FILED: June 27, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)
	) Docket Nos. 50-424
GEORGIA POWER COMPANY, ET AL.	) 50-425
	)
(Vogtle Electric Generating Plant,	)
Units 1 and 2)	)

AFFIDAVIT OF WILLIAM C. RAMSEY

State of Alabama

County of Jefferson

After being duly sworn according to law, the undersigned affiant, William C. Ramsey, states and deposes that the following is true and correct and of his own personal knowledge.

1. I am William C. Ramsey. I am employed by Southern Company Services, Inc. as Manager-Nuclear Plant Projects Licensing, Nuclear Safety and Fuel. I am a mechanical engineer and I have been involved in Nuclear Power Plant Design for the past thirteen years. I am a member of ASME, Chairman of the AIF Seismic Qualification Working Group, a member of the AIF Equipment Qualification Subcommittee, and a member of the EPRI Technical Advisory Committees for Electrical and Mechanical Equipment Qualification. I organized and chaired the Vogtle Electric Generating Plant Equipment Qualification Task Force.

2. Dose Rate: The qualification tests for the electric cables used at Vogtle complied with IEEE Standard 383-1974, "IEEE Standard for Type Test of Class 1E Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations," which was endorsed in NRC Regulatory Guide 1.131, "Qualification Tests of Electric Cables, Field

Splices, and Connections for Light-Water-Cooled Nuclear Power Plants" (August 1977). Paragraphs 2.3.3.3 and 2.4.2 provide that the rate of radiation exposure shall not be greater than 1×10^6 rad per hour.

3. Synergism: The qualification tests for electric cables considered the synergistic effects of heat and radiation. FSAR, Table 3.11.B.3-1 (Sheet 11). In accordance with Section 2.3.3 and subsections 2.3.3.1 - 2.3.3.4 of IEEE-383-1974, cable was subjected first to circulating air oven aging, then to gamma radiation in air. An inert atmosphere was not used.

4. Terminal Blocks: There are no terminal blocks in safety-related applications inside the Vogtle containment. Also, there are no terminal blocks in safety-related applications outside containment that are necessary for accident mitigation and that could be exposed to, and therefore need be qualified against, a steam environment.

5. Limitorque Motor Operators: In 1981 and 1982, Limitorque Motor Operators failed environmental qualification tests in high-temperature steam environments. As a result, Westinghouse and Limitorque designed new motors, which were then successfully qualified for a high temperature steam environment ($420^{\circ}F$). Negotiations for the procurement of these new motors as replacements for unqualified motors at Vogtle commenced in September 1982 and were recently completed. Applicants have ordered these new motors as replacements for the motors in containment.

6. Hydrogen Recombiners: In addition to the tests listed in the FSAR at S 6.2.5.4.1, the electrical components of the Westinghouse electric recombiner were subjected to 2×10^8 rad radiation. WCAP-7820 (Supp. 2) (Oct. 1973) at S 3.6 (Attachment 1 hereto). Then, to meet

the requirements of IEEE-383-1974, the power cable was subjected to thermal aging, irradiation, post-LOCA containment steam and spray exposure and voltage tests. WCAP-7820, Supp. 7 (August 1977) at 9, 12 (Attachment 2 hereto). The Westinghouse recombiner does not have pressure transducers.

William C. Ramsey
William C. Ramsey

Subscribed and sworn to me
this 26th day of June, 1984.

Deborah L. Brantley
Notary Public

My commission expires: May 21, 1985

June 27, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

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Units 1 and 2)	)	

CERTIFICATE OF SERVICE

I hereby certify that copies of the "Affidavit of William C. Ramsey," dated June 26, 1984, were served upon the persons on the attached Service List by deposit in the United States mail, postage prepaid, this 27th day of June, 1984.

George F. Trowbridge

DATED: June 27, 1984

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
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WESTINGHOUSE CLASS 3

WCAP-7820
Suppl. 7

ELECTRIC HYDROGEN RECOMBINER
LWR CONTAINMENTS
SUPPLEMENTAL TEST NUMBER 2

J. F. Wilson

Oct. 1977

APPROVED C. Eicheldinger
C. Eicheldinger, Manager
Nuclear Safety Department

Work Performed Under Shop Order No. EJPP-917

WESTINGHOUSE ELECTRIC CORPORATION
Nuclear Energy Systems
P. O. Box 355
Pittsburgh, Pennsylvania 15230

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SECTION 1
INTRODUCTION

The Westinghouse Electric Corporation has developed, tested, and produced an electric hydrogen recombiner for installation inside reactor containment for use following a postulated loss-of-coolant accident where such equipment is needed to meet the requirements of USNRC Guide 1.7.

The development and qualification program for the electric recombiner has involved extensive testing on both prototype and the production recombiners. This testing was described in WCAP-7709-L and Supplements 1, 2, 3, 4, 5 and 6 and demonstrates qualification of the recombiner to IEEE 323-1974 and IEEE 344-1975.

This report provides qualification test results for the recombiner power cable (located inside the containment), the recombiner control and power supply panels (located outside the containment) and additional features which may be selected by the customer. Also included are results of testing which further demonstrate the conservative design of the recombiner.

Supplement 7 concludes the qualification documentation for this hydrogen recombiner model.

SECTION 2
SUMMARY

The following tests were performed on the recombiner to provide additional information.

- Seismic tests were performed on the power supply and control panel using both biaxial, random frequency tests, and biaxial sine beat tests with the equipment energized. These tests again demonstrate the ability of these components to withstand seismic events.

- Capability of the recombiner to operate with some heaters inoperative was demonstrated by disconnecting varying numbers of heater elements, then testing to determine temperature distribution and maximum power attainable.

- Power cables were qualified to IEEE-383-1974 by performing environmental and flame tests.

- Power supply and control panel short-term operation in a high-temperature environment was demonstrated by operation in a temperature-controlled environment for 10 days. The power supply was operated at 135°F and the control panel at 155°F.

- A cold reference junction box, which permits the use of copper containment penetrations for the recombiner thermocouples, was developed and tested to facilitate recombiner installation.

- An automatic temperature controller for the recombiner was developed and tested to permit automatic temperature control for the recombiner should this mode of operation be desirable.

SECTION 3
TESTS AND TEST RESULTS

3-1. SEISMIC TESTS OF POWER SUPPLY AND CONTROL PANEL TO IEEE 344-1975

The power supply and control panel have been previously subjected to single-axis sine-beat testing while in the nonenergized mode. This information is reported in WCAP-7709-L Supplement 2. These previous tests were performed on both a prototype and production power supply and control panels. Since these tests were performed, IEEE 344-1975 revision has been issued.

A new seismic test was performed using biaxial motion and both random frequency and sine beat input. These tests were performed on a production power supply which was energized at normal power. These tests again demonstrate the ability of the power supply and control panel to perform their intended function after five Operating Basis Earthquakes (OBE) and a Safe Shutdown Earthquake (SSE).

3-2. Test Method

The power supply and control panel were mounted on the drive plate of a vibration table at the Westinghouse Advanced Energy Systems located at Large, Pennsylvania. The control panel was electrically connected to the power supply which was then connected to an electrical load (electric recombiner heaters held in a rack). The test series consisted of resonance frequency search plus five OBE's followed by an SSE. The input for the five OBE's was a biaxial, random frequency while the SSE was a biaxial, sine beat input. The angle of motion of the table was set to produce vertical accelerations which were 2/3 the magnitude of the horizontal acceleration. For the sine-beat test, four separate tests were run. First, the equipment was mounted 45° to the horizontal plane of motion, then rotated 90° for each of the next three test runs in accordance with paragraph 6.6.6 of IEEE 344-1975.

The acceleration levels for the OBE tests are shown on figure 3-1. The ordinate is the response spectra with a 2.5 percent damping factor. The input was made up of decaying sinusoids covering the frequency range of 1.25 to 35.0 Hz.

The sine beat test was performed at each resonance frequency and at the following frequencies: 1.25, 1.75, 2.5, 3.5, 5, 7, 9.5, 13, 18, 24.5 and 33.5 Hz. Each sine beat test consisted of five beats, each containing 10 cycles as shown in figure 3-2. The peak horizontal accelerations are shown on figures 3-3 and 3-4. The sine beat test was run four times. (Once for each equipment mounting direction) without component failure. It was necessary to add one wiring harness strap and to modify the temperature indicator mounting bracket early in the sine beat test, however, a total of four consecutive tests were run with the equipment in its final configuration. (The wiring harness straps and modified bracket will be incorporated in the new equipment.) This testing conforms to the requirements of IEEE 344-1975, "Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

3-3. RECOMBINER HEATER CAPABILITY UNDER OFF-DESIGN CONDITIONS

The purpose of this test was to demonstrate the reserve capacity of the hydrogen recombiner heater system. The heater banks and heater elements have been successfully tested under extreme post-LOCA environmental conditions as reported in WCAP-7709-L Supplements 2, 3, 4, and 5. These tests include post-LOCA environmental exposure for one year. Based on these tests, no heater element failures would be predicted during recombiner post-LOCA service. However, to demonstrate by test, the extent of the recombiner's ability to operate with less than the full complement of operational heater elements, a test series was performed.

3-4. Test Method

For this test, a production recombiner, power supply and control panel were connected to a power source. Thermocouples were attached to each heater bank and were read out on a strip recorder. The power output of the recombiner was measured with the power meter on the control panel. The control panel was equipped for automatic and manual power control as described in paragraph 3-14 of this report. Before test readings were taken, the exact voltage of the input power was measured and readings were normalized to 480 Vac. To establish a reference basis, the recombiner was first tested with all heater elements operational. The recombiner was heated to 1200°F and stabilized at this temperature. Readings were taken to measure the steady-state power required to maintain this temperature. The power controller was then set on full power and this value was recorded. This latter value is the maximum power the recombiner will draw at 1200°F. (Heater element filament resistance is slightly temperature-dependent).

11408-1

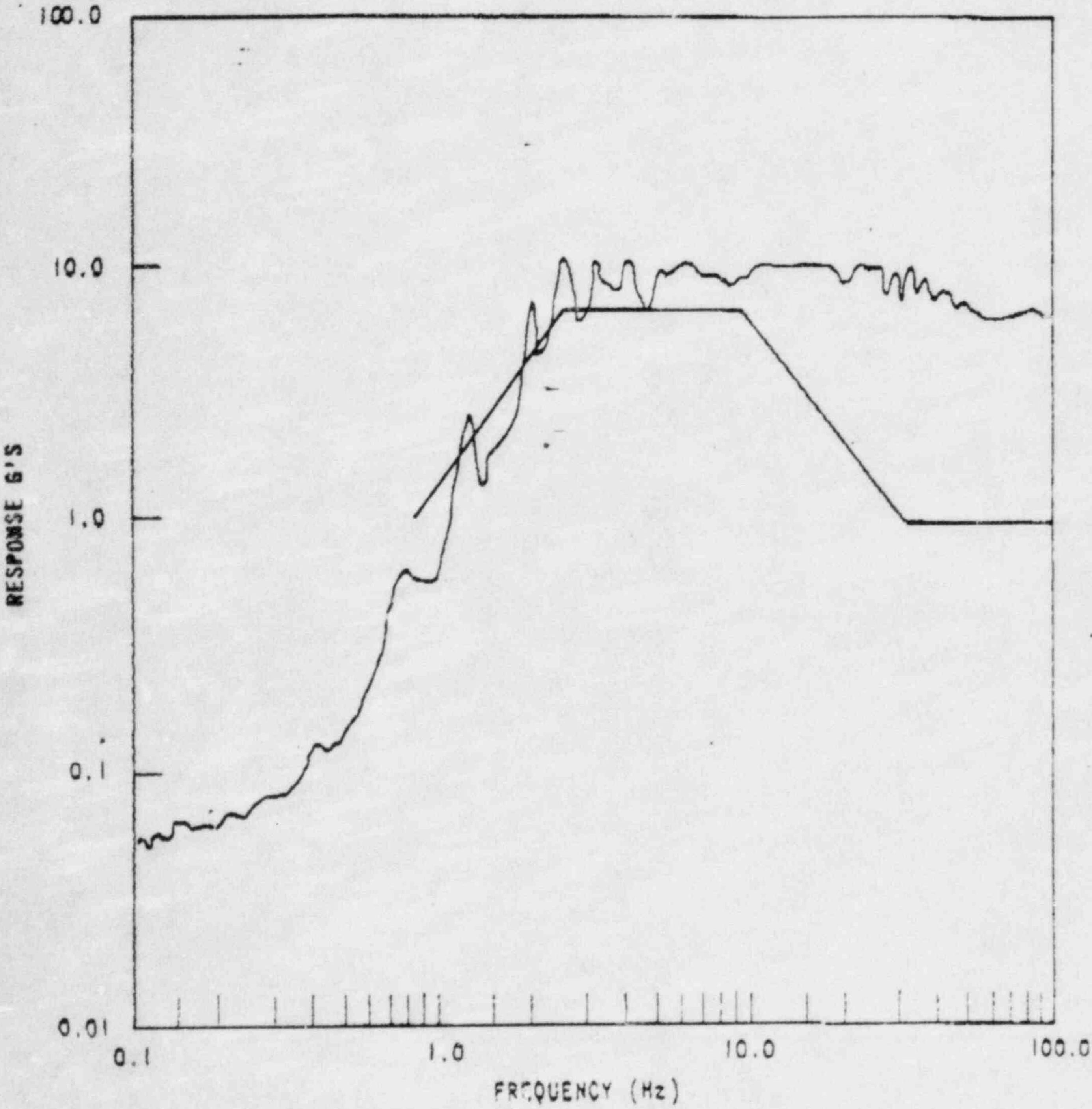

Figure 3-1. Operating Basis Earthquake, OBE 1

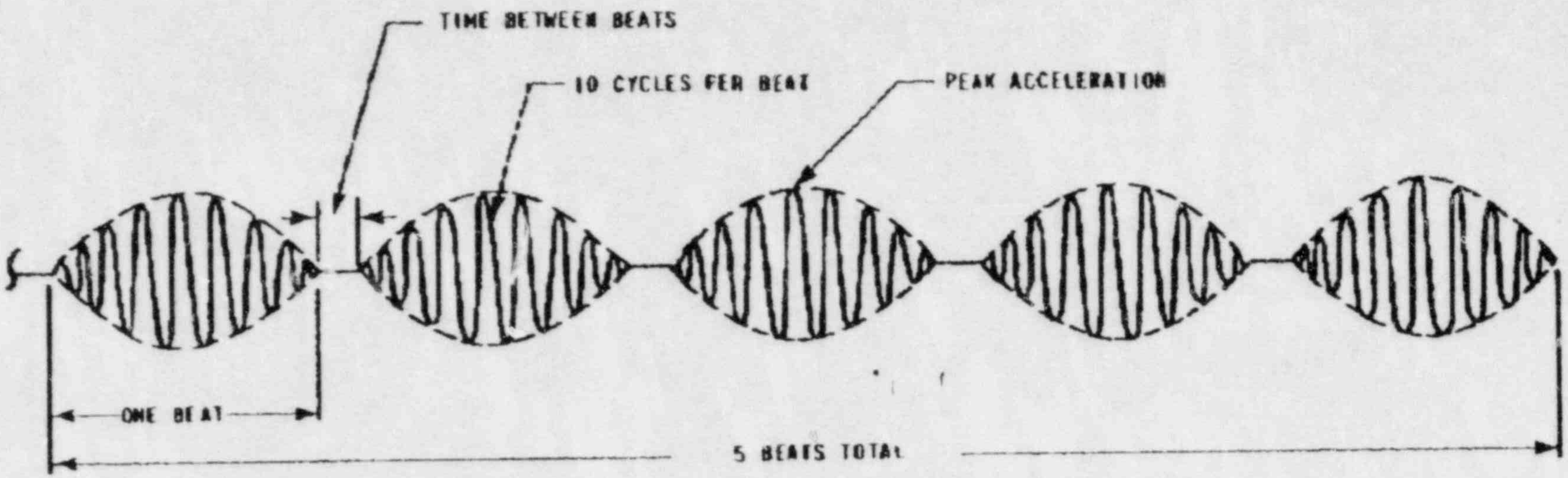

Figure 3-2. Sine Beat Input for Testing

6106-9

6106-8

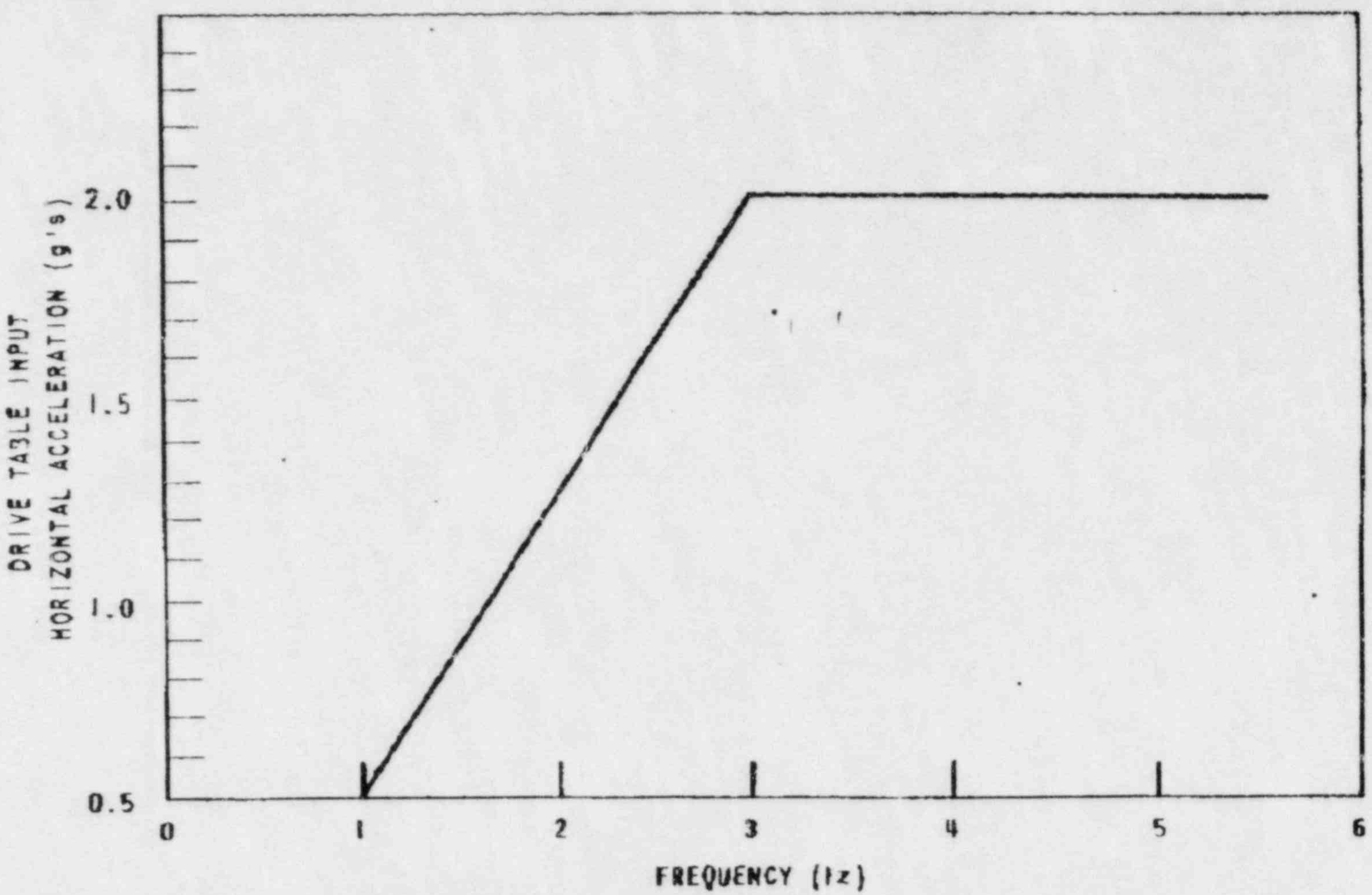

Figure 3-3. Acceleration versus Frequency

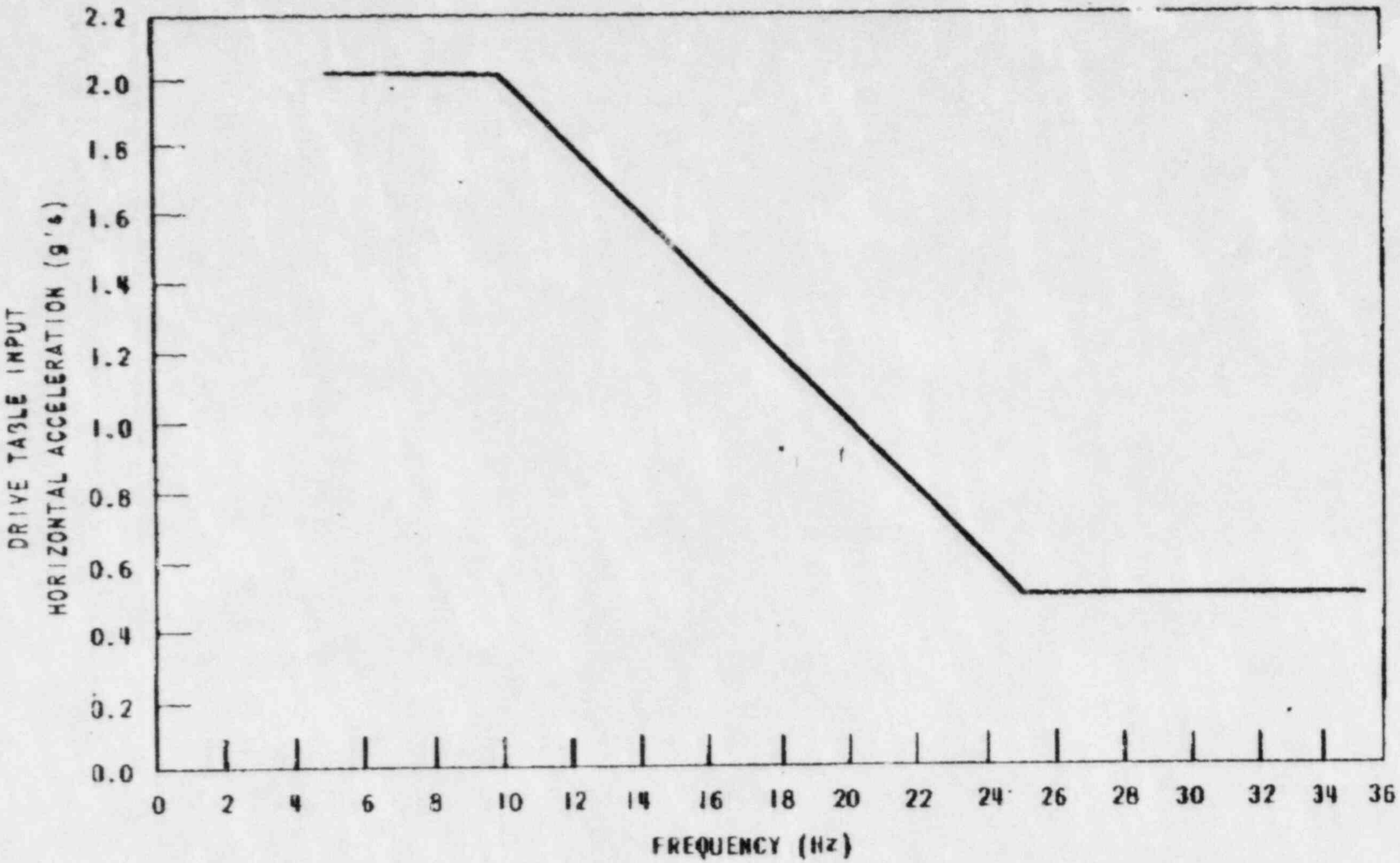

Figure 3-4. Acceleration Frequency

Following this, heater elements were disconnected in various heater banks as listed in table 3 1. This reduced the number of operational heater elements. The same test was then run for each case listed in this table. The temperature distribution within the recombiner for various combinations of heater elements disconnected is shown on figure 3 5. This shows that only slight variations occur in the temperature profile. Table 3-2 shows the amount of reserve capacity in the recombiner with various numbers of heater elements in nonoperation.

3-5. QUALIFICATION OF POWER CABLES TO IEEE 383-1974

The power cables for the recombiner have been previously tested, along with the heater banks in the post-LOCA steam and spray environment, subjected to 2 x 10^8 rad irradiation and seismically tested with the recombiner. This testing demonstrated that the cables are well qualified for the intended service; however, the testing did not completely conform to the procedure outlined in IEEE 383-1974, Standard for Type Test of Class 1E Electric Cables, Field Splices and Connections for Nuclear Power Generating Stations. To meet the requirements of Section 2.4 of the Standard, which treats environmental exposure, a series of tests were performed which included thermal aging, irradiation, post-LOCA containment steam and spray exposure and voltage tests. These tests were performed on cable take from a production run.

IEEE 383-1974 also includes Flame Testing under its paragraph 2.5. This test is to demonstrate that the cable does not propagate fire. The recombiner power cable was tested in accordance with this paragraph.

3-6. Test Material

The following is a description of the recombiner power cable which was tested:

4/c #8, 480-Volts Power Cable

Conductor	–	#8 AWG 7/0.0486 Nickel-Plated Copper
Insulation	–	Heat and radiation resistant polyimide tape, 8-mil wall covered with a glass braid saturated with a heat-and radiation-resistant varnish. Conductor coded by colored tracers in the glass braid. Conductors cabled with glass filters.
Jacket	–	Extruded heat-and radiation-resistant silicone rubber, 60-mil wall. A glass braid saturated with varnish is applied over silicone rubber.

Cable OD ---------- 0.590 inch (nominal)

Cable weight ---------- 329 lb/M' (nominal)

11408-2

Figure 3.5. Heater t ıe – °F

TABLE 3-1

HEATER TEST WITH ELEMENTS DISCONNECTED

b,c

TABLE 3-2

HEATER TEST RESERVE CAPACITY

b,c

The test material came from Westinghouse Sturtevant Division and was a part of a 1,000 ft. cable order.

Manufacturer: BOSTON INSULATED WIRE AND CABLE COMPANY
Boston, Massachusetts

Rated for 480 Vac. 60 Hz at 45 amps in 400°F ambient.

The installation of the cable utilizes ring-type metal lugs crimped onto each conductor.

3-7. Test Procedure for Post-LOCA Environmental Tests (Paragraph 2.4 of IEEE 383)

The testing was performed at the Atomic Power Department, Westinghouse Canada Limited, Hamilton, Ontario. The cable received from Westinghouse Sturtevant Division was cut into two test samples, each approximately 12 feet long. One sample was subjected to the following thermal aging.

- Form cable into a coil and place in air oven at [ ] b,c
  This simulates 40 years of normal life as determined from figure 4-2-3 of WCAP-8587 "Environmental Qualification of Westinghouse NSSS Class 1E Equipment."

- Following this, the aged cable sample and the unaged were coiled around a 14-inch-diameter metal mandrel and subjected to the following gamma irradiation.

  Total Dose ---------------------- 2.2×10^8 rad
  Dose Rate ---------------------- Average 1.86×10^5 rad/hour

The irradiation was conducted in the McMasters University Hot Cell located in Hamilton, Ontario. Since the cable is located inside the recombiner, the cable is shielded to some extent; however, no credit is taken for this in setting the dose rate at 2.2×10^8 rads.

3-8. Steam and Spray Testing

Upon completion of the irradiation, the cable samples (aged and unaged) were placed in a pressure vessel as shown on figure 3-6. This vessel was connected to a steam and air supply. The spray system was a part of the test facility. The cable was supported on a metal mandrel grounded to the vessel. Electrical power penetrations in the vessel wall were used to supply the power to the test cables. The two test cables were connected in series so that both cables

b,c

Figure 3.6 Test Setup for Steam Exposure

were subjected to voltage and current. The power to the cables come from the recombiner power supply and the electrical load was the recombiner. The 29 kw heater bank, which is the largest load on the cables, was attached to the cables and the power supply was energized to full power throughout the test.

For the shakedown test, the power to the cables was turned on to full power. The steam to the vessel was then rapidly injected to 106 psia. This pressure was then held for 26 minutes and then reduced to 66 psia. After 2 hours and 35 minutes, the spray system was started and operated for 15 minutes with the vessel pressure at 64.7 psia. The shakedown test was completed and the facility was shut down. The long-term pressure test was then begun. This consisted of rapid pressurization of the vessel to 106 psia (322°F) with full power on the cable (29 kw). The spray which contained 2,000 ppm boron as boric acid buffered with Na OH to a pH of 10.5, was turned on 2 minutes after the pressurization. After 15 minutes, the peak pressure was reduced to 85 psia (312°F) with the spray on. This pressure was held for 15 minutes. At this time, the pressure was reduced to 45 psia (227°F) with spray on and held for 1 hour and 27 minutes. At this time, each cable was checked electrically to verify that it was still properly energized. After 2 hours and 8 minutes, the pressure was reduced to 30 psia (257°F) with spray on. This pressure was held for 20 hours. The spray was on for 6 hours 10 minutes. (Since the spray cannot impinge on the cables inside the recombiner, the use of spray in the test is somewhat more severe than the real situation). The pressure was then reduced to 20 psia (160°F) and continued for 5 days. At this time, the pressure was raised to 25 psia, (195°F) for 10 days. The pressure was then reduced to 20 psia (160°F) for a total test time of 33 days. The cables were energized at full power throughout the test. After this test, the cables were removed from the vessel and visually examined. Some discoloration of the glass overbraid which covers the silicone rubber cable jacket was evident.

3-9. Voltage Testing

Following the steam testing, the cable was removed from the coil and straightened. It was then recoiled around a 24 inch-diameter metal mandrel. The cable and mandrel were then immersed in tap water and a voltage of 640 Vac was applied to the conductors for 5 minutes. The cables (aged and unaged) successfully passed this test.

3-10. Flame Testing Per IEEE 383, Paragraph 2.5

The purpose of this test is to demonstrate that the cable does not propagate fire even if its outer covering and insulation have been destroyed in the area of flame impingement. IEEE 383-1974, Paragraph 2.5 describes a method for flame testing cables.

For this test, cable samples from a production run were subjected to the vertical tray test using a ribbon gas burner as described in section 2.4.4.1 of the IEEE 383 Standard.

Testing was performed at the Boston Insulated Wire Company test facility at Plymouth, Massachusetts. The test procedure described in sections 2.5.4.4.2, 2.5.4.4.3, and 2.5.4.4.4 was used and the acceptance criteria as described in 2.5.5 was the basis for acceptance. The cable was tested and met the criteria in section 2.5.5.

3-11. HIGH TEMPERATURE ENVIRONMENTAL TESTS OF POWER SUPPLY AND CONTROL PANEL

The purpose of this test was to demonstrate that the power supply and control panel will not be adversely affected by operation in an elevated temperature environment. The power supply and control panel are located external to the containment and are accessible after a LOCA. For plants located in extremely warm climates, some areas otherwise suitable for power supply and control panel installation, may have short-term maximum post-LOCA temperatures higher than the normal NEMA Standard (40°C). To broaden the number of plant areas suitable for power supply and control panel installation, the power supply was tested at 135°F, and the control panel at 155°F for 10 days. These tests show that, short-term, high temperature exposure does not adversely affect these components.

3-12. Test Method

To form a high-temperature environment around the power supply and control panel, enclosures as shown on figure 3-7 were constructed. The heat losses from the power supply isolation transformer supplied sufficient heat to heat its enclosure to the desired temperature. The control panel enclosure was heated by a space heater which was thermostatically controlled. The power supply was connected to a production recombiner which served as the electrical load and also with the control panel. The test was conducted for ten days (240 hours) with no detectable adverse affect on either the power supply or control panel.

3-13. COLD REFERENCE JUNCTION BOX FOR RECOMBINER THERMOCOUPLES

The recombiner uses three chromel-alumel thermocouples to measure recombiner operating temperature. Since the recombiner is located inside the containment and the temperature readout instrument is located on the control panel located outside the containment, it is necessary to either provide chromel-alumel containment instrument wire penetrations or use a cold reference junction box located inside the containment. In some instances, containment design, including penetration design is complete before the recombiner installation design is complete so there are no chromel-alumel containment penetrations (usually copper penetrations are available).

b,c

Figure 3-7. Power Supply Test

To alleviate this problem, a simple cold reference junction box has been designed and tested which is compatible with the Honeywell Dialatrol temperature indicator which is supplied with the recombiner control panel.

Figure 3-8 shows schematically the installation of the junction box. Chromel-alumel leads are run from the recombiner to the junction box which can be located near the containment penetrations. Copper leads are then run through the penetrations to the control panel. The compensator in the junction box is connected to the indicator with copper leads. The compensator is a temperature-sensitive, wire-wound resistor encapsulated in a ceramic type material. The compensator was irradiated to 2×10^8 rad, then placed in a steam environment at 300°F while energized. No measurable degradation in resistor output was detected. The junction box and hardware containing the compensator and terminals is the same make as previously tested with the recombiner in steam and pressure; therefore, it has been previously qualified for in-containment usage.

3-14. AUTOMATIC TEMPERATURE CONTROL

The temperature of the recombiner is determined by the input power level to the recombiner. The normal recombiner operating procedure calls for a manual setting of this power level in accordance with Technical Manual instructions. If it is desirable to control the power level by a feedback signal from the recombiner thermocouples, a circuit has been developed to accomplish this.

All circuit modifications are made in the control panel. The major changes in design are the addition of a printed circuit card to the Temperature Indicator to add the control feature and addition of a switch to the Control Panel to enable switching from manual to automatic temperature control. Wiring modifications within the Control Panel are made, however the Control Panel interface with the power supply is not changed.

11908-5

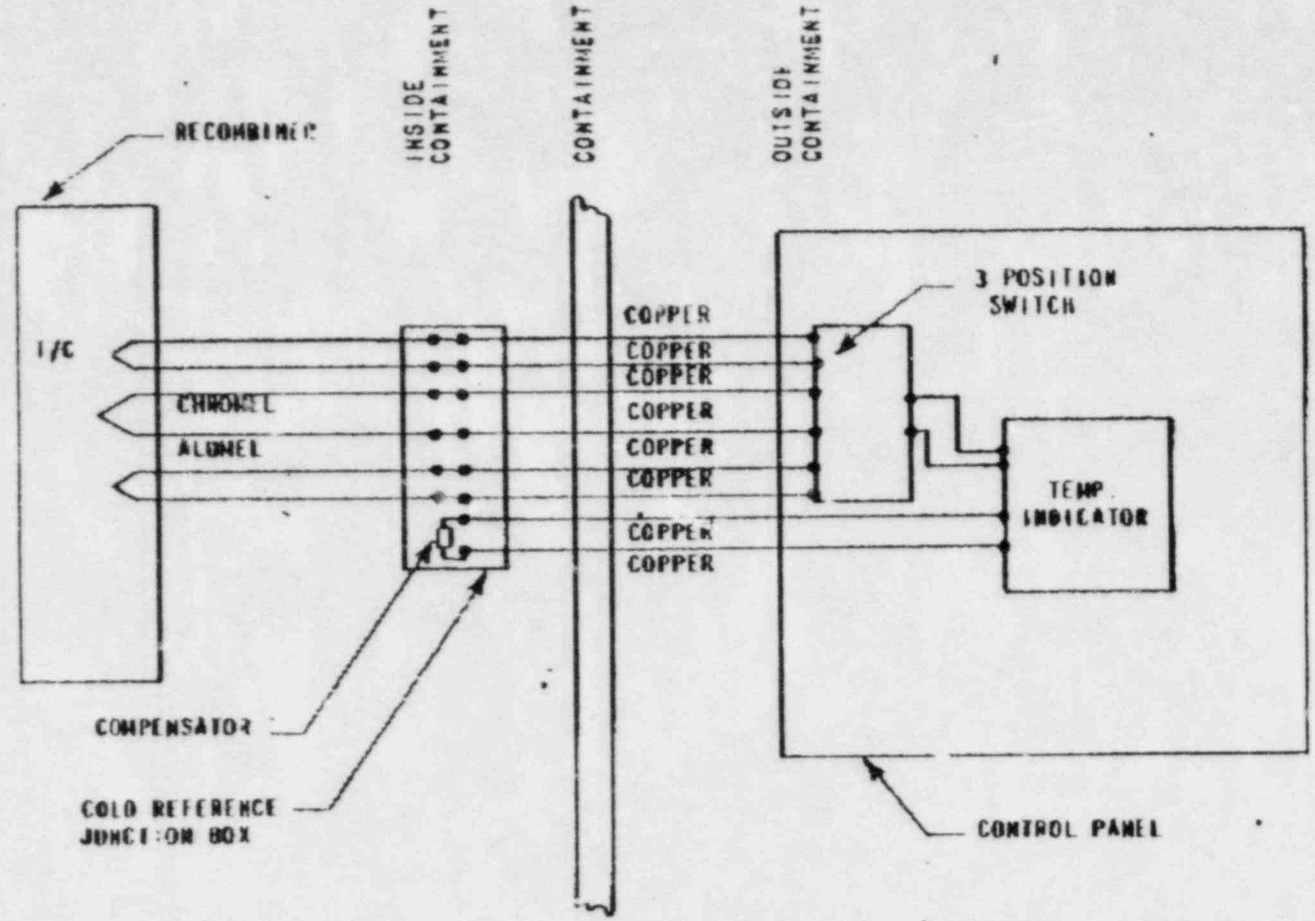

Figure 3.8. Cold Reference Junction Box Circuit Schematic

WCAP-7820
Supplement 2

ELECTRIC HYDROGEN RECOMBINER
FOR PWR CONTAINMENTS
EQUIPMENT QUALIFICATION REPORT

Energy Systems

NES Class 3

WCAP-7820
Supplement 2

ELECTRIC HYDROGEN RECOMBINER
FOR PWR CONTAINMENTS
EQUIPMENT QUALIFICATION REPORT

J. F. Wilson

October 1973

APPROVED: Romano Salvatori
R. Salvatori, Manager
Nuclear Safety

Work Sponsored by Nuclear Service Department

WESTINGHOUSE ELECTRIC CORPORATION
Nuclear Energy Systems
P. O. Box 355
Pittsburgh, Pennsylvania 15230

Material that is proprietary to the Westinghouse Electric Corporation has been deleted from this document where marked by means of brackets. The basis for marking the material proprietary is identified by marginal notes referring to the standards in Section 8 of the affidavit of R. A. Wiesemann of record "In the Matter of Acceptance Criteria for Emergency Core Cooling Systems for Light Water Cooled Nuclear Power Reactors (Docket No. RM-50-1)" at transcript pages 3706 through 3710 (February 24, 1972).

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SECTION 1

INTRODUCTION

The Westinghouse Electric Corporation has developed an electric hydrogen recombiner for installation inside reactor containments for use following a postulated loss-of-coolant accident where such equipment is needed to meet the requirements of AEC Safety Guide 7. This recombiner has no moving parts and does not require any piping, valves, pumps or systems which otherwise would be required if the recombiner were installed outside the containment. Also, it uses electric resistance heaters to heat a natural convection flow of containment atmosphere to a temperature above that required for the hydrogen-oxygen reaction, thereby causing the hydrogen to combine with the oxygen in the air which is being processed by the recombiner.

The development program for the electric recombiner has involved extensive testing on both a production unit recombiner and on a prototype recombiner. Two previous reports have been issued which describe the initial development plus the testing performed on the prototype recombiner.[1,2]

This report supplements these earlier reports and describes the subsequent extensive testing performed on a production unit recombiner with its associated power supply and control equipment. These tests show that the electric hydrogen recombiner will satisfactorily perform all its intended functions.

SECTION 2

SUMMARY

Extensive tests have been performed on a production unit electric recombiner system to confirm that the production equipment will perform satisfactorily. These tests are in addition to and supplement the tests on the prototype recombiner which were reported in WCAP-7820, Supplement 1.

A description of the production electric recombiner is given in Appendix A of this report; this recombiner is essentially the same as the prototype except for some minor design changes developed during the course of the development of this program.

The tests performed and described herein show that the production electric hydrogen recombiner is fully adequate for normal service and post-LOCA conditions. These tests and results obtained on the production recombiner and its associated equipment can be summarized as follows:

a. Air flow tests have confirmed that the air flow through the recombiner is well in excess of the specified 100 scfm flow.

b. Temperature tests have confirmed that the recombination temperature is reached using only about two-thirds of the power available from the system.

c. Heatup and cooldown thermal cycle tests (80 cycles) have confirmed the capability of the recombiner and its heaters to withstand well in excess of the number of such cycles expected during the life of a recombiner.

d. LOCA environment tests with simulated containment steam pressure (up to 77 psia) and thermal transients have confirmed the capability of the recombiner equipment including the recombiner heaters, electrical wiring, and thermocouple system to perform satisfactorily under these accident conditions.

e. To estimate the amount of reserve life present in the recombiner system, the equipment tested under (d) was subjected to a series of tests designed to produce failure. These tests consisted of a series of applications of the post-LOCA steam pressure and spray transient in the steam chamber. The heaters, electrical system and thermocouple system were energized repeatedly. After six post-LOCA pressure transients, no functional failure was produced so testing was discontinued. The heater banks were completely disassembled and tested. All heaters still functioned properly (heated up); however, 11 of the 240 individual heaters showed nondisabling sheath damage at the cold end. Further steam chamber tests were then performed on another group of heater banks which confirmed that at least four post-LOCA pressure transients are required to initiate this type of nondisabling damage.

f. Irradiation tests up to 2×10^{8} rads on all pertinent equipment, including all the electrical components of the recombiner, have confirmed the capability of the recombiner to withstand and perform satisfactorily after exposure to such radiation levels.

g. Seismic tests up to 2g acceleration using the sine beat method described in IEEE-344[3] confirm the capability of the equipment to withstand all anticipated seismic conditions. These tests together with additional calculations, if any, can be used to qualify recombiners for individual plant sites with specific seismic requirements.

h. Electric ground fault tests have confirmed the capability of the recombiner to function with no impairment of its operation if a single short circuit to ground occurs within any of the heaters. In addition, because of the excess heater capacity provided, an open circuit in any of these heaters would have essentially no effect on the recombiner performance.

The conclusion from the above summarized tests is that the production recombiner with its associated equipment has been demonstrated to be qualified for the intended service conditions. As a final step, long-term recombiner operation tests are also planned to be performed.

SECTION 3

TEST PROGRAM AND RESULTS

Production unit equipment of the Westinghouse electric recombiner system has been subjected to air flow, temperature distribution, thermal cycle, seismic, containment environment, steam pressure chamber, and electrical ground fault tests. These are described in this section.

3.1 AIR FLOW TEST AND TEMPERATURE DISTRIBUTION TESTS

These two tests were run on production recombiners to demonstrate that the orifice configuration which controls air flow through the recombiner was correct and permitted a minimum of 100 scfm air flow and also that the temperatures in the recombiner reached 1150°F.

3.1.1 Air Flow Tests

For these tests a special air flow duct, which fits over the inlet of the recombiner, was constructed. This duct, as installed on the recombiner, is shown in Figure 3-1. [

(a,c)

] These test data are shown in Figure 3-2. Air flow measurements from production units 8 and 9 are also shown.

CLASS 3
6106-14

(a,c)

[ ]

Figure 3-1 Electric Recombiner Air Flow Test

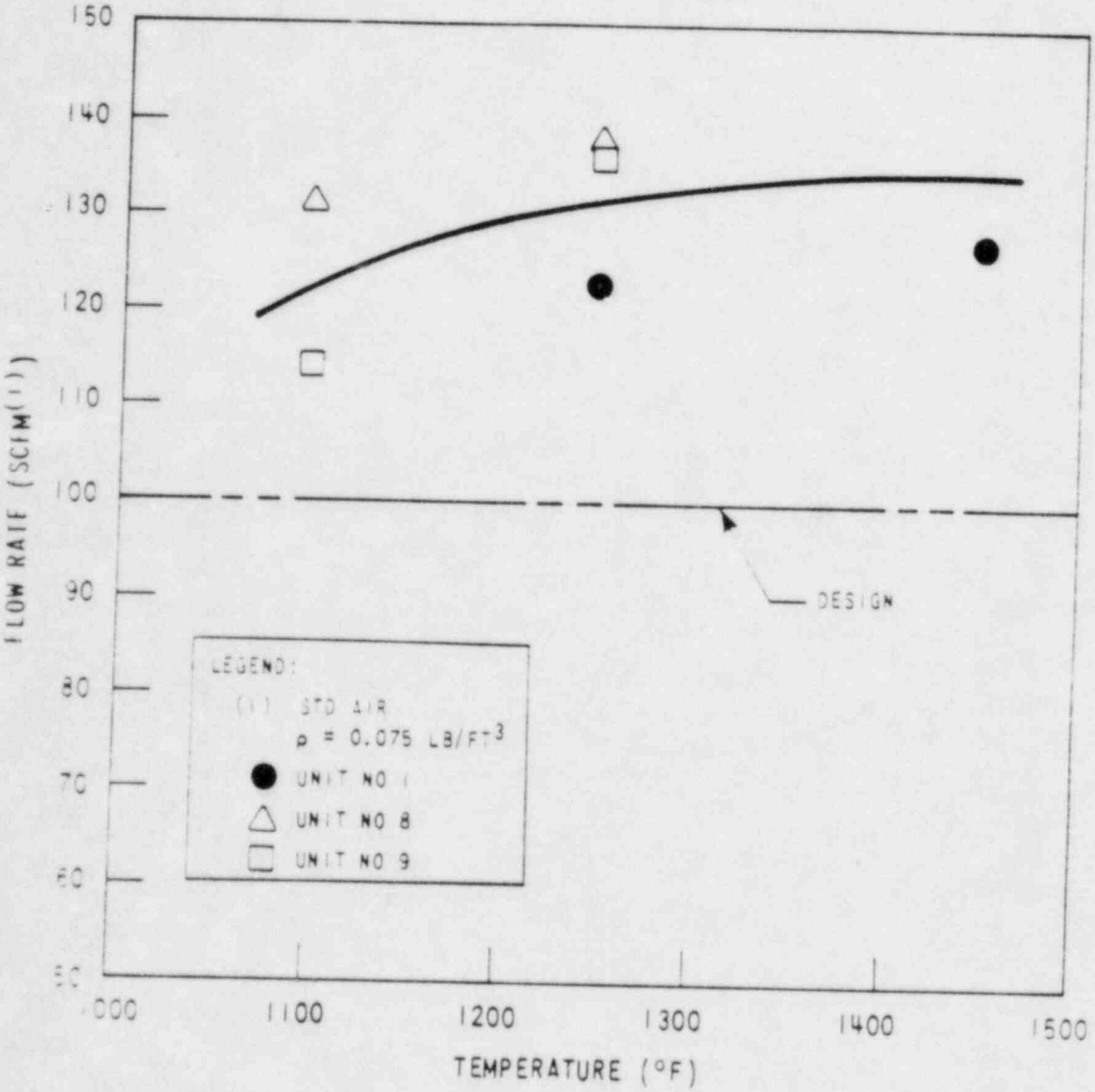


Figure 3-2 Recombiner Flow Rate

3.1.2 Temperature Tests

Two types of temperature measurements were made on production recombiners. The first type shows the recombiner heater temperature as a function of time, and the second shows the temperatures at various parts of the recombiner when the heaters are at recombination temperatures (operating temperature).

The first type of measurements was made by energizing the system at slightly under two-thirds of full power (48 kW) and measuring heater sheath temperature at various periods of time. The 48 kW value was based on the operating power requirements outlined in WCAP 7709-L Supplement 1, pp. 4-12. The temperatures achieved on the heaters for five production recombiners are shown on Figure 3-3. This shows recombination temperature is reached in approximately two hours at this power setting. It should be noted that 75-kW capability is provided in the recombiner to provide good operational flexibility to cope with off-design conditions.

For the second type of measurements, a portable thermocouple was connected to the readout instrument and positioned at the points shown in Figure 3-4. During these measurements, the recombiner was at recombination temperature. These data show that the recombiner exhaust temperature is quite low, which means good mixing of the exhaust air with cooling air is achieved.

3.2 NORMAL SERVICE LIFE THERMAL CYCLE TESTS

The normal service life of the recombiner system will require periodic in-plant heatup tests to demonstrate availability. This heatup and cooldown cycling produces thermal stresses in the heater frame and support structure. To prove the recombiner can sustain this repeated cycling, the first production recombiner was subjected to 80 heatup and cooldown cycles to simulate this repeated heatup and cooldown. (In a normal 40-year life, 40 annual heatup cycles are anticipated.) After the test, the recombiner was thoroughly inspected for damage. No damage was found. The heaters were removed and inspected. Again no damage was found.

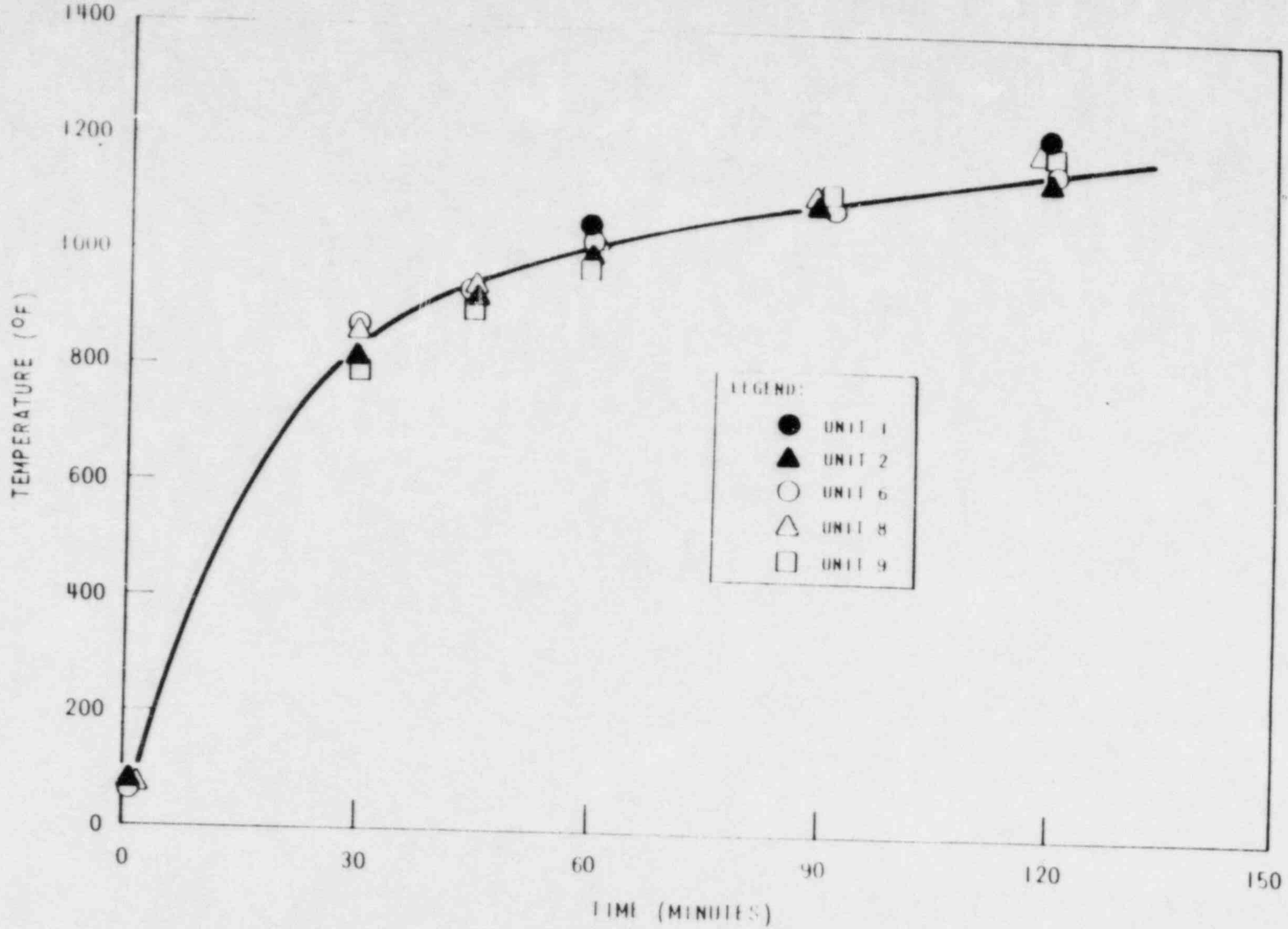


Figure 3-3. Recombiner Temperatures 64% of Full Power (48 kW)

6105-12

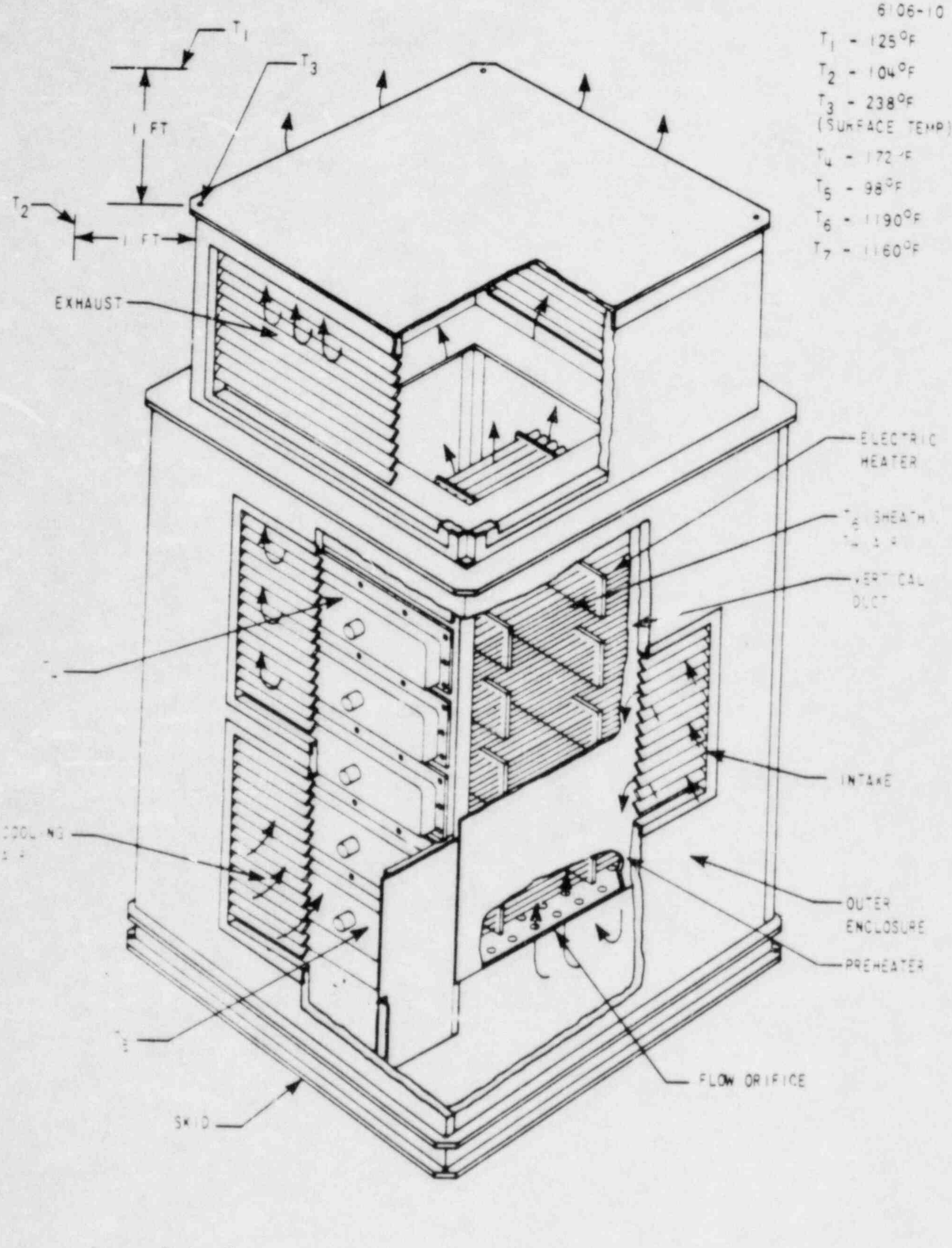


Figure 3-4 Temperatures Around Recombiner During Operation

3.3 SEISMIC TESTS

Westinghouse has established the following seismic criteria for the Electric Recombiner System:

For either the Design Basis Earthquake (DBE) or the Operational Basis Earthquake (OBE) the equipment will be designed to ensure that it does not lose its capability to perform its functions, i.e., recombine hydrogen with the oxygen in the air. However, for the DBE, there may be permanent deformation provided that capability to perform its function is maintained. The recombiner will be subjected to tests under simulated seismic accelerations to demonstrate its ability to perform its functions.

Since the electric recombiner control panel and power supply cannot be readily analyzed to demonstrate seismic capability, vibration testing was chosen as the method for verifying the performance of the equipment under earthquake conditions. The recombiner itself was vibration-tested to verify and supplement the calculations.

This section describes the seismic testing of the prototype recombiner, power supply, and control panel. Included is a description of the equipment tested, the test procedure used, and results of the tests. Seismic testing of the Production Recombiner is described in paragraph 3.3.4.

[illegible] Equipment Tested

The Electric Recombiner System consists of the following three basic components:

1. The recombiner, which is located in the reactor containment building.
2. The power supply, which is located in an auxiliary building.
3. The control panel, which is located in either the auxiliary building or the reactor control room.

A description of each component follows:

- Recombiner

  The design of the electric recombiner is shown in Figure 3-4. It consists of a vertical metal duct which houses five banks of electric heaters. Surrounding this duct is a thermally insulated enclosure. A top for the enclosure is provided and inlet and outlet flow louvers are provided as shown. The entire recombiner is fastened to a skid, which is then fastened to the reactor containment structure.

  Typical startup time after a major LOCA is 24 hours; therefore, the unit does not need to operate immediately after the incident.

- Power Supply

  This cabinet, shown in Figure 3-5, is located in the plant auxiliary building and supplies power to the recombiner. It consists basically of a 75-kW, 3-phase transformer, a silicon-controlled rectifier, and control circuitry. The purpose of this equipment is to convert from 3-phase delta input power to 3-phase, 4-wire wye output and to control output power level.

- Control Panel

  This panel, shown in Figure 3-6, is used to control the power supply and to read out temperatures from the three test thermocouples located in the recombiner. Instruments mounted on this panel include a power meter, thermocouple readout, potentiometer, off-on switch, and power available light.

3.3.2 Test Procedures

- Power Supply and Control Panel

  The power supply and control cabinet were tested at the same time at the Westinghouse Astronuclear Laboratory located at Large, Pennsylvania. The equipment was vibrated in three planes, i.e., vertical, horizontal front-to-back, and horizontal side-to-side. Figure 3-7 shows the equipment mounted on the test table.

6106-11

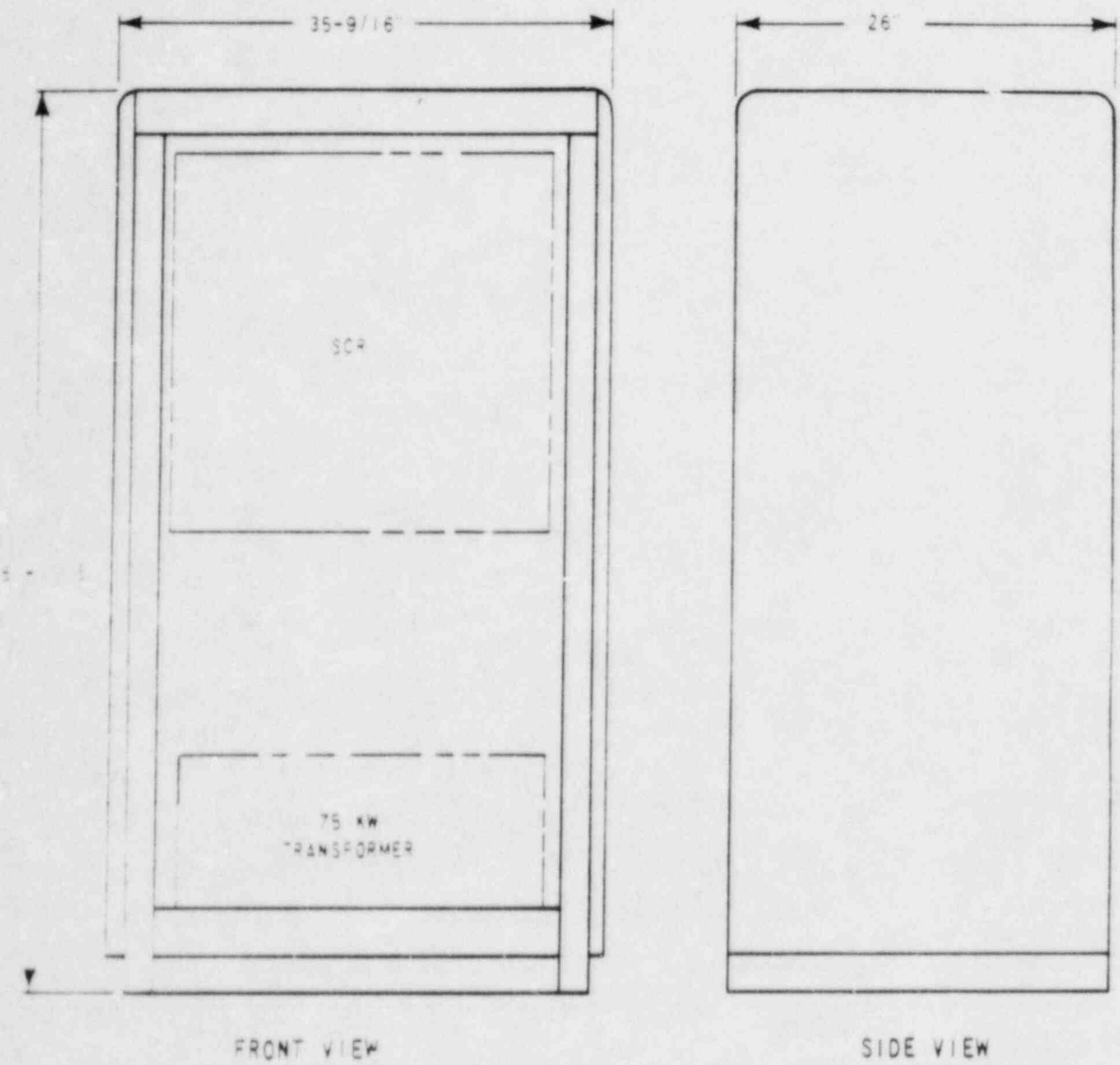


Figure 3-5 Power Supply

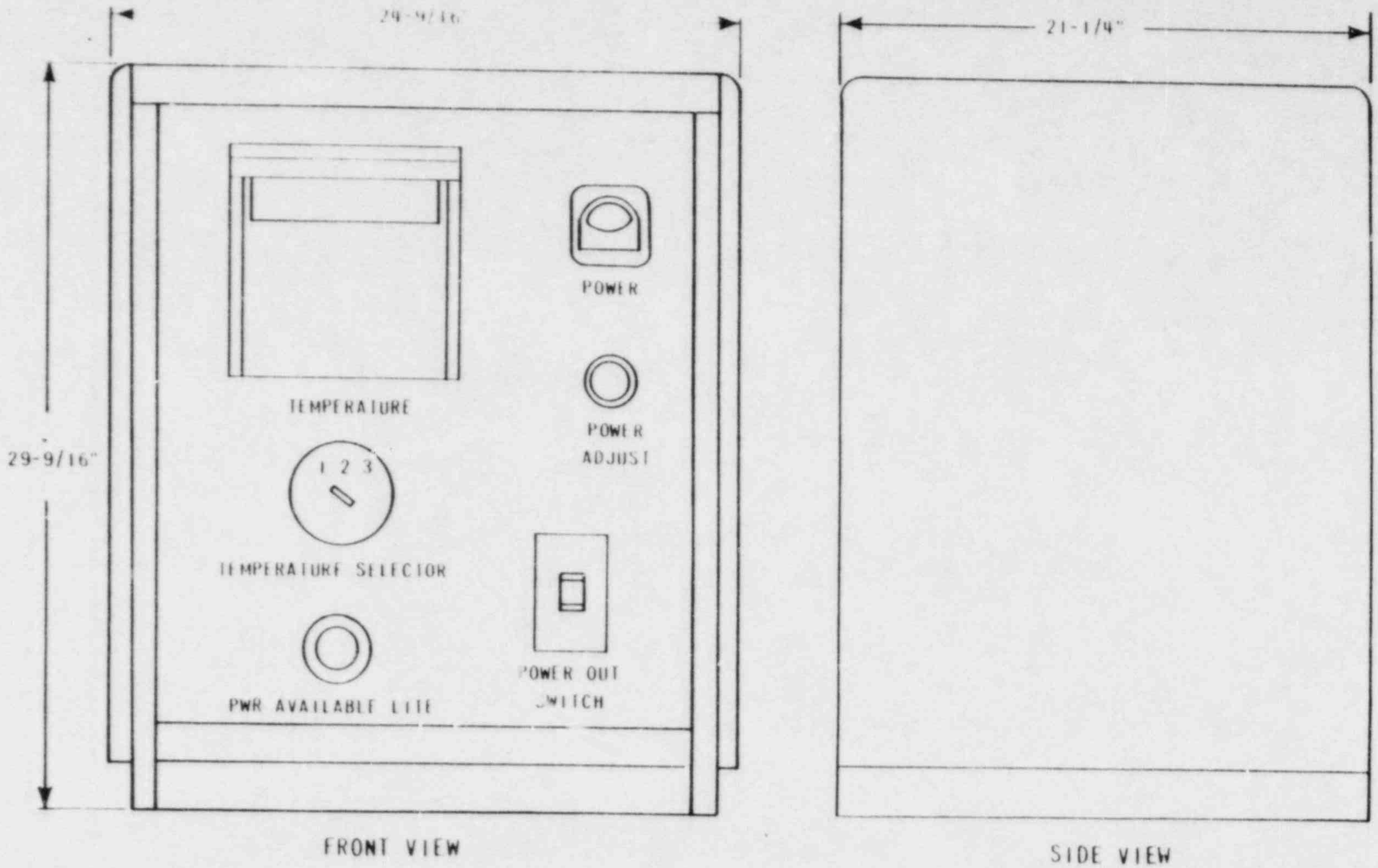


Figure 3-6. Control Panel

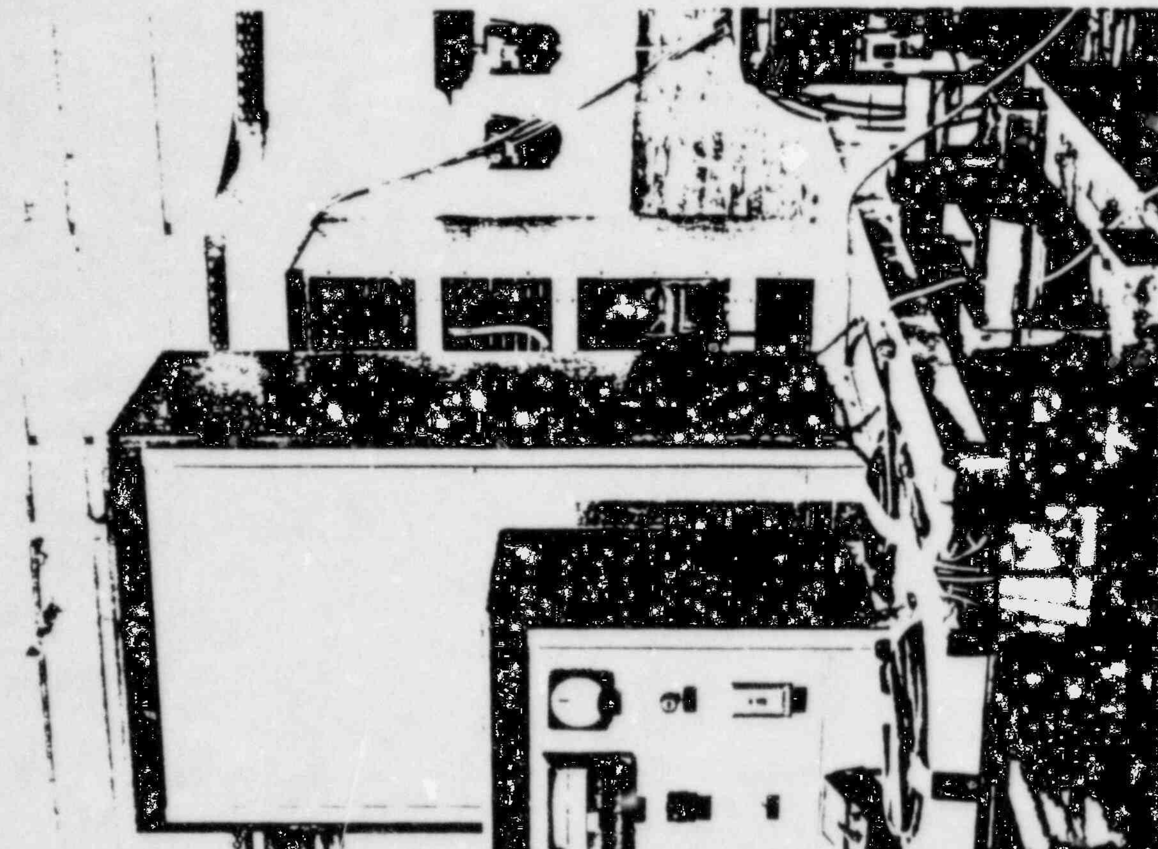


Figure 3-7. Power Supply and Control Panel on Shaker Table

- Vibration Input

  The vibration input to the base of the equipment being tested consisted of a sine beat type vibration as shown in Figure 3-8. Each sine beat consists of 10 cycles at the test frequency with the acceleration of "g" level increasing from zero to the specified maximum and returning to zero in a sine wave fashion. Five consecutive beats were applied at each test frequency, with an allowed maximum of two seconds between each beat. Figures 3-9 and 3-10 show the maximum applied horizontal acceleration level of the sine beat as a function of test frequency. These accelerations levels are expected to be much higher than the accelerations that would be produced by the DBE in any plant location where this equipment might be located. These high values were chosen to preclude the need for future seismic testing if the equipment should be purchased for some plant location with very high seismic requirements.

  The sine beat tests were performed at resonant frequencies determined by a frequency search test from 1 to 35 Hz plus the following frequencies listed in the following procedure.

(a,b,c)

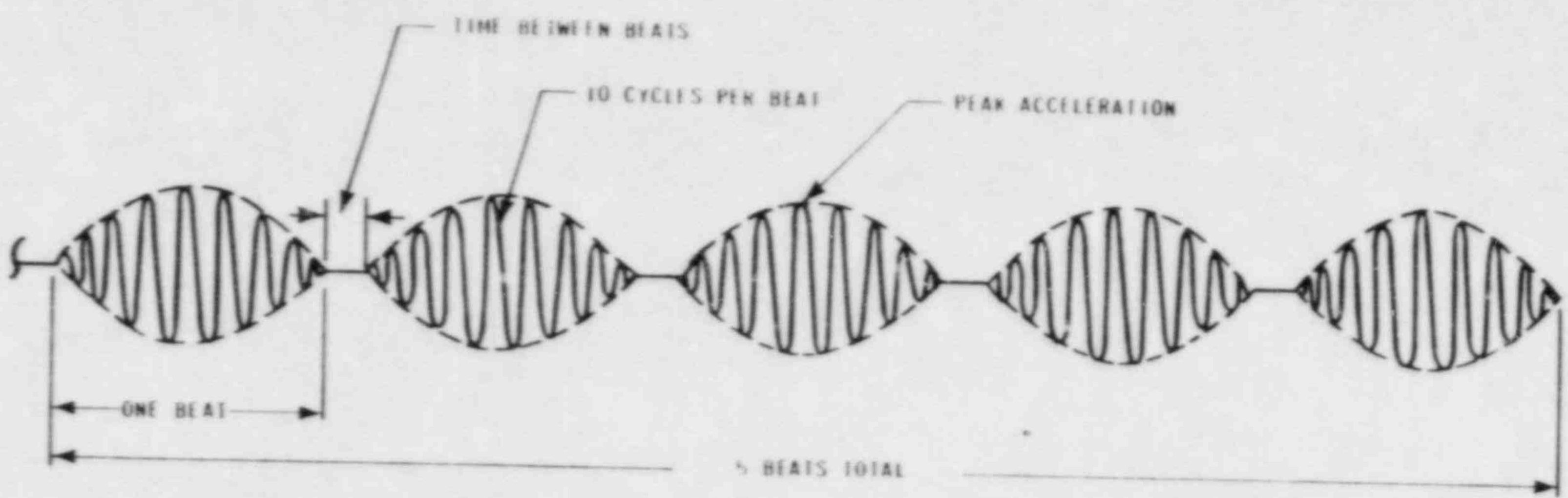


Figure 3-8 Sine Beat Input for Testing

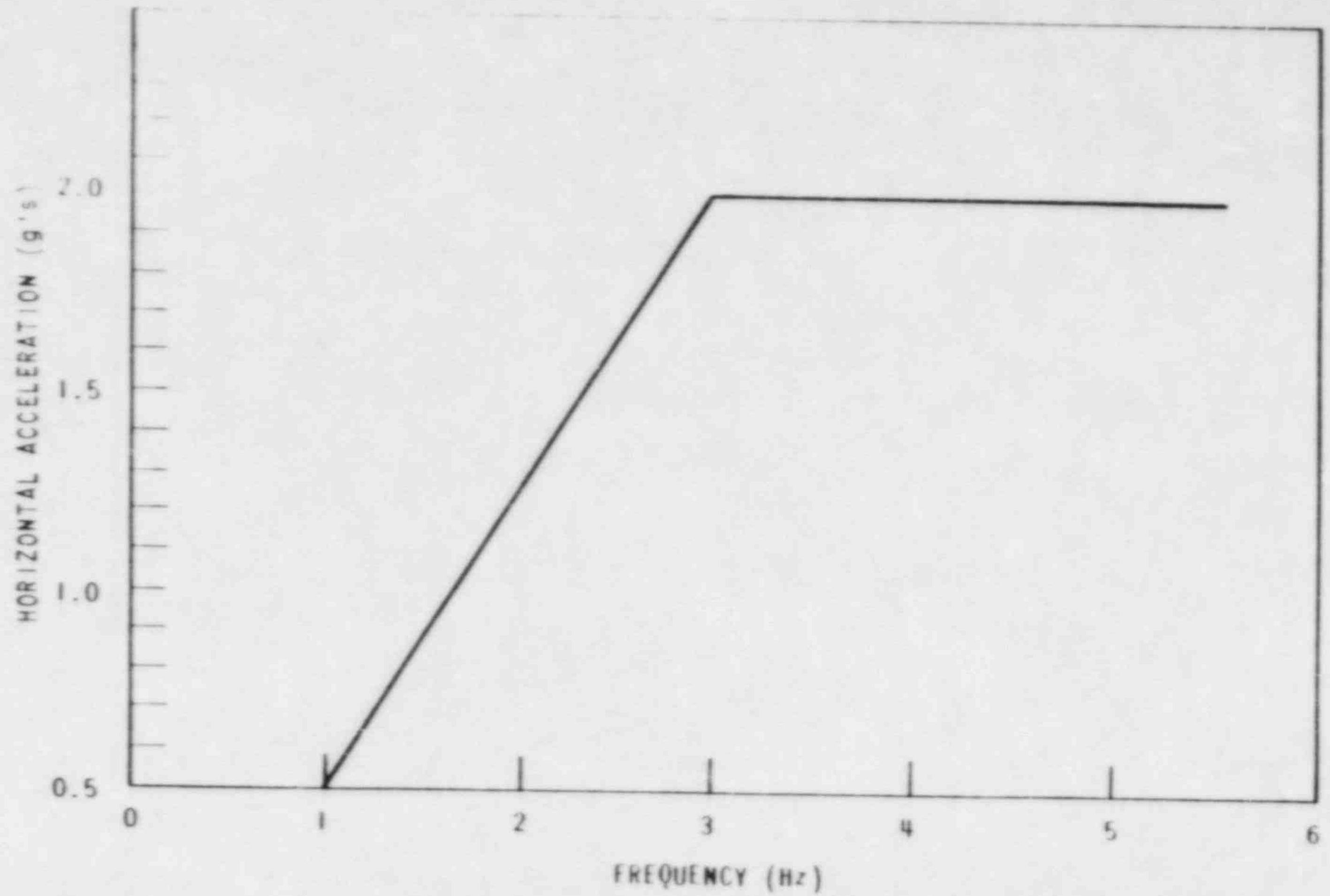
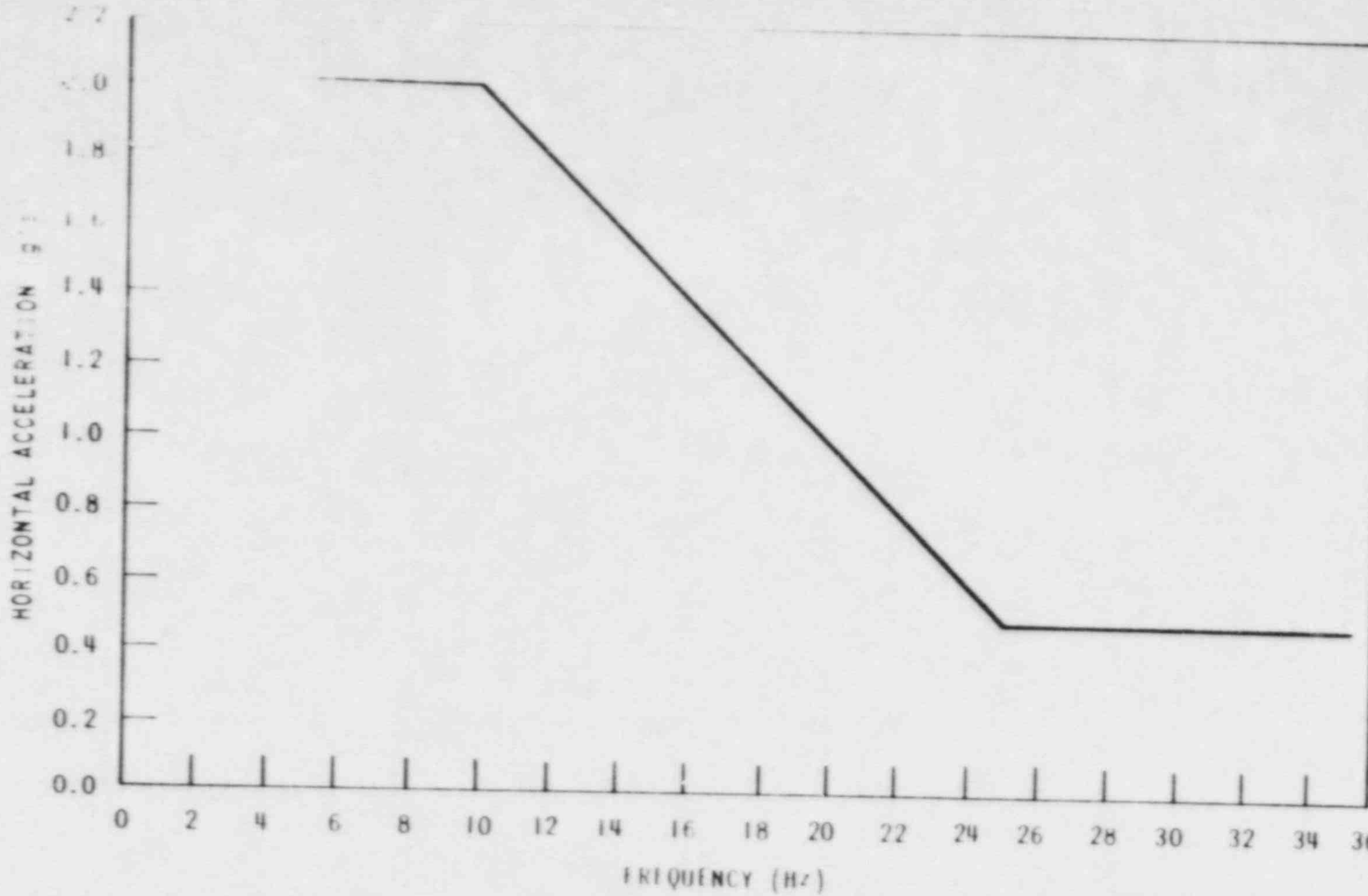


Figure 3-9 Acceleration versus Frequency

6104-8


HORIZONTAL ACCELERATION
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.8
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
FREQUENCY (Hz)

6106-7

3.3.3 Vibration Test Results

After each test (i.e., vertical, horizontal side-to-side, and horizontal front-to-back) the equipment was visually inspected for mechanical damage, loose connections, and overall appearance. The electrical functions were checked after all the tests were completed. The specific tests performed are described below.

- Control Panel

  Immediately after the test a millivolt input signal was imposed on the thermocouple readout instrument. It showed the instrument was in operating condition. A microamp signal was then imposed on the power meter and it was demonstrated to be in operating condition. (The power meter is actually a microammeter which measures the current output from a transducer circuit in the SCR.) Following these checks, the equipment was returned to Westinghouse Forest Hills Laboratory where it was tested in conjunction with the power supply and recombiner and found to be in operating condition.

- Power Supply

  After the vibration test, a test voltage was applied to the input terminals of the power supply and the output was monitored. The equipment was found to be in operating condition. Following this, the power supply was sent to the Westinghouse Forest Hills Laboratory and tested with the control panel and recombiner. Again it was found to operata satisfactorily.

- Recombiner

  During the horizontal side-to-side test it became apparent that addition of braces at the corners of the exhaust louvers would greatly strengthen the unit, therefore, these braces were added and the horizontal side-to-side test was repeated. The horizontal back-to-front test was then run. (It should be noted that the acceleration levels specified in Figures 3-9 and 3-10 were exceeded in these tests to determine the margin in the design.) Immediately after testing, the recombiner was visually inspected for mechanical deterioration and was checked electrically by measuring the

resistance between the input terminals and earth ground. The recombiner was in satisfactory operational condition. Following this, the equipment was returned to Forest Hills Laboratory and disassembled to permit inspection of the entire machine. The heaters were individually tested.

Inspection revealed no disabling damage to the recombiner from the seismic test. Some thermal insulation which was attached to the heater frame by wire fasteners became loose.

(In the production models this insulation is canned in stainless steel to preclude this possibility.)

The insulation cover sheet underneath on the top plate of the recombiner had vibrated loose. (In the production model, the attachment bolts have been increased from 3/8-inch diameter to 3/4-inch diameter and a one-inch diameter pipe mounting has been added for additional lateral restraint.)

No damage to the recombiner structure or wiring was noted. All heaters were tested and found to be in good operating condition.

3.3.4 Seismic Testing of Production Recombiner

The first production recombiner was subjected to the sine beat vibration test to demonstrate the seismic adequacy of the production recombiners. (Braces similar to those added to the prototype were incorporated in the design (paragraph 3.3.3). The resonance frequency test was performed and the recombiner was then vibrated in the two horizontal planes (front-to-back and side-to-side) at resonant frequencies plus predetermined intermediate frequencies. Acceleration levels were those shown in Figures 3-9 and 3-10. The vertical test was then performed which was the same as the horizontal except the acceleration levels were 2/3 the value shown on Figures 3-9 and 3-10. Following the seismic test the recombiner was examined and showed no signs of electrical or mechanical damage. It was then operated at recombination temperature and the air flow through the unit was measured. Both these checks showed no damage to the recombiner.

3.3.5 Seismic Testing of Production Power Supply and Control Panel

The production power supply and control panel were subjected to the same test as the production recombiner. At the end of the test it was connected to the production recombiner and run at full power. One deficiency was noted in the power-measuring circuit. A small instrument transformer broke loose from its mounting resulting in malfunction of the measuring circuit. The instrument transformer mounting is being redesigned, and the power supply will be retested to qualify the fix. (It should be noted that the power supply is located outside the reactor containment and is available for servicing.)

[illegible]

The primary purpose of these tests was to demonstrate that the recombiner will function properly in a containment post-LOCA pressurized steam and [illegible] environment.

[illegible] purpose was to estimate the amount of reserve life left in the [illegible] system. (The equipment had been previously subjected to the full normal service life thermal cycle test.) Accordingly, the equipment was subjected to a series of post-LOCA pressure and spray transients. In actual service the recombiner would be subjected to only one post-LOCA pressure transient.

[illegible]

[illegible] consisted of a large pressure vessel, boiler and control [illegible] pressure vessel is approximately seven feet in diameter by [illegible] and is mounted so the vessel centerline is horizontal (see Figure 3-[illegible]). [illegible] are wrapped around the vessel to permit the shell to be warmed up [illegible] pressurization of the vessel. The boiler has sufficient pressure and [illegible] to pressurize the vessel to about 75 psig in 10 seconds. [illegible] vessel pressure. Suitable drains remove condensate [illegible] of the vessel. Millivolt digital readout and recording equipment is available and was used to record temperatures and pressures in the pressure vessel and in the test equipment.

3.4.2 Equipment Tested

To demonstrate that the recombiner will function in the pressurized steam environment, components which might be affected by rapid pressurization and by high pressure steam were tested. These components were:

1. Heaters with junction boxes.*
2. Electrical junction box.*
3. Thermocouples on heaters.*
4. Thermocouple junction box and interconnecting leads.*
5. Electrical cabling.*
6. Typical door panel.*
7. Louvers.*

To test the above equipment, a special heater frame was designed and built. The frame holds four heater banks (which includes their junction boxes and thermocouples). The electrical junction box and T/C box were attached to the side of the heater frame and the electrical cabling and T/C leads were installed in a manner similar to that of the production recombiner. The compartment around the heater junction boxes was made similar to the production model and a typical louver was installed. A door panel was also placed in the pressure vessel to verify its ability to withstand external pressure. The recombiner heater frame in the pressure vessel is shown in Figure 3-11 The data acquisition equipment is shown in Figure 3-12.

3.4.3 Test Program

The test program consisted of six test runs at pressures and temperatures that represent maximum anticipated post-LOCA containment conditions. A summary of these test runs is as follows:

Test No.	Purpose
1	Exploratory - After pressure cycle check for any physical damage to heaters and resistance to ground of leads during and after pressurization. Check out test facility.

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*These items previously had been subjected to 80-cycle normal service life thermal cycle test.

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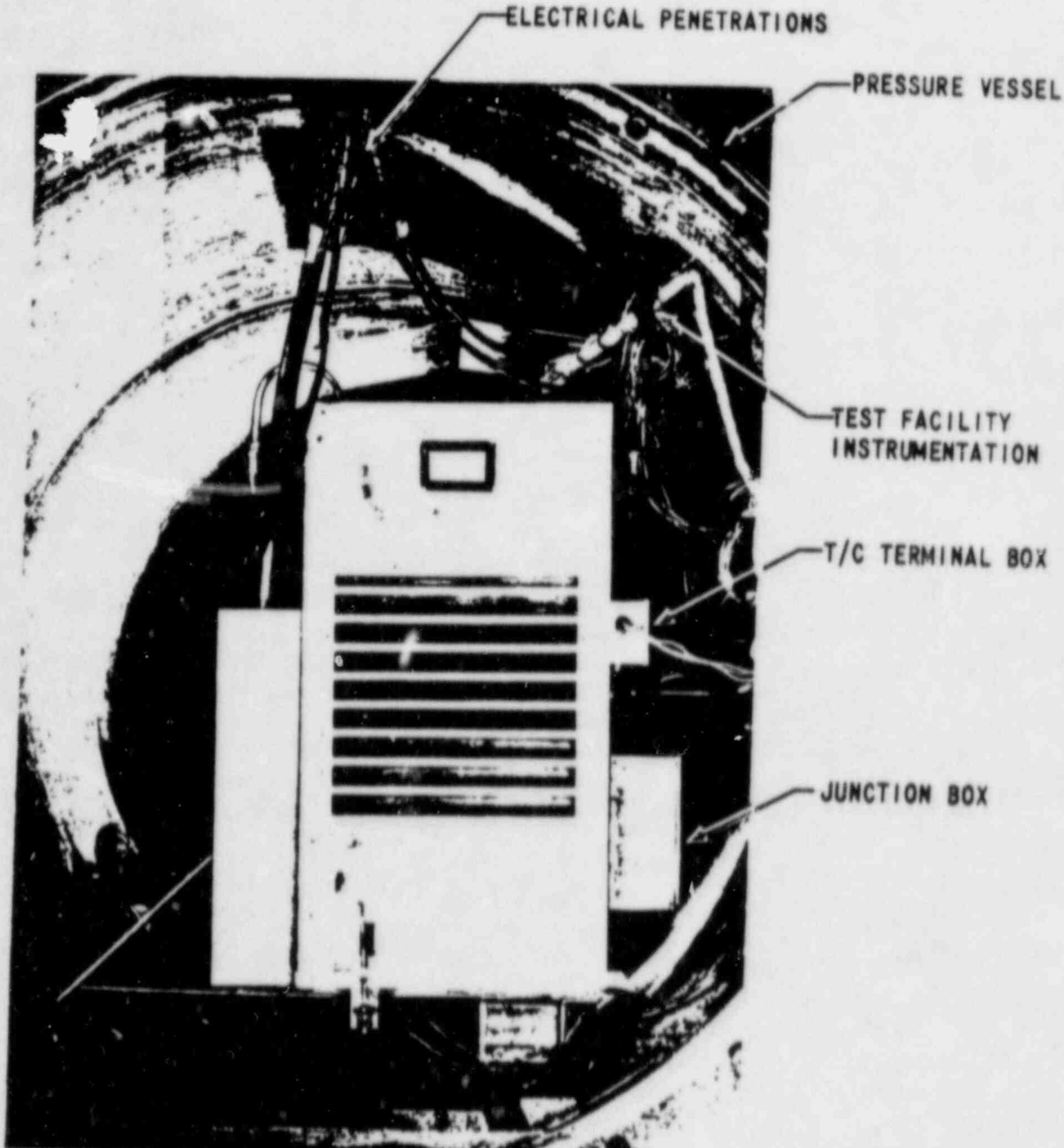

Figure 3-11. Heater Frame Test Assembly Installed in Pressure Chamber

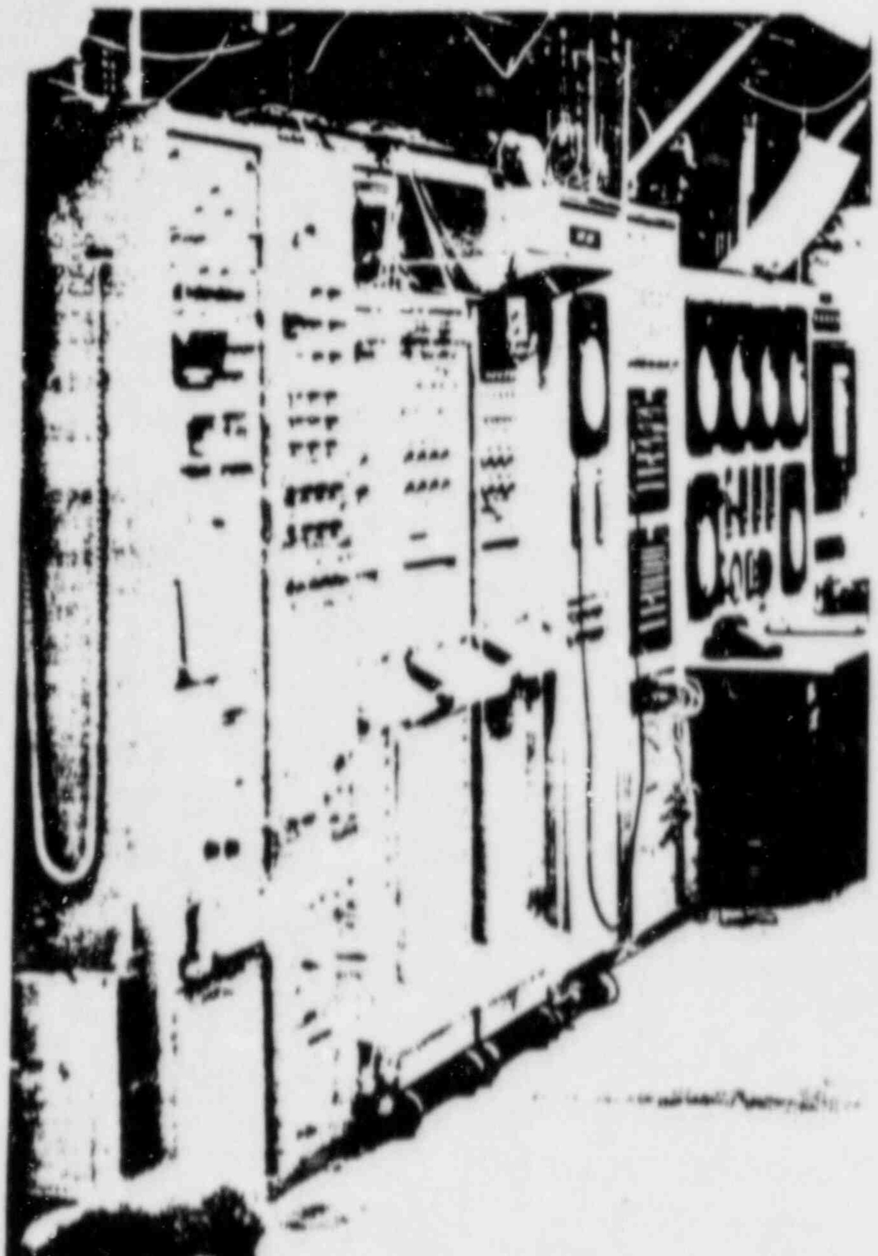

Figure 3-12. Data Aquisition Equipment

Test No.	Purpose
2	Test heaters by applying electrical power to heaters while they are in a high steam pressure environment (69 psia), moderate pressure (35 psia), and low pressure (20 psia) with containment spray added to the steam.
3.	Tests simulated containment environment transient by subjecting heaters to the 24-hour containment post-LOCA pressure transient and then applying power according to the proposed startup specification. Use containment sodium tetraborate spray with steam.
4	Retest simulated containment environment transient, but use sodium thiosulfate spray (1 w/o) instead of boric acid containment spray.
5	Repeat Test 4 with heater terminal boxes vented to dryer.
6	Heat the heater sheaths to 350°F to 400°F by applying power before the steam injection. Maintain power during and after steam injection.

A description of each test is as follows:

- Test No. 1

Prior to initiation of this test, the control panel, power supply and heaters were checked by energizing the system at approximately 5 kW for ten minutes. Thermocouples were checked for operability. The pressure chamber was then closed and chamber pressurization was initiated. The pressurization schedule was as follows:

(a,b,c)

• Test No. 2

Heater operation was tested by applying power to the heaters under steam pressure. Again the heaters and thermocouples of the system were checked out prior to chamber pressurization by applying 5 kW to the heaters. The T/C's were used to verify that they functioned. The pressurization and test procedures were as follows:

(a,b,c)

• Test No. 3

In this test the heaters were first connected to the power supply with the pressure vessel open. Forty kW electrical power was applied to the heaters for ten minutes. Thermocouple values were noted.

The heaters were then deenergized and the pressure vessel was closed. The following pressurization schedule was followed:

(a,b,c)

- Test No. 4.

Test No. 4 was identical to Test No. 3, with the following exceptions:

1. Sodium thiosulfate spray was substituted for the sodium tetraborate used in Test No. 3.
2. The maximum pressure achieved in the rapid pressurization phase was 77 psia in ten seconds.

- Test No. 5

This test was the same as Test No. 3 except that the heater junction boxes were vented to a mesh-filled container. There appeared to be no advantage in this vent scheme so it was removed.

• Test No. 6

This test was run to demonstrate that the recombiner will function properly if a LOCA occurs when the recombiner is electrically energized. The following schedule was followed:

(a,b,c)

3.4.4 Test Results

The following test results were obtained:

1. Each test was successfully completed and all test objectives were attained.

2. Inspection after each test for electrical damage revealed no damage to any of the equipment. This inspection included ground fault checks, continuity checks, and resistance checks on each heater. Physical inspection of the system, including junction boxes, electrical cabling, and electrical junction boxes showed no malfunctions. The door panel and louvers were also inspected periodically and showed no damage.

3. After the test series was complete, the heater banks were removed from the test frame. Each heater element was tested in each heater bank by applying power and noting that each element heated (an element is one U-shaped heater). All elements heated up. The electrical cabling was inspected, along with the T/C's and electrical and T/C junction boxes. No damage was found.

The heater banks were then completely disassembled. Visual inspection of the individual heater elements revealed that 11 out of 240 elements tested had sustained nondisabling sheath damage at the cold end. (This is located in the nonheated region inside the heater assembly insulation block as shown on Figure A-2.) The damage consisted of a short split in the sheath material. The damaged elements still had good electrical resistance between sheath and electrode and the electrode and filament were undamaged. The heaters continued to fulfill their function. Even though the elements lasted far beyond their anticipated life, the damage to the sheath was investigated further.

3.4.5 Confirmatory Steam Chamber Tests

To confirm that the sheath splits occured after a number of simulated post-LOCA transients, the steam chamber tests were repeated on another set of four heater banks. The test procedure used in Test No. 3 was followed and after each post-LOCA transient, the heaters were removed from the test chamber and completely inspected. As expected, no damage and no clad splits were found after the first post-LOCA transient (this demonstrates the heaters meet the requirement of availability after a LOCA). To confirm the reserve life left after the required post-LOCA transients, these heater banks were subjected to a series of further transients using the test method used for Test No. 3. No clad splits were found until the end of the fourth post-LOCA transient. This confirms the design margin available in the heater elements. (A fifth post-LOCA transient was then run to provide further information and more cladding splits occurred.) An investigation by Westinghouse Research and Development Center confirmed the cause of the split was due to partial MgO conversion to $Mg(OH)_2$ which was caused by repeated application of high pressure steam to the heater elements.

3.4.6 Conclusions

The steam chamber tests demonstrate that the heater elements plus other equipment described in paragraph 3.4.2 have a considerable margin over that required for operation after a single post-LOCA transient. Therefore, the recombiner meets the requirements for operation after a LOCA transient.

3.5 GROUND FAULT TEST

The recombiner electrical system contains an isolation transformer whose purpose is to isolate the recombiner electrical system from earth ground; thus, a single ground fault in the system will not result in failure of the recombiner. To demonstrate the effectiveness of this system, the recombiner system was operated at full power and a direct short to earth ground was activated by closing a contact in a cable leading from one power conductor to earth ground. The recombiner was also operated over the full range of power with the earth-grounded power conductor. As expected, no effect on the recombiner power was detected.

3.6 IRRADIATION TESTS

The purpose of this program was to demonstrate that the electrical components in the recombiner, which may be adversely affected by irradiation, will perform their post-LOCA function after irradiation.

Type tests were conducted on the electrical components to augment the irradiation information presently available on these components. Production components were subjected to normal life tests, post-LOCA environment, irradiation, and post-irradiation tests.

3.6.1 Description of Parts to be Type Tested

All electrical components furnished with the Westinghouse electric recombiner, which may be exposed to post-LOCA environment and which use electrical insulation were tested. (Metal parts, such as metal bus bars, connectors, and bolts were not tested.)

The following parts were tested. Unless otherwise noted all these components had been subjected to the preaging, which consists of 80 heatup and cooldown cycles followed by 6 post-LOCA steam pressure and spray cycles.

a. Power Cable - used to connect the heater banks to the electrical junction box.

b. Heater Connector Wire - This stranded cable connects the heater element bus bars to the heater bank terminal block.

c. Heater elements - U-Tube Incoloy-800 clad electric heaters. Overall length approximately four feet. (Irradiate the connector end.)

d. Thermocouple and extension wire.

e. Heater Bank Electrical Terminal Blocks. (Subjected to six post-LOCA transients.)

3.6.2 Test Program

All test material except Item (e) was preaged to simulate normal service life and post-LOCA steam pressure, containment spray and containment temperature. Preaging consisted of 80 heatup and cooldown cycles in a production recombiner to simulate normal service life testings. Six post-LOCA containment steam pressure, temperature and spray transients were then conducted using a large pressure vessel and steam source.

The preaged components were placed in a gamma irradiation chamber at McMaster University, Hamilton, Ontario. A total dose of 2×10^8 rad was administered to each material item. The following conditions prevailed in the irradiation chamber:

a. Temperature - 24°C ± 1°C

b. Humidity - 32% ± 2%

c. Irradiation Rate - 0.33 megarads/hr for all items except (e), which was 0.8 megarads/hr

d. Total Dosage - 2×10^8 for all but (e), which had $\sim 2.2 \times 10^8$ rads

3.6.3 Post-Irradiation Test Program

The following examinations of these components were made following irradiation.

(a,b,c)

3.6.4 Test Results

a. Power Cable - Phase-to-phase resistance 2 megohm. Phase-to-outer jacket resistance 1,000 megohm. Passed the high potential test at 1320v ac at 60 Hz.

b. Heater Connection Wire - Insulation resistance measure . Wire operated in heater and passed 1320v ac @ 60 Hz high potential test.

c. Heater Elements - No damage to heater noted. Heater operated during and after post-LOCA transient.

d. Thermocouple and Extension Wire - T/C and extension wire operated after irradiation and post-LOCA transients.

e. Heater Bank Electrical Terminal Blocks - No visual damage noted after irradiation or after post-LOCA transient.

SECTION 4

REFERENCES

1. J. F. Wilson, "Electric-Hydrogen Recombiner for Water Reactor Containments," WCAP-7820-L, 1971. (Westinghouse NES Proprietary.)
2. J. F. Wilson, "Electric-Hydrogen Recombiner for PWR Containments," WCAP-7820, Supplement 1, 1972.
3. IEEE Standard 344-1971, "IEEE Guide for Seismic Qualification of Class 1 Electric Equipment for Nuclear Power Generating Stations," Inst. of Electrical and Electronics Engineers, Inc., New York, 1971.

APPENDIX A

DESCRIPTION OF THE ELECTRIC HYDROGEN RECOMBINER

A.1 DESCRIPTION

The electric hydrogen recombiner is shown in Figure A-1. A summary of typical design parameters is presented in Table A-1. The recombiner consists essentially of a thermally insulated vertical metal duct with metal-sheathed electric resistance heaters provided to heat a continuous flow of containment air (containing a low concentration of hydrogen) up to a temperature which is sufficient to cause a reaction between hydrogen and oxygen.

Air and its contained hydrogen enter the recombiner and flow up through the heated section and out the top by natural convection. The intake of the recombiner is located only on one side and the exhaust ports are located above and on the other three sides of the recombiner. This arrangement of intake and exhaust ports serves to ensure that for downflow air currents external to the recombiner, there would be little tendency for recirculation of the recombiner process gases (from the exhaust back into the intake).

No circulation fans are required and the desired flow rate of air is established by providing the proper size inlet flow area through an orifice plate at the bottom of the recombiner. Thus, with the air flow rate regul' ed by a fixed orifice and with the supply of electric power determined by a control station outside the containment, controls are not needed inside the containment. Heat added to the containment air by the recombiner is removed by containment cooling systems already available for other much larger heat loads so that the containment air temperature will remain essentially unaffected by the recombiner.

The electric hydrogen recombiner uses conventional type electric resistance heaters sheathed with Incoloy-800, which is an excellent corrosion-resistant material for this service. These heaters, which are shown in Figure A-2, have

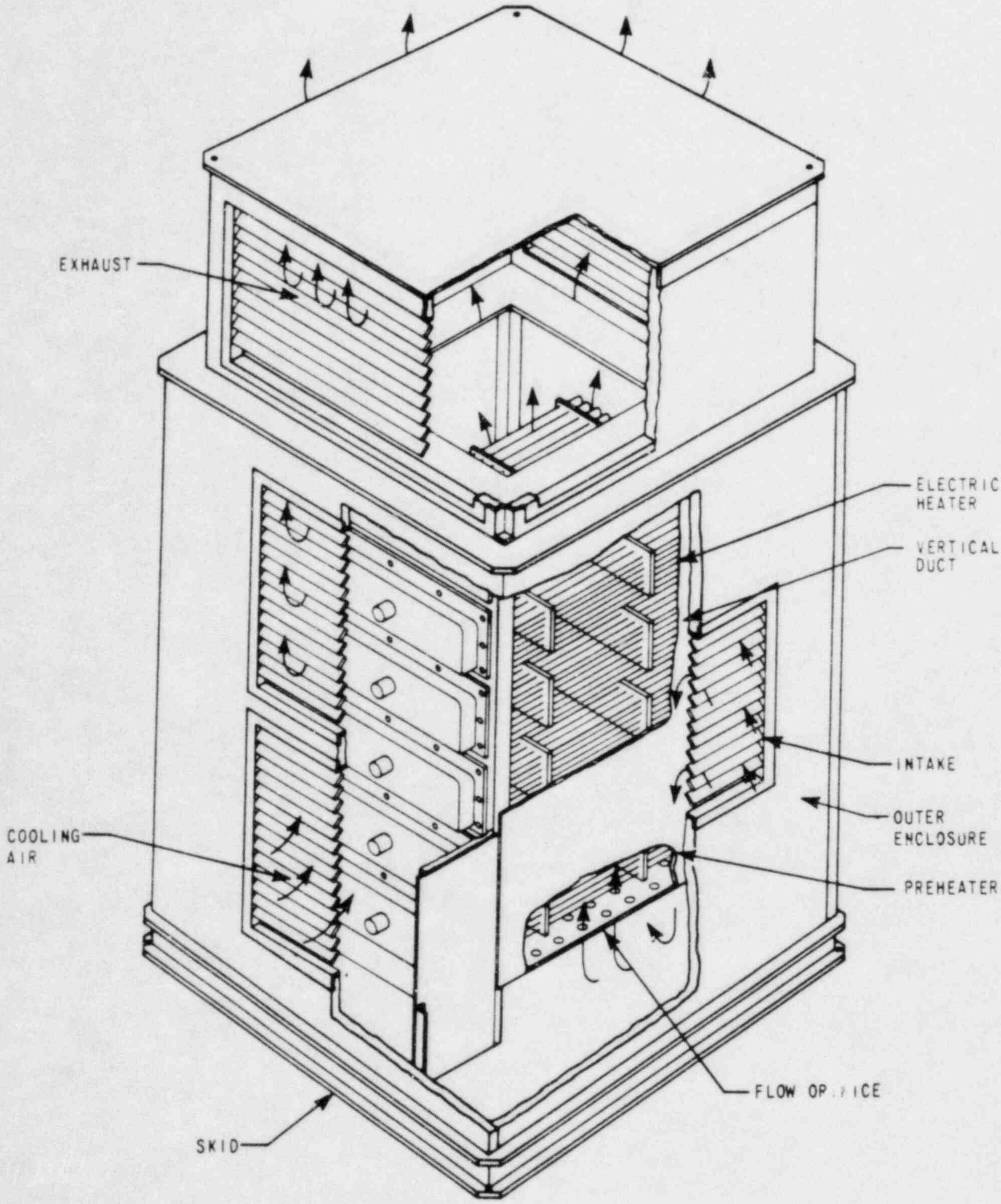

Figure A-1. Electric Hydrogen Recombiner

TABLE A-1

ELECTRIC HYDROGEN RECOMBINER TYPICAL PARAMETERS

Power (Maximum)	75 kW
Capacity (Minimum) At 1 atmosphere	100 scfm
Heaters	
-Number	5
-Heater Surface Area/Heater	35 ft^2
-Maximum Heat Flux	2850 Btu/hr-ft^2 or 5.8 watts/$in.^2$
-Maximum Sheath Temperature	1550°F
Gas Temperature	
-Inlet	80 to 155°F
-In Heater Section	1150 to 1400°F
Materials	
-Outer Structure	300-Series S.S.
-Inner Structure	Inconel-600
-Heater Element Sheath	Incoloy-800
Dimensions	
-Height	9 ft
-Width	4.5 ft
-Depth	5.5 ft

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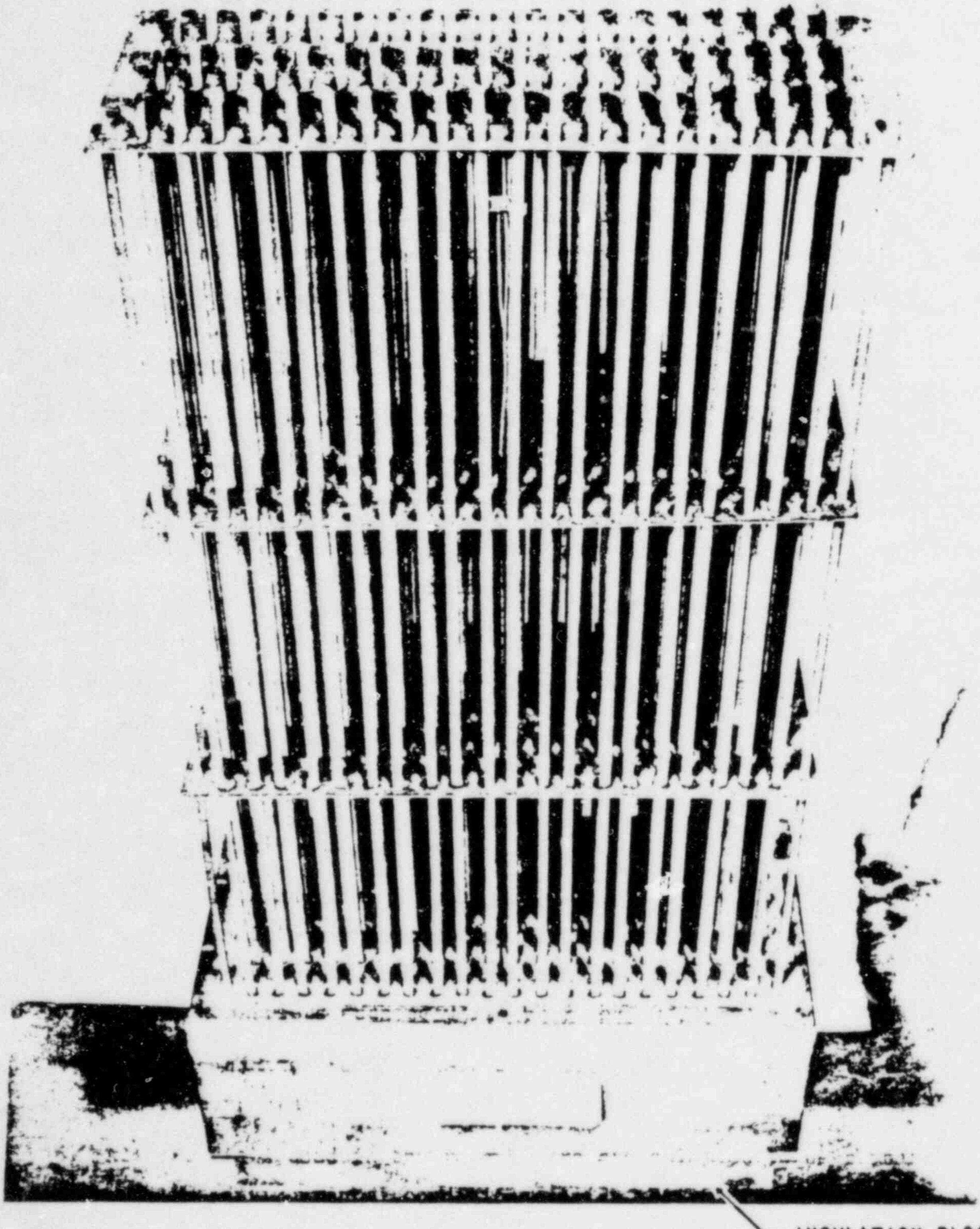

Figure A-2. Prototype Electric Hydrogen Recombiner Typical Heater

been designed to operate with the same sheath temperatures as commercial heaters, but at power densities much lower than normal. Each bank contains 60 individual heating elements. Operation of the unit is virtually unaffected if a few individual heating elements fail to function properly.

The major structural components are manufactured primarily of 300-Series stainless steel, except for the base which is carbon steel. Incoloy-800 is used for the heater sheaths, and Inconel-600 for other parts such as the heater duct, which operates at high temperature.

A.2 DESIGN CRITERIA

The following are criteria considered in the design of the electric hydrogen recombiner for pressurized water reactor containments:

1. The recombiners are designed to sustain all normal loads and accident loads including seismic loads and temperature and pressure transients from a loss-of-coolant accident.

2. The recombiners must be protected from damage from high-energy missiles or jet impingement from broken pipes.

3. The recombiners must be located in the containment such that they process a flow of containment air containing hydrogen at a concentration which is approximately typical of the average concentration throughout the containment.

4. The recombiners must be located away from high-velocity air streams, such as could emanate from fan cooler exhaust ports, or they must be protected from direct impingement of high-velocity air streams by suitable barriers such as walls or floors.

5. The recombiners are designed for a lifetime consistent with that of the reactor plant.

6. All materials used in the recombiners are selected to be compatible with the environmental conditions inside the reactor containment during normal operation or during accident conditions.

APPENDIX B

DETAILS OF RELATED TOPICS

This appendix elaborates on certain topics which have been covered in earlier reports on the electric recombiner.

B.1 SPRAY TESTS ON PROTOTYPE RECOMBINER

The spray tests conducted on the prototype electric recombiner were performed using spray nozzles in the simulated containment. The nozzles have an average droplet size similar to that expected in an actual containment at about the operating floor level. The average droplet size in the test (50 percent of accumulated volume percentage) varied from about 350 to 500 microns, depending on spray pressures. These data are based on the nozzle manufacturer's published information.

B.2 HEATER ELEMENTS

The heater elements used in the electric recombiner are a manufacturer's standard design. To provide a conservative design for the recombiner, these heater elements have been greatly derated. For example, the elements are rated for 1600°F and have a power rating of approximately 30 watts per square inch of surface. In the recombiner, the maximum power ranges from approximately 1 W per square inch in the upper heater bank to 5.8 W per square inch in the lower heater bank. Normal operating power is about 70 percent of these values.

Other parameters specific to the heaters elements are:

(a,c)

B.3 ANALYSIS OF TRANSIENT PRESSURE LOADS

The purpose of this analysis is to verify the structural adequacy under LOCA containment pressure transient loads of large sized parts of the production electric hydrogen recombiner. Their size restricted testing and verification by means of the autoclave test program.

The electric hydrogen recombiner is basically an open structure and only small pressure differentials are developed across major components of the assembly; however, there are some individual component parts which are not as open, and these parts may be subject to significant pressure differentials. Importantly, those component parts which may be subject to significant pressure differentials, e.g., the door panels, the heater assemblies, and the electrical junction boxes, were tested in the autoclave test program and were demonstrated to be satisfactory for the anticipated blowdown conditions.

The assemblies not tested are those which are large and inherently open; these include the heater frame assembly, the outer frame assembly (which includes the inlet plenum), and the outlet plenum assembly at the top of the recombiner. Each of these assemblies has been analyzed and the stresses resulting from pressure differentials were found to be low in all cases, as expected. The analysis of the heater frame assembly, which has the highest stresses (even though very low) is presented in the following paragraphs.

This analysis is presented in two parts: (1) the determination of the pressure acting across the heater frame assembly walls; and (2) the determination of the stresses in the heater frame walls resulting from these pressures.

1. Pressure Loading Analysis

The heater duct and frame assembly has a volume of about 32.3 ft^3 and an inlet area of about 0.688 ft^2.

The external pressure across the walls will be conservatively calculated as follows: Assume that the pressure inside the volume follows the external pressure, i.e., the containment pressure, with no time lag. Determine the mass flow rate into the chamber to keep the internal pressure equal to the external pressure. Determine the pressure drop across the inlet area required to develop this mass flow rate.

(a,c,e)

For the case of the heater duct and frame assembly, where V = 32.3 ft^3, and A = .688 ft^2; the differential pressure calculated by this conservative method would be 13.9 x 10^{-3} psi, which is small as expected.

2. Stress Analysis

The heater duct and frame assembly is a box structure with 1/8-in.-thick Inconel sheet metal sides, reinforced at the corners with thicker, 1/4-in. Inconel. The stresses in the box will be conservatively calculated by analyzing a strip of unit width with simply supported ends subjected to a lateral loading of Δp* and an end load, P. The maximum stress in the strip is given by the formula*

$$S = \frac{P}{A} + \frac{1}{\left(1 - \frac{\alpha P \ell^2}{EI}\right)} \times \frac{6M}{t^2}$$

where

P = compressive end loading = $13.9 \times 10^{-3} \frac{\text{lb}}{\text{in.}^2} \frac{(22.25 \text{ in.})}{2}$

$= 154.8 \times 10^{-3}$ lb/in.

A = area of strip - 0.125 $\text{in.}^2/\text{in.}$

M = bending moment for a simply supported beam under traverse loading

E = modulus of elasticity of Inconel-600 at room temperature = 31 x 10^6 psi

I = moment of inertia of strip = $\frac{1 \text{ in.}(.125 \text{ in.})^3}{12}$

$= 1.61 \times 10^{-4} \text{ in.}^4/\text{in.}$

*R. J. Roark, "Formulas for Stress and Strain," 4th ed., New York, McGraw-Hill, 1965.

t = thickness of panel = 0.125 in.

α = coefficient depending on beam support and loading conditions
= 0.104 for a beam with simple supports and uniformly distributed load

The bending moment is given by:

$$M = \frac{w\ell^2}{8}$$

where

w = load per inch of length = Δp^* = $13.9 \times 10^{-3} \frac{\text{lb}}{\text{in.}}$

ℓ = maximum length of beam = 37.50 in. (side panel)

$$M = 13.9 \times 10^{-3} \frac{\text{lb}}{\text{in.}} \frac{(37.50 \text{ in.})^2}{8}$$

$$= 2.44 \frac{\text{lb-in.}}{\text{in.}}$$

The maximum stress is:

$$S = \frac{154.8 \times 10^{-3}}{0.125}$$

$$+ \frac{1}{\left(1 - \frac{0.104(154.8 \times 10^{-3})(1.406 \times 10^3)}{(31 \times 10^6)(1.61 \times 10^{-4})}\right)} \times \frac{6(2.44)}{(1.56 \times 10^{-2})}$$

Thus,

$$S = 940 \text{ psi}$$

This stress is more than an order of magnitude less than the material yield strength under blowdown conditions and is, therefore, acceptable.

The other large assemblies such as the outer frame assembly and upper plenum assembly are also quite open and have similarly low stresses under the blowdown pressure transient. Thus, the structural adequacy of these large assemblies under LOCA containment transient pressure loads is considered to be verified.