SBWR vacuum breaker, is bounded by testing already performed on the valve and that the vacuum breaker reliability demonstrated supports the SBWR PRA conclusions.

- The SBWR PRA will demonstrate that the SBWR is acceptable using the demonstrated SBWR vacuum breaker reliability numbers plus appropriate data from other sources.

Your prompt action regarding the Test Program review would be appreciated.

Sincerely,

James E. Quinn, Projects Manager
LMR and SBWR Programs

cc: (1 paper copy plus E-Mail)

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MFN 021-96

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

February 14, 1996

Mr. James E. Quinn, Projects Manager
LMR and SBWR Programs
GE Nuclear Energy
175 Curtner Avenue, M/C 165
San Jose, California 95125

SUBJECT: VACUUM BREAKER TEST PROGRAM

Dear Mr. Quinn:

In your letter dated November 7, 1995, you requested that the staff provide you with feedback on the Simplified Boiling Water Reactor (SBWR) vacuum breaker test results. Specifically, you requested that the staff conclude that the test results, submitted by letter dated December 15, 1994, are "valid and acceptable for use in licensing, and meet the defined testing program objectives".

During your testing program, the Nuclear Regulatory Commission (NRC) staff members witnessed a portion of the seismic testing, the conclusion of the 3000-cycle reliability testing, the post-test inspection, and leakage-testing in the presence of debris and with various size pieces of wire placed under the soft seat. These tests were performed by competent and experienced personnel and, with the exception of concerns that arose during the leakage test and discussed below, the test program appeared to be thorough. This, together with a review of the test program results, leads the staff to believe that the test results are valid and acceptable for use in licensing. However, a number of concerns prevent the staff from concluding that the testing program meets its objectives.

In request for additional information (RAI) 900.176, the staff questioned GE's determination that a sealant, such as room temperature vulcanizing (RTV), was required on the back side of the EPDM soft seal to prevent excessive leakage around the back of the seal. This sealant was not subjected to the radiation and thermal aging to which the EPDM seal was subjected. Therefore, it will be necessary to qualify the RTV sealant following similar aging treatment. Alternatively, GE could demonstrate that the leakage is acceptable without the RTV sealant in place, or, if RTV is to be used in the SBWR vacuum breaker, periodic leak testing could be performed with regulatory oversight.

During the reliability testing, a loss of sealing was caused when the soft seal groove was spanned by a piece of wire whose diameter was small enough to pass through the intake screen. This loss of sealing and its potential impact on PCC performance will have to be analyzed, possibly referencing the results of the containment by-pass experiment run in the PANDA facility and other relevant tests. (This issue was also raised in RAI 900.176.)

Also, GE has not demonstrated that the following four specific test objectives were met by the test program, as described below:

1. "The vacuum breaker flow capacity could be made equivalent to 1.04 square feet."

   During the tests that the staff witnessed, the valve stroke was insufficient to meet this flow requirement; while the disc damper had been removed, the valve stroke had not been increased to take credit for this change. GE must provide the data from tests with the increased valve stroke.

2. "The main seal is air bubble tight as installed and has an equivalent leakage flow area of <0.02 square centimeters to steam in the fully degraded condition under design basis accident conditions."

   GE must explain how 'design basis accident conditions' were achieved.

3. "The dynamic loads which result in lift of the disk were acceptable."

   GE must submit an analysis of the test data to demonstrate that the loads and seismic response spectra to which the valve was subjected during the testing are valid and acceptable.

4. "The opening and closing reliability are maintained after subjecting the fully aged valve to grit ingestion."

   Although the vacuum breaker operated reliably and failure free during the 3,000-cycle test, GE must provide an analysis to support the relevant reliability numbers used in the SBWR PRA.

In summary, the staff cannot reach a conclusion on the acceptability of the test results or conclude that the objectives of the testing program have been met until GE has submitted its analyses of the test results and demonstrated that they support these conclusions.

If you have any questions regarding this matter, contact James H. Wilson at (301) 415-1108 or Son Q. Ninh at (301) 415-1125.

Sincerely,

Theodore R. Quay

Theodore R. Quay, Director
Standardization Project Directorate
Division of Reactor Program Management
Office of Nuclear Reactor Regulation

Docket No. 50-004

cc: See next page

Mr. James E. Quinn
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Docket No. 52-004

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March 12, 1996

MFN 035-96
Docket 52-004

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington DC 20555

Attention: Theodore R. Quay, Director
Standardization Project Directorate

Subject: **SBWR - CLOSURE OF THE VACUUM BREAKER TEST PROGRAM**

Reference: 1. Letter, T. R. Quay (NRC) to J. E. Quinn (GE), Same Subject, dated February 14, 1996.

We have received the Reference letter acknowledging the active role NRC played during the testing program, the competent and experienced test personnel who conducted the tests, and the thoroughness of the test program. We are pleased with the NRC conclusion that the staff believes that the test results are valid and acceptable for licensing. With that confirmation we believe that the SBWR Vacuum Testing task is complete until the production valve is manufactured and tested as discussed below.

Leakage between the backside of the seal and the disk

This leakage was discovered during initial seal testing. As an expedient solution to prevent this leakage and continue the tests, RTV was used to seal the gap between the disk retaining groove and the seal. After application of the sealant, the primary dynamic seal was found to be bubble tight. RTV is widely used in nuclear applications and has been qualified elsewhere for environmental conditions equivalent to this application. The radiation and thermal aging of the seals with the RTV was not repeated because the preferred solution is to add a static seal to the back of the production valve main seal. The design of a static seal is relatively simple compared to a dynamic seal. The performance of the static seal will be verified during production valve acceptance tests. The addition of a static seal to the backside of the primary seal will have no affect on the validity of the prototype test program.

Compression set of the main seal caused by design basis steam testing

The wires placed under the vacuum breaker seat to simulate debris interferance following thermal/radiation aging, design basis accident testing, and reliability testing, demonstrated that the seal had taken a permanent set nearly flush with the hard seat. This resulted in a reduction of main seal effectiveness if a particle was lodged on the hard seat. The preferred solution is a simple modification to the production valve seal to add a bead to the existing seal to resist compression set. This will ensure that sealing can be maintained if a particle lodges on the valve seat. The resistance of the production valve seal to compression set will be confirmed by thermal aging under compression loading. The addition of a properly designed bead to the seal will have no affect on the validity of the prototype test program.

Vacuum breaker flow capacity

A series of flow capacity tests were performed and are summarized in the figure on page 34 of: "SBWR Vacuum Breaker (VB) Prototype Experimental Qualification General Test Report ED45913" (MFN 155-94 dated 12/15/94). As shown on that figure, the stroke of the valve was not sufficient to meet the design flow capacity equivalent to 1.04 square feet. The stroke of the valve was then increased to establish that increasing the stroke would provide the required increase in flow capacity. Increasing the stoke by 40 mm increased the flow capacity by thirty percent to an equivalent of 1.0 square feet. This test established that stroke was limiting flow capacity and flow could be adjusted by varying stroke length to meet or exceed flow requirements considering the slightly reduced effective stroke with the chatter damper in place. The production valve will have adequate stroke and be tested to demonstrate the design flow requirement.

Design Basis Accident conditions

The design basis accident conditions were achieved in accordance with the requirements of IEEE 323. The term "fully degraded" means that the primary seal was thermally and radiation aged in accordance with IEEE 323 before being functionally tested for steam leak tightness as required by IEEE 323. This is described in the valve test specification 25A5445 (MFN 065-94 dated 5/2/94). Over the eighty hours of testing in a steam pressure vessel there was no measurable steam leakage through the valve. (Refer to Page 229 of ED 45913 for Design Basis Accident test report.)

Dynamic loads which result in lift of the disk

The valve was dynamically aged in accordance with IEEE 323 as described in Attachment E Page 88 of ED 45913. The test response spectra used for aging was an envelope of the SBWR SSE spectra at the elevation of the drywell floor where the valve is mounted. Following seismic aging, a fragility test of the valve was conducted up to the capability of the shake table. Movement of the valve disk was monitored by measuring changes in pressure across the disk. It was noted that at approximately 1G ZPA, deviations in pressure across the disk were observed. Refer to paragraph 3.4.2 of, "SBWR Vacuum Breaker Prototype Experimental Qualification General Test Notification Plan" ED 45841 (MFN 155-94 dated 12/15/94) for a discussion of disk lift measurements. Disk lift occurred at acceleration levels well in excess of those predicted for the SBWR SSE.

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Opening and closing reliability

The basis for the 3,000 cycle test is contained in report titled: "Bayesian Approach to the SBWR Vacuum Breaker Reliability Demonstration Testing" ECN-CX-93-135 provided to the NRC as part of a RAI 900.62 response (MFN 065-94 dated 5/2/94).

Sincerely,

James E. Quinn,
Projects Manager

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GE Nuclear Energy

NEDO-32391
Revision A
DRF A70-00002
Class I
September 1994

Licensing Topical Report

SBWR Test and Analysis Program Description

SBWR

GE Nuclear Energy

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September 15, 1994

MFN No. 110-94
Docket STN 52-004

Document Control Desk
U. S. Nuclear Regulatory Commission
Washington DC 20555

Attention: Richard W. Borchardt, Director
Standardization Project Directorate

Subject: *SBWR Test and Analysis Program Description*, NED0-32391 Revision A

This letter transmits Revision A of the *SBWR Test and Analysis Program Description* report, NED0-32391, for your review (Attachment 1). The report provides a comprehensive, integrated plan that addresses the testing and analysis elements needed for analysis of the SBWR performance. In particular, this document describes the final Test Plan (Appendix A).

Sincerely,

P. W. Marriott, Manager
Advanced Plant Technologies

Enclosure: *SBWR Test and Analysis Program Description (TAPD)*, NED0-32391, Revision A

cc: P. Boehnert (8 copies)
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NEDO-32391
Revision A
DRF A70-00002
Class I
September 1994

SBWR Test and Analysis Program Description

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APPENDICES

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ABBREVIATIONS AND ACRONYMS

ABWR	Advanced Boiling Water Reactor
AC	Alternating Current
ADS	Automatic Depressurization System
APRM	Average Power Range Monitor
ARI	Alternate Rod Insertion
ASME	American Society of Mechanical Engineers
ATLAS	GE's 8.6 MW Heat Transfer Loop
ATWS	Anticipated Transients Without Scram
BO	Boiloff
BWR	Boiling Water Reactor
CACS	Containment Atmospheric Control System
CCFL	Counter Current Flow Limiting
CISE	Centro Informazioni Studi Esperienze
COL	Combined Operating License
CPR	Critical Power Ratio
CRD	Control Rod Drive
CRIEPI	Central Research Institute of Electric Power Industry
CSAU	Code Scaling, Applicability and Uncertainty
CSHT	Core Spray Heat Transfer
DBA	Design Basis Accident
DC	Direct Current
DPV	Depressurization Valve
DW, D/W	Drywell
EBWR	Experimental Boiling Water Reactor
ECCS	Emergency Core Cooling System
EOPs	Emergency Operating Procedures
FAPCS	Fuel and Auxiliary Pool Cooling System
FIST	BWR Full Integral Simulation Test
FIX	Swedish Test Loop Used for Testing External Pump Circulation
FMCRD	Fine Motion Control Rod Drive
FRIGG	Research Heat Transfer Loop Operated for Danish Atomic Energy Commission
FW	Feedwater
FWCS	Feedwater Control System
GDCS	Gravity-Driven Cooling System
GE	General Electric Company

ABBREVIATIONS AND ACRONYMS (Continued)

GEXL	General Electric Critical Quality Boiling Length Correlation
GIRAFFE	Gravity-Driven Integral Full-Height Test for Passive Heat Removal
GIST	GDCS Integral System Test
HCU	Hydraulic Control Unit
HVAC	Heating, Ventilating and Air Conditioning
IC	Isolation Condenser
ICS	Isolation Condenser System
INEL	Idaho National Engineering Laboratory
LASL	Los Alamos Scientific Laboratory
LB	Large Break
LOCA	Loss-of-Coolant Accident
LOOP	Loss Of Offsite Power
LPCI	Low Pressure Coolant Injection
MCPR	Minimum Critical Power Ratio
MIT	Massachusetts Institute of Technology
MPL	Master Parts List
MSIV	Main Steamline Isolation Valve
MSL	Main Steamline
MW	Megawatt
NBS	Nuclear Boiler System
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
P&ID	Process and Information Diagram
PANDA	Passive Nachwarmeabfuehr-und Drueckabbau-Testanlage (Passive Decay Heat Removal and Depressurization Test Facility)
PANTHERS	Performance Analysis and Testing of Heat Removal Systems
PAR	Passive Autocatalytic Recombiners
PCCS	Passive Containment Cooling System
PCT	Peak Cladding Temperature
PIRT	Phenomena Identification and Ranking Tables
PSTF	Pressure Suppression Test Facility
QDB	Qualification Database
RC&IS	Rod Control and Information System
RPV	Reactor Pressure Vessel
RWCU	Reactor Water Cleanup
SB	Small Break

ABBREVIATIONS AND ACRONYMS (Continued)

SBWR	Simplified Boiling Water Reactor
S/C	Suppression Chamber (wetwell)
SDC	Shutdown Cooling
SIET	Societa Informazioni Esperienze Termoidrauliche
SLCS	Standby Liquid Control System
SPERT	Special Power-Excursion Reactor Tests
SRV	Safety/Relief Valve
SSAR	Standard Safety Analysis Report
SSLC	Safety System Logic Control
SSTF	Steam Sector Test Facility
TAPD	Test and Analysis Program Description
TCV	Turbine Control Valve
THTF	Thermal-Hydraulic Test Facility
TLTA	Two-Loop Test Apparatus
TPS	Turbine Protection System
TRAC	Transient Reactor Analysis Code
TRACG	Transient Reactor Analysis Code, GE version
TT	Turbine Trip
UCB	University of California, Berkeley
VB	Vacuum Breaker
WW	Wetwell

1.0 INTRODUCTION

1.1 Purpose

The purpose of the Simplified Boiling Water Reactor (SBWR) Test and Analysis Program Description (TAPD) is to provide, in one document, a comprehensive, integrated plan that addresses the testing and analysis elements needed for analysis of SBWR steady-state and transient performance. The program was developed by:

- Study of the calculated SBWR transients and identification of important phenomena.
- Identification of the unique SBWR design features and their effect on transient performance.
- Systematic definition of experimental and analytical modeling needs.
- Evaluation of the current experimental and analytical model plan against these needs.
- Definition of modifications as necessary.

This document describes the steps in this process leading to the final Test and Analysis Plan (Appendix A). The TRACG computer code is used for the analysis of SBWR transients, Loss-of-Coolant Accident (LOCA), Anticipated Transient Without Scram (ATWS) and stability. The Test Plan has been cross-referenced against the identified phenomena to create the TRACG Qualification Matrix. Section 1.3 describes in more detail the strategy employed to arrive at these objectives. The use of specific tests in the development of TRACG models, for test predictions and for post-test validation, is addressed in the report. Descriptions of the SBWR-specific test facilities and their fidelity with respect to scaling the SBWR plant are provided in Appendices A and B.

The SBWR TAPD thus provides the technology basis for determining the performance of the plant for transients and accidents. It ties together the ongoing diverse experimental and analytical efforts in support of SBWR certification. The ultimate output from this activity is a set of validated analytical methods (primarily the TRACG computer code) for SBWR performance analysis.

1.1.1 Scope

The SBWR Test and Analysis Program Description is directed at providing a sound technology basis for the prediction of SBWR system performance during normal operation, transients and LOCAs. The document scope includes (1) steady-state operation and startup conditions, (2) transients and ATWS, (3) stability, and (4) LOCA. LOCA response covers the vessel response [levels and peak cladding temperature (PCT)] with operation of the Emergency Core Cooling Systems (ECCS), as well as the containment pressure and temperature response to postulated breaks. Long-term core cooling by inventory makeup is also considered.

The document does not address "severe accident" issues. The requirement to design the containment to handle hydrogen generation assuming 100% metal-water reaction is, however, addressed as a Design Basis requirement. Issues related not to thermal-hydraulics but, for example, to material properties, crack resistance, water chemistry, etc., are not covered in this plan.

The TAPD focus is illustrated in Figure 1.1-1. Transients and accidents, short of severe core damage, have been analyzed and the experimental and modeling needs incorporated into the plan. In the time domain, the focus of the studies has been on the first three days following a postulated accident or transient. Quasi-steady-state conditions prevail well before this point in time. Interactions with active systems such as the Fuel and Auxiliary Pool Cooling System (FAPCS) have been studied. No new phenomena are introduced beyond this point.

The experimental and analytical modeling needs were analyzed in the context of the applicable criteria of 10CFR52.47(b)(2)(i)(A), which require in part that:

- The performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof.
- Interdependent effects among the safety features of the design have been found to be acceptable by analysis, appropriate test programs, experience, or a combination thereof.
- Sufficient data exist on the safety features of the design to assess the analytical tools used for safety analysis over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions.

The term "safety feature" in the preceding paragraph is understood to include safety-related passive systems as well as other active systems which may be available to operators during accidents or transients. The Bottom-Up process described in Section 3 specifically examines all SBWR-unique features that are relevant to safety. Issues related to these features have been evaluated and the supporting technology basis (analysis, experimental data, plant data) documented. Interdependent effects among safety features have been specifically considered. Analysis has been performed (Appendix C) to screen interactions that deserve experimental validation. Finally, a test program has been established which provides a sufficient database for the qualification of the TRACG Code for SBWR safety analysis.

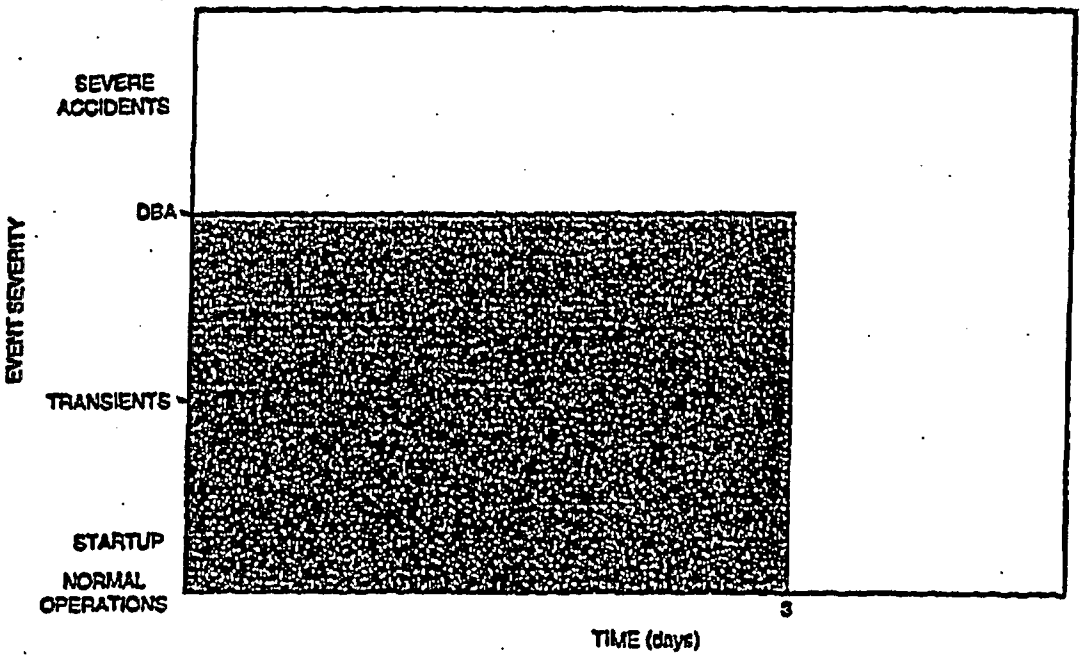


Figure 1.1-1. TAPD Focus

1.2 Background

SBWR Design Evolution

The SBWR design is an evolutionary step in boiling water reactor (BWR) design which traces its commercial demonstration and operating plant history back before 1960 (Figure 1.2-1). Since its inception, the BWR has had plant simplification as a goal for each product improvement (Figure 1.2-2). The SBWR has major simplifying improvements drawn from predecessor designs, notably pressure-suppression containment, natural circulation, isolation condenser handling of waste heat, and gravity-driven makeup water systems (Table 1.2-1). The incorporation of these features from predecessor designs into the SBWR has emphasized employment of passive means of dealing with operational transients and hypothetical LOCAs. The result of this evolution of previously licensed plant features is simplified operator response to these events (most plant upset conditions are dealt with in the same manner, as typified by the hypothetical steamline break), and a lengthened operator response time for all hypothetical events (from minutes for previously licensed reactors to days for the SBWR). Most features of the SBWR have been taken directly from licensed commercial BWRs and reviewed and redesigned as appropriate for the SBWR (Table 1.2-2). The SBWR draws together the best of previously licensed plant features to continue the simplification process. As an example, the evolution of the containment is shown in Figure 1.2-3.

Analysis and Design Tools

As implied above, data available from operating plants and from the testing and licensing efforts done to license the predecessor designs (most recently, ABWR) is the principal foundation of SBWR technology. As a measure of the SBWR's reliance on demonstrated technology, approximately 50% of the content of the SBWR SSAR is technically identical or technically similar (with minor differences) to the ABWR SSAR [31]. The 930 reactor-year database [40] of feature performance in operating reactors, combined with the recent thorough licensing review of the ABWR (Final Design Approval received July 1994), provides well-qualified foundation from which to make the modest extrapolations to the SBWR.

To make that extrapolation, GE has developed one computer code (TRACG) to use for design and for three out of the four most limiting licensing analyses. The TRACG Code, validated by operating plant experience and appropriate testing, is used to analyze the challenges to the fuel (10CFR50.46 and Appendix K, SSAR Section 6.3), the challenges to the containment (SSAR Section 6.2), and many of the operational transients (MCPR, SSAR Chapter 15). The radiological responses to hypothetical accidents are also presented in SSAR Chapter 15, but do not use TRACG for analysis. Thus, TRACG draws from the very large database of licensed BWRs which includes all features of the SBWR (albeit in various configurations) and appropriate testing, and allows direct application to SBWR design and analysis.

1.2.1 Use of TRACG

The TRACG Code and its application to the SBWR is documented in a series of GE Nuclear Energy Topical Reports ([1], [2], and [7]).

TRACG is a GE proprietary version of the Transient Reactor Analysis Code (TRAC). It is a best-estimate code for analysis of BWR transients ranging from simple operational transients to design basis LOCAs, stability, and ATWS.

1.2.1.1 Background

TRAC was originally developed for pressurized water reactor (PWR) analysis by Los Alamos National Laboratory (LANL), the first PWR version of TRAC being TRAC-P1A. The development of a BWR version of TRAC started in 1979 in a close collaboration between GE and Idaho National Engineering Laboratory. The objective of this cooperation was the development of a version of TRAC capable of simulating BWR LOCAs. The main tasks consisted of improving the basic models in TRAC for BWR applications and developing models for the specific BWR components. This work culminated in the mid-eighties with the development of TRACB04 at GE and TRAC-BD1/MOD1 at INEL, which were the first major versions of TRAC having BWR LOCA capability. Due to the joint development effort, these versions were very similar, having virtually identical basic and component models. The GE contributions were jointly funded by GE, the Nuclear Regulatory Commission (NRC) and Electric Power Research Institute (EPRI) under the REFILL/REFLOOD and FIST programs.

The development of the BWR version has continued at GE since 1985. The objective of this development was to upgrade the capabilities of the code in the areas of transient, stability and ATWS applications. Major improvements included the implementation of a core kinetics model and addition of an implicit integration scheme into TRAC. The containment models were upgraded for SBWR applications, and the simulation of the fuel bundle was also improved. TRACG was the end result of this development.

1.2.1.2 Scope and Capabilities

TRACG is based on a multi-dimensional two-fluid model for the reactor thermal-hydraulics and a three-dimensional neutron kinetics model.

The two-fluid model used for the thermal-hydraulics solves the conservation equations for mass, momentum and energy for the gas and liquid phases. TRACG does not include any assumptions of thermal or mechanical equilibrium between phases. The gas phase may consist of a mixture of steam and a noncondensable gas, and the liquid phase may contain dissolved boron. The thermal-hydraulic model is a multi-dimensional formulation for the vessel component and a one-dimensional formulation for all other components.

The conservation equations for mass, momentum and energy are closed through an extensive set of basic models consisting of constitutive correlations for shear and heat transfer at the gas/liquid interface as well as at the wall. The constitutive correlations are flow regime dependent and are determined based on a single flow regime map, which is used consistently throughout the code.

In addition to the basic thermal-hydraulic models, TRACG contains a set of component models for components, such as channels, steam separators and dryers. TRACG also contains a control system model capable of simulating the major control systems such as reactor pressure vessel (RPV) pressure and water level.

The neutron kinetics model is consistent with the GE core simulator code PANACEA. It solves a modified one-group diffusion model with six delayed neutron precursor groups. Feedback is provided from the thermal-hydraulic model for moderator density, fuel temperature, boron concentration and control rod position.

The TRACG structure is based on a modular approach. The TRACG thermal-hydraulic model contains a set of basic components, such as pipe, valve, tee, channel, steam separator, heat exchanger and vessel. System simulations are constructed using these components as building blocks. Any number of these components may be combined. The number of components, their interaction, and the detail in each component are specified through code input. TRACG consequently has the capability to simulate a wide range of facilities, ranging from simple separate effects tests to complete plants.

TRACG has been extensively qualified against separate effects tests, component performance data, integral system effects tests and full-scale plant data. A detailed documentation of the qualification is contained in the TRACG qualification report NEDE-32177P [2].

1.2.1.3 Scope of Application of TRACG to SBWR

The TRACG computer code has been qualified to Level 2 status at GE-NE. Thus, the code configuration is controlled, and the models and the results of validation testing have been reviewed and approved by an independent Design Review Team. In the development process, the separate effects and component data were used for model development and refinement.

The total effort and extent of qualification performed on TRACG, since its inception in 1979, now exceeds, both in extent and breadth, that for any other engineering computer program which GE has submitted to the NRC for design application approval. GE has chosen to perform SSAR analyses using the Best Estimate plus uncertainty method [10CFR50.46(a)(1)(i)]. The Level 2 application of TRACG includes LOCA analyses, transients, ATWS and Stability Analyses for the reactor and containment.

1.2.1.3.1 Transient Analysis

TRACG is used to perform safety analyses of nearly all of the Anticipated Operational Occurrences (AOO) described in SSAR Chapter 15, and of the ASME reactor vessel overpressure protection events in SSAR Chapter 5. The Loss of Feedwater Heating and the Control Rod Withdrawal Error events presented in SSAR Chapter 15 are analyzed using the GE 3-D core simulator model. Other SSAR Chapter 15 exceptions are the control rod drop and the fuel-handling accidents, and radiological calculations for all postulated accidents.

The analysis determines the most limiting event for the AOOs in terms of Critical Power Ratio (CPR) and margin loss (Δ CPR) and establishes the operating limit minimum CPR (OLMCPR). The OLMCPR includes the statistical CPR adder which accounts for uncertainty in calculated results arising from uncertainties associated with the TRACG model, initial conditions, and input parameters. Sensitivity analysis of important parameters affecting the transient results is performed using TRACG. Concepts derived from the Code Scaling, Applicability, and Uncertainty (CSAU) methodology are utilized for quantifying the uncertainty in calculated results.

The analysis also determines the most limiting overpressure protection events in terms of peak vessel pressure. The results are used to demonstrate adequate pressure margin to the reactor vessel design limit with the SBWR design safety/relief valve capacity. The overpressure protection analysis is performed based on conservative initial conditions and input values.

1.2.1.3.2 ATWS Analysis

TRACG is used for evaluation of the ATWS events in SSAR Chapter 15. The analysis determines the most limiting ATWS events in terms of reactor vessel pressure, heat flux, neutron flux, peak cladding temperature, suppression pool temperature, and containment pressure. The results are used to demonstrate the capability of the SBWR mitigation design features to comply with the ATWS licensing criteria.

1.2.1.3.3 ECCS/LOCA Analysis

TRACG is used for evaluation of the complete spectrum of postulated pipe break sizes and locations, together with possible single active failures, for Section 6.3 of the SBWR SSAR. This evaluation determines the worst case break and single failure combinations. The results are used to demonstrate the SBWR Emergency Core Cooling System (ECCS) capability to comply with the licensing acceptance criteria.

A sensitivity analysis of important parameters affecting LOCA results is performed using TRACG. For the SBWR, the LOCA analysis results are adjusted so that they provide 95% probability LOCA results for use as the licensing basis. The SBWR LOCA results have large margin with respect to the licensing acceptance criteria.

1.2.1.3.4 Containment Analysis

TRACG is also used for evaluation of containment response during a LOCA. The analysis determines the most limiting LOCA for containment (or Design Basis Accident, DBA) in terms of containment pressure and temperature responses. The DBA is determined from consideration of a full spectrum of postulated LOCAs. The results are used to demonstrate compliance with the SBWR containment design limits.

Sensitivity of the containment response to parameters identified as important is evaluated using TRACG to assess the effect of uncertainties of these parameters on the containment responses. The procedure derived from the CSAU methodology (Section 1.2.2) is used for this purpose.

1.2.2 Major SBWR Test Facilities

GE has used a procedure similar to the Code Scaling, Applicability and Uncertainty (CSAU) methodology developed by the NRC [4], [6] and submitted to the NRC by GE letter [41]. This procedure developed a list of phenomena important to the SBWR behavior in a large number of anticipated and hypothetical events and matched them against information available from operating plant and/or test experience. The Phenomena Identification and Ranking Table (PIRT) discussed in Section 2 of this report identifies over a hundred specific governing phenomena (summarized in Table 1.2-3 of this report), of which over half were concluded to be "important" in prediction of SBWR transient and LOCA performance. TRACG contains models capable of simulation of each of the important phenomena, and each has been qualified by the successful predictions of at least one, and in most cases, several test data sets. The PIRT defines more than 900 specific data sets, from 42 different tests and test facilities, that make up the TRACG qualification database. Data from separate effects tests, component tests, systems and systems interaction tests, and operating plant experience have been predicted by TRACG in its validation.

Early in the SBWR program one piece of information was identified as needed for the SBWR for which there was no information in the database: that is, a heat transfer correlation for steam condensation in tubes in the presence of noncondensable gases. A test program has since been conducted to secure this information, reported to the NRC in Reference 21.

The Single Tube Condensation Test Program was conducted to investigate steam condensation inside tubes in the presence of noncondensables. The work was independently conducted at the University of California at Berkeley (UCB) and at the Massachusetts Institute of Technology (MIT). The work was initiated in order to obtain a database and a correlation for heat transfer in similar conditions as would occur in the SBWR PCCS tubes during a DBA LOCA. Three researchers utilized three separate experimental configurations at UCB, while two researchers utilized one configuration at MIT. The researchers ran tests with pure steam, steam/air, and steam/helium mixtures with representative and bounding flow rates and noncondensable mass fractions. The experimenters found the system to be well behaved for all tests, with either of the noncondensables, for forced flow conditions similar to the SBWR design. The results of the tests at UCB have become the basis for the condensation heat transfer correlation used in the TRACG computer code.

While all SBWR features are extrapolations from current and previous designs, two features (specifically, the Passive Containment Cooling System and the Gravity-Driven Cooling System) represent the two most challenging extrapolations. Therefore, it was decided, for these two cases, to obtain additional test data, which could be used to demonstrate the capabilities of TRACG to successfully predict SBWR performance over a range of conditions and scales. Blind (in some cases double blind) predictions of test facility response use only the internal correlations of TRACG. No "tuning" of the TRACG inputs is to be performed, and no modifications to the coding are anticipated as a result of these tests.

For the case of the PCCS, it is planned to predict steady-state heat exchanger performance in full-vertical-scale 3-tube (GIRAFFE), 20-tube (PANDA), and prototypical 496-tube (PANTHERS) configurations, over the range of SBWR expected steam and noncondensable conditions (Appendix A). This process addresses scale and geometry differences between the basic phenomena tests performed in single tubes, and larger scales including prototype conditions. Transient performance is similarly investigated at two different scales in both GIRAFFE and PANDA.

TRACG GDCS performance predictions were performed against the GIST test series.

1.2.2.1 Major SBWR-Unique Test Programs

As noted previously, the majority of data supporting the SBWR design came from the design and operating experience of the previous BWR product lines. SBWR-unique certification and confirmation tests are briefly described below. They will be discussed in detail in Appendix A to this report.

1.2.2.1.1 GIST

GIST is an experimental program conducted by GE to demonstrate the Gravity-Driven Cooling System (GDCS) concept and to collect GDCS flow rate data to be used to qualify the TRACG computer code for SBWR applications. Simulations were conducted of DBA LOCAs representing main steamline break, bottom drain line break, GDCS line break, and a non-LOCA loss of inventory. Test data have been used in the qualification of TRACG to SBWR and documented in Reference 42. Tests were completed in 1988 and documented by GE in 1989. GIST data has been used for validation of certain features of TRACG.

1.2.2.1.2 GIRAFFE

GIRAFFE is an experimental program conducted by the Toshiba Corporation to investigate thermal-hydraulic aspects of the SBWR Passive Containment Cooling System (PCCS). Fundamental steady-state tests on condensation phenomena in the PCC tubes were conducted. Simulations were run of DBA LOCAs; specifically, the main steamline break. Tests have been completed and results have been documented in Reference 43. GIRAFFE data will be used to substantiate PANDA and PANTHERS data at a different scale and to support validation of certain features of TRACG.

1.2.2.1.3 PANDA

PANDA is an experimental program to be run by the Paul Scherrer Institut of Switzerland. PANDA is a full-vertical-scale 1/25 volume scale model of the SBWR system designed to model the thermal-hydraulic performance and post-LOCA decay heat removal of the PCCS. Both steady-state and transient performance simulations are planned. Testing at the same thermal-hydraulic conditions as previously tested in GIRAFFE and PANTHERS will be performed, so that scale-specific effects may be quantified. Blind pre-test analyses using TRACG will be submitted to the NRC prior to start of the testing. PANDA data will be used directly for validation of certain features of TRACG.

1.2.2.1.4 PANTHERS

PANTHERS is an experimental program to be performed by SIET in Italy, with the dual purpose of providing data for TRACG qualification and demonstration testing of the prototype PCCS and IC heat exchangers. Steam and noncondensables will be supplied to prototype heat exchangers over the complete range of SBWR conditions to demonstrate the capability of the equipment to handle post-LOCA heat removal. Testing at the same thermal-hydraulic conditions as performed in GIRAFFE and PANDA is planned. Blind pre-test analyses of selected test conditions using TRACG has been submitted to the NRC prior to the start of testing [35]. PANTHERS data will be used directly for validation of certain features of TRACG.

In addition to thermal-hydraulic testing, an objective of PANTHERS is to investigate the structural adequacy of the heat exchangers. This objective is beyond the scope of this report.

1.2.2.1.5 Scaling of Tests

A discussion of scaling of the major SBWR tests is contained in Reference 32. That report contains a complete discussion of the features and behavior of the SBWR during challenging events. It includes the general (Top-Down approach) scaling considerations, the scaling of specific (Bottom-Up approach) phenomena, and the scaling approach for the specific tests discussed above. Appendix B of this report supplements the scaling report with detailed quantitative analyses of the major SBWR test facilities.

Table 1.2-1. Evolution of the General Electric BWR

Product Line Number	Year of Introduction	Characteristic Plants/Features
BWR/1	1955	Dresden 1, Big Rock Point, Humboldt Bay, KRB, Dodewaard • Natural circulation (HB, D) • Internal steam separation • Isolation Condenser • Pressure suppression containment
BWR/2	1963	Oyster Creek • Large direct cycle
BWR/3/4	1965/1966	Dresden 2/Browns Ferry • Jet pump driven recirculation • Improved ECCS: spray and flood • Reactor Core Isolation Cooling System (replaced Isolation Condenser) (BWR/4)
BWR/5	1969	LaSalle • Improved ECCS systems • Valve recirculation flow control
BWR/6	1972	Grand Gulf • Improved jet pumps and steam separators • Improved ECCS performance • Gravity containment flooder
ABWR		Internal recirculation pumps FMCRDs
SBWR		Gravity flooder, passive containment cooling • Return to Isolation Condenser • Return to natural circulation

Table 1.2-2. SBWR Features and Related Experience

SBWR Feature	Plants	Testing
IC	Dodewaard, Dresden 1,2,3, Big Rock Pt., Tarapur 1,2, Nine Mile Pt. 1, Oyster Creek, Millstone 1, Tsuruga, Nuclenor, Fukushima 1	Operating Plants
Natural Circulation	Dodewaard Humboldt Bay	Operating Plants
Squib Valves	BWR/1-6 and ABWR SLC Injection Valves	Operating Plants IEEE 323 Qualification Testing
Gravity Flooder	BWR/6 Upper Pool Dump System, Suppression Pool Flooder System	Operating Plants Preoperational Testing
Internal Steam Separators	BWR/1-6 and ABWR	Operating Plants
Chimney (Core to Steam Separators)	Dodewaard, Humboldt Bay	Operating Plants
FMCRDs	ABWR	ABWR Test/Development Program (Demonstration at LaSalle Plant)
Automatic Depressurization Valves (MSIVs)	All BWRs	Operating Plants
Pressure Suppression	BWR/1-6 and ABWR	Mk I, Mk II, Mk III and ABWR Tests
Horizontal Vents	BWR/6 and ABWR	Mk III Testing ABWR Testing
Quenchers	BWR/2-6 and ABWR	Mk I/II/III Testing Operating Plants
PCC (Dual Function Heat Exchangers)	BWR/6, RHR HX Steam Condensing Mode	Operating Plants, PANDA, GIRAFFE, PANTHERS

Table 1.2-3. TRACG SBWR Qualification

Region	Phenomena Identified	Major Phenomena
Lower Plenum	9	4
Bypass	10	6
Core	39	29
Guide Tube	7	3
Downcomer	7	6
Upper Plenum	5	4
Steam Separator	3	3
Steam Dryer	2	0
Steam Dome	3	0
Steamline	6	5
Containment	68	48
Total	159	108

NOTE:

Key SBWR Phenomena Identified (summary)

- Phenomena are ranked according to importance and major phenomena identified.

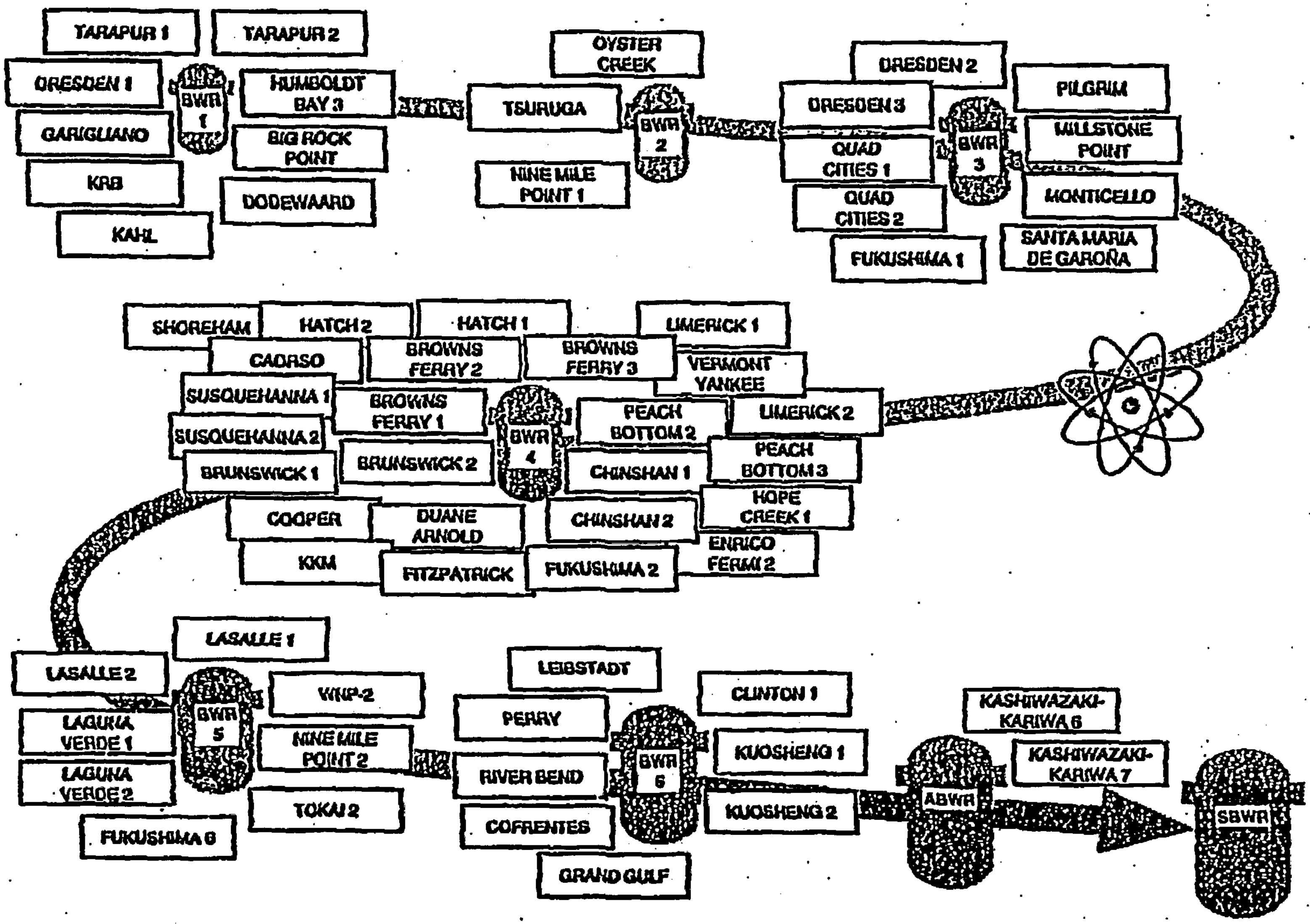


Figure 1.2-1. Evolution of the BWR

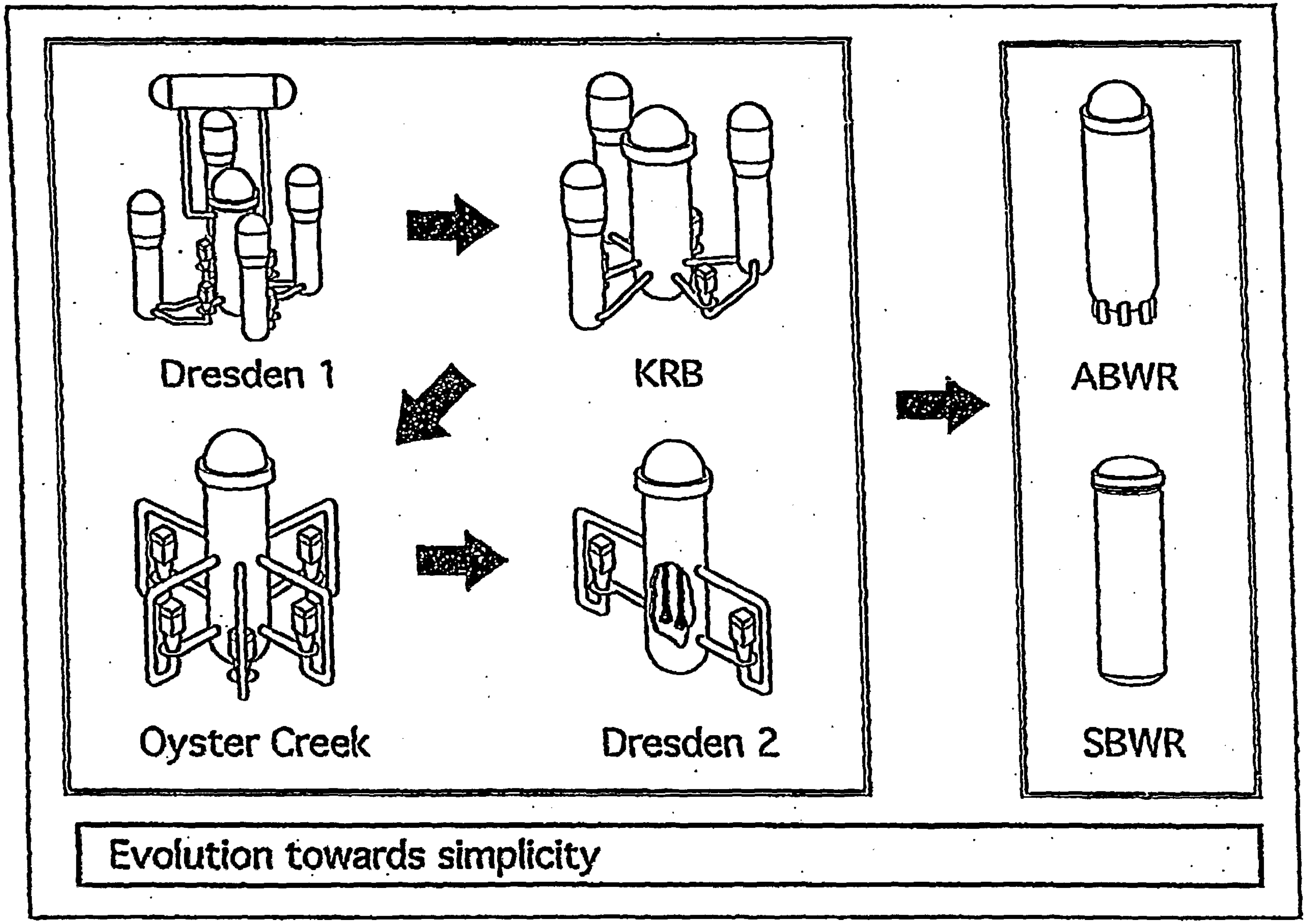
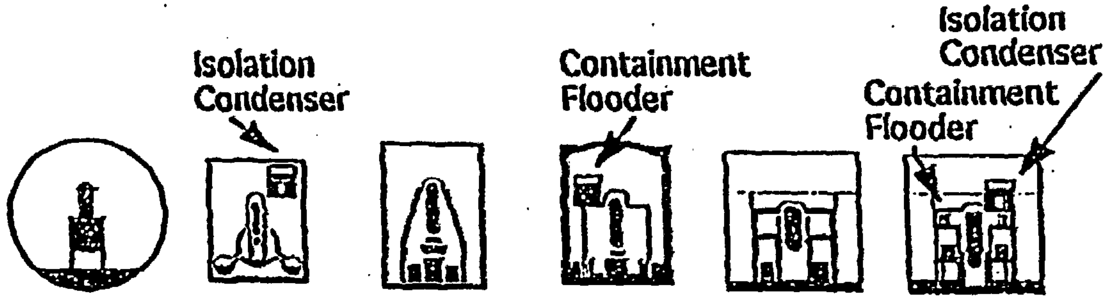


Figure 1.2-2. Evolution of the BWR



	Dry	Mark I	Mark II	Mark III	ABWR	SBWR
Pressure Suppression	No	Yes	Yes	Yes	Yes	Yes
Number of Barriers						
Containment	1	2	2	3	2	2
Fission	2	4	4	4	4	4
Volume, million ft^3	2.5	0.4	0.5	1.6	0.5	0.3
Heat Capacity, BTU x 10^9	0.3	1.7	1.3	1.3	1.3	1.3
Design Pressure, psig	50	62	45	15	45	55
LOCA Pressure, psig	50	44	42	9	39	42

Figure 1.2-3. Comparison of BWR Containments

1.3 Strategy for Determination of Test and Analysis Needs

The process of defining test and analysis needs for analysis of SBWR transient and accident performance is based on developing a thorough understanding of the key phenomena to be simulated and modeled. Once such a list of phenomena and interactions between systems is compiled, the test and analysis plans can be checked against it to determine their sufficiency. In this study, a dual approach was used to arrive at a comprehensive list of controlling phenomena. Figure 1.3-1 shows the overall strategy. The Top-Down process starts with the calculated scenarios for the classes of transients and accidents to be studied. The scenario is divided into different phases based on the key events in the evolution of the transient. For example, the LOCA/containment scenario can be divided into (1) the *Blowdown phase*, where the reactor vessel depressurizes, enabling the Gravity-Driven Cooling System (GDCS) to start injecting water into the reactor vessel; (2) the *GDCS phase* during which the GDCS tanks drain into the reactor pressure vessel; and (3) the *long-term cooling phase*, after the GDCS tanks have drained and the Passive Containment Cooling System (PCCS) removes decay heat and recycles condensed steam to the reactor vessel. For each phase of the transient, phenomena that might be important were listed and ranked to produce Phenomena Identification and Ranking Tables (PIRT). These tables were developed for each region of the reactor vessel and containment. This Top-Down process and the results are described in Section 2.

In the Bottom-Up process, unique SBWR design features were listed. Phenomena and issues related to these features that might influence SBWR operation and transient behavior were then compiled. This list was then reviewed and ranked by an independent team of experts. The resulting table of important phenomena and interactions is thus developed by an approach that is different from that used for the PIRT. Of course, both approaches require familiarity with SBWR transients and phenomena. This Bottom-Up process is described in Section 3.

The information developed through both approaches was combined into a comprehensive tabulation of SBWR phenomena. Because the Bottom-Up approach focused on SBWR-unique features, the PIRT contains 'generic' SBWR phenomena (common to all BWRs) that were not picked up by the SBWR-unique issues. On the other hand, because the Bottom-Up approach starts with specific SBWR components and systems, it was more suitable to identify interactions between components and the various SBWR systems. The composite table can be found in Section 4.1.

All the phenomena and interactions identified as important were evaluated. For the phenomena generic to all BWRs, the evaluation consisted of confirming that data exist in the BWR database covering the phenomena. For the SBWR-unique phenomena, a more formal evaluation process was implemented. A Qualification Database sheet was prepared for each phenomenon, issue or interaction, showing the expected range of SBWR parameters, the range of test data available and an analysis of the adequacy of the database. This led to the identification of needs for additional test data or for TRACG qualification, which were factored into the test plan. The component and system interactions were also treated in the same manner. Numerous SBWR scenarios were analyzed to screen interactions that merited further study or experimental validation. This set was then compared with available integral system data that would capture these interactions. The test plan was amended to incorporate identified gaps in the database. The results of the analytical studies are summarized in Section 4.2. Further details on the calculations are contained in Appendix C.

The iterative evaluation process discussed above results in the TRACG Qualification Matrix (Section 5). The Qualification Matrix is a rearrangement of the Test Matrix showing how the identified phenomena are covered by specific tests. The Qualification Matrix has been divided into four categories: Separate Effects Data, Component Data, Integral System Data, and BWR Operating Plant Data.

The Test and Analysis Plan is discussed in Appendix A. It includes a brief description of each major SBWR test facility, and the test matrix, which contains the test conditions and the purpose and projected use for each category of tests. Planned analyses with TRACG for pre- and post-test calculations are identified. Detailed scaling studies were performed on the GIST, GIRAFFE, PANDA and PANTHERS facilities. The results show that the facilities are properly scaled to yield data for certification. Results of the scaling studies have been summarized in Appendix B.

Section 6 shows how the data will be used for TRACG development and validation. Separate effects and component data are used mainly for model development. Because interactions among component and are present during the overall system response of integral test facilities, these data validate the overall performance of the TRACG Code for prediction of complex system response characteristics. Integral system tests provide confirmation of the validity of the models. The feedback from these tests may, also, be used to improve nodalization in the TRACG representation of the test facility, and possibly, the SBWR.

This process is illustrated with the help of an example. One of the phenomena considered important for the LOCA/ECCS events is critical flow from the downcomer region, including the effects of break uncovery and two-phase break flow. This is listed as Phenomenon E1 in Table 2.3-1, "SBWR PIRT for LOCA/ECCS". Because it is given an importance ranking of 7 for the large break (blowdown period), it is a candidate for incorporation in the composite table of highly ranked phenomena in Section 4. This issue is also listed in the Bottom-Up process, Table 3.2-1, "SBWR Thermal-Hydraulic Phenomena" under B21, Nuclear Boiler System. It is evaluated in Table 3.3-1, "Issue Evaluations Summary" (#13) as having a sufficient data base. It is carried forward to Table 4.1-1a, "Composite List of Highly Ranked Phenomena for LOCA/ECCS" (Item E1). Section 5 shows that the phenomena of critical flow, including break uncovery and a range of upstream two-phase conditions (E1), are covered by the PSTF vessel blowdown, Edwards depressurization test and the Marviken Critical Flow tests in Table 5.1-1, "Separate Effects Tests for TRACG Qualification for SBWR - Reactor Vessel and Core". The integral system tests which cover the phenomena are found in Table 5.3-1 (TLTA and FIST large break tests and the SSTF test). Table 5.5-1 shows that Item E1 is covered by Separate Effects, Component and Integral System Tests. Because of this, it is not included in Table 6.1-1, which lists the additional needs for TRACG qualification.

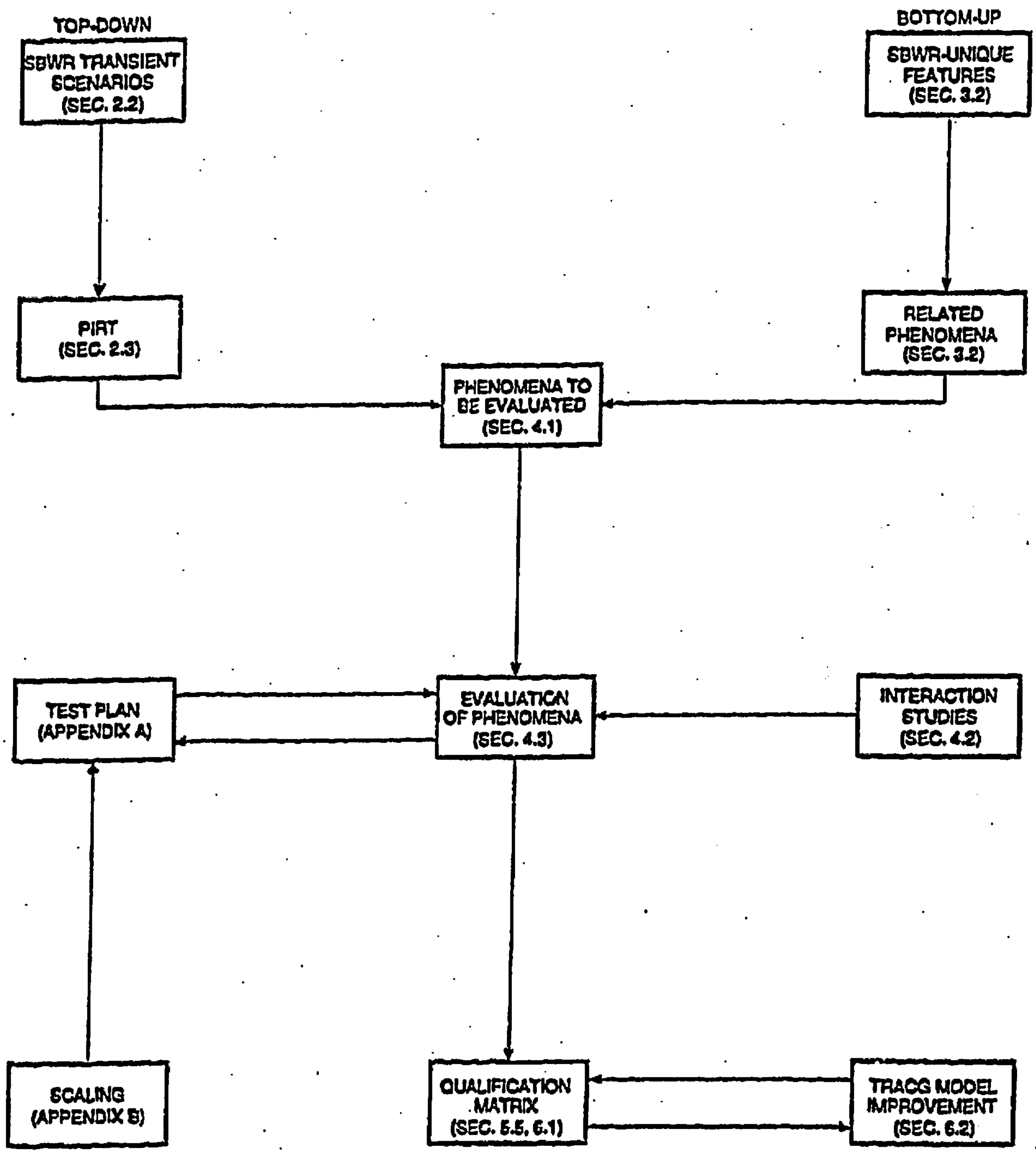


Figure 1.3-1. Strategy for Determination of Test Needs

1.4 Overall Test and Analysis Plan

This section shows the relationships between the various testing, qualification, licensing and design activities. In this study, the overall TRACG qualification needs are determined and additional SBWR related testing is defined as shown on Figure 1.4-1. As mentioned in the previous section, the primary output from the test and qualification activities is a final version of the TRACG computer program, which has been comprehensively validated for application to the SBWR. Figure 1.4-2 shows this process, which qualifies TRACG against large-scale component and integral system test data. A Licensing Topical Report describing TRACG Qualification against SBWR related test data will be prepared and submitted to the NRC for review and approval. Upon completion of the technology-related activities the SSAR calculations in Chapters 6 and 15 will be re-performed with the final version of the TRACG Code.

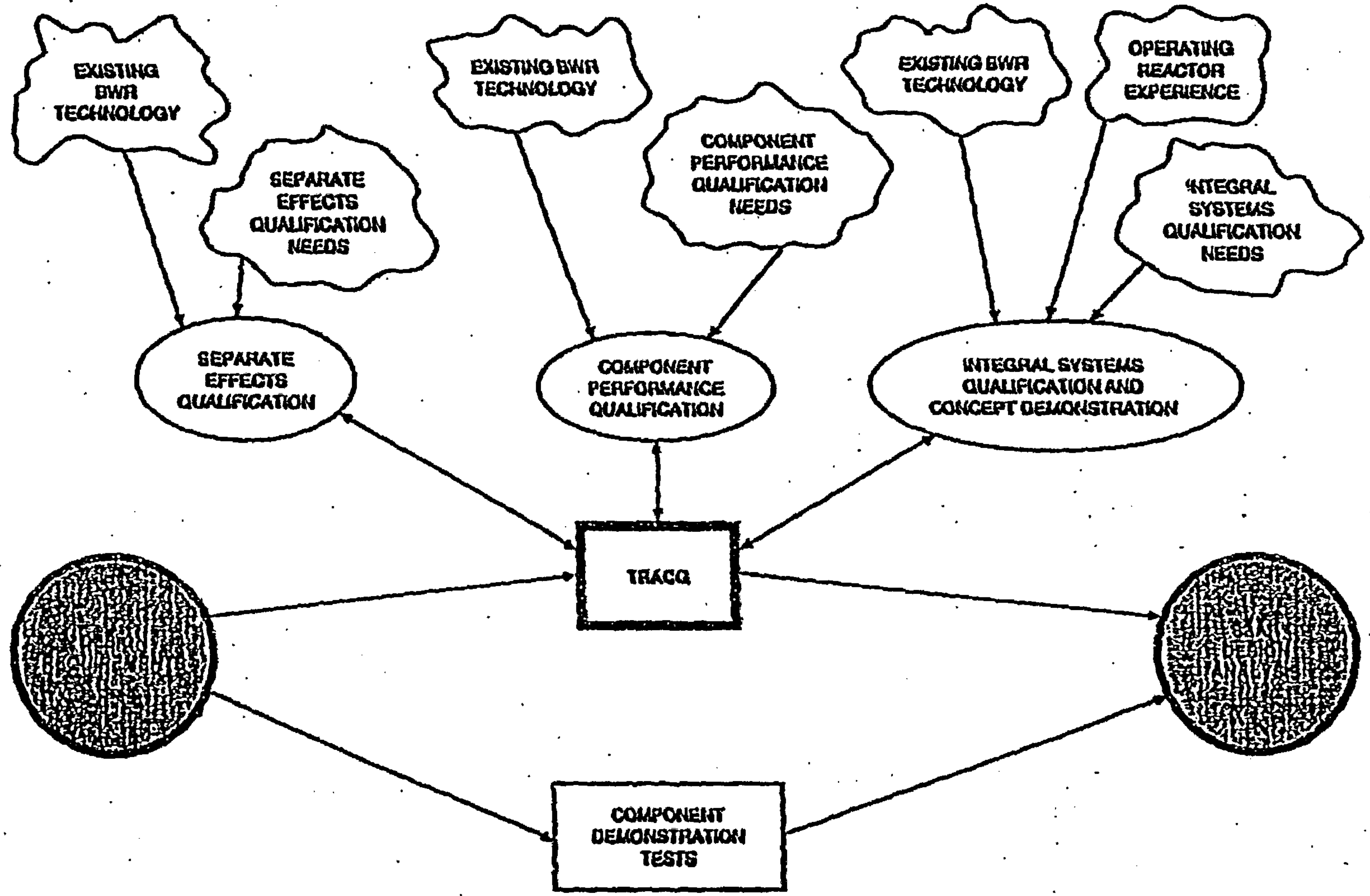


Figure 1.4-1. Technology Basis for SBWR Design

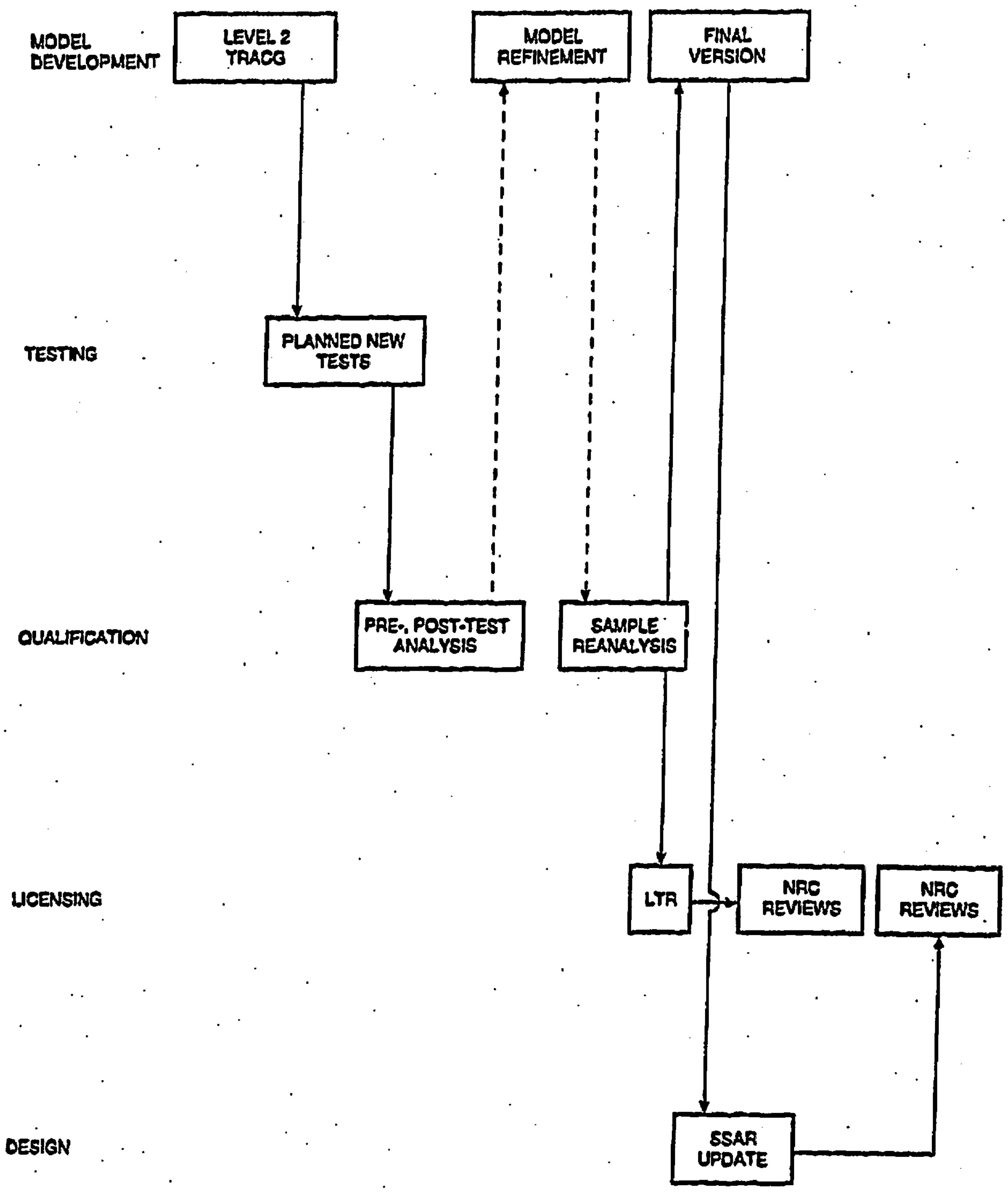


Figure 1.4-2. Overall Test and Analysis Plan

2.0 IDENTIFICATION OF IMPORTANT THERMAL-HYDRAULIC PHENOMENA: TOP-DOWN PROCESS

2.1 Introduction

As explained in Section 1.3 and illustrated in Figure 1.3-1, the process of defining test and analysis needs for analysis of SBWR transient and accident performance is based on developing a thorough understanding of the key phenomena to be simulated and modeled. This is done in this report in two ways: (1) a Top-Down process based on analyses and sensitivity studies, and (2) a Bottom-Up process based on examination of individual design features. The Top-Down process identifies phenomena and their importance based on how the overall system behaves; the Bottom-Up process, by component and subsystem requirements. This section discusses the Top-Down approach, leading to Phenomena Identification and Ranking Tables (PIRT). Section 3 discusses the Bottom-Up process. They are merged in Section 4.

The PIRT is a summary of analytical modeling needs for a physical system (in this case, the SBWR). The principal feature of the PIRT is an assessment of the "importance" of each modeling need by interdisciplinary teams of experts. The approach used in the SBWR follows the methodology of Boyack, et al. [6]. TRACG calculations established the scenarios of various events (LOCA, anticipated transients, ATWS and stability). These are described in Section 2.2. The descriptions stress the phenomenological evolution of the transients. A detailed description of the sequence of events can be found in the SSAR [3]. (It is noted that, due to modeling and design changes since SSAR submittal, the event sequences have been updated somewhat from the SSAR versions.)

The analyses were then reviewed by interdisciplinary teams to identify each thermal-hydraulic phenomenon that plays a role in the analysis, and to rank all of them in terms of "importance"; that is, degree of influence on some figure of merit (e.g., reactor water level, containment pressure). For a brief view of the output of this process, see the first sheet of Table 2.3-1. The PIRT process is discussed in Section 2.3, where the PIRT tables are presented.

2.2 Analysis of Events

2.2.1 Loss-of-Coolant Accident (LOCA)

Chapter 6 of the SSAR includes the entire matrix of calculations of postulated pipe rupture locations and single failures. For a complete PIRT evaluation, the entire spectrum of events must be covered, including analyses with less limiting conditions than the design-basis case with no auxiliary power. To facilitate understanding, a large break in the Gravity-Driven Cooling System (GDCS) line has been chosen to illustrate the sequence of events during the LOCA. The sequence of events is similar for all the LOCA events, particularly after initiation of the GDCS flows, when the vessel and containment transients are closely coupled. While there are some differences in the assumptions made for analysis of the different breaks, these are not very important in determining the phenomenological progression of the LOCA or the importance of various parameters. The limiting LOCA from the perspective of margin to core uncovery is the GDCS line break; from the viewpoint of containment pressure, it is the large steamline break. A schematic of the SBWR's passive safety systems is shown in Figure 2.2-1.

The overall LOCA sequence can be divided into three periods: blowdown period, GDCS period and the long-term cooling PCCS period. These periods are shown in Figure 2.2-2. The *blowdown period* is characterized by a rapid depressurization of the vessel through the break, safety relief valves (SRVs) and depressurization valves (DPVs). The steam blowdown from the break and DPVs pressurize the drywell, clearing the main containment vents and the PCCS vents. First, noncondensable gas and then steam flows through the vents and into the suppression pool. The steam is condensed in the pool and the noncondensable gas collects in the wetwell air space above the pool. At about 500 seconds, the pressure difference between the vessel and the drywell is small enough to enable flow from the GDCS pools to enter the vessel. This marks the beginning of the *GDCS period*, during which the GDCS pools drain their inventory. Depending on the break, the pools are drained in between 2000 and 7000 seconds. The GDCS flow fills the vessel to the level of the break, after which the excess GDCS flow spills over into the drywell. The GDCS period is characterized by condensation of steam in the vessel and drywell, depressurization of the vessel and drywell and possible openings of the vacuum breakers which returns noncondensable gas from the wetwell airspace to the drywell. The decay heat eventually overcomes the subcooling in the GDCS water added to the vessel and boiloff resumes. The drywell pressure rises until flow is reestablished through the PCCS. This marks the beginning of the *long-term PCCS cooling period*. During this period, the noncondensable gas that entered the drywell through the vacuum breakers is recycled back into the wetwell. Condensation of the boiloff steam in the PCCS is recycled back into the vessel through the GDCS pool. The most important part of the LOCA transient for vessel response is the blowdown period and the early part of the GDCS period when the vessel is reflooded and level restored. For some breaks, the equalization line from the suppression pool to the reactor vessel may open during the long-term cooling period to provide the vessel an additional source of makeup water.

2.2.1.1 Primary System Response for the GDCS Line Break

The GDCS line break scenario is a double ended guillotine break of a GDCS drain line. There are three GDCS pools in the SBWR containment, each with its own drain line from the pool to the vessel. Each drain divides into two branches before entering into the pressure vessel. Each branch has a check valve followed by a squib operated injection valve and finally a nozzle in the vessel wall to control the blowdown flow in case of a break. The check valve prevents backflow from the vessel to the pool. The GDCS break is assumed to occur in one branch, between the squib operated valve and the nozzle entering the vessel. Additional assumptions for the LOCA analysis include a simultaneous loss of auxiliary power and no credit for the on-site diesel generators. The only AC power assumed available is that from battery powered inverters.

- *Blowdown Period* — At break initiation, the assumed simultaneous loss of power trips the generator, causing the turbine bypass valves to open and the reactor to scram. The bypass valves close after 6 seconds. No credit is taken for this scram or the heat sink provided by the bypass. The power loss also causes a feedwater coastdown. Drywell cooling is lost and the control rod drive (CRD) pumps trip. The blowdown flow quickly increases the drywell pressure to the scram setpoint, although no credit is taken for this safety function.

  High drywell pressure isolates several other functions, including the Containment Atmosphere Control System (CACS) purge and vent, Fuel and Auxiliary Pool Cooling System (FAPCS), high and low conductivity sumps, fission product sampling, and reactor building Heating, Ventilating and Air Conditioning (HVAC) exhaust.

  Loss of feedwater and flow out the break cause the vessel water level to drop past the Level 3 (L3) scram setpoint. This setpoint is assumed to scram the reactor. The scram will temporarily increase the rate of level drop and the Level 2 (L2) trip will quickly follow the L3 trip. This trip will isolate the steamlines and open the isolation condenser (IC) drain valves, but no credit is taken for heat removal by the IC. After L2, the rate of level decrease will slow and, without external makeup, the Level 1 (L1) trip will be reached, but not for several minutes. During this delay, the IC, if available, would be removing energy and reducing pressure and break flow. After a 10-second delay to confirm the L1 condition, the Automatic Depressurization System (ADS) logic will start a timed sequential opening of depressurization and injection valves. Four SRVs (two on each steamline) open first. The remaining four SRVs open 10 seconds later to stagger SRV line clearing loads in the suppression pool and minimize vessel level swell. Similarly, opening of the depressurization valves (DPVs) is delayed 45 seconds. Two DPVs on the main steam lines open first, followed in 45 seconds by two additional DPVs. The remaining two DPVs open after an additional 45 seconds. Ten seconds after the last DPV opens, the six GDCS injection valves are opened. When the GDCS injection valves first open, the hydrostatic head from the pool is not sufficient to open the check valves and GDCS flow does not begin immediately. When the GDCS check valves do open, the cold GDCS water further depressurizes the vessel. Blowdown through the break and the SRVs and DPVs causes a level swell in the vessel, which collapses at the end of the blowdown period, with the GDCS injection.

- *GDCS Period* — The GDCS flow begins refilling the vessel and the downcomer level rises. When the level reaches the break, the GDCS flow spills back into the drywell. For the GDCS break, the flow of GDCS water is sufficient to raise the downcomer level above the break, until the pools empty, then the level drains back to the break level. Inside the core shroud, the level in the chimney also decreases after depressurization, but is restored after the GDCS refills the vessel. Figure 2.2-3 shows the chimney level during the first 25 minutes of the transient. The level swell during the initial blowdown and opening of the SRVs and DPVs is not shown in the figure (note the level drop and then rise during the GDCS period as the vessel is refilled).

2.2.1.2 Containment Response for the GDCS Line Break

Containment response calculations assume loss of all AC power except that available from battery powered inverters, reactor power at 102% of rated power and no credit for IC operation.

The single failure used is the failure to open a check valve in one of the GDCS pool drain lines. Initial conditions are containment normal operating pressure and temperature, with the suppression pool at its maximum allowable operating temperature.

- *Blowdown Period* — The blowdown for the GDCS line break occurs from the vessel side of the broken line. Simultaneously, the pool side of the broken line drains the inventory of the one affected GDCS pool into the containment. The check valve keeps the vessel from blowing down through the unbroken branch of the GDCS line. As noted earlier, the break flow is initially a liquid blowdown, and after the downcomer water level falls below the GDCS line elevation, the break becomes a vapor blowdown. The ADS, activated by the downcomer level, opens the SRVs and the DPVs. The flashing liquid (and later, steam) entering the drywell increases its pressure, opening the main containment vents and sweeping most of the drywell noncondensable gas through the main vents, the suppression pool and into the wetwell airspace. The steam flow through the vents is condensed in the suppression pool. During the blowdown phase of the transient, the majority of the blowdown energy is transferred into the suppression pool through the main vents. The increase in drywell pressure establishes flow through the PCCS, which also picks up part of the blowdown energy. For the GDCS break, this period of the accident lasts less than 10 minutes.
- *GDCS Period* — Once the vessel pressure drops below the setpoint of the check valves in the two unbroken GDCS lines, the GDCS pools begin to empty their inventory into the vessel. The subcooled GDCS water quenches the core voids, stopping the steam flow from the vessel. The GDCS flow refills the vessel to the level of the break and then spills over into the drywell. Spillover from the break into the drywell begins at about 20 minutes into the accident and continues throughout the GDCS period of the accident. Once the GDCS flow begins, the drywell pressure peaks and begins to decrease. The decrease in drywell pressure stops the steam flow through the PCCS and main vents. The drop in drywell pressure is sufficient to open the vacuum breakers between the drywell and the wetwell airspace several times. Once the GDCS flow begins to spill from the vessel into the drywell, the drywell pressure drops further and additional vacuum breaker openings occur. Some of the noncondensable gas in the wetwell airspace is returned to the drywell through the vacuum breakers. The GDCS period of the transient continues until the GDCS pools empty and the decay heat is able to overcome the subcooling of the GDCS inventory in the vessel. Then, the drywell pressure rises and flow is reestablished through the PCCS. The PCCS heat removal capacity, even while recycling noncondensable gas back to the wetwell, is sufficient to handle the steam generated by decay heat, and the main vents are not reopened. This period of the accident is expected to last approximately 3 hours for the GDCS break.
- *Long-Term PCCS Period* — After the drywell pressure transient initiated by the GDCS flow is over, the drywell pressure settles out, slightly above the wetwell airspace pressure. A drywell-to-wetwell pressure difference is established which is sufficient to open the PCCS vent and drive the steam generated by decay heat through the PCCS. The drywell pressure and temperature during the first 12 hours of the GDCS line break transient are shown in Figure 2.2-4. The drywell pressure rises rapidly during the blowdown period, decreases at GDCS initiation, drops as the GDCS spills into the drywell and finally levels off as boiloff resumes. The temperature shown is for a node high in the drywell. At this location, the temperature rises during blowdown, then actually superheats during the GDCS period, but levels off as flow to the PCCS resumes. In lower regions of the drywell, affected by GDCS spill, the temperature may drop during the GDCS period.

Figure 2.2-5 shows the PCCS power during the first 12 hours of the transient. Also shown is the decay heat. During the blowdown period, the PCCS picks up part of the energy released during the blowdown, most of which is deposited in the suppression pool. During the GDCS period, steam flow to the PCCS stops and the PCCS power drops to zero. As soon as the decay heat can overcome the GDCS subcooling, boiloff and steam flow to the PCCS resumes and by 12 hours, the PCCS power increases back to nearly equal to the decay heat power.

By way of comparison, the drywell pressure at the beginning of the long-term period for the GDCS break is below the drywell pressure for the large steam line break. During the 72 hours which define the long-term cooling period, the drywell pressure remains below the large steam-line break pressure. As with other breaks, the drywell pressure established at the end of the GDCS period defines the containment behavior during the long-term cooling period.

For this particular break, depending on which GDCS line is broken, the vessel level may slowly drop during the long-term cooling period because part of the inventory that is boiled off and condensed in the PCCS may be returned to the GDCS pool with the break. This part of the PCCS flow will drain into the lower drywell instead of returning to the vessel. To avoid uncovering the core, an equalization line between the vessel and suppression pool is designed to open before the vessel water level can drop below one meter above the top of the core. This ensures sufficient liquid inventory to keep the core covered, even if the boiloff continues. For some breaks, the level in the lower drywell may rise enough to reach the spillover holes in the main vents. Inventory added to the lower drywell past this point is returned to the suppression pool and back to the vessel through the equalization line. Analysis of the GDCS break indicates that for this break, the drywell level will not reach the spillover holes.

During this final period of the transient, drywell pressure will rise slowly. This results from a slow increase in the wetwell airspace pressure, due to the assumed leakage flow between the drywell and wetwell airspace and conduction across the wall separating the drywell and wetwell. This energy addition is partially offset by heat losses to the surroundings from the outside wetwell wall. Without the leakage, the containment pressure remains nearly constant during the long-term period of the transient.

2.2.1.3 GDCS Line Break Summary

Although the discussion of the GDCS line break has been described in two parts, the primary system and containment response are not independent, particularly after the blowdown period. The sequence of events occurring in the GDCS line break transient is summarized in Table 2.2-1. The events which produce actions are listed as symptoms and the actions resulting from the event are listed as actions. The timing of the symptoms is also shown.

For the GDCS break, the reactor core does not uncover, so there is no cladding heatup above saturation temperature of the coolant. In evaluating the "importance" of various phenomena in the PIRT process, the phenomena associated with cladding heatup (e.g., radiation heat transfer, metal-water reaction) are comparatively unimportant, while phenomena associated with reactor water level (e.g., decay heat, energy release from heat slabs) are comparatively important. For the containment, after the blowdown and release of energy to the suppression pool, the effectiveness of the PCCS controls the containment response, with no pumped decay-heat removal system available. In the long-term cooling period, the containment pressure and temperature increase slowly till the end of the 72-hour period, at which time credit for non-safety decay-heat removal systems is permitted. Thus, containment pressure and temperature become the primary figure of merit for the containment and the phenomena affecting them are important.

The LOCA scenario develops slowly for the SBWR. The accident detection system logic functions almost instantaneously, but thereafter, the time scales are measured in hours rather than seconds. The reactor water level (Figure 2.2-3) dips briefly about 10 minutes into the LOCA due to void collapse following GDCS injection. The minimum water level occurs at about 7 hours after the break. This slow response, which is due to the large volume of water in the reactor vessel and GDCS pools, makes the LOCA a very slow moving event from the reactor systems and operator response standpoint. Similarly, containment response (Figure 2.2-4) is gradual, not reaching the design pressure even 72 hours after the break. This slow response permits well-considered, deliberate operator actions.

2.2.2 Anticipated Transients

As with the LOCA, anticipated transients are discussed in the SSAR (Chapter 15) and no additional analyses are presented in this report. The PIRTs for anticipated transients were synthesized from consideration of the phenomena involved in various classes of events.

2.2.2.1 Fast Pressurization Events

These are the limiting pressurization events. Principal figures of merit on which "importance" is defined are critical power (MCPR) and reactor pressure.

- Turbine Trips — initiated by trip of turbine stop valves from full open to full closed. Analyzed with bypass valves functional, and with bypass failure.
- Generator Load Rejection — initiated by fast closure of turbine control valves from partially open position to full-closed. This event is analyzed with bypass valves functioning, and with bypass failure. The turbine control valves may be initially at the same position (full arc turbine admission) or at different positions (partial arc turbine admission).
- Loss of AC Power — Similar to load rejection; however, bypass valves are assumed to close after 6 seconds due to loss of power to condenser circulating water pumps.
- Main Steamline Isolation Valve (MSIV) Closure — In this case, the scram signal on valve position is further in advance of complete valve closure. This effectively mitigates the shorter line length to the vessel available as a compression volume.
- Loss of Condenser Vacuum — This event is similar to the Loss of AC Power and a Turbine Trip with Bypass. Because a turbine trip occurs at a higher vacuum setpoint than the bypass valve isolation, the bypass valves are available to mitigate the initial pressure increase.

2.2.2.2 Slow Pressurization Events

These are analyzed principally to ensure that they are bounded by the fast pressurization events. MCPR and reactor pressure determine "importance."

- Pressure Regulator Downscale Failure — Simultaneous closure of all turbine control valves in normal stroke mode. The triplicated fault tolerant control system prevents any single failure from causing this and makes its frequency below the anticipated abnormal occurrence category.
- Single Control Valve Closure — This event could be caused by a hydraulic failure in the valve or a failure of the valves rotor/actuator.

2.2.2.3 Decrease in Reactor Coolant Inventory

Loss of feedwater flow is characteristic of this category of transient. The IC maintains water level. Reactor water level is the principal figure of merit on which "importance" is defined.

2.2.2.4 Decrease in Moderator Temperature

These events challenge MCPR and stability, which are the figures of merit on which "importance" is defined:

- Loss of Feedwater Heating — initiated by isolation or bypass of a feedwater heater.
- Feedwater Controller Failure — hypothesizes an increase in feedwater flow to the maximum possible with all three feedpumps operating at maximum speed. Similar to turbine trip but with more severe power transient due to colder feedwater.

To determine the phenomena important in modeling anticipated transients, the sequence of events and system behavior for each class of events should be understood. To provide an example of this, the sequence of events for a fast pressurization transient is discussed below. For this class of transients, important phenomena are those affecting the MCPR and reactor pressure.

2.2.2.5 Generator Load Rejection Event Description

A fast pressurization event will occur due to the fast closure of the turbine control valves (TCVs), which can be initiated whenever electrical grid disturbances occur which result in significant loss of electrical load on the generator. Closure of the turbine stop valves is initiated by the turbine protection system. The valves are required to close rapidly to prevent excessive overspeed of the turbine-generator rotor.

At the same time, the turbine stop or control valves are signaled to close, and the turbine bypass valves are signaled to open in the fast opening mode. The bypass valves are full open only slightly later than the turbine valves are closed, and can relieve more than one-third of rated steam flow to the condenser, greatly mitigating the transient. The bypass valves also use a triplicated digital controller. No single failure can cause all turbine bypass valves to fail to open on demand. The worst single failure can only cause one turbine bypass valve to fail to open on demand.

The closing time of the TCVs is short relative to the sonic transit time of the steamline, so their closure sets up a pressure wave in the steamlines. When the pressure wave reaches the vessel steam dome, the flow rate leaving the vessel effectively undergoes a step change. The area change entering the steam dome partially attenuates the pressure wave, propagating a weaker pressure disturbance down through the chimney and downcomer, increasing the vessel pressure, and reducing voids in the core. The void-reactivity feedback results in an increase in the neutron flux. A reflection of the pressure wave also travels back toward the turbine, producing an oscillation in flow and pressure in the steamlines.

Concurrent with closure of the turbine control valves, a scram condition is sensed by the reactor protection system. A turbine stop valve position less than approximately full open triggers a scram, as does the low hydraulic fluid pressure in the turbine control valve solenoids which start their fast closure mode. The SBWR digital multiplexed Safety System Logic Control (SSLC) will initiate a scram when any two turbine stop valves are sensed as closing, or any two turbine control valves are sensed as fast closing.

The core reactivity is decreased by the control blade insertion and increased by the decrease in core voids and increase in inlet flow. The net effect may be either an immediate shutdown of the reactor and decrease in neutron flux (in cases where there are control blades partially inserted in high worth areas of the core) or a short period of increased reactivity and neutron flux followed by shutdown (in the safety analysis case where there are no control blades initially inserted, and a slower bounding CRD scram insertion time is assumed.)

In the case where the neutron flux undergoes a transient increase, the energy deposition in the fuel pellet will increase clad heat flux. The minimum value of critical power ratio during this transient is found to occur in the upper part of the bundle.

Eventually, as the blades are fully inserted, the reactor is driven subcritical, power drops to decay heat levels, and clad temperature equilibrates near saturation temperature.

The vessel pressure increase is terminated by the bypass valve opening. The water level drops below the feedwater sparger and sprays subcooled water into the steam dome. This quenching of vapor also helps to terminate the pressure increase. If the bypass and feedwater systems are assumed to be unavailable, the duration of increased pressure would be long enough to initiate the isolation condenser.

In the ASME overpressure protection analysis, the Isolation Condenser is not considered, causing the pressure to slowly increase to the SRV opening pressure. The pressure increase is terminated immediately with SRV activation, and the maximum vessel pressure occurs at the vessel bottom. The overpressure protection case conservatively assumes the first scram signal to fail, and scram on neutron flux terminates the power increase in both turbine valve closure and the MSIV closure events.

The water level response in pressurization events is driven by the transfer of water from the downcomer to core and chimney caused by the collapse of voids in the core and chimney regions. The sensed water level decreases rapidly below the L3 low water scram setpoint. The feedwater system flow increases fast enough to prevent the L2 setpoint being reached in high frequency events (events where feedwater and bypass valves are available). The feedwater control system will demand maximum feedwater flow for approximately one minute, until normal level is restored. Without feedwater, the level drop will progress to L2, initiating the IC, isolating the MSIVs and transferring the CRD system to high pressure injection mode. The IC can independently maintain the water level near the L2 setpoint. CRD high pressure injection will cause level to slowly recover to above normal, and then automatically trip off.

2.2.3 Anticipated Transients Without Scram (ATWS)

The most limiting ATWS event in terms of reactor vessel pressure, heat flux, neutron flux, peak cladding temperature, suppression pool temperature and containment pressure is the inadvertent closure of all main steamline isolation valves with failure of rod insertion. This event is described in Section 15.8 of the SSAR. It is the only ATWS event considered in determining the phenomena needs for qualification of TRACG.

2.2.4 Stability

Because the SBWR core flow is driven by natural circulation, the most limiting stability condition is at the rated power/flow condition. This is unlike operating forced-circulation BWRs, and it simplifies the stability analysis for the SBWR.

For the SBWR, a stability criterion is used which is very conservative compared to operating plants (Figure 2.2-5). The core decay ratio is maintained less than 0.4 and the channel decay ratio less than 0.3.

The stability performance of the SBWR is evaluated at various conditions.

2.2.4.1 In Steady-State Operation

In *steady-state operation*, the highest power/flow ratio occurs at 104.2% power and 100% flow conditions. The decay ratio is well within the conservative design criteria (Figure 2.2-5). At reduced power level, the power/flow ratio is lower, so the decay ratios for both core and hot channel are lower than at the rated condition. This conclusion is supported by Dodewaard test data as shown in the figure. The decay ratios during normal operation at Dodewaard have been very low. In Figure 2.2-6, the power/flow map of SBWR normal operation is compared with the stability limit calculated in the Oak Ridge National Laboratory (ORNL) study. The results show that there is large margin for stability. This indicates that the SBWR is very stable under normal operation conditions.

2.2.4.2 Of the Anticipated Transients

Of the *anticipated transients*, the loss of 55.6°C (100°F) feedwater heating case gives the highest power/flow ratio. Loss of feedwater flow is another limiting event. However, the scram quickly mitigates the transient and the power conditions are reduced to hot shutdown. For both events, the decay ratios for core and hot channel meet the design criteria shown in Figure 2.2-5. In Figure 2.2-6, both of these transient events are seen to result in power/flow conditions that are well below the exclusion region.

2.2.4.3 Under ATWS Conditions

Under *ATWS* conditions, the persistent high reactor power poses the most challenge to the stability criteria. However, feedwater runback reduces the core power, and the SBWR's low power density also helps to alleviate the severity of the challenge to the stability criteria. Even though the reduced vessel water level effectively decreases the core flow rate and increases the power/flow ratio to a higher value than those for the steady state and anticipated transient conditions, the analysis of performance in the ATWS study indicates the reactor remains stable and no power oscillation is predicted. The injection of boron will eventually shut down the reactor and mitigate the situation.

2.2.4.4 During Startup

During *startup*, there is a special concern that is not present at power. At very low flows, a periodic "geysering" flow oscillation can be postulated to occur caused by either of two mechanisms. First, condensation of core exit vapor in the subcooled chimney region and the top of the core might cause a reduced pressure in the channels and a resultant flow reversal in the core. Oscillations of this kind are unlikely given the SBWR startup procedures, which are similar to those of the Dodewaard reactor (Dodewaard has experienced no "geysering" oscillation in its 22 refuel cycles of operation). Second, vapor production in the lower-hydrostatic-head chimney region could cause a reduction of hydrostatic head and a resultant core flow increase. This, in turn, could cause voids to collapse in the chimney, leading to a reduction in flow. Oscillations of this second kind have also never been seen at Dodewaard. If they were to occur, they would be mild oscillations with little, if any, reactivity impact.

Table 2.2-1. GDCS Line Break Sequence of Events

Symptom	Action(s)	Time (hr)
Loss of offsite power	Instantaneous GDCS line break. Generator trips, bypass valves open and reactor scrams. Bypass valves close after 6 seconds. No credit for this scram or the bypass heat sink is taken in the SSAR Chapter 6 analysis	0.
	Feedwater coastdown (diesel generators fail to start)	
	Fuel pool cooling lost	
	DW coolers lost	
	CRD pumps trip	
High drywell pressure	Scram (no credit taken)	0.01 (Note 1)
	CACS (Cont. Atm. Control Sys) purge & vent isolates	
	FAPCS (Fuel and Aux. Pool Cooling Sys.) isolation	
	PCC condensation begins	
	PCC pool boiloff begins, HX tubes remain covered >72 hr	
	Isolate high and low conductivity sumps, fission product sampling, reactor building HVAC exhaust	
Low water level L3	Scram	0.01 (Note 1)
Low water level L2	IC drain valve opens (MSIV closure also initiates)	0.01 (Note 1)
	Isolate high and low conductivity sumps, fission product sampling, reactor building HVAC exhaust	
	DW coolers isolate	
Low water level L1	ADS/GDCS initiation. Timed sequential opening of: 4 SRVs/4 SRVs/2 DPVs/2 DPV's/2 DPV's/6 GDC injection valves	0.1
	DW coolers isolate	
	Same equipment which isolated on L2 receives redundant isolation signal.	
P rpv < GDC pool head	Injection flow begins	0.2
Post LOCA radiolytic H_2 and O_2	PARs (Passive Autocatalytic Recombiners) function. (PARs are not simulated in fuel peak temperature and minimum water level calculations)	0.2 (Note 2)
P dw < P ww –0.5 psi	Vacuum breakers open	0.3
GDCS pool empties	DW pressure stabilized	2.4
	DW-WW Δp initiates PCCS flow	
	PCCS condensate returns to GDCS pool, drains to vessel and DW	
Reactor water level falls to one meter above top of core	Vessel to S/P equalization line opens, keeps core covered	6.6
Liquid in DW reaches spillover holes in main vents	Inventory added to DW now returns to S/P (then to vessel)	9.3 (Note 3)
Design-basis leakage and sensible heat transfer from DW to WW causes gradual increase of DW pressure	Pressure rises slowly for 72 hours (defined as end of design basis)	to 72

NOTES:

(1) Scram on high drywell pressure and level decrease to L2 occur within one minute of the line break.
(2) PARS will actuate as soon as they are exposed to radiolytic hydrogen, estimated to occur within a few minutes of the line break.
(3) Increase of DW level to the spillover holes only occurs if it is assumed that inward flow through the break cannot occur. Otherwise, the inventory spilled to the DW returns to the RPV through the break.

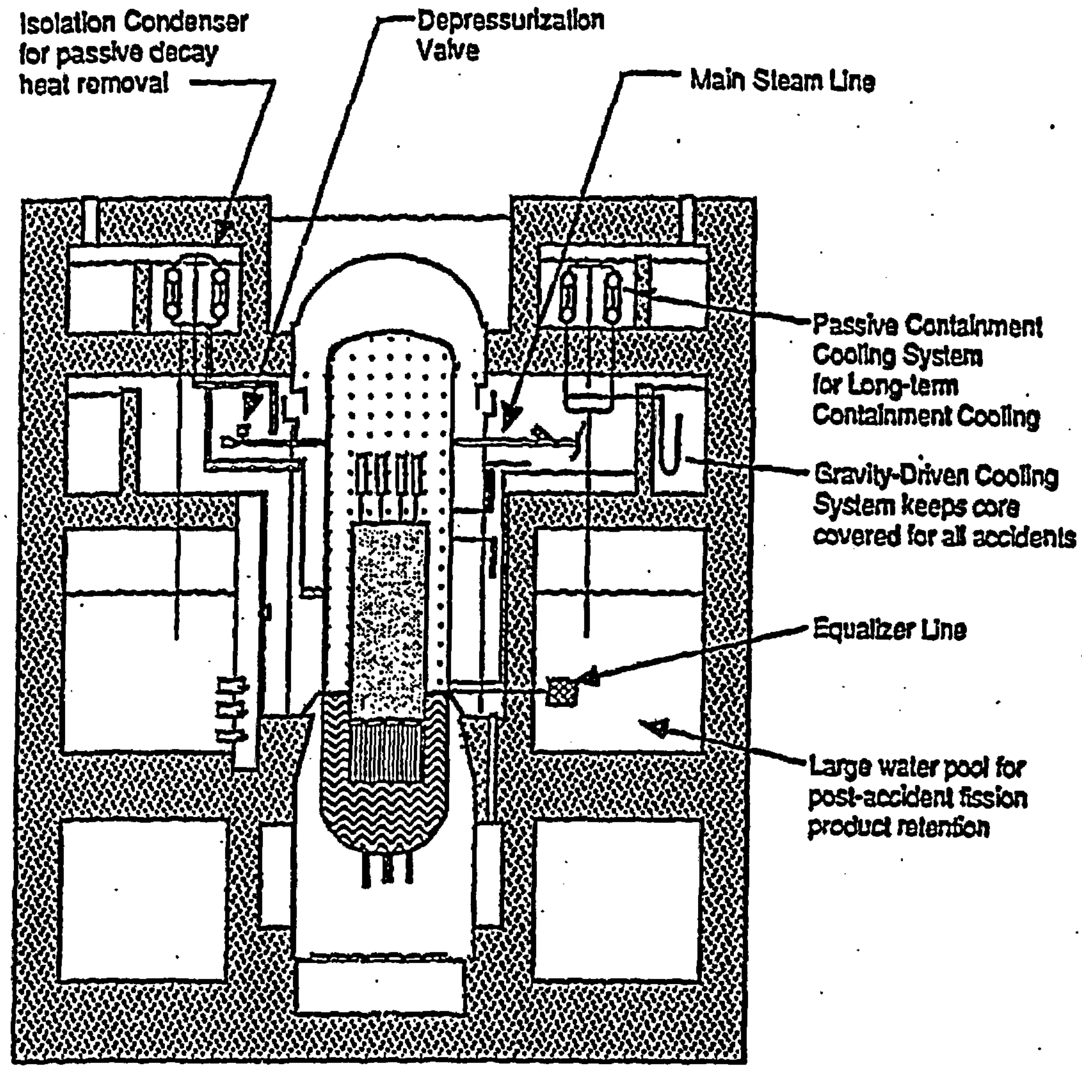


Figure 2.2-1. SBWR Passive Safety Systems

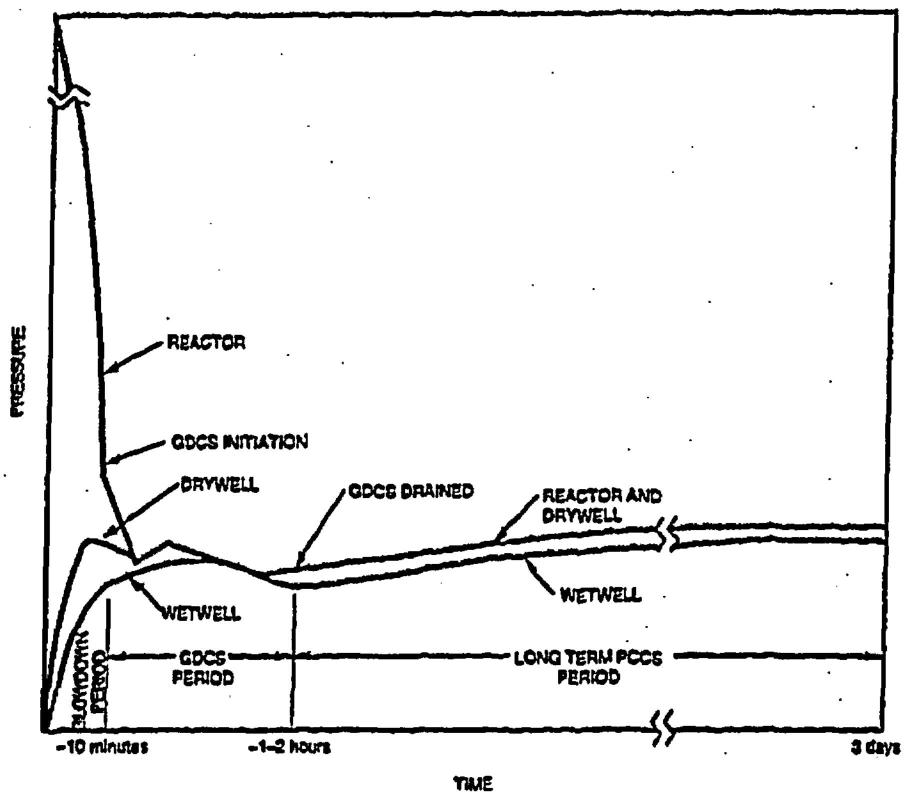


Figure 2.2-2. Phases of the LOCA Transient

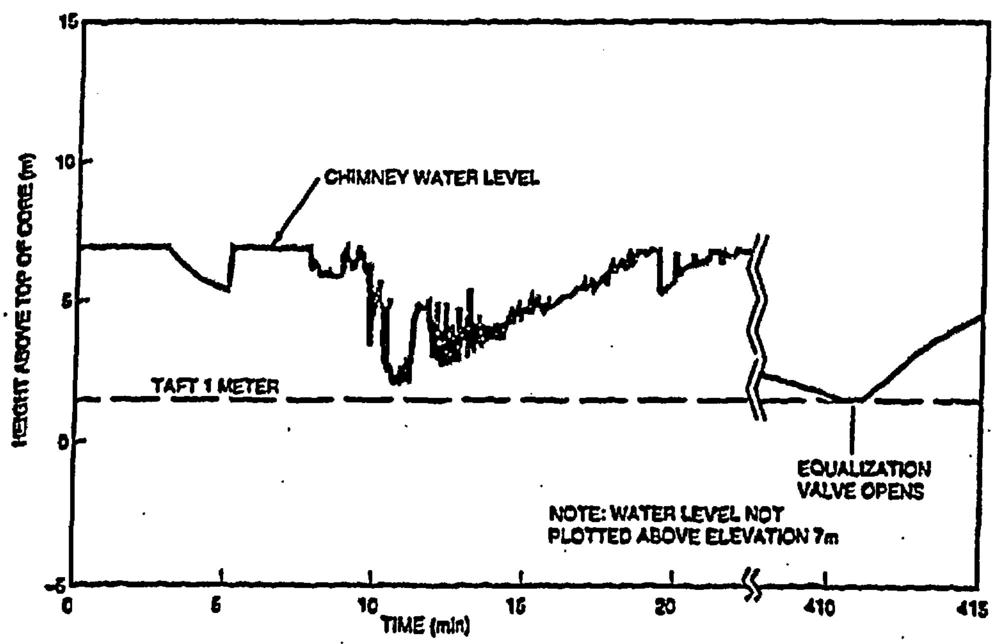


Figure 2.2-3. GDCS Line Break Reactor Water Level vs. Time

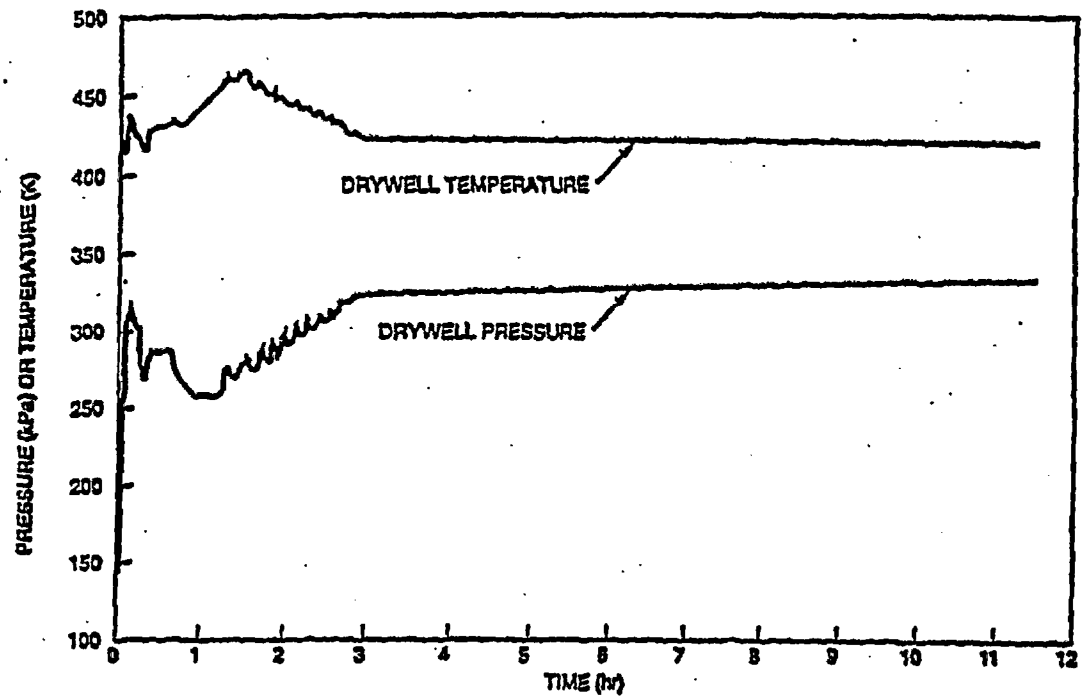


Figure 2.2-4. GDCS Line Break Containment Pressure and Temperature vs. Time

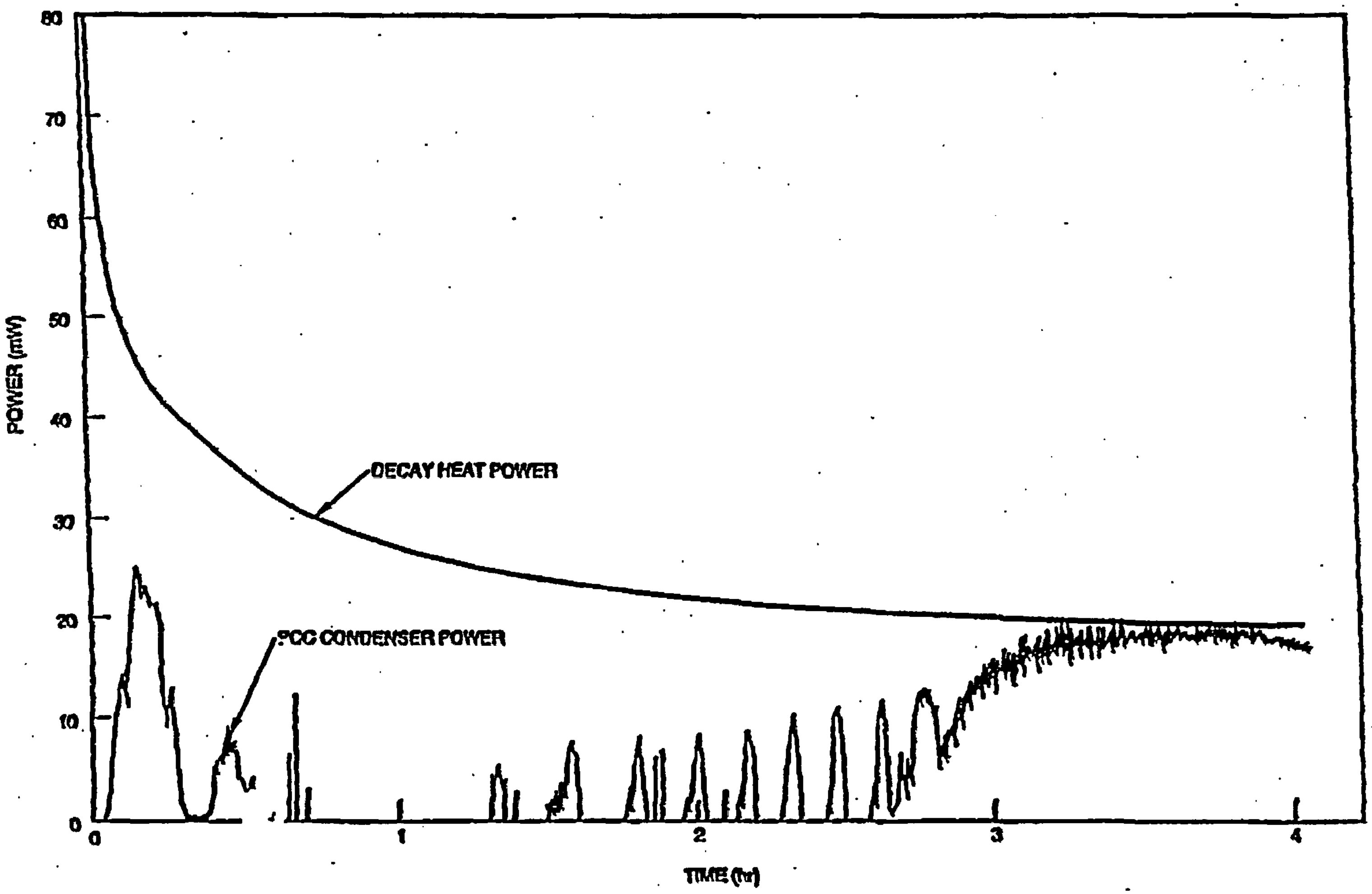


Figure 2.2-5. GDCS Line Break Decay Heat and PCC Power vs. Time

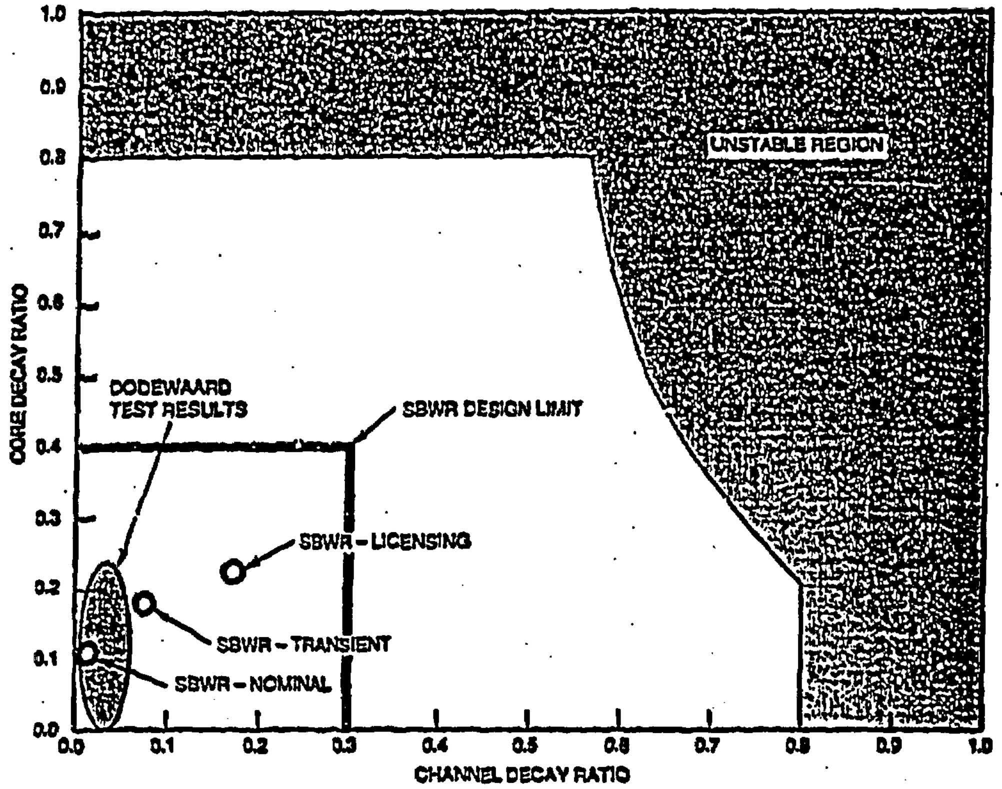


Figure 2.2-6. SBWR Stability Design Criteria and Performance

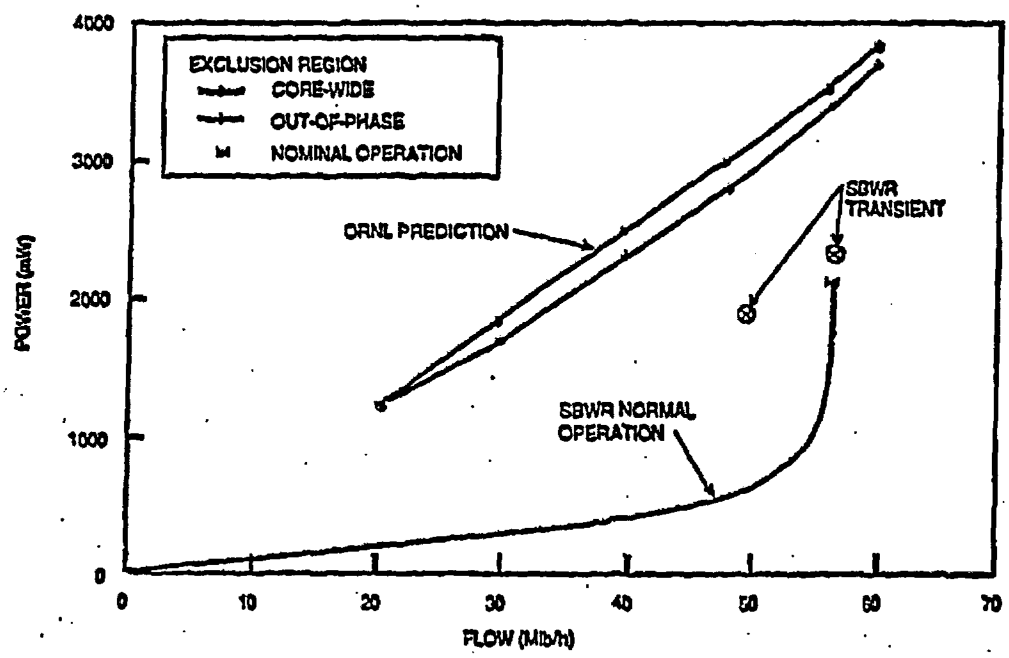


Figure 2.2-7. SBWR Power/Flow Map Comparison With Calculated Stability Limit

2.3 Phenomena Identification and Ranking Tables (PIRT)

The process of Top-Down analysis and qualification of the performance of the SBWR starts with the identification of the important physical phenomena. For this purpose, Phenomena Identification and Ranking Tables (PIRT) [6] were developed. This was done by assembling a team of experts knowledgeable about thermal-hydraulics and transient analysis, and obtaining consensus on the relative importance of various phenomena. Phenomena were given a rank between 0 and 9 based on their "importance" as defined in Section 2.2. Tables were developed for small break LOCAs, large break LOCAs, operational transients, stability and reactivity insertion accidents such as control rod withdrawal error and control rod drop. In each case, the importance of the phenomena was evaluated for each reactor region: lower plenum, core, upper plenum/ chimney, downcomer, containment, etc. For the LOCA events, the tables were further subdivided into the blowdown, GDCS and long-term periods of the transients.

The tables were first condensed to include only the highly ranked phenomena. It was apparent that for many transients and subregions, the phenomena of importance are the same as for operating BWRs. As an example, for pressurization transients, the most important parameters are the nuclear parameters (void, Doppler and scram reactivity), the interfacial shear (void fraction), subcooled boiling and steam line dynamics. The phenomena that are unique to SBWR are given primary emphasis in this report. These are primarily factors affecting the PCCS performance, GDCS interactions and phenomena associated with natural circulation flow in the core.

The PIRT tables are used for two purposes. First, the capabilities of the TRACG models are examined to see if all the important phenomena can be treated. Secondly, the qualification database is examined for completeness against the important phenomena. The second task is discussed in Chapter 5.

2.3.1 Loss-of-Coolant Accident (LOCA)

The overall transient consists of three periods: the blowdown period, the GDCS period and the long-term cooling PCCS period. These periods are described in previous sections and shown in Figure 2.2-1. For each of these periods, the important thermal/hydraulic phenomena were listed and ranked. This was done by experts familiar with BWR and SBWR characteristics and with transient analysis. The group was interdisciplinary, drawn from several technical areas, such as SBWR design, methods development, and plant transient analysis. The phenomena were classified by reactor and containment region (e.g., lower plenum, core, downcomer, chimney, drywell, wetwell, etc.).

2.3.2 Anticipated Transients

Plant startup and three types of operating transients (pressurization, depressurization, and cold water transients) are evaluated. The importance rankings for various phenomena are tabulated by region. "Importance" is ranked by the influence these phenomena have on the Critical Power Ratio (CPR) and maximum pressure reached in the transient. For plant startup, the key criterion is the likelihood of large oscillations in the core flow and power. The nuclear parameters and thermal-hydraulic parameters in the core dominate the pressurization and cold water transients.

2.3.3 Anticipated Transients Without Scram, Stability

These are considered in determining the matrix of tests needed for SBWR performance analysis in Chapter 5.

3.0 IDENTIFICATION OF SBWR-UNIQUE FEATURES AND PHENOMENA — BOTTOM-UP PROCESS

3.1 Introduction

This section describes the Bottom-Up process, one of two methods used to develop the test and analysis needs for SBWR. It complements the Top-Down process described in Section 2, with which it will be merged in Section 4. This approach compiles a list of SBWR-unique features, associated thermal-hydraulic phenomena and supporting TRACG qualification data. The purpose is to evaluate, from the system and component point of view, the adequacy of the database used to qualify TRACG in the areas important to SBWR thermal-hydraulic response.

3.2 Methodology

In order to perform a systematic and thorough review of all systems in the design, the SBWR System Structure (Figure 3.2-1) was used as a starting point.

Each of the 127 SBWR systems was reviewed to determine if the system was unique or had unique features that do not exist in the BWR operating fleet. Those systems that did not directly affect the thermal-hydraulic response of the SBWR were eliminated. System-unique features, the safety classification of the system, and the MPL number were documented. The principal design engineers were consulted with respect to the current reference system design and unique features, as well as References 3, 31, 32 and Tables 2.3-1 and 2.3-2, to determine any new issues associated with that unique feature. For each of the issues, associated important thermal-hydraulic phenomena were identified.

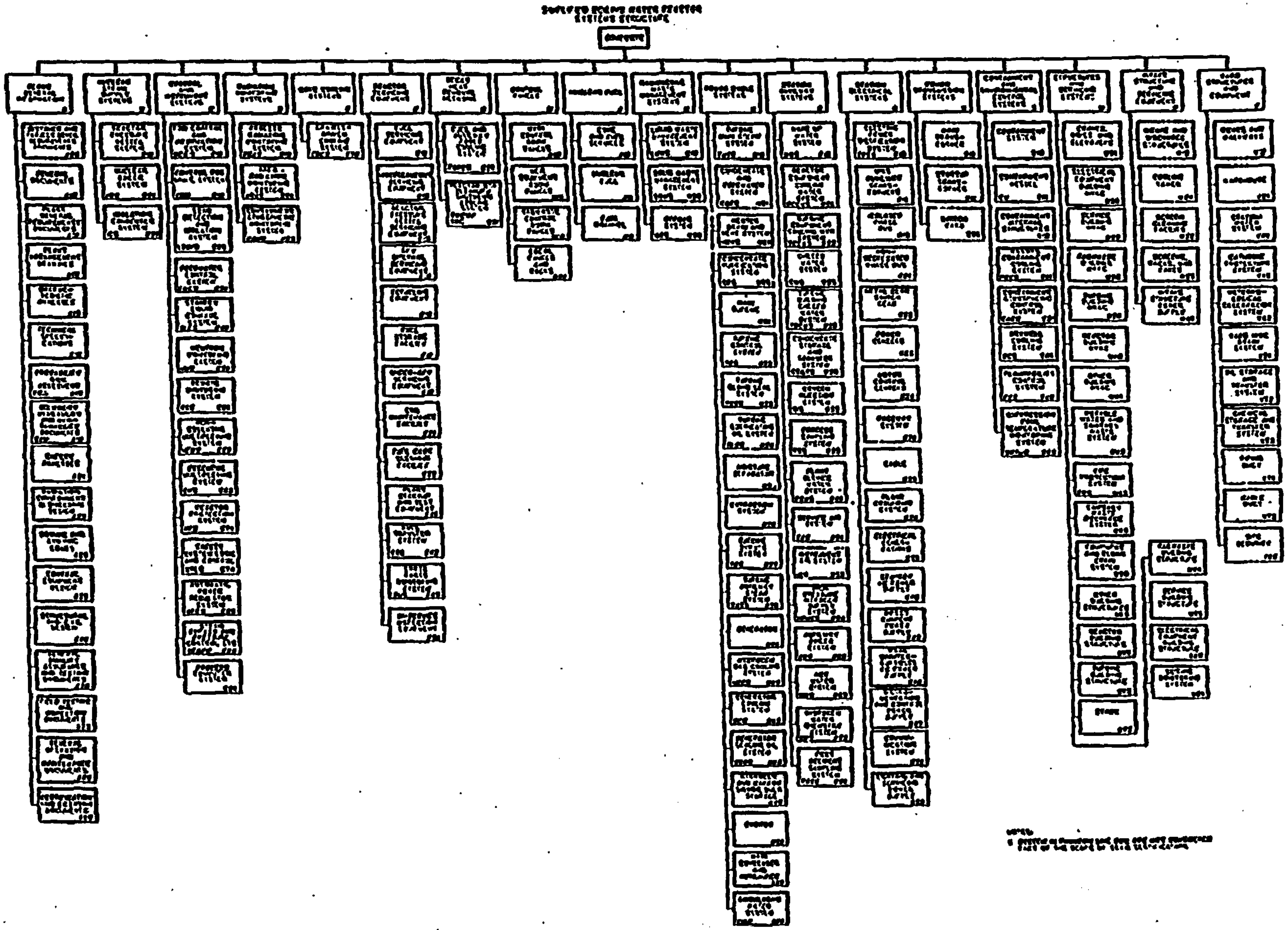


Figure 3.2-1. SBWR Product Structure

3.3 Results

A discussion of key results by system is provided in the sections below.

3.3.1 RPV and Internals (B11)

Ten thermal-hydraulic phenomena were evaluated in detail.

3.3.2 Nuclear Boiler System (B21)

Three thermal-hydraulic phenomena were evaluated in detail.

3.3.3 Isolation Condenser System (B32)

Eight thermal-hydraulic phenomena were evaluated in detail.

3.3.4 Standby Liquid Control System (C41)

Five thermal-hydraulic phenomena were evaluated in detail.

3.3.5 Gravity-Driven Cooling System (E50)

Six thermal-hydraulic phenomena were evaluated in detail.

3.3.6 Fuel and Auxiliary Pools Cooling System (G21)

Two thermal-hydraulic phenomena were evaluated in detail.

3.3.7 Core (J-Series)

In the area of the SBWR core, four issues/phenomena were identified as unique to the SBWR.

3.3.8 Containment (T10)

During the review of the SBWR design, 21 unique containment system thermal-hydraulic phenomena were identified.

3.3.9 Passive Containment Cooling System (T15)

The systematic review of the SBWR design identified 13 thermal-hydraulic phenomena related to the design of the PCCS.

4.0 EVALUATION OF IDENTIFIED PHENOMENA AND INTERACTIONS

The PIRT analysis in Section 2 identified important phenomena for different types of transients and LOCAs. These were grouped by the period of the transient and listed separately for each region of the reactor vessel and containment. In Section 3, a Bottom-Up process was employed to identify SBWR unique design features and associated phenomena and interactions. These were classified according to the SBWR system (e.g., FAPCS, Nuclear Boiler, etc.) where the particular feature was found. Following the overall strategy described in Section 1.3, the highly ranked phenomena from these lists are now combined in this section to yield a comprehensive, composite list of phenomena that need to be considered. The list is composed of separate tables for phenomena and interactions for each type of transient (LOCA, operational transients, ATWS, etc.). The list of interactions is screened in Section 4.2 and reduced to a final table of phenomena for which data are needed for qualification of TRACG in Section 4.3. In Section 5, these tables will be compared against the Test Plan to confirm that all elements of the tables are covered by tests.

4.1 Composite List of Identified Phenomena and Interactions

These are also picked up by the PIRT. The main additions to the PIRT list came from detailed consideration of the Isolation Condenser units.

4.2 Analytical Evaluation of System Interactions

The purpose of the system interaction study was to investigate the effect of both active and passive systems which could be available to support Engineered Systems Feature (ESF) systems during a LOCA; and to determine if interactions between the systems could degrade the performance of the ESF systems from what it would be if they were acting alone. The study extends earlier work presented in Chapter 6 of the SSAR [3], which evaluated the effect of the break location and of various single failures. A part of this earlier study examined the possible adverse effect of reverse flow through the Isolation Condenser during an inadvertent opening of a DPV. Additional analysis in Chapter 19 of the SSAR [3] examined use of non-safety grade engineered systems to prevent core damage.

The present study examines both system interactions which could affect the SBWR primary system response, as measured by the fuel temperature and vessel water level, and system interactions which could affect the containment response, as measured by the containment temperature and pressure. The study was performed using the TRACG code with two different input models. System interactions affecting the primary system were studied with the TRACG input model used for LOCA analysis of the SBWR, which provides a detailed representation of the reactor core, vessel internals and associated systems, but a less detailed representation of the containment. For system interactions affecting the containment, the TRACG input model for containment analysis was used. This input model provides a more detailed representation of the containment and its systems but a less detailed reactor pressure vessel model. Both input models have been compared to assure that they predict similar global response behavior of the reactor pressure vessel and containment.

The use of analysis methods is a practical and effective way to evaluate system interactions. The TRACG code and the input models for the primary system and containment which were discussed above include detailed modeling of the important passive and active systems available in the SBWR and can simulate the interactions between these systems during various accident scenarios. This makes it possible to screen a large number of possible system combinations and accident paths to identify those system combinations and accidents most likely to produce adverse interactions. Based on this type of study, final confirmation of interaction effects can then be obtained from integral tests.

4.2.1 Accident Scenario Definition

The systems selected for the study were those that would likely be available during a LOCA and which could produce adverse interactions with the safety grade engineered systems for core and containment cooling.

4.2.2 Results from the Primary Systems Interactions Study

Several different break locations were considered for the primary system interactions study.

4.2.3 Results from the Containment Systems Interactions Study

The containment system interactions study investigated interactions between available safety grade engineered systems as well as interactions of these systems with other systems which could be available for containment cooling without a loss of power.

4.2.4 Summary of System Interaction Studies

The system interactions considered in this study have included those which were considered the most likely to occur when some form of external power was available and which were not clearly beneficial to the operation of the safety grade engineered safety systems.

4.3 Summary of Evaluations

This section summarizes the results of screening the phenomena of Section 4.1, primarily in the area of interactions, as a result of the studies of Section 4.2. This constitutes the final step in determining the needs for test data for TRACG qualification. These needs are detailed in Sections 4.3.1 and 4.3.2 for LOCA and Transients, respectively. Section 4.3.3 covers ATWS and stability. Section 5 then presents the results of comparing these needs against the test plan.

4.3.1 Transients

All issues but one have been carried forward to Section 5 as needs for TRACG qualification.

4.3.2 ATWS and Stability

For ATWS, the majority of the phenomena are captured either by the transient PIRT (neutronic and thermal hydraulic issues, Isolation Condenser, etc.) for the reactor parameters or by the containment PIRT for the SRV discharge to the suppression pool (critical flow, pool stratfication and heatup, etc.).

5.0 MATRIX OF TESTS NEEDED FOR SBWR PERFORMANCE ANALYSIS

The important phenomena and interactions from Section 4 were compared with the original Test Plan as it existed when this study began. It was found that most of the identified effects were covered by tests which could be used to qualify TRACG. In a few cases, additional testing or qualification was proposed and incorporated into the Test Plan. The tests have been divided into (1) Separate Effects Tests, (2) Component Performance Tests, (3) Integral System Tests, and (4) Operating Plant Data. The first two types of tests are suitable for model development, the latter two for checking the overall performance of the code.

5.1 Separate Effects Tests

The facilities are listed in Appendix A, where the types of tests, test purpose and data available from each are also briefly described.

5.2 Component Performance Tests

A large number of phenomena related to the blowdown and refill processes in the lower plenum, bypass and core are covered by the component tests. Parallel channel effects and separator characteristics are also part of this database.

5.3 Integral System Response Tests

Integral system response tests model overall behavior of a facility subjected to transients simulating specific accidents or transient events. Tests are performed on a scaled simulation of the reactor system.

5.4 Plant Operating Data

The performance of the SBWR is similar to that of other BWRs for operational transients. Plant data are very valuable in validating code performance for complex systems involving an interplay between thermal hydraulics, neutron kinetics and control system response.

5.5 Summary of Test Coverage

The previous sections specified the test facilities and BWR plants from which data have been used (or will be used) for TRACG qualification. This information was tabulated for each of the identified important phenomena, by category of tests (separate effects, component performance, etc.).

6.0 INTEGRATION OF TESTS AND ANALYSIS

This section examines the tasks necessary to complete the qualification of TRACG. Figure 6.0-1 shows the "Road-Map" of how the new and existing test data support SBWR certification.

6.1 TRACG Qualification Plan

Details on the tests and TRACG runs to be performed can be found in the Test Plan in Appendix A. The Analysis Plan in Appendix A shows specifically which tests will be used for blind predictions, and which tests will be used for post-test analysis.

6.2 Use of Data for TRACG Model Improvement and Validation

The TRACG computer code has been qualified to Level 2 (verified, production) status at GE-NE. Thus, the code configuration is controlled, and the models and the results of validation testing have been reviewed and approved by an independent Design Review Team. In the development process, the separate effects and component data were used for model development and refinement. These data also provided guidelines for the nodalization which was used for all the SBWR calculations. The new data and the results of the post-test analyses will be used in the same way. If changes are necessary to the TRACG models, a new version of the code will be created and brought to controlled Level 2 status under the GE-NE quality assurance procedures for computer codes. If changes in the nodalization are indicated, calculations affected by the changes will be redone and reverified.

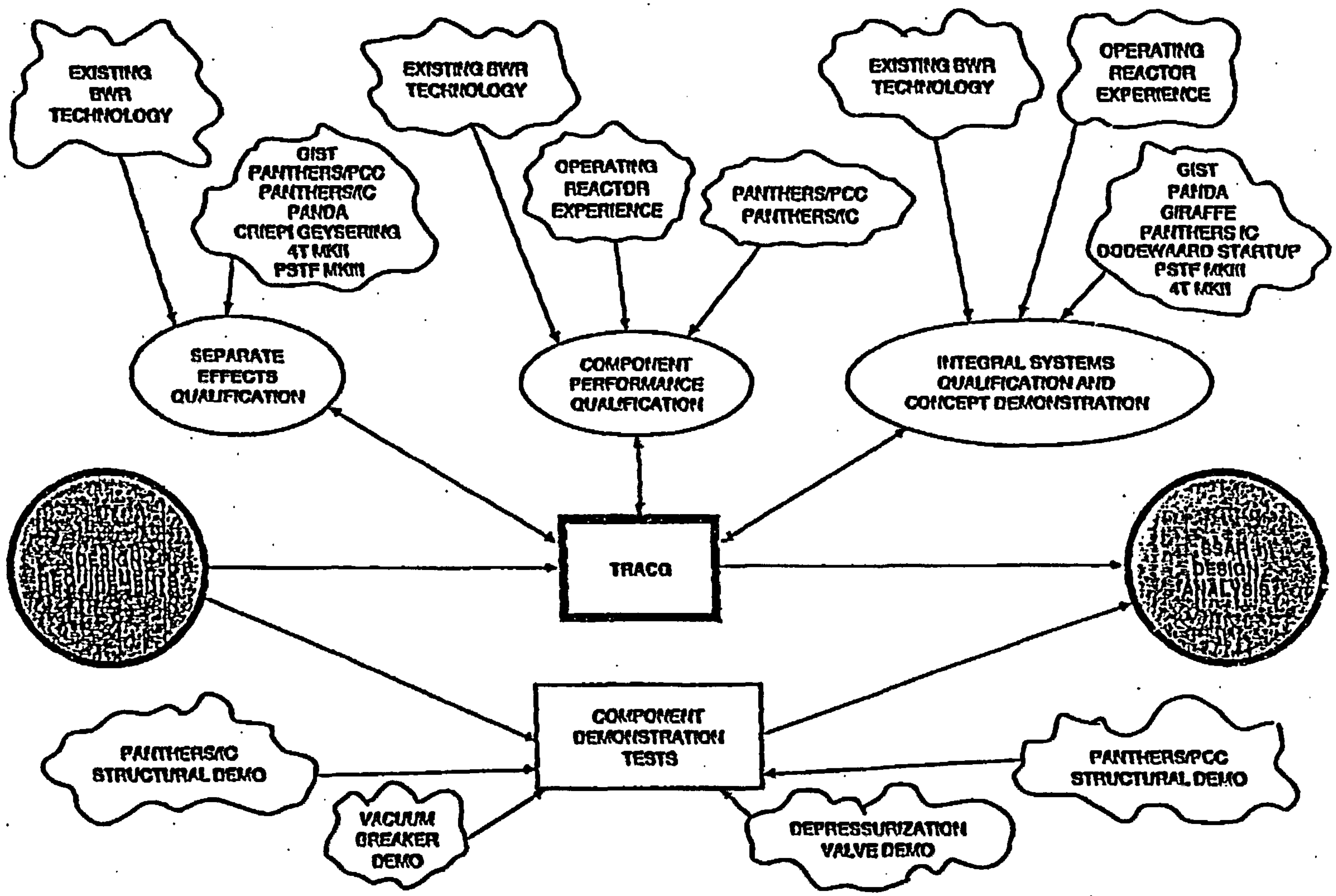


Figure 6.0-1. Technology Basis for SBWR Design

7.0 SUMMARY AND CONCLUSIONS

The Test and Analysis Program Description (TAPD) systematically defined tests and analysis needs using Top-Down and Bottom-Up approaches to identify key phenomena, issues and interactions between phenomena and systems (Sections 2, 3, and 4 and Appendix C). These needs were compared with the existing test plan and the existing TRACG qualification plan, and modifications were made where necessary to fill in gaps in the database and the TRACG qualification base (Sections 5 and 6). The Test and Analysis Plan defined the remaining activities for closure (Appendix A). The scaling of the test facilities has been addressed quantitatively (Appendix B). This document supersedes previous submittals with regard to test objectives, test conditions, data use, and anticipated test analysis.

Several changes in the test and analysis programs resulted from the study documented here. A number of tests were added. In several instances, tasks to be performed have been defined in more detail, and the focus and data usage from some facilities has been modified. The following summarizes the changes:

Test Plan

- GIST: No changes in testing. Data usage focused on GDCS flow and GDCS initiation time.
- GIRAFFE: No changes in testing. Use of data focused on specific Phase 1 and Phase 2 tests. Data usage changed from primary qualification of TRACG to support use.
- PANTHERS/PCC: No changes in testing or data usage.
- PANTHERS/IC: Program added to list of tests required for certification. No changes in testing or data usage.
- PANDA: Program added to list of tests required for certification. Test matrix expanded from two to nine transient tests. Program becomes primary containment and systems interaction data base.

Analysis Plan

- GIST: Seven additional tests identified for TRACG analysis.
- PANTHERS/PCC: Fifteen specific runs identified for TRACG analysis.
- PANTHERS/IC: Six specific runs identified for TRACG analysis.
- PANDA: All six steady-state tests and nine LOCA tests identified for TRACG analysis.
- OTHER TESTS: TRACG analysis of tests from five other tests and one operating plant experience to address specific identified qualification needs.

The TAPD specifically addresses the requirements of 10CFR52.47 by establishing that a technology basis (a combination of test data, analysis and plant data) exists for the SBWR safety features, for interdependent effects between safety features, and for qualification of the TRACG code used for SBWR safety analysis. Specifically:

- 10CFR52.47 requires that "The performance of each safety feature of the design has been demonstrated through either analysis, appropriate test programs, experience, or a combination thereof." The studies summarized in Sections 2, 3 and 4 defined the phenomena important to SBWR safety in two independent ways. These are merged in Section 5 where the testing and experience bases applicable to each are shown. Each important phenomenon is covered by at least one separate effects test, component test, integral systems test, or operating reactor datum.

- 10 CFR52.47 requires that "Interdependent effects among the safety features of the design have been found to be acceptable by analysis, appropriate test programs, experience, or a combination thereof." The studies summarized in Section 4 and Appendix C identified the important interactions. For most of these, analyses or tests already planned suffice to show the effects are negligible or bounded. For a few, additional tests were judged to be necessary. These have been added to the SBWR program.

- 10CFR52.47 requires that "Sufficient data exist on the safety features of the design to assess the analytical tools used for safety analysis over a sufficient range of normal operating conditions, transient conditions, and specified accident sequences, including equilibrium core conditions." The matrix of tests and operating plant data shown in Chapter 5 identifies elements which have been used to date, elements in which existing test data will be used, and elements in which forthcoming test data will be used to qualify the SBWR analytical model, TRACG. These are collected in Section 6 to show the composite TRACG qualification plan.

GE believes that if the overall TRACG qualification plan described in Section 6, and the SBWR-specific test programs (and associated TRACG analyses) described in Appendix A, are completed with no major surprises, it will be possible to conclude that the provisions of 10CFR52.47(b)(2)(i)(A)(1), (2), and (3) have been satisfied.

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Appendix A – Test and Analysis Plan (TAP)

A.1 Introduction

The study described in the main body of this document culminated in Table 6.1-1, which identified the qualification in addition to that presented in Reference [2] which is necessary for TRACG to be applied to SBWR safety analysis. This appendix identifies those specific tests and analyses that will be performed to meet the identified supplemental needs.

The overall goal of the SBWR Test Program is to provide a sufficient data base to support certification of the SBWR as a standard design. Consequently, the overall scope of the test program goes beyond establishment of the TRACG qualification database, in that demonstration testing of concepts unique to the SBWR, or equipment having design requirements not previously analyzed or tested, is also included. This testing is also described in this appendix. In many cases, the same test data are used for both applications.

Section A.2 provides an overview of the philosophy used in determination of specific test and analysis runs, definition of test types, and a overview of the test effort. Section A.3 presents the Test and Analysis Plan. The following information is provided for each identified test:

Test Plan

- Test matrices defining test conditions
- Test objectives
- Description of how the test data meets the specified objectives

Analysis Plan

- Test runs identified for TRACG analysis
- Description of how the identified comparisons between test and analysis meet the qualification needs

This document supersedes previous submittals with regard to test objectives, test conditions, data use, and anticipated test analysis.

A.2 Test and Analysis Philosophy

A.2.1 Test Types

The overall goals of the SBWR Test and Analysis Program are to be met by several types of testing, in several different facilities, world wide. Testing is divided into:

- *Thermal-Hydraulic Testing* – provides data necessary for qualification of TRACG and for demonstration of the concepts of passive safety systems design. Thermal-hydraulic testing is further subdivided into (1) steady-state and separate effects tests, (2) component performance tests, (3) integral systems tests, and (4) concept demonstration tests.
- *Component Demonstration Testing* – provides data on the capability of specific equipment to meet its design objectives.

A.2.2 Test Overview

SBWR thermal-hydraulic testing is summarized in Table A.2-1. The test program consists of 197 steady-state test conditions, 14 transient performance demonstrations, and 38 integral systems tests. Section A.3.1 describes each of the four facilities (PANTHERS, PANDA, GIST, and GIRAFFE) in which these tests will be or have been performed, and includes specific test objectives, test matrices and descriptions of how each of the test groups addresses the test objectives. Additionally, those test conditions chosen for analysis with TRACG are identified and cross-referenced to the qualification needs. Section A.3.1.6 also gives an overview of other data that will be used for TRACG qualification beyond the qualification described in [2].

SBWR component performance tests are described in Section A.3.2, including testing of the PCC and IC heat exchanger components, depressurization valves (DPVs), and vacuum breaker valves (VB).

A.2.3 Test Approach

The philosophy of testing is to focus on those features and components that are SBWR-unique or performance-critical, and to test over a range that spans and bounds the SBWR parameters of importance. In general, TRACG is used to predict the SBWR parameter range over a range of accidents and transients, and then that range is bounded in the test matrix. Some SBWR tests are performed in a scaled configuration. In this case, the values of the important parameters are scaled to be consistent with this philosophy. This approach is discussed in Reference 32 and Appendix B.

Additionally, it is the program philosophy to test in multiple scales wherever possible. In these cases, initial conditions for the various tests have been made as similar as possible. Multiple scale testing is useful, since it validates the scaling approach and allows a better understanding of the thermal-hydraulic phenomena involved.

A comprehensive Licensing Topical Report will be submitted documenting the testing, data analysis, and conclusions, following completion of all testing.

A.2.4 Analytical Approach

The analytical approach to be used is consistent with that previously documented in the TRACG Qualification Licensing Topical Report, NEDE-32177P [2]. Briefly, the approach is to choose a representative sampling of test data which comprise separate effects, component performance, and integral systems effects, and to perform either pre-test or post-test analysis using TRACG. Tests are chosen for analytical prediction based on their adequacy to demonstrate model prediction capability over the range of predicted SBWR conditions. Sufficient tests are chosen from certification data to establish model adequacy. Additional tests have been chosen from supporting data to confirm the certification predictions, over a wider range of test conditions, or at intermediate points.

It is planned to produce a number of "double blind" pre-test analyses for those certification data experiments not yet performed. Double blind indicates that the analyst has no information on either the results or the exact initial conditions of the experiments. These predictions are based on the as-designed facility configurations, and will be verified. They will be documented and transmitted to the NRC prior to initiation of matrix testing. (This has already been done for the PANTHERS PCC thermal-hydraulic tests [35].)

Following completion of individual tests, additional test runs will be analyzed with TRACG and compared with the test results. These post-test analyses will be performed with the analyst having knowledge of the test results, but will utilize the same nodalization and modeling as the "double blind" predictions, corrected, if necessary, to reflect facility as-built geometry and the actual initial conditions. The objective is to establish the adequacy of the TRACG model in this application. All input decks will be verified.

TRACG modeling or nodalization changes are not expected, but will be made if deemed necessary following an assessment of TRACG predictive capability.

A.3 Test and Analysis Plan

A.3.1 Thermal-Hydraulic Tests

A.3.1.1 PANTHERS/PCC

A.3.1.1.1 Test Description

PANTHERS/PCC (Passive Containment Cooling) testing is being performed as a joint study by GE, Ansaldo, ENEA, and ENEL at Societa Informazioni Esperienze Termoidrauliche (SIET) in Piacenza, Italy. The test facility consists of a prototype PCC unit, steam supply, air supply, and vent and condensate volumes sufficient to establish PCC thermal-hydraulic performance. Both thermal-hydraulic and component structural demonstration tests will be performed in this facility. This section covers the thermal-hydraulic portion of the testing; component structural performance tests are covered in Section A.3.2.1.

The PCC condenser being tested is a full-scale, two-module vertical tube heat exchanger designed and built by Ansaldo. Figure A.3-1 is an outline drawing of the heat exchanger assembly. It should be noted that the heat exchanger is a prototype unit, built to prototype procedures and using prototype materials. Three heat exchanger units of the type being tested would be found in a SBWR. The PCC is installed in a water pool having the appropriate volume for one SBWR PCC assembly.

Figure A.3-2 is a schematic of the PANTHERS/PCC facility. Primary instrumentation is that required to ascertain heat exchanger thermal-hydraulic performance, by performing mass and energy balances on the facility. Additionally, four heat exchanger tubes are instrumented in such a way that local heat flux information may be obtained.

A.3.1.1.2 Test Objectives

The test objectives of the PANTHERS/PCC Test Program are:

1. Demonstrate that the prototype PCC heat exchanger is capable of meeting its design requirements for heat rejection. *(Component Performance)*
2. Provide a sufficient database to confirm the adequacy of TRACG to predict the quasi-steady-heat rejection performance of a prototype PCC heat exchanger, over a range of air flow rates, steam flow rates, operating pressures, and superheat conditions, that span and bound the SBWR range. *(Steady-State Separate Effects)*
3. Determine and quantify any differences in the effects of noncondensable buildup in the PCC heat exchanger tubes between lighter-than-steam and heavier-than-steam gases. *(Concept Demonstration)*

A.3.1.1.3 Test Matrix and Data Analysis

Steady-State Performance Tests

The majority of the PANTHERS/PCC testing is steady-state performance testing. For these tests, the facility is placed in a condition where steam or air-steam mixtures are supplied to the PCC, and the condensed vapor and vented gases are collected. All inlet and outlet flows are measured. The condensate is returned to the steam supply, and the vented gas is released to the atmosphere. Once steady-state conditions are established, data are collected for a period of 15 minutes. The time-averaged data are reported and analyzed.

Table A.3-1a shows the PANTHERS/PCC Steady-State Performance Matrix for Steam-Only Tests. Thirteen test conditions are included.

- Test Conditions 37 through 43 (Test Group P1) will be used to determine the baseline heat exchanger performance over a range of saturated steam flow rates without the presence of noncondensable gases. Test Group P1 data will be compared with design requirements to meet Test Objective 1. Test Conditions 44 through 49 (Test Group P2) address the effect of superheat conditions in the inlet steam. Test Conditions 38, 44, 45, and 46 may be used to establish the effects of superheat at a relatively low steam flow condition, while Test Conditions 41, 47, 48, and 49 will give the same information at a steam flow rate near rated conditions.

Table A.3-1b shows the PANTHERS/PCC Steady-State Performance Matrix for Air-Steam Mixture Tests (150 individual test conditions are specified). As noted previously, the independent variables are steam mass flow rate, air mass flow rate, steam superheat conditions, and absolute operating pressure. Figure A.3-3 shows the relationship between the steam and air flow rates specified for PANTHERS/PCC testing and the SBWR expected range.

- Test Conditions 9, 15, 18, and 23 (Test Group P3) will be used to compare heat rejection rates over a range of air flow rates to the saturated, steam-only condition determined from Test Condition 41 in the pure steam series. Holding steam flow constant at near rated conditions, these tests yield the effect of air on the condensation process.
- Test Conditions 2, 13, 16, 17, 19, 22, and 25 (Test Group P4) supplement Test Group P3, in that they define condensation performance at the extremes of the SBWR air/steam mixture ranges, and at several intermediate points. These tests will be used to quantify noncondensable effects at off-rated conditions. They will be compared to the appropriate Test Conditions in the P1 group.
- Test Conditions 35 and 36 (Test Group P5) further supplement Test Group P4 by extending the effect of noncondensable gases over the superheated steam range. These tests can be compared to Test Conditions 48 and 49 to establish the effect of air content at the same superheat condition, and to Test Condition 23 at the same air flow, but with saturated steam.
- Test Conditions 1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 14, 20, 21, 24, 31, 32, 33, and 34 (Test Group P6) are lower priority tests. They may be run to supplement the previously identified tests by increasing the data density within the already established air/steam flow map.

Transient Test Conditions

PANTHERS/PCC transient tests will be used to establish noncondensable buildup effects and PCC pool water level effects. They are not intended to be systems transient tests.

Table A.3-1c shows the PANTHERS/PCC noncondensable buildup test matrix. Six test conditions are specified as Test Group P7. In these test conditions, steam will be supplied at a constant rate, and steady-state conditions established, similar to what was done in the steady-state performance tests. Air, helium, or air/helium mixtures will then be injected into the steam supply, with the vent line closed and the transient degradation in heat transfer performance will be measured, as a function of the total noncondensable mass injected.

- Tests Conditions 50 and 51 provide a baseline condition with air as the only noncondensable. Air is similar to nitrogen in molecular weight, and is heavier than steam. Test Conditions 75 and 76 are repeats of Test Conditions 50 and 51, but utilize helium as the noncondensable gas instead of air. Helium is lighter than steam, and will mix in a manner similar to hydrogen. The results of these four tests can be compared to establish performance differences between lighter-than-steam and heavier-than-steam gases as they build up in the heat exchanger tubes. Test Conditions 77 and 78 can be used to evaluate the effects of a combination of air and helium concurrently flowing into the heat exchanger.

- Test Group P7 data will be evaluated to meet the requirements of Test Objective 3.

Table A.3-1d shows the PANTHERS/PCC Pool Water Level Effect Test Matrix. Three test conditions are specified as Test Group P8. In these test conditions, steam and air/steam mixtures will be supplied to the PCC heat exchanger, and steady-state conditions established, similar to the steady-state performance tests. In these tests, however, the water level in the PCC pool will be allowed to drop and the PCC tubes to uncover. Both the PCC pool level and the PCC heat rejection rate will be monitored as a function of time.

- Test Conditions 54, 55, and 56 will establish the effects of water level in the PCC pool for a range of steam and air/steam supply rates to the PCC. Data from Test Conditions 54, 55, and 56 may be compared to Test Conditions 41, 15, and 25, respectively, to obtain the effects of lowered water level on condensation performance. Test Conditions 54 and 55 may be compared to establish the effect of air content on the rate of pool boiloff.

- Test Groups P1 through P5, P7 and P8 provide a database for TRACG qualification and meet test objective 2.

A.3.1.1.4 TRACG Analysis Plan

Table A.3-2 lists those PANTHERS/PCC tests that will be analyzed with TRACG, cross-referenced to the qualification needs. Fifteen TRACG runs are included in this group, which is intended to demonstrate the capability of TRACG to predict the heat rejection rate of the PCC heat exchanger over a wide range of conditions. The focus will be on rated conditions, with the qualification points also established near the extremes of the SBWR range. Twelve of the qualification data points come from the steady-state performance test matrix (Test Groups P1 through P5), and the remaining three from the transient group (two from P7 and one from P8).

Figure A.3-4 illustrates the locations of the ten saturated condition steady-state TRACG Qualification Points within the overall PANTHERS/PCC steady-state test performance test matrix. The remaining two conditions are superheated, and cannot be shown on this figure.

Analysis results will be compared with test data as defined in Table A.3-2. For the steady-state saturated and superheated steam conditions, the assessment of adequacy will be made on the *total heat rejection rate* and *PCC pressure drop*. For air/steam and helium/steam mixtures, the *degradation factor*, defined as the ratio of the heat rejection rate in the noncondensable case to that in the pure steam case, will be the figure of merit. The air/steam mixture data are taken at five different pressures. The degradation factor will be based on the air/steam mixture case having the absolute pressure nearest to the pure steam case:

Pure Steam Condensation – Analysis of Test Conditions 41 and 43 demonstrates TRACG capability to predict pure saturated steam condensation rates at and above rated conditions. Test Condition 49 addresses superheat in this state.

Air/Steam Mixtures – Analysis of Test Conditions 9, 15, 18, and 23 addresses the effects of noncondensable mass fraction at rated steam flow conditions, over the complete range of potential air fractions. Test Conditions 2 and 22 address the effects of air in the low steam flow range, but at the limits of air flows. Test Conditions 17 and 19 are in the intermediate range. Test Condition 35 addresses superheat effects.

Noncondensable Density – Analysis of Test Conditions 51 and 76 addresses the buildup of noncondensables in the PCC tubes, and will be predicted on a transient basis. Test Condition 51 uses air and Test Condition 76 uses helium.

PCC Pool Level – Transient analysis of Test Condition 55 addresses the capability of TRACG to predict the effects of PCC pool water level.

A.3.1.2 PANTHERS/IC

A.3.1.2.1 Test Description

PANTHERS/IC (Isolation Condenser) testing will be performed at Societa Informazioni Esperienze Termoidrauliche (SIET) in Piacenza, Italy. The tests will be performed in the same facility used for the PANTHERS/PCC program, but using several pieces of different equipment, in order to better simulate the performance environment of the IC. For the IC testing, the facility consists of a prototype IC module, a steam supply vessel which simulates the SBWR reactor vessel, a vent volume, and associated piping sufficient to establish IC thermal-hydraulic performance. Both thermal-hydraulic and component demonstration tests will be performed during these tests. This section covers the thermal-hydraulic portion of the testing; component performance tests are covered in Section A.3.2.2.

The IC being tested is one module of a full-scale, two-module vertical tube heat exchanger designed and built by Ansaldo. Only one module unit is being tested because of the much higher energy rejection rate of the IC relative to the PCC unit, and inherent limitations of facility and steam supply size. Figure A.3-5 gives an outline drawing of the heat exchanger assembly. Like the PCC unit, the IC is a prototype unit, built to prototype procedures and using prototype materials. Six modules (three heat exchanger units) of the type being tested are used in the SBWR. The IC is installed in a water pool having one half the appropriate volume for one SBWR IC assembly.

Figure A.3-6 is a schematic of the PANTHERS/IC facility. Primary instrumentation is that required to ascertain heat exchanger thermal-hydraulic performance, by performing mass and energy balances on the facility.

A.3.1.2.2 Test Objectives

The test objectives of the PANTHERS/IC Test Program are:

1. Demonstrate that the prototype IC heat exchanger is capable of meeting its design requirements for heat rejection. *(Component Performance)*
2. Provide a sufficient data base to confirm the adequacy of TRACG to predict the quasi-steady heat rejection performance of a prototype IC heat exchanger, over a range of operating pressures that span and bound the SBWR range. *(Steady-State Separate Effects)*
3. Demonstrate the startup of the IC unit under accident conditions. *(Concept Demonstration)*
4. Demonstrate the noncondensable venting capability of the SBWR IC design, and condensation restart capability following venting. *(Concept Demonstration)*

A.3.1.2.3 Test Matrix and Data Analysis

Steady-State Performance Tests

As for PANTHERS/PCC, the majority of the IC tests are steady-state performance tests. Table A.3-3a provides the PANTHERS/IC Steady-State Performance Test Matrix. Ten test conditions are specified. For these tests, the steam generator and IC module will be pressurized to an inlet pressure of 8.618 MPa, and the IC drain valves opened to initiate IC operation. When the steam generator pressure has reached desired test condition inlet pressure, the facility will be stabilized at that pressure, and heat transfer performance data taken for a period of between fifteen minutes and one-half hour. The time averaged steady-state data will be reported and analyzed.

- Test Conditions 2 through 11 are identified as Test Group I1. These data will establish the IC heat rejection rate as a function of inlet pressure

Transient Test Conditions

PANTHERS/IC transient tests will be used to demonstrate the startup of the IC heat exchanger under full-scale thermodynamic conditions. These tests are designed to demonstrate heat exchanger performance; they are not intended to be systems simulations.

Table A.3-3b gives the PANTHERS/IC Transient Demonstration Test Matrix. Four Test Conditions are specified. These tests will be performed in much the same manner as the steady-state performance tests, but transient data will be recorded over the course of the experiment. Test Condition 1 (Test Group I2) is a set of two duplicate tests designed to demonstrate the startup and operation of the IC in a situation comparable to a reactor isolation and trip. Test Conditions 12 and 13 (Test Group I3) will have air injected slowly after the steam generator pressure has been reduced to the value specified as "inlet pressure" in Table A.3-3b. The IC will be vented when the inlet pressure reaches 7.653 MPa (1110 psig) or when the pressure peaks, if at a lower value. Re-establishment of condensation following venting will be recorded. Test Condition 16 (Test Group I4) is a repeat of Test Condition 1, but with the water level in the IC pool allowed to drop, exposing the IC tubes. Both the IC pool level rate and the IC heat rejection rate will be monitored as a function of time.

- Test Group I2 will demonstrate startup of the IC under near prototype conditions, provide heat rejection data at a higher pressure than the data from Test Group I1, and demonstrate test repeatability. Test Conditions 12 and 13 will demonstrate restart of the IC following venting of noncondensables. Test Condition 16 will establish the degradation of heat rejection ability of the IC as the IC pool water level decreases.
- Test Groups I1 and I2 will be compared with design requirements to meet Test Objective 1.
- Test Groups I1, I2, and I4 provide a database for TRACG qualification and meet Test Objective 2.
- Test Group I2 demonstrates restart of the IC and meets Test Objective 3.
- Test Group I3 demonstrates restart of the IC following venting, and meets Test Objective 4.

A.3.1.2.4 TRACG Analysis Plan

Table A.3-4 lists those PANTHERS/IC tests that will be analyzed with TRACG. Six TRACG runs are included in this group, which is intended to demonstrate the capability of TRACG to predict the heat rejection rate of the IC heat exchanger over the range of reactor pressures where it will be expected to perform. Three of the six points come from the steady-state performance test matrix (Test Group I2), with the remaining three points coming from the transient data set.

Analysis will be compared with test data as defined in Table A.3-4. In all cases, the primary comparison will be on the *total heat rejection rate*. Additionally, for the transient cases, *IC inlet pressure* will be compared as a function of time:

Pure Steam Condensation – Analysis of Test Conditions 2, 6, and 11 demonstrates TRACG capability to predict pure steam IC condensation rates over the expected SBWR operating range (7.92 to 1.38 MPa) (1150 to 200 psig).

Noncondensable Buildup and Venting – Analysis of Test Conditions 12 and 13 demonstrates TRACG capability to predict the effect of noncondensable buildup in degradation of the overall heat transfer capability of the IC, including re-establishment of steam-only condensation following venting.

IC Pool Level Effects – Analysis of Test Condition 16 demonstrates TRACG capability to predict the effect of pool level on the degradation of IC performance.

A.3.1.3 PANDA

A.3.1.3.1 Test Description

PANDA is a large-scale integrated SBWR containment experiment that will be performed by the Paul Scherrer Institut in Wuerenlingen, Switzerland. The test facility is an approximately 1/25 volumetric, full scale height simulation of the SBWR containment system. Pressure vessels representing the reactor pressure vessel, drywell, wetwell and wetwell air space, and GDCS pool are interconnected with appropriate piping to simulate a variety of containment transients. The facility is equipped with three scaled PCC heat exchangers and one isolation condenser unit, each with its own water pool. The PCC and IC units are both scaled by holding the heat transfer tubes at full scale, but reduced in number from the prototype. The reactor pressure vessel volume is equipped with electrical heaters to simulate decay heat and thermal capacitance of the vessel and internals. The facility is capable of simulating SBWR accident scenarios starting approximately one hour into the LOCA.

Figure A.3-7 shows a schematic of the PANDA test facility. Two interconnected vessels are used for the drywell and wetwell volumes in order to simulate potential asymmetric effects. In addition to its transient capabilities, PANDA also has piping connections such that a PCC heat exchanger may be tested in a quasi-steady manner.

The PANDA data acquisition system is capable of recording up to 720 channels with each channel recorded once every two seconds. Sufficient instrumentation and data recording will be installed to characterize the thermal-hydraulic containment performance for tests lasting up to 24 hours.

A.3.1.3.2 Test Objectives

The test objectives of the PANDA Test Program are:

1. Provide additional data to: (a) support the adequacy of TRACG to predict the quasi-steady heat rejection rate of a PCC heat exchanger, and (b) identify the effects of scale on PCC performance. *(Steady-State Separate Effects)*
2. Provide a sufficient database to confirm the capability of TRACG to predict SBWR containment system performance, including potential systems interaction effects. *(Integral Systems Tests)*
3. Demonstrate startup and long-term operation of a passive containment cooling system. *(Concept Demonstration)*

A.3.1.3.3 Test Matrix and Data Analysis

Steady-State Performance Tests

A series of steady-state tests will be conducted using one of the PANDA PCC condensers. The facility will be configured to inject known flow rates of saturated steam and air directly to the PCCS heat exchanger. The condenser inlet pressure will be maintained at 300 kPa for all tests by controlling the wetwell pressure. The steam and air flow to the heat exchanger will be controlled and measured. In addition, the condenser drain flow will be measured.

Table A.3-5a shows the PANDA Steady-State PCC Performance test matrix. Six test conditions are included. The independent parameters are the steam and air mass flow rates. Conditions were chosen so that a direct comparison can be made to PANTHERS and GIRAFFE test points. Table A.3-5a identifies the test conditions in PANDA and the corresponding PANTHERS and GIRAFFE Test Conditions.

- Five Test Conditions (Test Conditions S1 through S5) are planned with various constant air flows and a constant steam flow of 0.20 kg/sec. In addition, one test will be run with a pure steam flow equivalent to that expected to match the steam condensing capacity of the condenser (Test Condition S6).
- PANDA Test Conditions S1 through S6 provide a data base for TRACG qualification to meet the requirements of Test Objective 1(a).
- The results of PANDA Test Conditions S1 through S6 will be compared with the PANTHERS and GIRAFFE steady state performance data as noted in Table A.3-5a to meet the requirements of Test Objective 1(b).

Transient Integral Systems Tests

A series of tests is planned for the PANDA facility to provide an integral systems database for PCC system performance with conditions representative of the long-term post-LOCA SBWR containment response. Table A.3-5b provides the test matrix summarizing the key characteristics of each test, and data use:

The following provides the purpose and additional descriptive information on each PANDA transient test:

- *Test M1* is a simulation of a break in the main steamline of the SBWR. The initial conditions in the containment will be the same as those tested in the GIRAFFE Phase 2 main steamline break test. These initial conditions are similar to SBWR containment conditions consisting of a mixture of air and steam at one hour into the LOCA. One-third of the steam from the break will be directed to drywell DW1 which has one PCC condenser, and two-thirds of the steam will be directed to DW2 with two PCC condensers. These test conditions represent a symmetrical situation in the PANDA facility

  PANDA test M1 will be compared with GIRAFFE Phase 2 Main Steamline Break Test to assess the effects of facility scale on integral system performance.
- *Test M2* is a repeat of Test M1 with all of the break flow steam directed into drywell DW2. DW2 has two PCC condensers, and this test maximizes the steam content of DW2 and the air content of DW1. It is the most asymmetric condition that can be set in PANDA. Test M2 results will be compared with Test M1 results to quantify asymmetric effects on PCCS containment performance.
- *Test M3* is very similar to Test M1, but with nominal initial containment conditions as calculated for the SBWR under SSAR assumptions at one hour into the LOCA. The initial drywell pressure will be approximately 300 kPa (43.5 psi). This test will provide a base case for comparison to all other tests.
- *Test M4* is a repeat of test M3 to demonstrate transient system response repeatability.

- *Test M5* is a repeat of M3, but with continuous water supply flow to the RPV. In the SBWR, if AC power is available, an operator might use the Fuel and Auxiliary Pools Cooling System, for example, to provide active core cooling. This test will demonstrate potential systems interaction effects for cases with continuous cold water addition to the RPV. Continuous water supply flow to the RPV will result in filling of the RPV and flow of relatively cold water out of the break and into the drywell. This, in turn, is expected to result in opening of the drywell-to-wetwell vacuum breakers and reintroduction of air from the wetwell into the drywell. This test will provide data on PCC performance when air is reintroduced to the heat exchangers following essentially pure steam operation.
- *Test M6* is a repeat of Test M3 but with the IC operating in parallel with the three PCC condensers throughout the test period. This test will provide data showing the interaction between the PCC condensers and the IC, as well as the effect of the additional heat removal by the IC on containment and reactor system performance.
- *Test M7* will utilize the same nominal initial conditions as Test M3, but with the drywells and PCC units filled with air at the start of the transient. Additionally, this test will begin as early in the SBWR transient as is possible with the PANDA facility design. This test will provide data to demonstrate the PCC condenser startup characteristics when initially blanketed with noncondensable gas.
- *Test M8* is a repeat of Test M3, but with drywell-to-wetwell bypass leakage. This test will provide the effect of bypass leakage on containment performance.
- *Test M9* is a combination of tests M5 and M7, with cold water injection into the RPV, and this test will begin as early as possible in the SBWR LOCA scenario, consistent with the PANDA facility design.
- PANDA tests M1 through M9 provide a database for TRACG qualification that meets Test Objective 2.
- PANDA tests M1 through M9 address long-term operation of the PCCS. Tests M5 through M7 and M9 address systems interaction and PCCS restart issues. These tests meet the requirements of Test Objective 3.

A.3.1.3.4 TRACG Analysis Plan

All six PANDA steady-state and all nine PANDA integral systems tests will have TRACG analysis performed. Analyses will be performed post-test or both pre- and post-test.

- *Pure Steam Condensation* – Analysis of Tests S1 and S6 demonstrates TRACG capability to predict pure saturated steam condensation rates at and above rated conditions.
- *Air-Steam Mixtures* – Analysis of Tests S2 through S5 addresses the effects of non-condensable mass fraction in the PANDA PCC configuration.
- *Drywell-Wetwell Noncondensable Distribution* – Analysis of tests M1, M2, and M5 through M9 addresses the effects of initial gas and vapor distribution within the containment system, including vacuum breaker flow, and demonstrate TRACG capability to model integral systems performance.
- *Systems Interactions* – Analytical studies of systems interactions have identified vacuum breaker and IC operation as the most likely candidates for systems interaction effects. Analysis of tests M5 through M9 address TRACG capability to model systems interactions.
- *Bypass Leakage* – TRACG analysis of test M8 provides qualification of the bypass leakage modeling.

A3.1.4 GIST

A3.1.4.1 Facility Description

The Gravity-Driven Integrated Systems Test (GIST) was performed by GE Nuclear Energy in San Jose, California, in 1988. Testing is complete, and results were reported in Reference 42. The GIST facility was a section-scaled simulation of the 1988 SBWR design configuration, with a 1:1 vertical scale and a 1:508 horizontal area scale of the RPV and containment volumes. Because of the 1:1 vertical scaling, the tests provided real-time response of the expected SBWR pressures and temperatures.

An integrated systems test was performed in order to include the effects of various plant conditions on GDCS initiation and performance. Figure A.3-8 provides a facility schematic, and Figure A.3-9 shows the major interconnecting lines. The GIST facility consisted of four pressure vessels: the RPV, upper drywell, lower drywell and the wetwell. The RPV included internal structures, an electrically heated core, and bypass and chimney regions.

Key interconnecting lines, such as drywell vents and depressurization lines with quenchers, were also included. The suppression pool/wetwell includes the water supply tank, a recirculation pump system used to heat and cool the pool water, and the air lines for pressurizing the wetwell air space.

The GIST facility was a simulation of the SBWR design as it existed in 1988. Several differences exist between the GIST configuration and the final SBWR design. These differences are listed and reconciled in Appendix B.

One hundred twenty test instruments were mounted on the vessels and piping in the GIST facility. These instruments were used to measure ADS initiation, drywell and pool temperatures, break flow rates, GDCS initiation and flow rates, and RPV conditions such as temperature, pressure and water level.

A3.1.4.2 Test Objectives

The test objectives for the GIST Test Program were:

1. Demonstrate the technical feasibility of the GDCS concept. *(Concept Demonstration)*
2. Provide a sufficient data base to confirm the adequacy of TRACG to predict GDCS flow initiation times, GDCS flow rates, and RPV water levels. *(Integrated Systems Test)*

A3.1.4.3 Test Matrix

The GIST Test Matrix is shown in Table A.3-7. Twenty-six test conditions were specified. These 26 individual tests were divided into four test types, three of them loss-of-coolant accidents (LOCAs):

- Bottom Drain Line Break (BDLB)
- Main Steamline Break (MSLB)
- GDCS Line Break (GDLB)
- No-Break (NB)

A broad spectrum of test parameters was varied within each one of these test types. In each one of the four test categories, a base test case was performed and then subsequent tests were run where only one parameter at a time was varied from that used in the base case. The GIST facility modeled the SBWR plant behavior during the final stages of the RPV blowdown. The tests started with the vessel at 100 psig and continued until the GDCS flow initiated and flooded the RPV.

- *Series BDLB* (Bottom Drain Line Break) consisted of parametric variations around the base case of a relatively small break below the core. Seven cases were run in this configuration.
- *Series MSLB* (Main Steamline Break) consisted of eight tests, six of which were parametric variations and two of which were repeat-performed to establish repeatability of results.
- *Series GDLB* (GDCS Line Break) consisted of four tests. Variations in ADS configuration were the parameter in this series.
- *Series NB* (No-Break) consisted of seven tests. This series typically utilized conditions well removed from the SBWR 1988 design. These are among the most interesting runs, since they form a data set at or outside the limits of SBWR potential, and are the most challenging for TRACG analysis. For example, this series included several tests where the wetwell initial pressure was atmospheric, and no air-purge occurred since there was no break. Perhaps the major difference between the GIST and final SBWR configurations is the location of the GDCS pool. From the standpoint of GDCS injection, the GIST configuration is conservative relative to the SBWR because the GDCS driving head is always slightly less in GIST than in the SBWR. In the case of zero wetwell pressure, the GDCS injection head is much less than in the SBWR. This makes GDCS injection in GIST more challenging.
- Analysis of GIST data as reported in Reference 42 has proven the technical feasibility of the GDCS concept, and meets Test Objective 1.
- The overall GIST database provides a sufficient basis for TRACG qualification and meets the requirements of Test Objective 2.

A3.1.4.4 TRACG Analysis Plan

As part of the GIST program, five TRACG comparisons were previously performed. The objective of this effort was to confirm the capability of TRACG to accurately predict the GIST facility response to a variety of LOCA initiating events. The main areas of interest were the effectiveness of the modeling of the GDCS and the modeling of the RPV and containment at low pressure conditions. The qualification consisted of post-test calculations with TRACG and comparison against GIST data. Comparisons were made for *RPV pressure*, *RPV water level*, *core* ΔP, *GDCS flow rate*, and *GDCS initiation time*. Good agreement was found. Results are reported in Reference 2.

GIST tests which have had TRACG analysis completed are identified in Table A.3-8. These tests represent a full variety of break types, a wide range of initial liquid inventories in the pressure vessel, variations of containment initial conditions and a variety in the degree of availability of GDCS.

Table A.3-9 defines the additional cases that will be performed. In all cases, comparisons will performed on *GDCS flow rate*, *GDCS initiation time*, and *RPV pressure*.

A.3.1.5 GIRAFFE

A.3.1.5.1 Test Description

GIRAFFE Isolation Condenser/Passive Containment Cooling testing was performed at the Toshiba Nuclear Engineering Laboratory in Kawasaki City, Japan. The results are reported in Reference 43. The test facility consisted of five major components which represent the SBWR primary containment and suppression chamber pools (S/C), the isolation condenser/passive containment cooling (IC/PCC) heat exchanger, and the connecting piping. Separate vessels represented the reactor pressure vessel (RPV), drywell (D/W), wetwell (WW), Gravity-Driven Cooling System pools (GDCS pools) and the IC/PCC pools, which house the IC/PCC condenser unit. A schematic of the facility is shown in Figure A.3-10.

The IC/PCC condenser tested was a full-length, three-tube heat exchanger. The single unit could be utilized as either an IC or a PCC. Figure A.3-11 gives an outline drawing of the heat exchanger assembly. The IC/PCC was installed in a water pool composed of a makeup pool with a chimney and cavity arrangement in which the IC/PCC unit was set.

Measurements were taken throughout the system for absolute pressure, differential pressure, temperature, and flow rate. Instrument locations are given in Reference 38.

A.3.1.5.2 Test Objectives

The test objectives of the GIRAFFE Test Program are:

1. Provide a database to support primary data taken at other scales to confirm the capability of TRACG to predict the quasi-steady heat rejection rate of a PCC heat exchanger. *(Steady-State Separate Effects)*
2. Provide a database to support primary data taken at other scales to confirm the capability of TRACG to predict PCCS system performance. *(Integral Systems Tests)*

A.3.1.5.3 Test Matrix and Data Analysis

Steady-State Tests

The majority of the GIRAFFE data used are steady-state performance data of the IC/PCC unit under PCC conditions. For these tests, the facility was placed in a condition where steam or nitrogen-steam mixtures were supplied to the IC/PCC, and the condensed vapor and vented nitrogen were directed to volumes modeled to act as the reactor vessel (RPV) and suppression chamber pool (S/C), respectively. Condensate outlet flows from the IC/PCC were measured by measuring the RPV level increase, which, in turn, was used to determine heat removal rate by multiplying it by the latent heat of vaporization. The condensate was returned to the RPV, and the vented nitrogen was released to the S/C gas space. Once steady-state conditions were established, data were collected for a period of 10 minutes. The time averaged data were reported and analyzed.

Table A.3-10 shows the GIRAFFE PCC Steady-State Performance Matrix used to provide data in support of the test objectives. Thirteen test conditions are included. These tests are identified in the test report as the Phase 1, Step 1 Tests, and comprise Test Group G1. These tests cover the SBWR range of steam and air mass flow rates, as has been previously discussed in the PANTHERS/PCC section.

- Data from Test Group G2 will be compared to that from corresponding PANDA and PANTHERS tests to corroborate those results at a third scale. Data from Test Group G1 provide a support database for TRACG qualification and meet the requirements of Test Objective 1.

System Response Tests

In the GIRAFFE system response tests, the RPV supplies steam to the drywell, simulating release of decay heat through a main steamline break. Steam and nitrogen flow from the drywell to the IC/PCC, with condensate returning to the RPV, and gases venting to the S/C.

Two GIRAFFE systems tests are useful in support of the test objectives. These two test conditions are identified in Table A.3-11, and comprise Data Group G2. The two tests identified are a simulated Steamline Break Test from Phase 1 Step 3, and a similar steamline break test from Phase 2. The Phase 2 test is more like the current SBWR configuration, and has initial conditions which more closely resemble SBWR conditions under SSAR assumptions.

- Data from Test Group G2 will be compared to the corresponding PANDA test (GIRAFFE Phase 2 to PANDA M1) to address scale effects. Test Group G2 provides a support data base for TRACG PCCS performance and meets the requirements of Test Objective 2.

Recently, TOSHIBA has conducted a GIRAFFE integral system test with initial conditions similar to the Test Group G2 steamline break test from Phase 2, but with helium in place of nitrogen in the drywell. Initial conditions are specified in Table A.3-12. This test was not reported in [43]. It is identified as Test Group G3.

- Data from Test Group G3 provide a database for light density gas behavior. It may be used for TRACG PCCS performance prediction in this situation, and meets the requirement of Test Objective 2.

A3.1.5.4 TRACG Analysis Plan

A significant number of GIRAFFE TRACG comparisons have been performed as part of the qualification effort. The objective was to confirm the capability of TRACG to accurately predict PCC steady state performance. Results are reported in Reference 2.

TRACG comparisons have been performed for all the Test Group G1 conditions, and for the Phase 1, Step 1 main steamline break test.

A.3.1.6 Other Analyses Planned

This section will give a brief overview of these tests and the anticipated corresponding TRACG analyses.

A.3.1.6.1 1/6 Scale Boron Mixing Test

GE Nuclear Energy has performed a set of boron mixing injection tests for the BWR/5 and BWR/6 geometries. These tests were reported in Reference 28. The tests were performed in a 1/6 scale three-dimensional model of a 218-in. reactor pressure vessel, and used the high pressure core spray HPCS spargers as the primary injection location of the simulated boron solution. Using scaled boron injection rates of either 400 or 86 gpm, with and without HPCS flow, the parametric effects on mixing were examined in the upper plenum and core bypass regions. Two alternate injection locations were also examined.

Standby Liquid Control injection locations are different in the SBWR from previous product lines, due primarily to the natural circulation recirculation feature of the SBWR. The SBWR utilizes direct injection into the core region through the shroud at 16 locations.

A series of TRACG predictions of the BWR/5-6 data is planned. Specific test cases to be analyzed have not yet been identified. Primary data comparisons will be made against data on the *mixing coefficient*, which is defined as the concentration of injected solution at the measured location divided by the concentration that would be present if the injected solution were uniformly mixed with the entire vessel inventory. Comparisons will be made at several locations. These comparisons will address the mixing issues identified as qualification needs ATW1, ATW2, and ATW3.

A.3.1.6.2 CRIEPI Natural Circulation Thermal-hydraulic Test Facility

The CRIEPI test facility is a parallel channel test facility intended to study the stability characteristics of a natural circulation loop during startup conditions. The two parallel channels are 1.79m high and are equipped with heaters with a maximum power input of 64 kW each. At the channel exit, there is an adiabatic chimney which is 5.7m high. The loop has a separator, a condenser and a subcooler which are used to return the condensed steam to the downcomer. A preheater with a capacity of 150 kW controls the inlet temperature to the channels. Tests have been run at low pressure to simulate low pressure loop startup. Oscillations have been observed under some conditions and a stability map has been created for the test loop. These tests serve to address qualification needs C12 (natural circulation) and F4 (geysering during startup).

A.3.1.6.3 Dodewaard Plant Startup

The Dodewaard reactor is a natural circulation BWR with internal free surface steam separation. The reactor, with a maximum thermal power of 183 MWth, is connected to a turbogenerator capable of producing 60 MWe. Initial startup of the reactor was in 1969, and it has been operating continuously since that time. While relatively small in size, it is thermodynamically and neutronically similar to the SBWR, and SBWR startup procedures will be similar to those of Dodewaard.

On February 15 and 16, 1992, the reactor was started up for its 23rd fuel cycle. During that startup, data were recorded to characterize the startup for potential TRACG analysis. Data were taken at discrete time intervals during the startup. Typically, the reactor was in a state of semi-equilibrium during the measurement. The results of the measurement show early establishment of recirculation flow during low power operation. No indication of any reactor instability, including geysering, was observed. Data are reported in References 15 and 45.

TRACG analysis of this startup is being performed. Comparisons with plant data will be made for *reactor pressure, downcomer subcooling, and downcomer pressure difference (a measure of recirculation flow)* to address qualification needs F4 and C12 of Table 6.1-1.

A.3.1.6.4 Containment System Response – PSTF Mark III

In the early 1970s, GE Nuclear Energy performed several series of tests at the Pressure Suppression Test Facility (PSTF) to support the Mark III containment design. The SBWR and Mark III containments share a similar horizontal vent system geometry. Qualification needs XC7, MV1, MV3, and WW1 can be addressed by TRACG analysis of this data.

The test series chosen for these comparisons is PSTF Series 5703, which was reported in [20]. Test Series 5703 utilized a full-scale, three horizontal vent system with geometry very similar to that used in the SBWR. Three comparisons will be performed, to test data from Runs 5703-1, 2, and 3, for which simulated steamline break size was the primary variable. Comparisons will be made on *drywell pressure and wetwell pressure* to address qualification needs XC7 and WW1, *main vent flow rate* to address qualification need MV1, and *top vent clearing time* to address qualification need MV3.

A.3.1.6.5 Containment System Response – Mark II 4T

In the mid-1970s, GE Nuclear Energy conducted a series of containment tests supporting the Mark II containment design in the 4T (Temporary Tall Test Tank) facility in San Jose, California. While the primary focus of this testing was suppression pool dynamics, three of the tests runs are particularly useful in addressing TRACG qualification needs XC7, WW2, and WW5.

Test Series 5101 is reported in Reference 38. These tests were a full-scale, single-vent simulation of Mark II (vertical vent pipe) performance. Normally, the drywell was heated to 135°F prior to test initiation to minimize steam condensation. One test, Run 35, used a unheated drywell. Very different response was seen due to steam condensation in the drywell. Additionally, two other runs, 34 and 35, were performed specifically to investigate the effect of a wetwell-to-drywell vacuum breaker. (In the Mark II containment, pressurization of the wetwell air space by pool swell causes a short term opening of the vacuum breaker.)

These three runs will be analyzed with TRACG. *Drywell pressure* and *vent flow rate* from Run 33 will be compared to address qualification need WW5. *Drywell pressure, wetwell pressure, vent flow rate, and vacuum breaker opening/closing time* will be compared to address qualification need XC7.

A.3.1.6.6 Suppression Pool Stratification - PSTF

In the late 1970s, two series of experiments were performed in the PSTF specifically to investigate pool condensation and thermal stratification in the Mark III containment system. These data were initially reported in References 46 and 47, and extensively analyzed in Reference 48. More recently, these data were reviewed as one element of an effort to define an appropriate nodalization for the TRACG SBWR suppression pool, but specific comparisons to the data have not yet been performed.

The tests reported in Reference 46 utilized a full-scale single cell 9-degree segment of the Mark III vent system and suppression pool, while those reported in Reference 47 used a vent system and pool having the same full-scale height, but with flow areas and pool surface areas reduced by a factor of 3. Suppression pool temperatures were monitored by an array of thermocouples suspended throughout the pool. Initial pool temperatures and blowdown flow rates were measured.

TRACG will be used to analyze Test 5707 Run 1 and 5807 Run 29. Qualification need WW6 will be addressed by comparison of *suppression pool temperature distribution*.

A.3.2 Component Demonstration Testing

A.3.2.1 PANTHERS/PCC

A.3.2.1.1 Test Description

Component testing of the prototype PCC heat exchanger is being performed using the same hardware and test facility as described in Section A.3.1.1. The component demonstration tests will be very similar in conduct to the thermal-hydraulic testing. The test article (PCC module "A") is instrumented with strain gages, accelerometers, and thermocouples. Structural instrumentation is shown on Table A.3-13. Data will be collected during the thermal-hydraulic tests as well as the structural performance tests described in this section.

A.3.2.1.2 Test Objectives

The test objective of the PANTHERS/PCC Component Demonstration Test is:

1. Confirm that the mechanical design of the PCC heat exchanger is adequate to assure its structural integrity over a lifetime that exceeds that required for application of this equipment to the SBWR.

A.3.2.1.3 Test Matrix and Data Analysis

The approach taken to address the test objective is to subject the equipment to a total number of pressure and temperature cycles well in excess of that expected over the anticipated SBWR lifetime. The test matrix is shown in Table A.3-14. The number of cycles was conservatively chosen as 10 LOCA cycles and 300 pressure test cycles. This represents five times the design requirement number of hypothetical LOCAs (2) and nearly 17 times the number of expected pneumatic test cycles in accordance with 10CFR50, Appendix J over the 60-year design life of the PCC [18]. (Credit is taken for the thermal cycles experienced during the PCC thermal-hydraulic testing in determination of this Component Demonstration test matrix.)

Two types of tests will be performed during the PANTHERS/PCC component demonstration test: simulated LOCA pressurizations and simulated pneumatic leak test pressurizations.

Simulated LOCA Pressurizations

Simulated LOCA cycles will be performed by pressurizing the PCC units with steam, so that both the temperature and pressure effects of a LOCA are simulated. The PCC pool will be at ambient temperature at the beginning of a test, but will be allowed to heat up to saturation as each cycle proceeds. Table A.3-15 gives the time history of the LOCA pressurizations. Each LOCA cycle will last approximately 30 minutes. Ten cycles will be performed.

Simulated Pneumatic Leak Test Pressurizations

Simulated pneumatic tests are performed by pressurizing the PCC heat exchanger with air to 758 kPa (110 psig). The PCC pool temperature will be at ambient conditions during these pressurizations. The test pressure will be held for 2 minutes for each cycle. A total of 300 cycles will be performed.

- The test data will be analyzed by review of strains and acceleration data against component acceptance requirements, both in terms of magnitude and frequency content.

A.3.2.2 PANTHERS/IC

A.3.2.2.1 Test Description

Component testing of the prototype PCC heat exchanger will be performed using the same hardware and test facility as described in Section A.3.2.1. The component demonstration tests will be very similar in conduct to the thermal-hydraulic testing. The test article (the IC condenser unit) is instrumented with strain gages, accelerometers, and thermocouples. Structural instrumentation is shown on Table A.3-16. Data will be collected during the thermal-hydraulic tests as well as the structural performance tests described in this section.

A.3.2.2.2 Test Objectives

The test objective of the PANTHERS/IC Component Demonstration Test is:

1. Confirm that the mechanical design of the IC heat exchanger is adequate to assure its structural integrity over a period of time between SBWR In-Service Inspections (ISI).

A.3.2.2.3 Test Matrix and Data Analysis

The approach taken to address the test objective is to subject the equipment to a total number of pressure and temperature cycles well in excess of that expected over the anticipated duration of an SBWR ISI cycle. Specifically, it is planned to subject the IC to cycles equivalent to one-third of the SBWR's 60 year lifetime (i.e., 20 years). Prototype non-destructive tests (NDT) will be performed before and after the cyclic testing. The test matrix is given as Table A.3-15. (Credit is taken for the thermal cycles experienced during the IC thermal-hydraulic testing in determination of this Component Demonstration Test Matrix.)

Simulated operational cycles will be performed by pressurizing the IC unit with steam, so that both the temperature and pressure effects of a LOCA are simulated. Tests will be performed at different pressures, and with varying pressurization rates and durations to simulate "normal" IC cycles, reactor heatup/cooldown cycles (without IC operation), and an ATWS event. The IC pool will be at ambient temperature at the beginning of a test, but will be allowed to heat up to saturation as each cycle proceeds. Cycles will last between 7 and 12 hours. 120 cycles will be performed. Data will be recorded for durations of several minutes, periodically through each cycle.

The test data will be analyzed by review of strains and acceleration data against component acceptance requirements, both in terms of magnitude and frequency content. Evidence of crack initiation or growth will be obtained from comparison of the pre-test and post-test NDT.

A.3.2.3 DEPRESSURIZATION VALVE (DPV)

A.3.2.3.1 Test Description

A Depressurization Valve (DPV) test program was performed in order to confirm the adequacy of a squib-actuated valve to provide a reliable means of rapidly depressurizing the reactor vessel. Performance tests were performed on the primer and propellant materials after exposure to the SBWR environmental conditions. Functional tests were performed on a full-scale prototype valve at the vendor's shop. The DPV was subjected to steam flow tests to measure the steam flow capacity and reaction loads. Finally, the DPV was subjected to accelerated environmental aging of the nonmetallic components, and dynamic testing. Results are reported in Reference 44.

A.3.2.3.2 Test Objectives

The test objectives of the DPV Test Program were:

1. Confirm that the DPV is a zero leakage valve, and that it opens on demand with a momentary electrical signal, opens within the required response time and remains open without an external power source.
2. Obtain data from flow testing to determine stresses in the DPV and confirm that the DPV saturated steam flow rate meets the minimum expected blowdown flow rate.
3. Obtain additional information on primer and propellant performance to provide evidence for later qualification testing.

A.3.2.3.3 Test Matrix and Data Analysis

Samples of the primer and propellant materials were subjected to irradiation, accelerated thermal aging and LOCA steam aging. Firing tests were subsequently performed and the results confirmed that the pressure output versus response time met the performance requirements for the DPV.

Two full-scale prototype squib actuated DPVs were manufactured, assembled and tested by Pyronetics Devices, Inc., which is a subsidiary of OEA, Inc., of Denver Colorado. Firing tests were performed on a full-scale valve under both a high pressure (1500 psig) condition at the valve inlet and a low pressure (1 psig) condition at the valve inlet. A momentary electrical signal was supplied and it was confirmed that the valve opened within the required response time and remained open without an external power source. A thermal exposure heat transfer test was performed on the valve in order to assess the effects of ambient temperature and steamline temperature. It was confirmed that the booster surface temperature was acceptable when the valve was exposed to the SBWR environmental temperature conditions. A leakage test was performed for each valve metal diaphragm seal. Each seal was pressurized to 1650 psig and it was confirmed that there was zero leakage.

Flow and reaction load tests were performed on a full-scale valve at Wyle Laboratories of Huntsville, Alabama. The test facility was modified to incorporate a prototypical SBWR steam line section. The DPV was connected to this prototypical section and instrumented with pressure, temperature and strain gages, accelerometers and displacement transducers. Four steam blowdown tests were performed. The test data confirmed that the DPV mass flow rate would be on the order of 2.4×10^6 lbm/hr at an operating pressure of 1100 psia.

Potential environmental qualification effects were investigated by addressing two elements. One element was the accelerated aging of those DPV components that contain non-metallic materials to ensure their reliability under adverse in-plant conditions. The second element was to subject a full-size prototype DPV to dynamically induced loads to simulate in-plant vibration. The booster assemblies with the non-metallic materials were subjected to accelerated aging conditions and then successfully fired, confirming that adequate pressure was delivered. The dynamic simulation was performed on a triaxial seismic table at Wyle Laboratories. The DPV was assembled using the aged components and then instrumented. The dynamic aging tests included resonance search, vibration exposure (slow sine sweep) and a series of triaxial multi-frequency random input motion tests. It was confirmed that when signaled to actuate, the DPV opened and remained open.

A.3.2.4 VACUUM BREAKER VALVE

A.3.2.4.1 Test Description

The vacuum breaker valve test program was designed to confirm that the vacuum breaker valve will provide a reliable leak tight boundary between the drywell and wetwell and prevent the pressure in the wetwell from exceeding that of the drywell by more than three pounds per square inch. Leak tightness is achieved by use of a nonmetallic main seal and a backup hard seat. The double seal design provides assurance that maximum leakage requirements will not be exceeded in the event that an obstruction should lodge on either seat. A full scale prototype valve was built and subjected to flow testing to verify lift pressure, flow capacity, and stability at low flow. The primary nonmetallic seal was radiation and thermally aged. Following thermal aging the valve was dynamically aged and subjected to design basis accident conditions to confirm its leak tightness to steam. Finally the fully aged valve was subjected to reliability testing to confirm that its intrinsic reliability was consistent with the assumptions of the SBWR PRA.

A.3.2.4.2 Test Objectives

The objectives of the vacuum breaker test program are to demonstrate that:

- The vacuum breaker flow capacity could be made equivalent to 1.04 square feet.
- The vacuum breaker lift pressure was less than 0.5 psi.
- The disk was dynamically stable under low flow conditions.
- The hard seat equivalent flow area was less than 0.2 square centimeters.
- The main seal was air bubble tight as installed and has an equivalent leakage flow area of less than 0.02 square centimeters to steam in the fully degraded condition under design basis accident conditions.
- Determine dynamic loads which result in lift of the disk.

- The opening and closing reliability are maintained after subjecting the fully aged valve to grit ingestion.

A3.2.4.3 Test Matrix and Data Analysis

The vacuum breaker was air leak tested with a new seal and it was confirmed that the seal was bubble tight. The valve was then placed in the flow test facility and evaluated for lift pressure and low flow stability. The flow stability and lift pressure met requirements. The flow test determined that the valve stroke was not sufficient to meet minimum flow requirements. Since the natural stability of the valve eliminated the need for a disk damper, the stroke was increased to take credit for damper deletion. It was demonstrated that increasing the valve stroke would result in achieving the required flow performance. A seal was then aged with radiation and placed in the valve for thermal aging. The valve leak test was then repeated and it was determined the seal was air bubble tight.

The valve was then placed on a shake table for fragility testing to determine at what acceleration lift occurred. The valve was then subjected to ten Safe Shutdown Earthquake acceleration time histories. Upon disassembly of the valve it was discovered that the ballast ring and the position sensor screws had come loose due to failure to engage existing lock washers. Screws had been ingested by the valve and hammered by the disk. Leak rate testing confirmed the main seal was undamaged and the hard seat still exceeded leak tightness requirements despite marring. The valve ruggedness and resistance to seal damage was demonstrated by this event.

The Design Basis Accident test demonstrated that the fully aged valve meets leak requirements at steam pressures and temperatures characteristic of a loss-of-coolant accident followed by water spray. The leaktightness of the valve was demonstrated by measuring the condensate from the steam that passed through the valve seals. During pressure peaks, water sprays and 80 hours of endurance testing, no measurable condensate leaked through the valve. The test demonstrated the inherent steam leak resistance of the valve.

The final test is the reliability testing, which will subject the fully-aged valve to grit ingestion to simulate possible environmental conditions that could affect bearing surfaces and seals during normal service. The valve will be cycled three thousand times to demonstrate reliability at its required statistical failure rate of 10^{-4}.

Table A.2-1. Thermal-Hydraulic Test Data Groups and Description

Facility	Data Group	Test Conditions	Description
PANTHERS/PCC	P1	7	PCC steady-state performance; saturated steam
PANTHERS/PCC	P2	6	PCC steady-state performance; superheated steam
PANTHERS/PCC	P3	4**	PCC steady-state performance; air/steam mixtures
PANTHERS/PCC	P4	7**	PCC steady-state performance; air/steam mixtures
PANTHERS/PCC	P5	2**	PCC steady-state performance; air/steam mixtures
PANTHERS/PCC	P6	18**	PCC steady-state performance; air/steam mixtures
PANTHERS/PCC	P7	6	PCC performance; noncondensable buildup
PANTHERS/PCC	P8	3	PCC performance; water level effects
PANTHERS/IC	I1	10	IC steady-state performance; inlet pressure effects
PANTHERS/IC	I2	1*	IC startup demonstration
PANTHERS/IC	I3	2	IC restart demonstration, noncondensable venting
PANTHERS/IC	I4	1	IC performance; water level effects
PANDA/PCC	S	6	PCC steady-state performance; steam and air/steam mixtures
PANDA	Phase 1	2	Containment performance – basic
PANDA	Phase 2	7	Containment performance – integrated systems effects
GIRAFFE	G1	13	PCC steady-state performance – steam and air/steam mixtures
GIRAFFE	G2	2	Containment performance – integral system effects
GIRAFFE	G3	1	Containment performance – light density gas effects
GIST	BDLB	7	GDCS performance – integrated system effects – bottom drain
GIST	MSLB	8	GDCS performance – integrated system effects – main steam
GIST	GDLB	4	GDCS performance – integrated system effects – GDCS breaks
GIST	NB	7	GDCS performance – integrated system effects – transients

*Test to be performed twice to demonstrate repeatability.
**Test to be performed five times at different absolute pressures.

Table A.3-1a. PANTHERS/PCC Steady-State

Performance Matrix – Steam Only Tests

Test Group Number	Test Condition Number	Steam Flow [kg/s (lb/s)]	Air Flow [kg/s (lb/s)]	Superheat* [°C (°F)]
P1	37	0.45 (1.0)	0 (0)	0 (0)
P1	38	1.4 (3.0)	0 (0)	0 (0)
P1	39	2.5 (5.5)	0 (0)	0 (0)
P1	40	3.6 (8.0)	0 (0)	0 (0)
P1	41	4.5 (10.0)	0 (0)	0 (0)
P1	42	5.7 (12.5)	0 (0)	0 (0)
P1	43	7.0 (15.4)	0 (0)	0 (0)
P2	44	1.4 (3.0)	0 (0)	15 (27)
P2	45	1.4 (3.0)	0 (0)	20 (36)
P2	46	1.4 (3.0)	0 (0)	30 (54)
P2	47	4.5 (10.0)	0 (0)	15 (27)
P2	48	4.5 (10.0)	0 (0)	20 (36)
P2	49	4.5 (10.0)	0 (0)	30 (54)

*Superheat conditions are relative to the steam partial pressure.

Table A.3-1b. PANTHERS/PCC Steady-State Performance Matrix – Air-Steam Mixture Tests

Test Group Number	Test Condition Number	Steam Flow [kg/s (lb/s)]	Air Flow [kg/s (lb/s)]	Inlet Pressure [kPa g (psig)]	Superheat* [°C (°F)]
P3	9-1	4.5 (10.0)	0.073 (0.16)	207 (30)	0 (0)
P3	9-2	4.5 (10.0)	0.073 (0.16)	328 (48)	0 (0)
P3	9-3	4.5 (10.0)	0.073 (0.16)	448 (65)	0 (0)
P3	9-4	4.5 (10.0)	0.073 (0.16)	569 (83)	0 (0)
P3	9-5	4.5 (10.0)	0.073 (0.16)	689 (100)	0 (0)
P3	15-1	4.5 (10.0)	0.14 (0.31)	193 (28)	0 (0)
P3	15-2	4.5 (10.0)	0.14 (0.31)	317 (46)	0 (0)
P3	15-3	4.5 (10.0)	0.14 (0.31)	441 (64)	0 (0)
P3	15-4	4.5 (10.0)	0.14 (0.31)	565 (82)	0 (0)
P3	15-5	4.5 (10.0)	0.14 (0.31)	689 (100)	0 (0)
P3	18-1	4.5 (10.0)	0.36 (0.79)	186 (27)	0 (0)
P3	18-2	4.5 (10.0)	0.36 (0.79)	274 (40)	0 (0)
P3	18-3	4.5 (10.0)	0.36 (0.79)	362 (53)	0 (0)
P3	18-4	4.5 (10.0)	0.36 (0.79)	450 (65)	0 (0)
P3	18-5	4.5 (10.0)	0.36 (0.79)	538 (78)	0 (0)
P3	23-1	4.5 (10.0)	0.83 (1.83)	159 (23)	0 (0)
P3	23-2	4.5 (10.0)	0.83 (1.83)	240 (35)	0 (0)
P3	23-3	4.5 (10.0)	0.83 (1.83)	321 (47)	0 (0)
P3	23-4	4.5 (10.0)	0.83 (1.83)	402 (59)	0 (0)
P3	23-5	4.5 (10.0)	0.83 (1.83)	483 (70)	0 (0)
P4	2-1	1.4 (3.0)	0.014 (0.030)	207 (30)	0 (0)
P4	2-2	1.4 (3.0)	0.014 (0.030)	328 (48)	0 (0)
P4	2-3	1.4 (3.0)	0.014 (0.030)	448 (65)	0 (0)
P4	2-4	1.4 (3.0)	0.014 (0.030)	569 (83)	0 (0)
P4	2-5	1.4 (3.0)	0.014 (0.030)	689 (100)	0 (0)
P4	13-1	2.5 (5.5)	0.14 (0.31)	193 (28)	0 (0)
P4	13-2	2.5 (5.5)	0.14 (0.31)	283 (41)	0 (0)
P4	13-3	2.5 (5.5)	0.14 (0.31)	373 (54)	0 (0)
P4	13-4	2.5 (5.5)	0.14 (0.31)	462 (67)	0 (0)

*Superheat referenced to steam partial pressure.

Table A.3-1b. PANTHERS/PCC Steady-State Performance Matrix – Air-Steam Mixture Tests (Continued)

Test Group Number	Test Condition Number	Steam Flow [kg/s (lb/s)]	Air Flow [kg/s (lb/s)]	Inlet Pressure [kPa g (psig)]	Superheat* [°C (°F)]
P4	13-5	2.5 (5.5)	0.14 (0.31)	552 (80)	0 (0)
P4	16-1	7.0 (15.4)	0.14 (0.31)	200 (29)	0 (0)
P4	16-2	7.0 (15.4)	0.14 (0.31)	322 (47)	0 (0)
P4	16-3	7.0 (15.4)	0.14 (0.31)	445 (65)	0 (0)
P4	16-4	7.0 (15.4)	0.14 (0.31)	567 (82)	0 (0)
P4	16-5	7.0 (15.4)	0.14 (0.31)	689 (100)	0 (0)
P4	17-1	2.5 (5.5)	0.36 (0.79)	172 (25)	0 (0)
P4	17-2	2.5 (5.5)	0.36 (0.79)	255 (37)	0 (0)
P4	17-3	2.5 (5.5)	0.36 (0.79)	338 (49)	0 (0)
P4	17-4	2.5 (5.5)	0.36 (0.79)	420 (61)	0 (0)
P4	17-5	2.5 (5.5)	0.36 (0.79)	503 (73)	0 (0)
P4	19-1	5.7 (12.5)	0.36 (0.79)	193 (28)	0 (0)
P4	19-2	5.7 (12.5)	0.36 (0.79)	283 (41)	0 (0)
P4	19-3	5.7 (12.5)	0.36 (0.79)	373 (54)	0 (0)
P4	19-4	5.7 (12.5)	0.36 (0.79)	462 (67)	0 (0)
P4	19-5	5.7 (12.5)	0.36 (0.79)	552 (80)	0 (0)
P4	22-1	1.4 (3.0)	0.83 (1.83)	97 (14)	0 (0)
P4	22-2	1.4 (3.0)	0.83 (1.83)	161 (23)	0 (0)
P4	22-3	1.4 (3.0)	0.83 (1.83)	225 (33)	0 (0)
P4	22-4	1.4 (3.0)	0.83 (1.83)	288 (42)	0 (0)
P4	22-5	1.4 (3.0)	0.83 (1.83)	352 (51)	0 (0)
P4	25-1	7.0 (15.4)	0.83 (1.83)	179 (26)	0 (0)
P4	25-2	7.0 (15.4)	0.83 (1.83)	262 (38)	0 (0)
P4	25-3	7.0 (15.4)	0.83 (1.83)	345 (50)	0 (0)
P4	25-4	7.0 (15.4)	0.83 (1.83)	427 (62)	0 (0)
P4	25-5	7.0 (15.4)	0.83 (1.83)	510 (74)	0 (0)
P5	35-1	4.5 (10.0)	0.83 (1.83)	159 (23)	20(36)
P5	35-2	4.5 (10.0)	0.83 (1.83)	240 (35)	20(36)
P5	35-3	4.5 (10.0)	0.83 (1.83)	321 (47)	20(36)

*Superheat referenced to steam partial pressure.

Table A.3-1b. PANTHERS/PCC Steady-State Performance Matrix – Air-Steam Mixture Tests (Continued)

Test Group Number	Test Condition Number	Steam Flow [kg/s (lb/s)]	Air Flow [kg/s (lb/s)]	Inlet Pressure [kPa g (psig)]	Superheat* [°C (°F)]
P5	35-4	4.5 (10.0)	0.83 (1.83)	402 (58)	20(36)
P5	35-5	4.5 (10.0)	0.83 (1.83)	483 (70)	20(36)
P5	36-1	4.5 (10.0)	0.83 (1.83)	159 (23)	30(54)
P5	36-2	4.5 (10.0)	0.83 (1.83)	240 (35)	30(54)
P5	36-3	4.5 (10.0)	0.83 (1.83)	321 (47)	30(54)
P5	36-4	4.5 (10.0)	0.83 (1.83)	402 (58)	30(54)
P5	36-5	4.5 (10.0)	0.83 (1.83)	483 (70)	30(54)
P6	1-1	0.45 (1.0)	0.014 (0.030)	193 (28)	0 (0)
P6	1-2	0.45 (1.0)	0.014 (0.030)	317 (46)	0 (0)
P6	1-3	0.45 (1.0)	0.014 (0.030)	441 (64)	0 (0)
P6	1-4	0.45 (1.0)	0.014 (0.030)	565 (82)	0 (0)
P6	1-5	0.45 (1.0)	0.014 (0.030)	689 (100)	0 (0)
P6	3-1	2.5 (5.5)	0.027 (0.060)	207 (30)	0 (0)
P6	3-2	2.5 (5.5)	0.027 (0.060)	328 (48)	0 (0)
P6	3-3	2.5 (5.5)	0.027 (0.060)	448 (65)	0 (0)
P6	3-4	2.5 (5.5)	0.027 (0.060)	569 (83)	0 (0)
P6	3-5	2.5 (5.5)	0.027 (0.060)	689 (100)	0 (0)
P6	4-1	3.6 (8.0)	0.027 (0.060)	207 (30)	0 (0)
P6	4-2	3.6 (8.0)	0.027 (0.060)	328 (48)	0 (0)
P6	4-3	3.6 (8.0)	0.027 (0.060)	448 (65)	0 (0)
P6	4-4	3.6 (8.0)	0.027 (0.060)	569 (83)	0 (0)
P6	4-5	3.6 (8.0)	0.027 (0.060)	689 (100)	0 (0)
P6	5-1	4.5 (10.0)	0.027 (0.060)	207 (30)	0 (0)
P6	5-2	4.5 (10.0)	0.027 (0.060)	328 (48)	0 (0)
P6	5-3	4.5 (10.0)	0.027 (0.060)	448 (65)	0 (0)
P6	5-4	4.5 (10.0)	0.027 (0.060)	569 (83)	0 (0)
P6	5-5	4.5 (10.0)	0.027 (0.060)	689 (100)	0 (0)
P6	6-1	5.7 (12.5)	0.027 (0.060)	207 (30)	0 (0)
P6	6-2	5.7 (12.5)	0.027 (0.060)	328 (48)	0 (0)

*Superheat referenced to steam partial pressure.

Table A.3-1b. PANTHERS/PCC Steady-State Performance Matrix – Air-Steam Mixture Tests (Continued)

Test Group Number	Test Condition Number	Steam Flow [kg/s (lb/s)]	Air Flow [kg/s (lb/s)]	Inlet Pressure [kPa g (psig)]	Superheat* [°C (°F)]
P6	6-3	5.7 (12.5)	0.027 (0.060)	448 (65)	0 (0)
P6	6-4	5.7 (12.5)	0.027 (0.060)	569 (83)	0 (0)
P6	6-5	5.7 (12.5)	0.027 (0.060)	689 (100)	0 (0)
P6	7-1	7.0 (15.4)	0.027 (0.060)	207 (30)	0 (0)
P6	7-2	7.0 (15.4)	0.027 (0.060)	328 (48)	0 (0)
P6	7-3	7.0 (15.4)	0.027 (0.060)	448 (65)	0 (0)
P6	7-4	7.0 (15.4)	0.027 (0.060)	569 (83)	0 (0)
P6	7-5	7.0 (15.4)	0.027 (0.060)	689 (100)	0 (0)
P6	8-1	1.4 (3.0)	0.073 (0.16)	193 (28)	0 (0)
P6	8-2	1.4 (3.0)	0.073 (0.16)	317 (46)	0 (0)
P6	8-3	1.4 (3.0)	0.073 (0.16)	441 (64)	0 (0)
P6	8-4	1.4 (3.0)	0.073 (0.16)	565 (82)	0 (0)
P6	8-5	1.4 (3.0)	0.073 (0.16)	689 (100)	0 (0)
P6	10-1	5.7 (12.5)	0.073 (0.16)	207 (30)	0 (0)
P6	10-2	5.7 (12.5)	0.073 (0.16)	328 (48)	0 (0)
P6	10-3	5.7 (12.5)	0.073 (0.16)	448 (65)	0 (0)
P6	10-4	5.7 (12.5)	0.073 (0.16)	569 (83)	0 (0)
P6	10-5	5.7 (12.5)	0.073 (0.16)	689 (100)	0 (0)
P6	11-1	7.0 (15.4)	0.073 (0.16)	207 (30)	0 (0)
P6	11-2	7.0 (15.4)	0.073 (0.16)	328 (48)	0 (0)
P6	11-3	7.0 (15.4)	0.073 (0.16)	448 (65)	0 (0)
P6	11-4	7.0 (15.4)	0.073 (0.16)	569 (83)	0 (0)
P6	11-5	7.0 (15.4)	0.073 (0.16)	689 (100)	0 (0)
P6	12-1	0.45 (1.0)	0.14 (0.31)	138 (20)	0 (0)
P6	12-2	0.45 (1.0)	0.14 (0.31)	212 (31)	0 (0)
P6	12-3	0.45 (1.0)	0.14 (0.31)	286 (42)	0 (0)
P6	12-4	0.45 (1.0)	0.14 (0.31)	360 (52)	0 (0)
P6	12-5	0.45 (1.0)	0.14 (0.31)	434 (63)	0 (0)
P6	14-1	3.6 (8.0)	0.14 (0.31)	193 (28)	0 (0)

*Superheat referenced to steam partial pressure.

Table A.3-1b. PANTHERS/PCC Steady-State Performance Matrix – Air-Steam Mixture Tests (Continued)

Test Group Number	Test Condition Number	Steam Flow [kg/s (lb/s)]	Air Flow [kg/s (lb/s)]	Inlet Pressure [kPa g (psig)]	Superheat* [°C (°F)]
P6	14-2	3.6 (8.0)	0.14 (0.31)	317 (46)	0 (0)
P6	14-3	3.6 (8.0)	0.14 (0.31)	441 (64)	0 (0)
P6	14-4	3.6 (8.0)	0.14 (0.31)	565 (82)	0 (0)
P6	14-5	3.6 (8.0)	0.14 (0.31)	689 (100)	0 (0)
P6	20-1	4.5 (10.0)	0.59 (1.29)	179 (26)	0 (0)
P6	20-2	4.5 (10.0)	0.59 (1.29)	262 (38)	0 (0)
P6	20-3	4.5 (10.0)	0.59 (1.29)	345 (50)	0 (0)
P6	20-4	4.5 (10.0)	0.59 (1.29)	428 (62)	0 (0)
P6	20-5	4.5 (10.0)	0.59 (1.29)	510 (74)	0 (0)
P6	21-1	7.0 (15.4)	0.59 (1.29)	186 (27)	0 (0)
P6	21-2	7.0 (15.4)	0.59 (1.29)	274 (40)	0 (0)
P6	21-3	7.0 (15.4)	0.59 (1.29)	362 (53)	0 (0)
P6	21-4	7.0 (15.4)	0.59 (1.29)	450 (66)	0 (0)
P6	21-5	7.0 (15.4)	0.59 (1.29)	538 (78)	0 (0)
P6	24-1	5.7 (12.5)	0.83 (1.83)	165 (24)	0 (0)
P6	24-2	5.7 (12.5)	0.83 (1.83)	248 (36)	0 (0)
P6	24-3	5.7 (12.5)	0.83 (1.83)	331 (48)	0 (0)
P6	24-4	5.7 (12.5)	0.83 (1.83)	413 (60)	0 (0)
P6	24-5	5.7 (12.5)	0.83 (1.83)	496 (72)	0 (0)
P6	31-1	2.5 (5.5)	0.027 (0.060)	207 (30)	20(36)
P6	31-2	2.5 (5.5)	0.027 (0.060)	328 (48)	20(36)
P6	31-3	2.5 (5.5)	0.027 (0.060)	448 (65)	20(36)
P6	31-4	2.5 (5.5)	0.027 (0.060)	569 (83)	20(36)
P6	31-5	2.5 (5.5)	0.027 (0.060)	689 (100)	20(36)
P6	32-1	2.5 (5.5)	0.027 (0.060)	207 (30)	30(54)
P6	32-2	2.5 (5.5)	0.027 (0.060)	328 (48)	30(54)
P6	32-3	2.5 (5.5)	0.027 (0.060)	448 (65)	30(54)
P6	32-4	2.5 (5.5)	0.027 (0.060)	569 (83)	30(54)
P6	32-5	2.5 (5.5)	0.027 (0.060)	689 (100)	30(54)

*Superheat referenced to steam partial pressure.

Table A.3-1b. PANTHERS/PCC Steady-State Performance Matrix – Air-Steam Mixture Tests (Continued)

Test Group Number	Test Condition Number	Steam Flow [kg/s (lb/s)]	Air Flow [kg/s (lb/s)]	Inlet Pressure [kPa g (psig)]	Superheat* [°C (°F)]
P6	33-1	7.0 (15.4)	0.027 (0.060)	207 (30)	20(36)
P6	33-2	7.0 (15.4)	0.027 (0.060)	328 (48)	20(36)
P6	33-3	7.0 (15.4)	0.027 (0.060)	448 (65)	20(36)
P6	33-4	7.0 (15.4)	0.027 (0.060)	569 (83)	20(36)
P6	33-5	7.0 (15.4)	0.027 (0.060)	689 (100)	20(36)
P6	34-1	7.0 (15.4)	0.027 (0.060)	207 (30)	30(54)
P6	34-2	7.0 (15.4)	0.027 (0.060)	328 (48)	30(54)
P6	34-3	7.0 (15.4)	0.027 (0.060)	448 (65)	30(54)
P6	34-4	7.0 (15.4)	0.027 (0.060)	569 (83)	30(54)
P6	34-5	7.0 (15.4)	0.027 (0.060)	689 (100)	30(54)

*Superheat referenced to steam partial pressure.

Table A.3-1c. PANTHERS/PCC Noncondensable – Buildup Test Matrix

Test Group Number	Test Condition Number	Steam Flow [kg/s (lb/s)]	Helium Flow [kg/s (lb/s)]	Air Flow [kg/s (lb/s)]	Superheat* [°C (°F)]
P7	50	1.4 (3.0)	0 (0)	low	0 (0)
P7	51	4.5 (10.0)	0 (0)	low	0 (0)
P7	75	1.4 (3.0)	low	0 (0)	0 (0)
P7	76	4.5 (10.0)	low	0 (0)	0 (0)
P7	77	1.4 (3.0)	low	3.4 x He	0 (0)
P7	75	4.5 (10.0)	low	3.4 x He	0 (0)

*Superheat referenced to steam partial pressure.

Table A.3-1d. PANTHERS/PCC Pool Water Level Effects – Test Matrix

Test Group Number	Test Condition Number	Steam Flow [kg/s (lb/s)]	Air Flow [kg/s (lb/s)]	Superheat* [°C (°F)]
P8	54	4.5 (10.0)	0 (0)	0 (0)
P8	55	4.5 (10.0)	0.14 (0.31)	0 (0)
P8	56	7.0 (15.4)	0.83	0 (0)

*Superheat referenced to steam partial pressure.

Table A.3-2. PANTHERS/PCC TRACG QUALIFICATION POINTS

Test Condition Number	Pre/Post Test Analysis	Data Comparison
41	Post	Heat Rejection Rate
		PCC Pressure Drop
43	Post	Heat Rejection Rate
9	Post	Heat Rejection Rate Degradation Factor
		PCC Pressure Drop
15	Pre/Post	Heat Rejection Rate Degradation Factor
		PCC Pressure Drop
18	Post	Heat Rejection Rate Degradation Factor
		PCC Pressure Drop
23	Pre/Post	Heat Rejection Rate Degradation Factor
		PCC Pressure Drop
2	Post	Heat Rejection Rate Degradation Factor
17	Post	Heat Rejection Rate Degradation Factor
19	Post	Heat Rejection Rate Degradation Factor
22	Post	Heat Rejection Rate Degradation Factor
35	Post	Heat Rejection Rate Degradation Factor
49	Post	Heat Rejection Rate
55	Post	Heat Rejection Rate
51	Post	Degradation Factor
76	Post	Degradation Factor

Table A.3-3a. PANTHERS/IC Steady-State Performance – Test Matrix

Test Condition Number	No. of Cycles	Test Group No.	Inlet Pressure [MPa g (psig)]	Initial Pool Temp. [°C (°F)]
2	1	I1	7.920 (1150)	<32 (90)
3	1	I1	7.240 (1050)	<32 (90)
4	1	I1	6.21 (900)	<32 (90)
5	1	I1	5.52 (800)	<32 (90)
6	1	I1	4.83 (700)	<32 (90)
7	1	I1	4.14 (600)	<32 (90)
8	1	I1	3.45 (500)	<32 (90)
9	1	I1	2.76 (400)	<32 (90)
10	1	I1	2.07 (300)	<32 (90)
11	1	I1	1.38 (200)	<32 (90)

Table A.3-3b. PANTHERS/IC Transient Demonstration – Test Matrix

Test Condition Number	No. of Cycles	Test Group Number	Initial Pressure, P1 MPag (psig)	Inlet Pressure [MPa g (psig)]	Initial Pool Temp. [°C (°F)]
1	2	I2	9.480 (1375)	8.618 (1250)	<21 (70)
12	1	I3	8.618 (1250)	0.48 (70)	<32 (90)
13	1	I3	8.618 (1250)	2.08 (300)	<32 (90)
16	1	I4	8.618 (1250)	8.618 (1250)	<32 (90)

Table A.3-4. PANTHERS/IC TRACG Analysis Cases

Test Condition Number	Pre/Post Test	Data Comparison
2	Post	Heat Rejection Rate
6	Pre/Post	Heat Rejection Rate
11	Post	Heat Rejection Rate
12	Post	Heat Rejection Rate Inlet Pressure
13	Pre/Post	Heat Rejection Rate Inlet Pressure
16	Pre/Post	Heat Rejection Rate

Table A.3-5a. PANDA Steady-State PCC Performance Test Matrix

PANDA Test No.	Steam Flow (kg/s)	Air Flow (kg/s)	PANTHERS Test Condition No.	GIRAFFE Phase 1, Step 1 Test No.
S1	0.20	0	41	2
S2	0.20	0.003	9	4
S3	0.20	0.006	15	6
S4	0.20	0.016	18	8
S5	0.20	0.03	23	10
S6	0.26	0	43	3

Table A.3-5b. PANDA Integral Systems Test Matrix

Panda Test No.	Break Type	No. of PCC	RPV Water Supply Flow	No. of IC	Bypass Leakage Area	Initial Conditions	Comments
M1	MSL -33% to DW1 -67% to DW2	1 in DW1 2 in DW2	0	0	0	GIRAFFE	Repeat of Giraffe Phase 2 MSLB Test
M2	MSL -0% to DW1 -100% to DW2	1 in DW1 2 in DW2	0	0	0	GIRAFFE	Repeat of Giraffe Phase 2 MSLB Test with asymmetric steam flow to DW1 and 2
M3	Same as M1	1 in DW1 2 in DW2	0	0	0	SSAR	Repeat of M1 with SSAR conditions
M4	Same as M1	1 in DW1 2 in DW2	0	0	0	SSAR	Repeat of M3
M5	Same as M1	1 in DW1 2 in DW2	Yes	0	0	SSAR	Repeat of M3 with continuous RPV injection water
M6	Same as M1	1 in DW1 2 in DW2	0	1	0	SSAR	Repeat of M3 with IC
M7	Same as M1	1 in DW1 2 in DW2	0	0	0	PCC filled with air, early start	Repeat of M3 with PCC blanketed with air
M8	Same as M1	1 in DW1 2 in DW2	0	0	TBD	SSAR	Repeat of M3 with DW to WW bypass leakage
M9	Same as M1	1 in DW1 2 in DW2	Yes	0	0	SSAR, early start	Cold water injection to open vacuum breaker

Table A.3-6. PANDA TRACG Analysis Cases

Test Number	Pre/Post Test	Data Comparison
S1	Pre/Post	Heat Rejection Rate
S2	Pre/Post	Heat Rejection Rate Degradation Factor
S3	Pre/Post	Heat Rejection Rate Degradation Factor
S4	Pre/Post	Heat Rejection Rate Degradation Factor
S5	Pre/Post	Heat Rejection Rate Degradation Factor
S6	Pre/Post	Heat Rejection Rate
M1	Pre/Post	Drywell Pressure
		Wetwell Pressure
		Drywell Temp
		Wetwell Temp
		Suppression Pool Temp
		PCC Flows
M2	Pre/Post	Drywell Pressure
		Wetwell Pressure
		Drywell Temp
		Wetwell Temp
		Suppression Pool Temp
M3	Post	Drywell Pressure
		Wetwell Pressure
		Drywell Temp
		Wetwell Temp
		Suppression Pool Temp
M4	Same as M3	

Table A.3-6. PANDA TRACG Analysis Cases (Continued)

Test Number	Pre/Post Test	Data Comparison
M5	Pre/Post	Drywell Pressure
		Wetwell Pressure
		Drywell Temp
		Wetwell Temp
		Suppression Pool Temp
		PCC Flows
		Vacuum Breaker Flow
M6	Post	Drywell Pressure
		Wetwell Pressure
		Drywell Temp
		Wetwell Temp
		Suppression Pool Temp
		PCC Flows
		IC Flow
M7	Pre/Post	Drywell Pressure
		Wetwell Pressure
		Drywell Temp
		Wetwell Temp
		Suppression Pool Temp
		PCC Flows
M8	Post	Drywell Pressure
		Wetwell Pressure
		Drywell Temp
		Wetwell Temp
		Suppression Pool Temp

Table A.3-6. PANDA TRACG Analysis Cases (Continued)

Test Number	Pre/Post Test	Data Comparison
M9	Pre/Post	Drywell Pressure
		Wetwell Pressure
		Drywell Temp
		Wetwell Temp
		Suppression Pool Temp
		PCC Flows

Table A.3-7. GIST Test Matrix Initial Conditions (RPV at 100 psig)

Test (1)	No. of GDCS Lines	RPV Level (in)(2)	Scram Time (sec)(3)	Decay Heat (kW)	LDW Level (in)	UDW Press (psig)	S/P Level (ft)	S/P Temp. (°F)	WW Press (psig)
BDLB Tests:									
A01 Base Case	3	347	369	89	4	13.0	67.2	105	6.5
A02 Low S/P Water Level	3	347	369	89	4	13.0	59.2	105	6.5
A03 Maximum GDCS Flow	4	347	369	89	4	13.0	67.2	105	6.5
A04 Low RPV Water Level	3	327	369	89	4	13.0	67.2	105	6.5
A05 CRD Flow	3	347	369	89	4	13.0	67.2	105	6.5
A06 Minimum GDCS Flow	1	347	369	89	4	13.0	67.2	105	6.5
A07 No Low Press DPVs	3	347	369	89	4	13.0	67.2	105	6.5
MSLB Tests:									
B01 Base Case	3	340	212	99	6	14.5	67.2	110	7.0
B02 Low RPV Water Level	3	320	212	99	6	14.5	67.2	110	7.0
B03 Low S/P Water Level	3	340	212	99	6	14.5	59.2	110	7.0
B04 First Repeat Test	3	340	212	99	6	14.5	67.2	110	7.0
B06 Last Repeat Test	3	340	212	99	6	14.5	67.2	110	7.0
B07 Low-Low RPV WL	3	300	212	99	6	14.5	67.2	110	7.0
B08 Accumulator Makeup	3	300	212	99	6	14.5	67.2	110	7.0
B09 Accumulator Makeup	3	286	212	99	6	14.5	67.2	110	7.0
GDLB Tests:									
C01A Base Case	2	347	373	88	5	11.5	67.2	105	7.0
C02 Max HP DPV Area	2	347	373	88	5	11.5	67.2	105	7.0
C03 Min HP DPV Area	2	347	373	88	5	11.5	67.2	105	7.0
C04 High LP DPV Setpt.	2	347	373	88	5	11.5	67.2	105	7.0

Table A.3-7. GIST Test Matrix Initial Conditions (RPV at 100 psig) (Continued)

Test(1)	No. of GDCS Lines	RPV Level (in)(2)	Scram Time (sec)(3)	Decay Heat (kW)	LDW Level (in)	UDW Press (psig)	S/P Level (ft)	S/P Temp. (°F)	WW Press (psig)
NB Tests:									
D01A Base Case	3	347	865	74	0	0.0	67.2	107	0.0
D02 Maximum GDCS Flow	4	347	865	74	0	0.0	67.2	107	0.0
D03A App. K Decay Heat	3	347	865	94	0	0.0	67.2	107	0.0
D04 Pressurized WW	3	347	865	74	0	14.7	67.2	107	14.7
D05 High Pool Temp	3	347	865	74	0	0	67.2	157	0.0
D06 Low GDCS Injection	4	347	865	74	0	0	67.2	107	0.0
D07 No Power	3	347	—	0	0	0	67.2	107	0.0

(1)Suffix "A" in Test Number signifies a repeat test.

(2)Collapsed water level relative to bottom of RPV.

(3)Time since reactor scram in SBWR. Used to determine decay heat.

Table A.3-8. GIST Runs With Existing TRACG Analysis

Run	Type
B01	MSLB, Base Case
B07	MSLB, Low Initial RPV Level
C01A	GDLB, Base Case
A07	BDLB, No Low Pressure DPVs
D03A	NB, Zero Containment Pressure

Table A.3-9. Additional GIST Runs for TRACG Analysis

Run	Type
B03	MSLB, Low Suppression Pool Level
A01	BDLB, Base Case
A03	BDLB, Max GDCS Flow Area
A05	BDLB, CRD Flow
D01A	NB, Base Case
D02	NB, Max GDCS Flow Area
D04	NB, Pressurized Wetwell

Table A-3.10. GIRAFFE Test Matrix (Phase 1 Step – 1)

Test No.	Test Group	Steam Flow Rate (kg/s)	Nitrogen Partial Pressure (fraction of total press.)	Pressure (kPa)
1	G1	0.02	0	300
2	G1	0.03	0	300
3	G1	0.04	0	300
4	G1	0.03	0.01	300
5	G1	0.02	0.02	300
6	G1	0.03	0.02	300
7	G1	0.04	0.02	300
8	G1	0.03	0.05	300
9	G1	0.02	0.10	300
10	G1	0.03	0.10	300
11	G1	0.04	0.10	300
12	G1	0.03	0.02	200
13	G145	0.03	0.02	400

Table A-3.11. GIRAFFE System Response Tests (Test Group G2)

	Parameter	S/C	RPV	IC/PCC Pool	D/W
PHASE 1 STEP 3	Pressure Total (MPa)	0.301	0.314		0.314
	N2 Partial Pressure (MPa)	0.278			0.016
	Temperature (deg C)	63	134	100	133
	Level (m)	5.55	11	3.55	0
PHASE 2 MSL Break	Pressure Total (MPa)	0.174	0.193		0.192
	N2 Partial Pressure (MPa)	0.164			0.054
	Temperature (deg C)	53	119	100	108
	Level (m)	5.8	8.1*	3.55	0.0

*Elevation above GDCS nozzle

Table A.3-12. GIRAFFE Helium Test Conditions (Test Group G3)

Parameter	S/C	RPV	D/W
Total Pressure (MPa)	0.174	0.189	0.188
He Partial Press			0.135
N2 Partial Press			0.053
Temperature (deg C)	53	118	108

Table A.3-13. PCC Containment Cooler Structural Instrumentation

Measurement/Location	No. of Positions	Quantity at each Position	Total Meas.	Direct
Acceleration:				
steam distributor	1	3	3	X, Y, Z
mid-length of tube	5	2	10	X, Y
upper header cover	1	3	3	X, Y, Z
Displacement:				
inlet/header junction	1	2	2	X, Z
steam distributor	1	1	1	Z
lower header support	2	1	2	Y
Total Strain:				
inlet elbow	1	2	2	axial
inlet/header junction	1	2	2	Z
upper header/tube junction	5	1 or 2	7	Z
tube/lower header junction	3	1	3	Z
lower header	2	2	4	X, Y
lower header cover	1	2	2	Z, X
upper header	2	4	8	X, Z
upper header cover	1	4	4	X, Z
upper header cover bolts	3	1 or 2	5	Y
lower header cover bolts	3	1 or 2	5	Y
drain/lower header junction	1	2	2	X, Z
lower header supports	1	2	2	Z
Permanent strain:				
inlet/header junction	1	1	1	Z
upper header/tube junction	3	1	3	Z
lower header/drain junction	1	2	2	Z
Temperature:				
steam line	2	1	1	1
Temperature				
inlet/header junction	1	1	1	
upper header/tube junction	3	1	3	
tube/lower header junction	3	1	3	
lower header	2	1	2	
lower header cover	1	1	1	
upper header	2	2	4	
upper header cover	1	2	2	
drain/lower header junction	1	1	1	

Table A.3-14. PCC Component Demonstration Test Matrix

Cycle Type	Number of Cycles	Maximum Pressure kPa	Maximum Temperature Deg C	Cycle Duration Min
LOCA	10	379	Saturation	30
Pneu. Test	300	758	Ambient	2

Table A.3-15. LOCA Cycle Time History

PCC Inlet Pressure kPa (psig)	Time to Reach Pressure Sec
0 (0)	0
175 (25.4)	<2.3
249 (36.1)	<32
261 (37.8)	<67
379 (55)	<30 minutes

Table A.3-16. Isolation Condenser Structural Measurements

Measurement/Location	No. of Positions	Quantity at each Position	Total Meas.	Direct
Acceleration:				
mid-length of tube	5	2	10	X, Y
drain line curve	1	3	3	X, Y, Z
lower header cover	1	1	1	Z
upper header cover	1	5	3	X, Y, Z
Displacement:				
steam distributor	1	1	1	Z
drain/lower header junction	1	1	1	Z
steam pipe lower zone	1	1	21	Z
Total Strain:				
inlet/upper header junction	1	6	6	X, Y, Z
upper header/tube junction	5	1 or 2	7	Z
mid-length of tube	3	1	3	circ.
tube/lower header junction	3	1	3	Z
lower header	2	2	4	X, Y
lower header cover	1	2	2	X, Z
upper header	2	4	8	X, Y
upper header cover	1	4	4	X, Z
drain/lower header junction	1	4	4	X, Z
drain line curve	1	2	2	Y
drain line/drain tube	1	4	4	X
upper header cover bolts	3	2 or 1	5	Y
lower header cover bolts	3	2 or 1	5	Y
guard pipe/distributor	1	3	3	X, Z
support	1	2	2	X, 45°
upper header near support	1	4	4	X, Y
Permanent strain:				
inlet/header junction	1	3	3	Y, Z, 45°
upper header/tube junction	3	1	3	Z
lower header/drain junction	1	1	2	Z
Temperature:				
guard pipe/distributor	1	1	1	
inlet pipe/upper header	2	2	4	
upper header/tube junction	3	1	3	
tube/lower header junction	3	1	3	
lower header	2	1	2	
upper header	2	2	4	
drain line bend	1	1	1	
upper header cover	1	2	2	
lower header cover	1	1	1	

Table A.4-17. IC Component Demonstration Test Matrix

Test Cond. No.	No. of Cycles	Cycle Type	Initial Pressure MPa g (psig)	Inlet Pressure MPa g (psig)	Initial Pool Temp. °C (°F)
1	1	1	9.480 (1375)	8.618 (1250)	<21 (70)
2	1	2	8.618 (1250)	7.920 (1150)	<32 (90)
3	1	2	8.618 (1250)	7.240 (1050)	<32 (90)
4	1	2	8.618 (1250)	6.21 (900)	<32 (90)
5	1	2	8.618 (1250)	5.52 (800)	<32 (90)
6	1	2	8.618 (1250)	4.83 (700)	<32 (90)
7	1	2	8.618 (1250)	4.14 (500)	<32 (90)
8	1	2	8.618 (1250)	3.45 (500)	<32 (90)
9	1	2	8.618 (1250)	2.76 (400)	<32 (90)
10	1	2	8.618 (1250)	2.07 (300)	<32 (90)
11	1	2	8.618 (1250)	1.38 (200)	<32 (90)
12	2	3	8.618 (1250)	0.48 (70)	<32 (90)
13	2	3	8.618 (1250)	2.07 (300)	<32 (90)
14	3	3	8.618 (1250)	4.83 (700)	<32 (90)
15	1	3	8.618 (1250)	7.24 (1050)	<32 (90)
16	15	1	8.618 (1250)		<32 (90)
17	85	4	8.618 (1250)		<32 (90)
18	1	5	9.480 (1375)	8.618 (1250)	<32 (90)

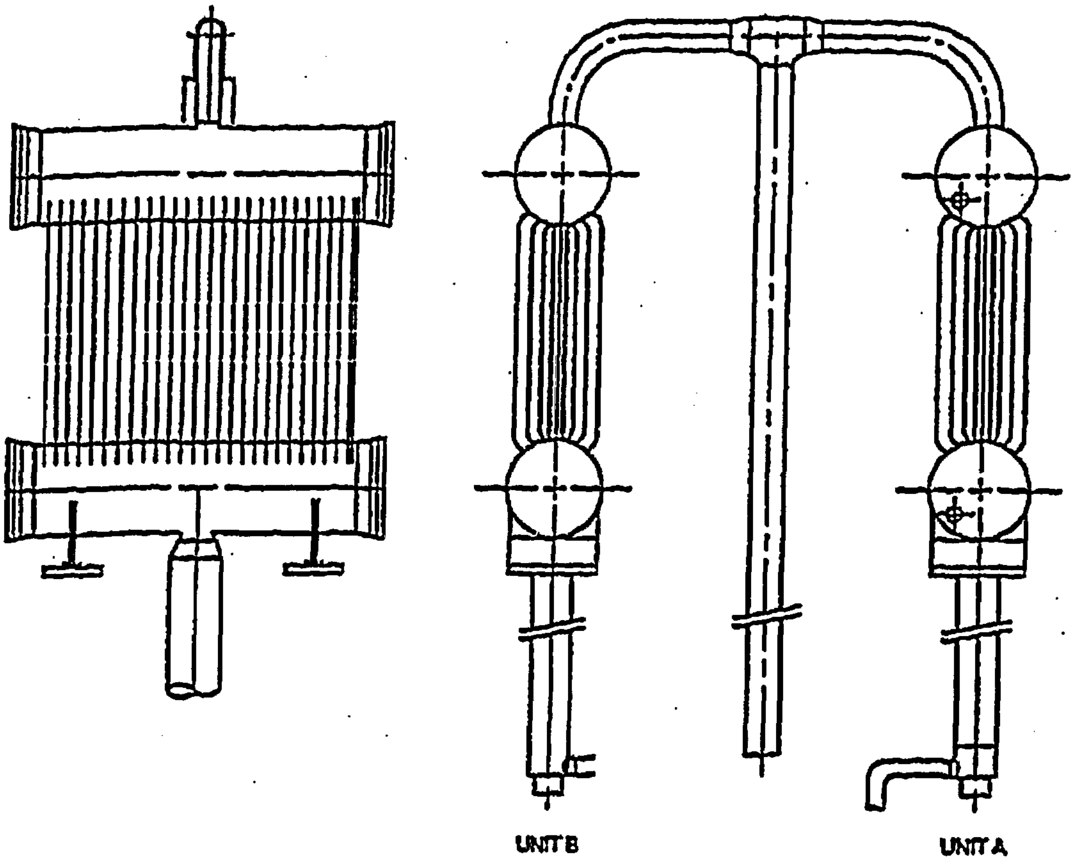

Figure A.3-1. Passive Containment Cooler Test Article

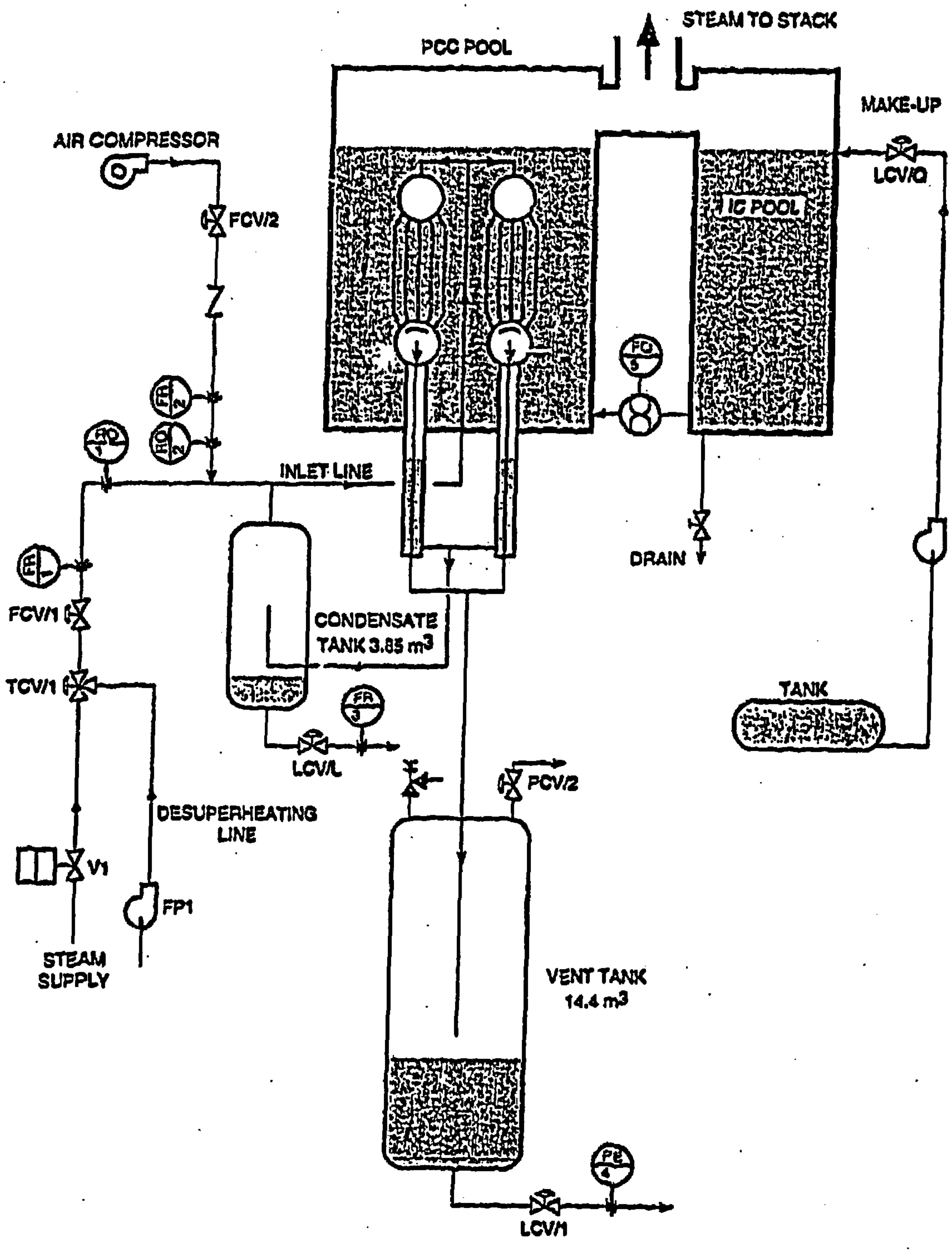

Figure A.3-2. PANTHERS/PCC Test Facility Schematic

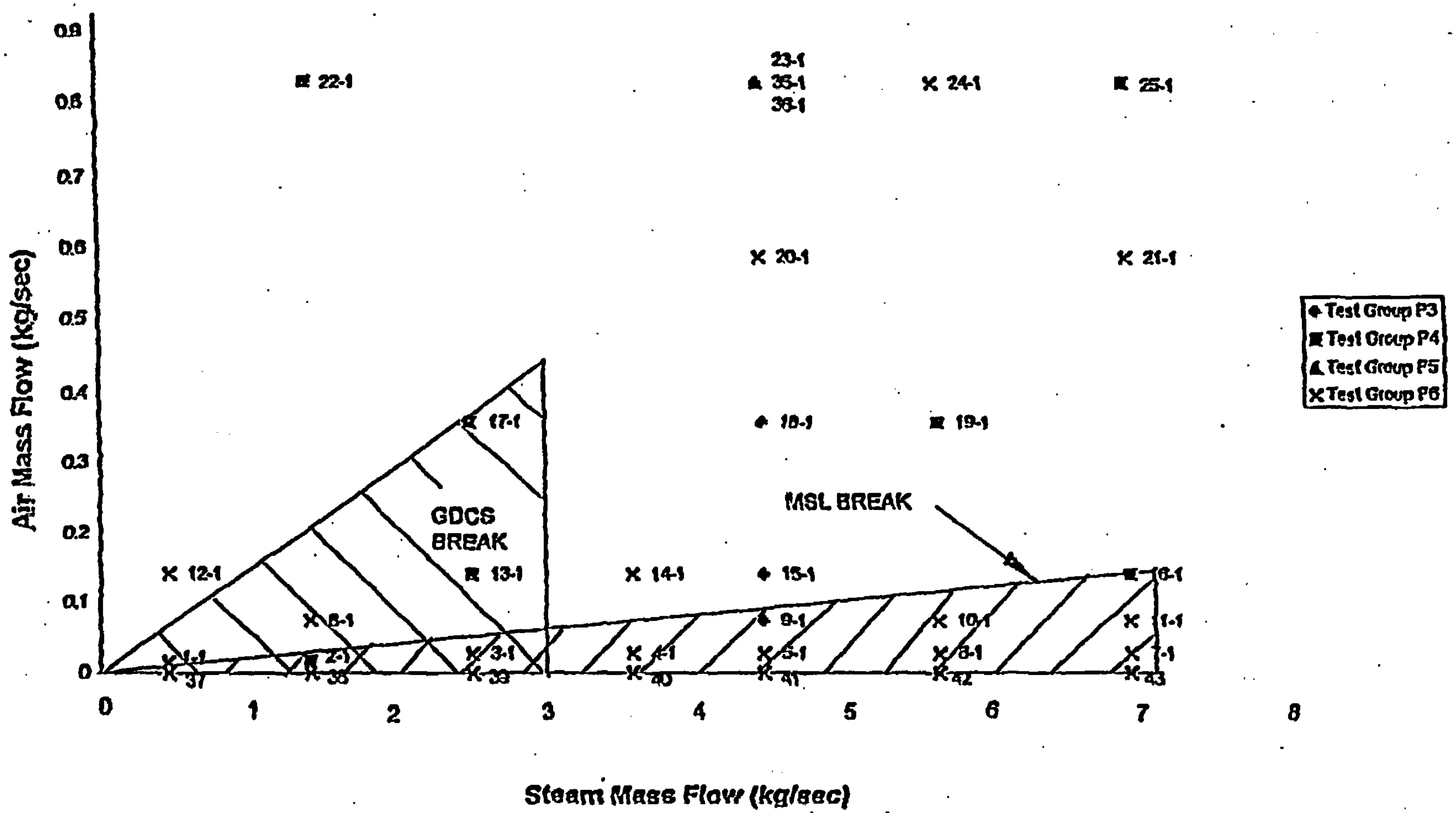

Figure A.3-3. Comparison of PANTHERS/PCC Steam-Air Test Range to SBWR Condition

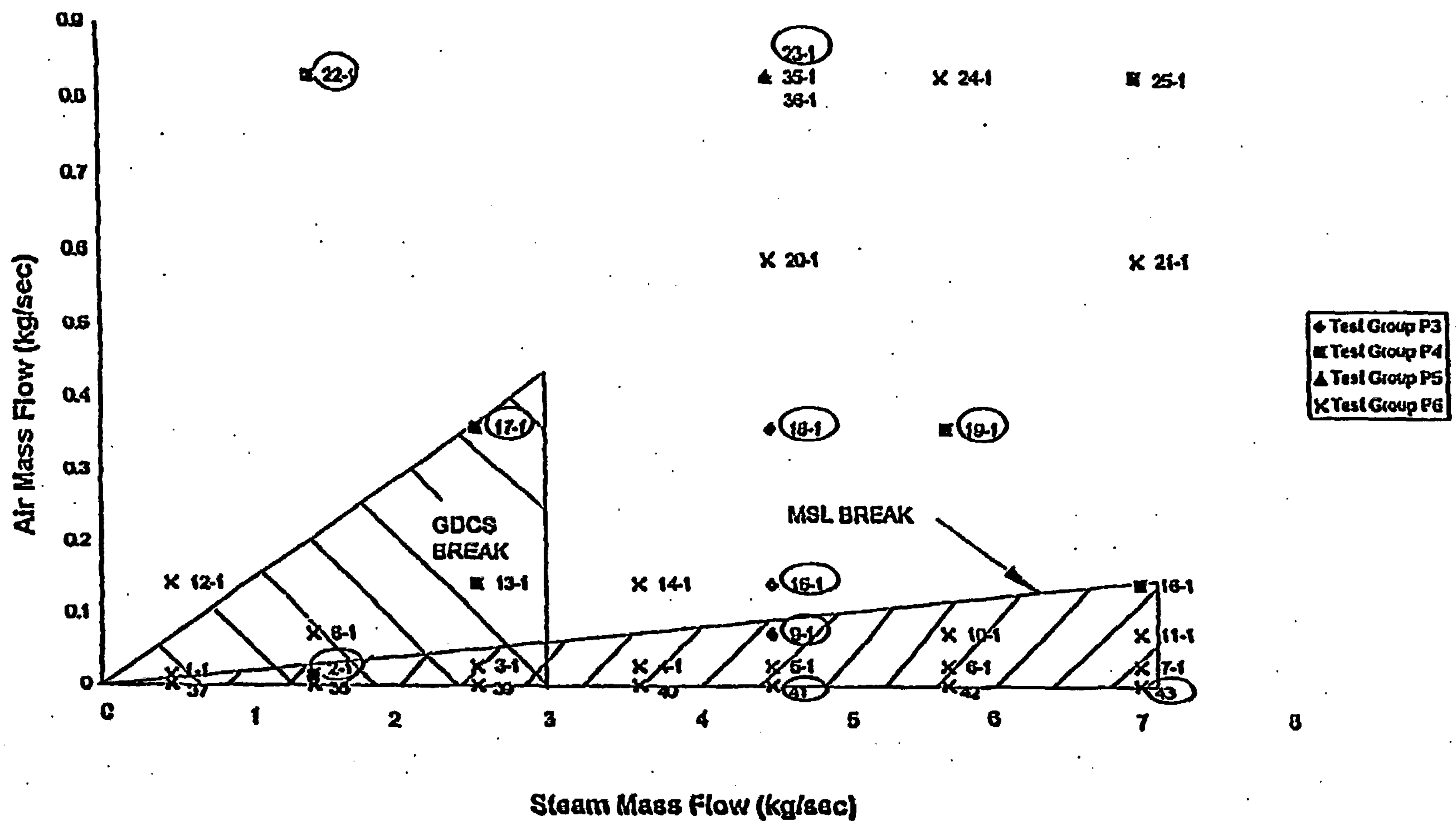

Figure A.3-4. TRACG PANTHERS/PCC Qualification Points

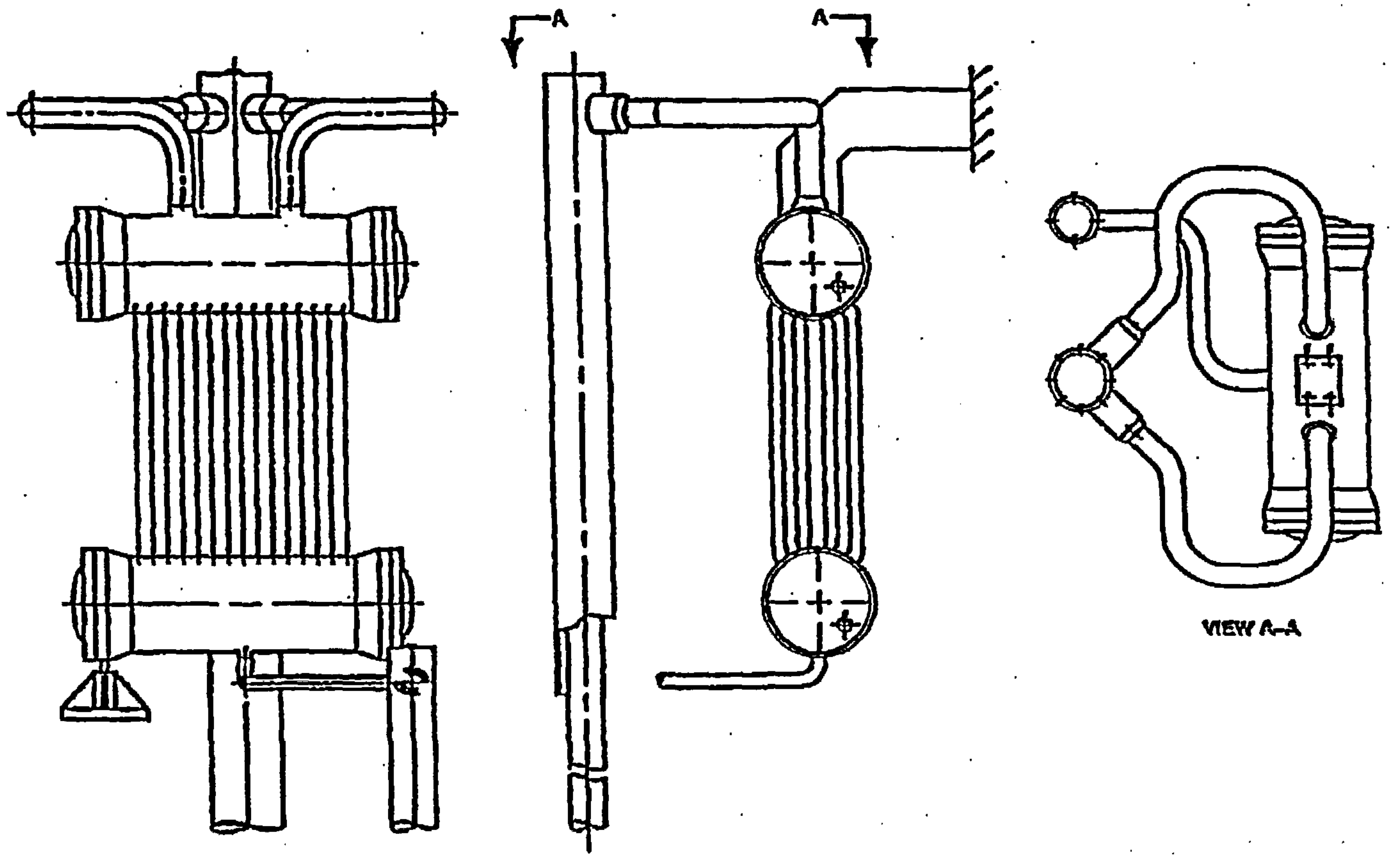

Figure A.3-5. Isolation Condenser Test Article

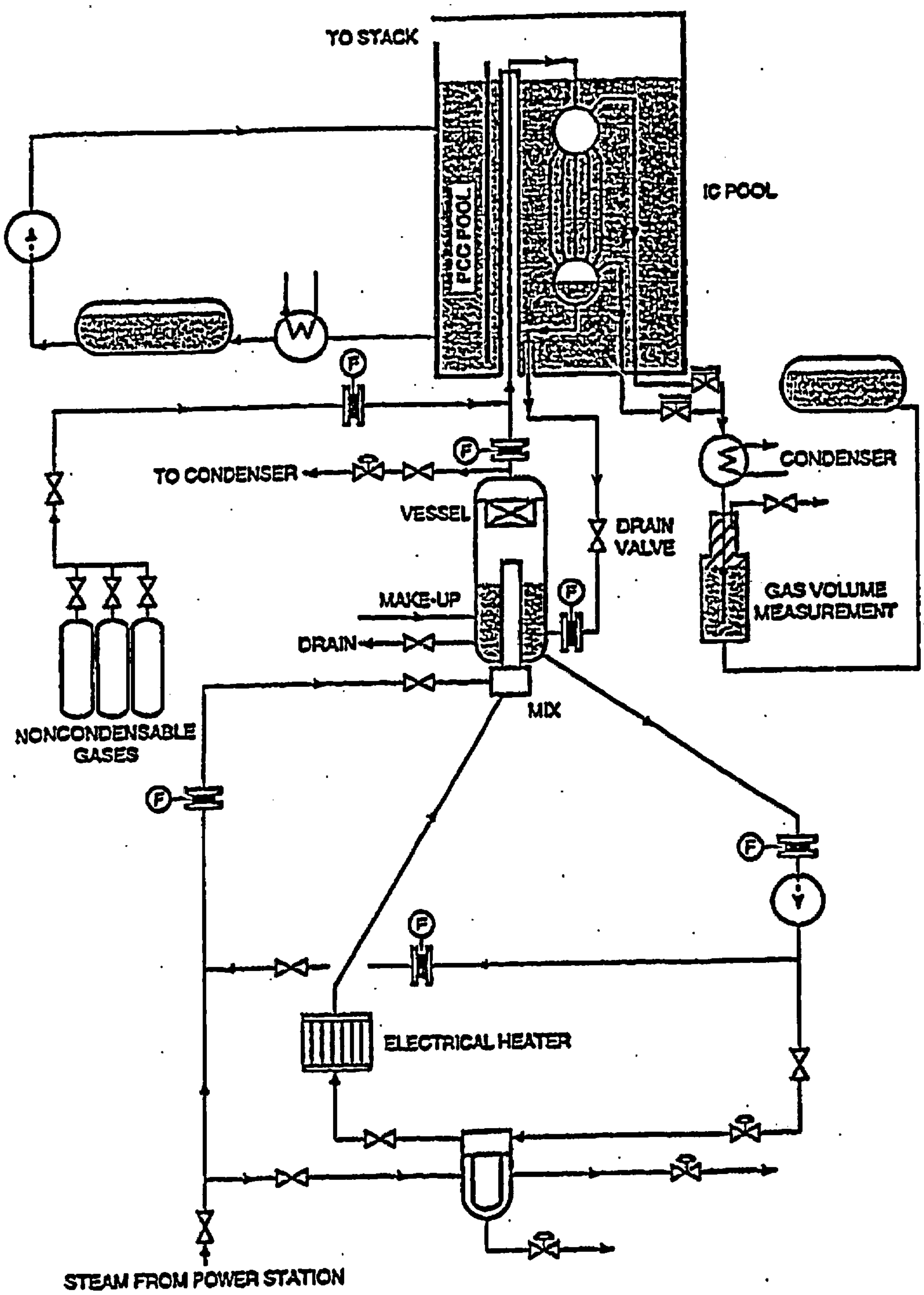

Figure A.3-6. PANTHERS/IC Test Facility Process Diagram

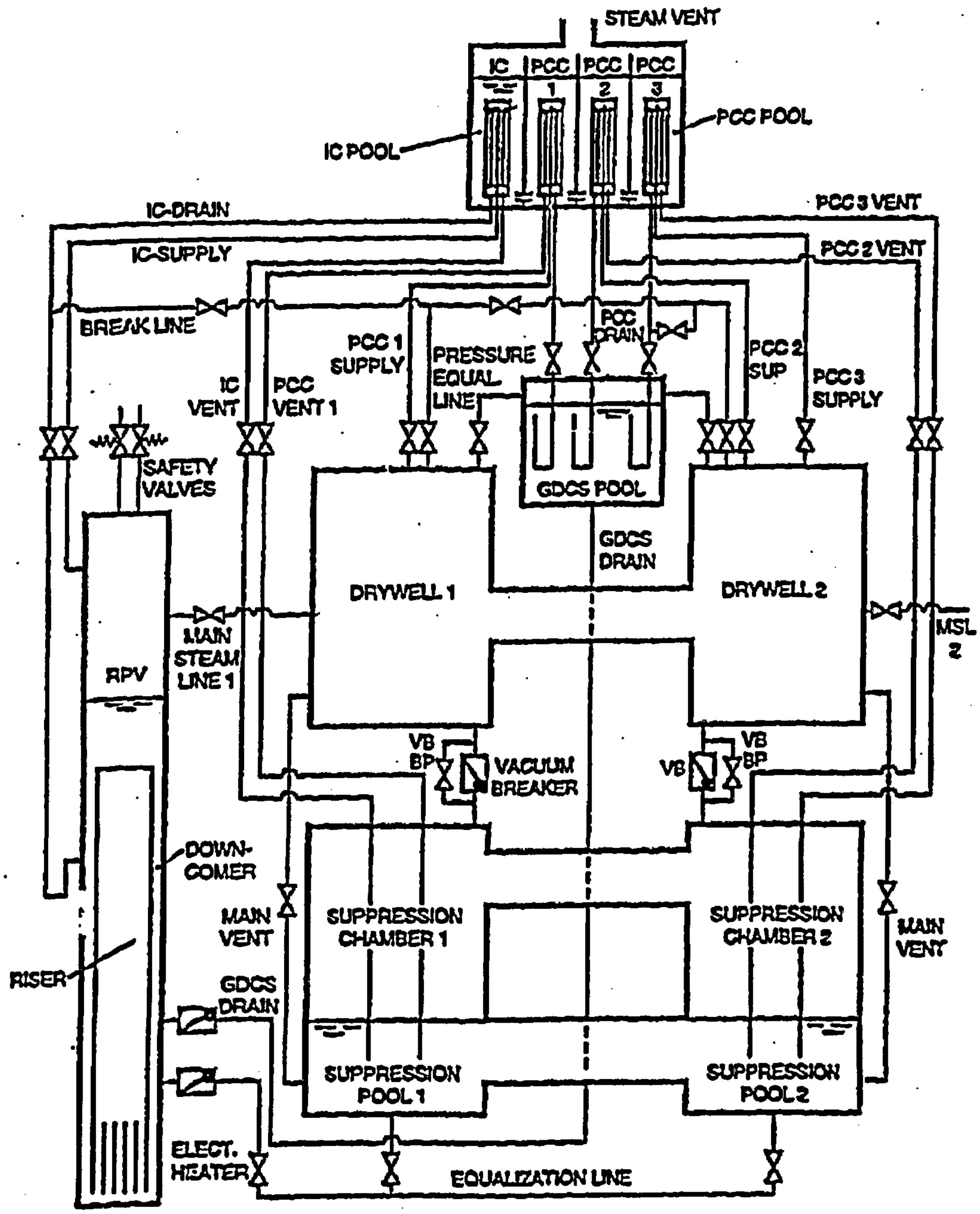

Figure A.3-7. PANDA Facility Schematic

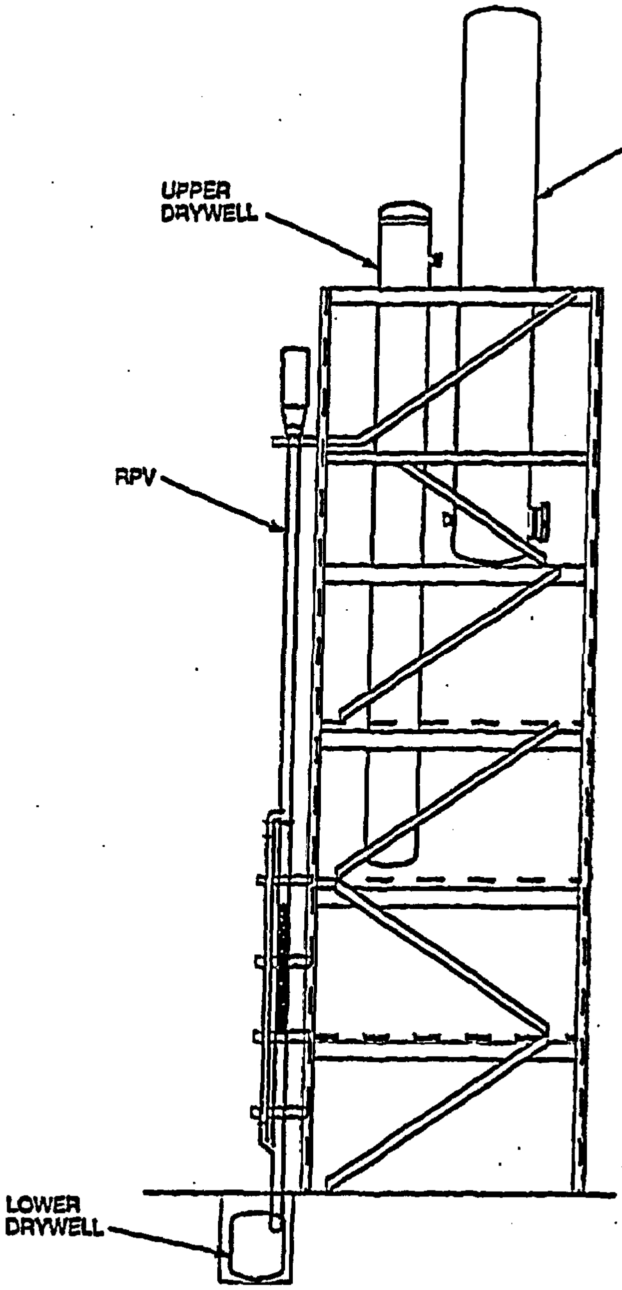

Figure A.3-8. GIST Facility Schematic

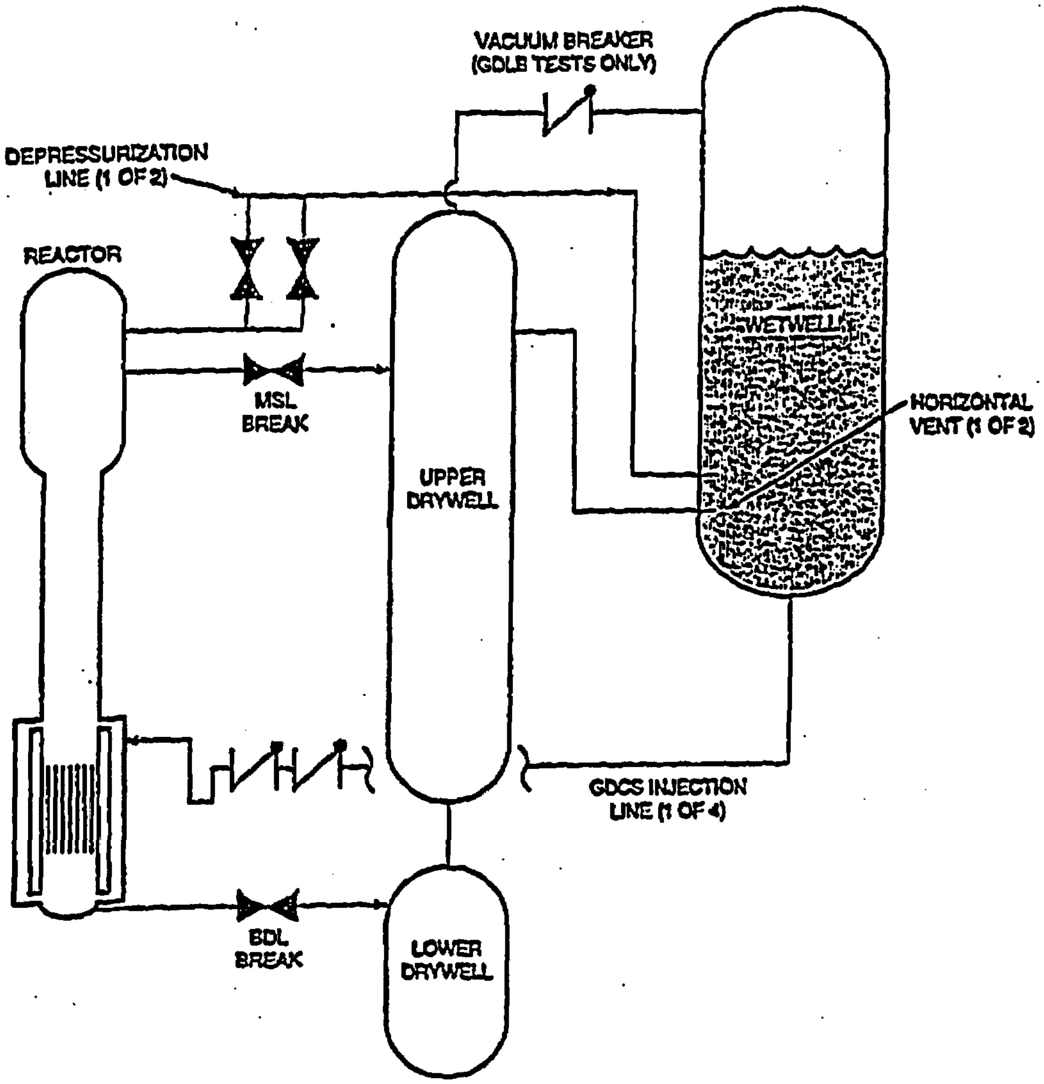

Figure A.3-9. GIST Facility Piping Arrangement

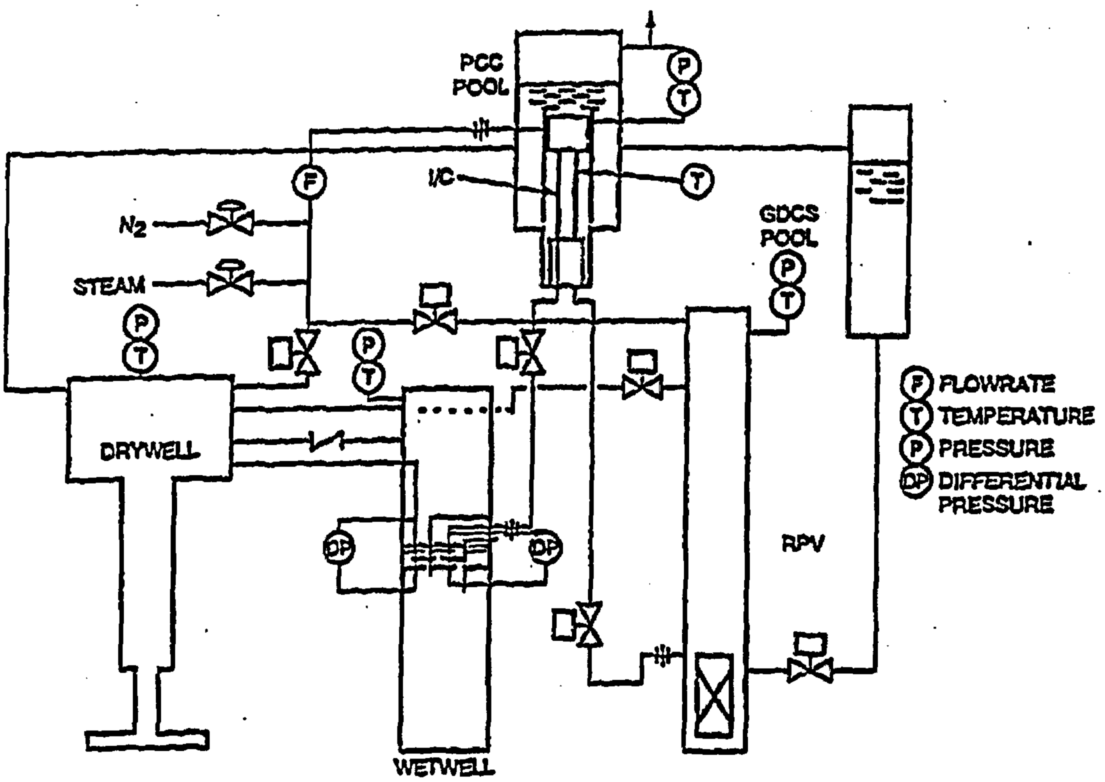

Figure A.3-10. GIRAFFE Test Facility Schematic

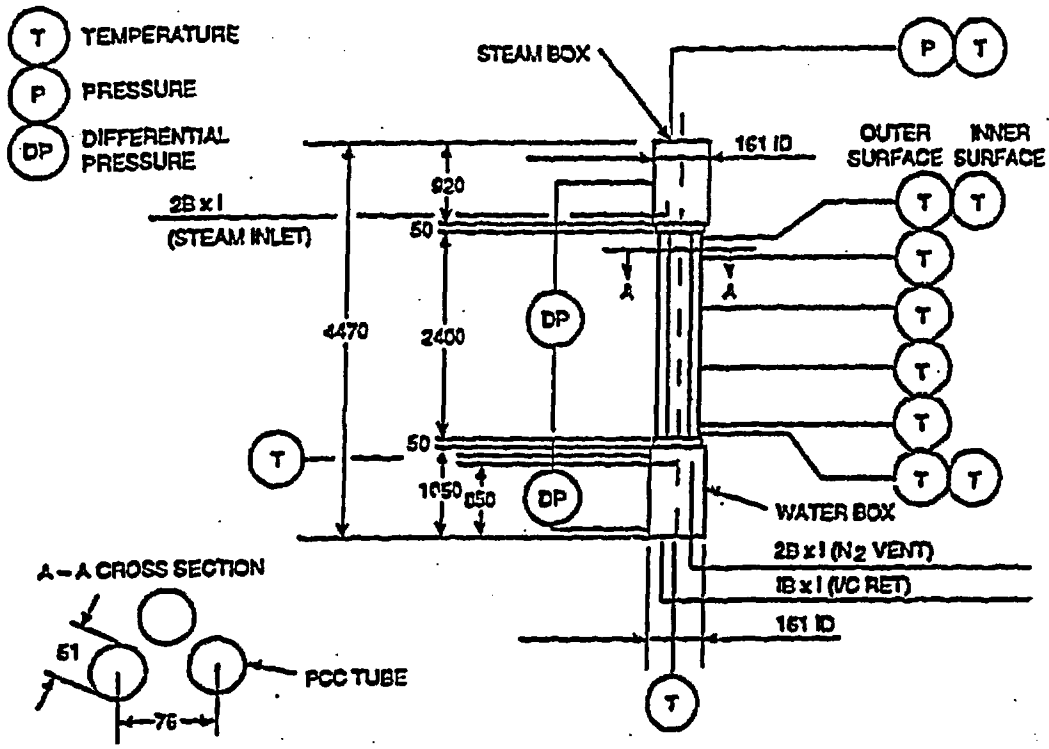

Figure A.3-11. GIRAFFE PCC Unit

Appendix B – Scaling Applicability

B.1 Introduction

This appendix contains a discussion of the scaling analyses which show that the SBWR thermal-hydraulic test facilities – PANTHERS, PANDA, GIST, and GIRAFFE – are scaled appropriately to meet the objectives outlined in Appendix A.

The scaling reported in Reference 32 follows the Hierarchical, Two-Tiered Scaling (H2TS) outlined in Reference 39. Before presenting numerical comparisons of the SBWR and scaled test facilities, it is important to understand what level of differences between the two is acceptable. As noted in Reference 32:

> "System tests (such as the GIST, GIRAFFE and PANDA tests) do not have to provide exact system simulations of the prototype. In fact, it is neither practical nor desirable to attempt to provide such exact simulations. However, system tests do provide data covering all essential phenomena and system behavior under a variety of conditions, which are used to qualify a system code (in this particular case, the TRACG code used for safety analysis by GE).
>
> To obtain data in the proper range of systems conditions, the relative importance of the phenomena and processes present in the tests should not differ significantly from what is expected to take place in the SBWR. Similarly, the overall behavior of the test facility should not diverge significantly from that of the SBWR; in particular, one should not observe bifurcations in the system behavior leading to quite different intermediate or end states. Finally, the test should provide sufficiently detailed information, obtained under well-controlled conditions, to provide an adequate and sufficient database for qualifying a systems code, TRACG."

B.2 Application to Test Facilities

In applying the scaling equations to the SBWR and test facilities, a single point in time during a single event was selected, the beginning of the test simulation for a Main Steam Line Break (MSLB).

B.3 Scaling of GIST Facility

B.3.1 Facility Description and Test Characteristics

The GIST facility is a full-vertical-scale, muti-component integrated system test as outlined in Reference 42.

The system scale is 1:508 and the facility is composed of the following regions:

- Reactor Vessel
- Upper Drywell
- Lower Drywell
- Wetwell/GDCS pool

The ICS and PCCS are not represented.

There are two substantial differences in configuration between the GIST facility, which represented an early SBWR design, and the final SBWR design. First, the GIST GDCS pool is combined with the suppression pool and located in the wetwell, rather than being a separate pool located in the drywell, as in the final SBWR design. Second, all of the RPV depressurization in GIST occurs via SRVs that exhaust to the suppression pool rather than the combination of SRVs (exhausting to the suppression pool) and DPVs (exhausting to the drywell) used in the SBWR. A complete discussion of the differences is contained in the appendix of Reference 42.

B.4 Scaling of GIRAFFE Facility

B.4.1 Facility Description and Test Characteristics

The GIRAFFE facility is a full-vertical-scale, multi-component integrated containment system test with a system scale of 1:400.

B.5 Scaling of PANDA Facility

B.5.1 Facility Description and Test Characteristics

The PANDA facility is a full-vertical-scale multi-component integrated containment system test. The system scale is 1:25.

B.6 PANTHERS Scaling

The PANTHERS tests are full-scale component tests. Therefore, scaling analysis is not necessary for the majority of the facility. The facility includes a full-scale PCC unit (two modules) and one module of an IC unit. Complete descriptions of the PANTHERS facility and test objectives are contained in Appendix A, Section A.3.1.2.

B.7 Scaling Conclusions

Based on the findings from these scaling analyses, the following conclusions can be drawn about each of the test facilities:

- GIST – The GIST tests cover the period of late blowdown and GDCS initiation in a postulated LOCA event. The facility was scaled well to provide data for code qualification in the areas of GDCS initiation time and GDCS flow rate. The SBWR design changes since the time of the GIST test affect the data in such a way that GIST is not representative of the final SBWR design performance; however, nothing in the scaling precludes the use of GIST data for SBWR TRACG qualification.

- GIRAFFE – The GIRAFFE tests provide data on the long-term containment performance, PCC performance and systems interactions of the PCC and GDCS. The large heat losses in the Phase 1 tests result in deviation in the long-term containment performance. Since these heat losses can be modeled with high certainty with the system models, the data can still be used for TRACG qualification. The relatively small system scale results in rather large distortions in the bottom-up parameters. However, these local bottom-up effects are not expected to have a significant impact on the large scale system performance. The heat losses were substantially reduced in the Phase 2 configuration providing results more characteristic of the final SBWR design.

- PANDA – The PANDA facility is scaled very well and the data from this test can be used to qualify TRACG for long-term containment system and component performance as well as system interactions. The system is scaled to 1/25 of the final SBWR design for the time frame to be studied in the tests. The larger test scale results in reduced distortions in the bottom-up phenomena compared to GIRAFFE.

- PANTHERS – The PANTHERS tests are full-scale component tests of the PCC and IC. The test will provide data for TRACG qualification of the PCC and IC performance. In addition, the tests will give information about scaling effects on PCC and IC heat transfer performance when compared to the smaller GIRAFFE and PANDA tests.

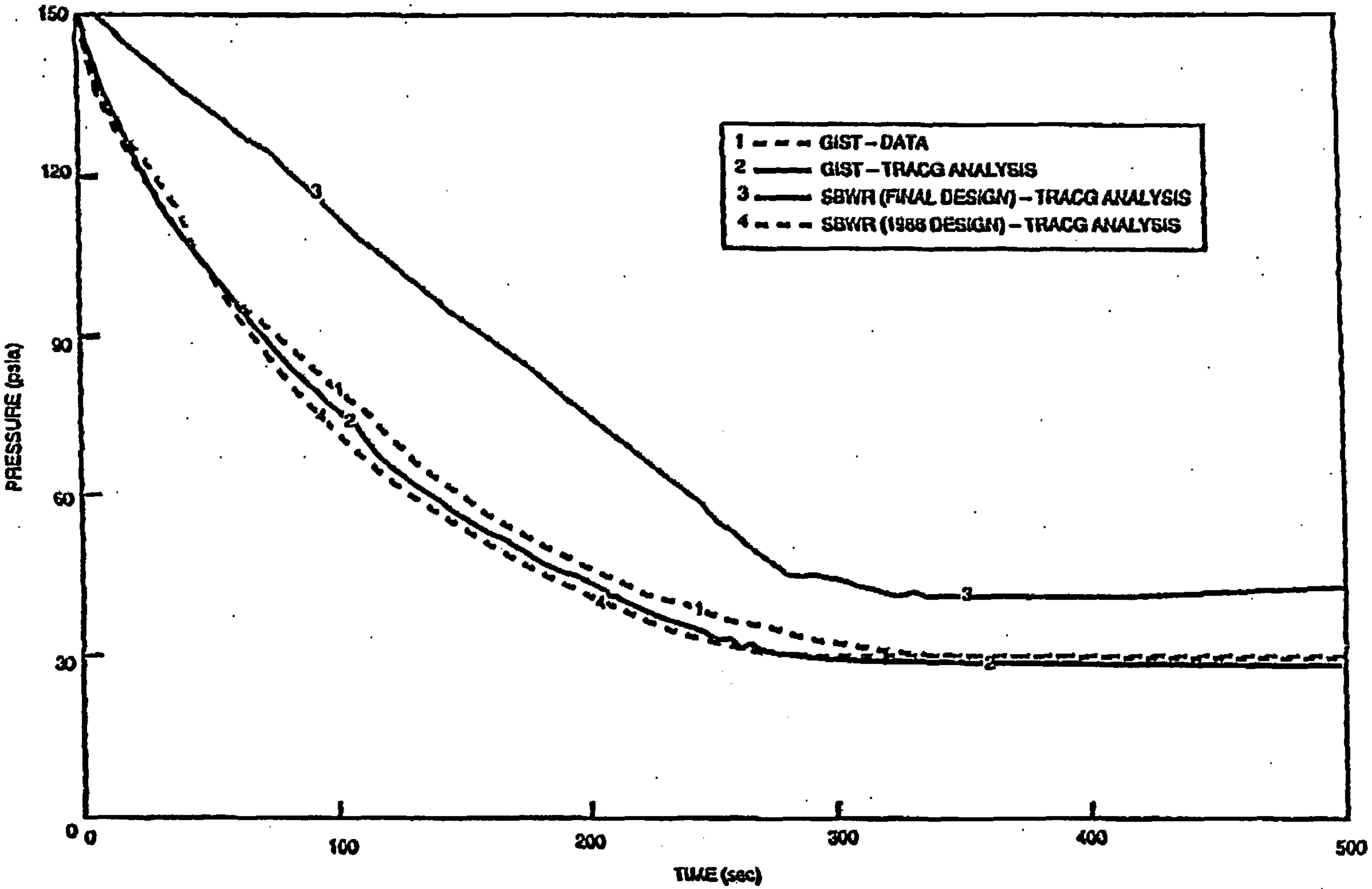

Figure B.3-1. Comparison of RPV Pressure Response for MSLB in GIST and SBWR

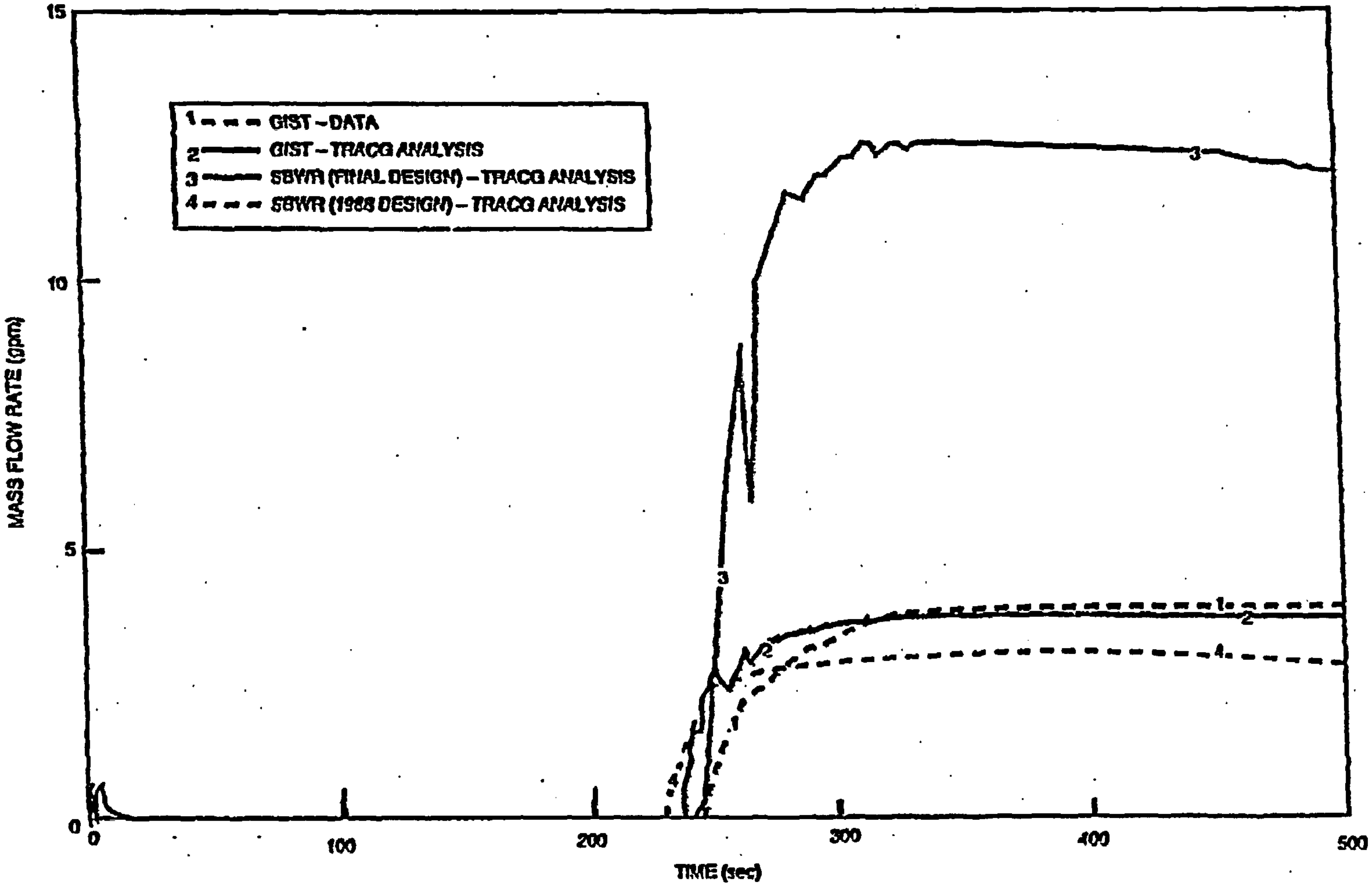

Figure B.3-2. Comparisons of GDCS Flow for MSLB in GIST and SBWR

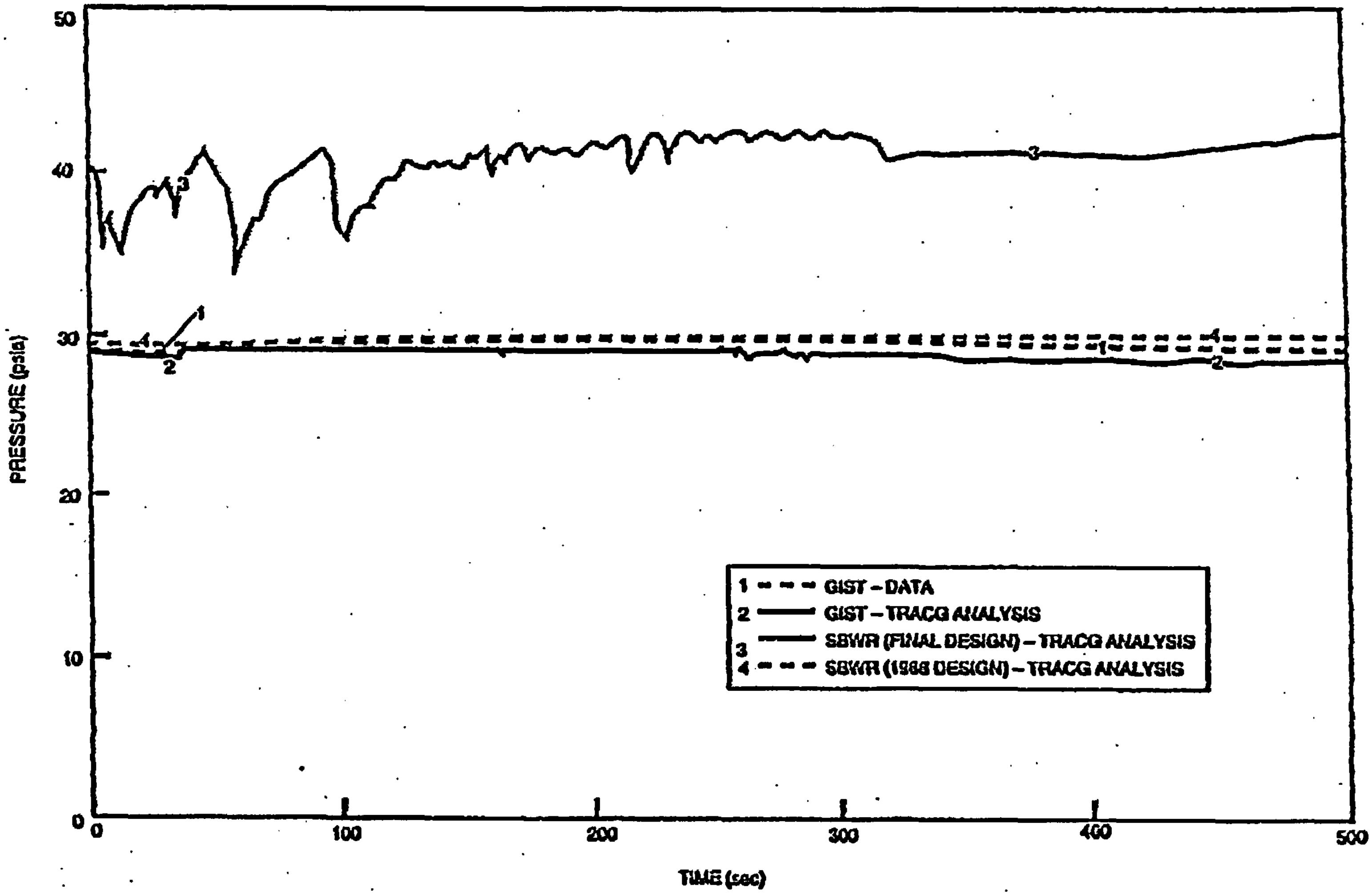

Figure B.3-3. Comparison of Drywell Pressure Response for MSLB in GIST and SBWR

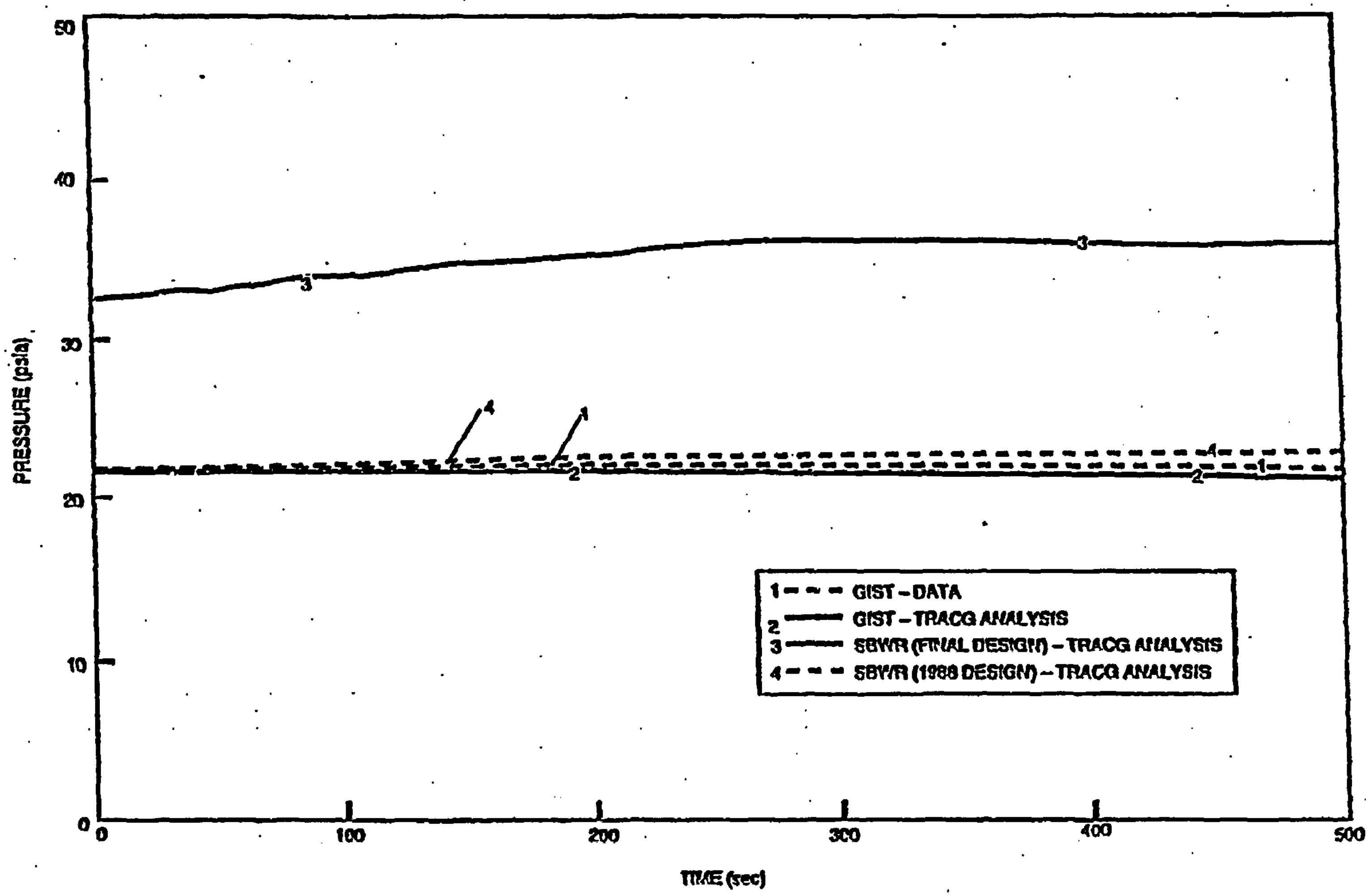

Figure B.3-4. Comparison of Wetwell Pressure Response for MSLB in GIST and SBWR

Attachment B1 – Detailed Scaling Calculations and Theory

Nomenclature and Abbreviations

A	Surface area [m^2]
a	Cross-sectional area [m^2]
c_p	Specific heat at constant pressure [J/kg K]
c_v	Specific heat at constant volume [J/kg K]
D	Diameter [m]
f	Friction factor
F	defined in text
F_n	defined in text
H	Height [m]
h	Specific enthalpy [J/kg]
h_{fg}	Latent heat of vaporization [J/kg]
g	Acceleration of gravity [9.81 m/s^2]
j	Volumetric flow rate [m^3/s]
l	Length [m]
L	Sum of lengths [m]
M	Mass [kg]
p	Pressure [Pa]
Q	Heat addition rate [W]
R	System Scale
T	Temperature [K]
t	Time [s]
u	Velocity [m/s]
V	Volume [m^3]
v	Specific volume [m^3/kg]
y	Mass fraction
z	Axial coordinate [m]
δ	Kronecker delta
υ	Viscosity
π	Non-dimensional number
ρ	Density [kg/m3]
τ	Time constant [s]

Subscripts

G	Gas
L	Liquid

LG	Change liquid to gas
R	Scaling factor between prototype and model

Additional subscripts are defined in the text

Superscripts

o	Reference scale or variable

Abbreviations

DPV	Depressurization Valve
DW	Drywell
GDCS	Gravity Driven Cooling System
GDLB	GDCS Line Break
H2TS	Hierarchical Two-Tier Scaling
IC	Isolation Condenser
ICS	Isolation Condenser System
LOCA	Loss-of-Coolant Accident
MSL	Main Steam Line
MSLB	Main Steam Line Break
PCC	Passive Containment Cooler
PCCS	Passive Containment Cooling System
PIRT	Phenomena Identification and Ranking Table
RPV	Reactor Pressure Vessel
SBWR	Simplified Boiling Water Reactor
SC	Pressure Suppression Chamber
SP	Suppression Pool
SRV	Safety/Relief Valve
WW	Wetwell

B1-1 Introduction

This Attachment contains the scaling equations used in scaling the facilities.

B1-2 Top-Down Scaling

B1-2.1 Methodology

The general Top-Down scaling criteria for the SBWR are outlined in Section 2.4 of Reference 32. The resulting parameters are repeated here.

The six non-dimensional numbers are:

Enthalpy-pressure

$$\Pi_{hp} = \left\{ \frac{\Delta h^o}{\Delta p^o / \rho^o} \right\}$$

Phase-change

$$\Pi_{pch} = \left\{ \frac{\dot{Q}^o}{J^o \rho^o \Delta h^o} \right\}$$

Interfacial Phase Change

$$\Pi_{ipch} = \left\{ \frac{A_{LG} \dot{m}^o_{LG}}{J^o \rho^o} \right\}$$

Inertial Pressure Drop

$$\Pi_{in} = \left\{ \frac{\rho^o u_r^{o\,2}}{\Delta p^o} \right\}$$

Submergence

$$\Pi_{sub} = \left\{ \frac{\rho_l g H^o_{sub}}{\Delta p^o} \right\}$$

Hydrostatic Pressure Drop

$$\Pi_{hyd} = \left\{ \frac{\rho^o g L_g}{\Delta p^o} \right\}$$

Additionally, there are three time scales:

Volume time constant

$$\tau^o = \frac{V^o}{J^o}$$

Transit time constant

$$\tau_{tr} = \left\{ \frac{L_V}{u_r^o} \right\}; \quad L_V = \sum \frac{a_n}{a_r} l_n$$

Inertial time constant

$$\tau_{in} = \left\{ \frac{L_I}{u_r^o} \right\}; \quad L_I = \sum \frac{a_r}{a_n} l_n$$

and two geometric parameters:

Ratio of equivalent inertia and volume lengths

$$\frac{L_I}{L_V}$$

Total flow resistance

$$F = \sum F_n \frac{a_r^2}{a_n^2} + 2\left\{ \frac{a_r^2}{a_2^2} - \frac{a_r^2}{a_1^2} \right\}; \qquad F_n = \frac{4 f_n l_n}{D_n} + k_n$$

As outlined in Reference 32, it is not necessary to preserve both Π_{in} and F; only their product,

$$\Pi_{loss} = \Pi_{in} * F,$$

must be preserved. Additionally, the time scales, τ_{tr} and τ_{in} will be small compared to τ^o and will, therefore, not affect the overall behavior of the system. Thus, it is sufficient to preserve τ^o as the dominant timescale.

A brief discussion of the significance of each scaling parameter is given below. The first three Π value parameters are related to a volume with heat and mass entering or exiting, while the last three relate to flow in a pipe:

- *Enthalpy-pressure* relates additions of enthalpy to changes in the control volume pressure.
- *Phase-change* relates additions of heat to changes in fluid phase.
- *Interfacial Phase Change* essentially shows how well the phase change surface areas were modeled.
- *Inertial Pressure Drop* represents the pressure drop associated with the fluid velocity.
- *Submergence* represents the dynamic head needed to overcome the submergence of a pipe.
- *Hydrostatic Pressure Drop* indicates the pressure drop associated with fluid elevation changes.

Since the fluid properties are prototypic, the submergence and hydrostatic pressure drop numbers become a measure of how well the different elevations were maintained.

Additionally, two-phase behavior is important inside of the reactor vessel. The following list of two-phase parameters describes the scaling of this phenomena:

Void Fraction

$$\alpha$$

Volumetric flow ratio

$$\frac{J_g^o}{J^o}$$

Vaporization number

$$\frac{\dot{m}_{fg}^o \; V^o}{J^o \rho_g^o}$$

Pressure change time constant ratio

$$\frac{\tau_{prate}}{\tau^o}$$

Phase Change Number

$$\Pi_{pch} = \frac{Q^o}{J^o \rho^o h_{fg}^o}$$

Depressurization Number

$$\Pi_{dp} = \frac{Q^o J^o}{\Delta p^o V^o}$$

Flashing Number

$$\Pi_{fl} = \frac{\rho_L J_L^o \Delta h_{Axial}^o}{J^o \rho_g^o h_{fg}^o}$$

Density ratio

$$\frac{\rho_L}{\rho_g^o}$$

A review of the parameters shows that they will be scaled for a full height facility as long as the initial conditions of pressure, temperature, and mass fractions are preserved. The initial conditions are matched in all of the tests, therefore these parameters are not calculated specifically.

Appendix C - TRACG Interaction Studies

C.1 Introduction

If a LOCA were actually to occur in an SBWR, several of the limiting assumptions used in the licensing analysis may not (in fact, probably will not) apply. In particular, not all power may be lost, and non-safety grade systems and safety grade systems that are not engineered safety features (ESF) may be available to support accident management. This Appendix investigates interactions between active and non-ESF systems with the safety systems designed to operate during the LOCA, to determine if adverse effects due to interactions could result in conditions worse than the case if the non-ESF systems had not been available. The figure-of-merit used to measure the effect of system interactions inside the reactor vessel is the water level inside the chimney. Outside the vessel, the containment pressure and temperature are used. These studies are an extension of earlier work described in the SSAR which examined the effect of break location on the LOCA and the use of non-ESF systems to prevent core damage.

The TRACG code has been used for these studies. For interactions affecting the primary system response (inside the vessel) the TRACG input model for LOCA analysis was used. This input model provides a detailed representation of the reactor core, vessel internals and associated systems, but a less detailed representation of the containment. For interactions which may affect the containment response (outside the vessel) the TRACG input model used for containment response was used. This input model provides a more detailed representation of the containment and its systems but a less detailed pressure vessel model. Both input models have been benchmarked to assure that they predict similar global response for the pressure vessel and containment.

Accident scenarios used for the study are similar to those used for LOCA licensing analysis, but additional systems are made available. The use of any additional systems is guided by the SBWR emergency procedure guidelines (EPGs).

C.2 Scenario Definition for Interaction Studies

The systems selected for the study were those that would likely be available and could produce adverse interactions with the ESF systems. Systems that would clearly benefit the system response were not considered. For example, with power and the feedwater system available, vessel inventory could be controlled and there would be no threat of core damage and no need for the passive systems. The Reactor Water Cleanup (RWCU) System is another beneficial system. It removes water from the vessel, cools it and return it through the feedwater line. For all but a feedwater line break, it provides heat removal capability in addition to the passive systems. The exception is for a feedwater line break, where operation of the RWCU System could reduce vessel inventory, and this potentially adverse interaction is considered in the study.

For the several different breaks which were analyzed, three cases were considered:

- Loss of all AC power, except that provided from inverters
- On-site diesel generator power available
- Normal auxiliary power available

The first case is the basis used for the LOCA licensing analysis, and the results provide a measure of the system performance for the other cases where additional systems are available. The first case also provides an opportunity to examine system interactions between those safety systems that are expected to be available during the design basis accident. In all cases, the ESF systems were assumed to operated as designed.

C.3 Primary System Interaction Studies

The primary system interactions study investigated the effects of non-ESF systems on the vessel downcomer level and chimney level response. Several different break locations were considered.

C.4 Containment Interaction Studies

The containment system interactions study investigated interactions between the ESF systems, and interactions of these systems with other systems which could be available for containment cooling without a loss of power.

C.5 Summary of Interaction Studies

The system interactions in this study included those considered most likely to occur when some form of external power was available and which were not clearly beneficial to the operation of the ESF systems.