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Aging Evaluation of Class 1E Batteries: Seismic Testing

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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

This report presents the results of a seismic testing program on naturally aged class 1E batteries obtained from a nuclear plant. The testing program is a Phase II activity resulting from a Phase I aging evaluation of class 1E batteries in safety systems of nuclear power plants, performed previously as a part of the U.S. Nuclear Regulatory Commission's Nuclear Plant Aging Research Program and reported in NUREG/CR-4457. The primary purpose of the program was to evaluate the seismic ruggedness of naturally aged batteries to determine if aged batteries could have adequate electrical capacity, as determined by tests recommended by IEEE Standards, and yet have inadequate seismic ruggedness to provide needed electrical power during and after a safe shutdown earthquake (SSE) event. A secondary purpose of the program was to evaluate selected advanced surveillance methods to determine if they were likely to be more sensitive to the aging degradation that reduces seismic ruggedness. The program used twelve batteries naturally aged to about 14 years of age in a nuclear facility and tested them at four different seismic levels representative of the levels of possible earthquakes specified for nuclear plants in the United States. Seismic testing of the batteries did not cause any loss of electrical capacity.

EXECUTIVE SUMMARY

Batteries are the only installed source of electrical power to provide for monitoring of plant conditions and control of some systems of the nuclear reactor in the event of a station blackout (all offsite power is lost and the diesel generators do not start). These batteries are composed of negative and positive plates that contain a lead compound known as active material that chemically combines with the electrolyte to provide the current during discharge. The plates are separated by an insulating material and are connected to output terminals. The assembly of plates and separators is submersed in an electrolyte, which is enclosed in a container. Approximately 60 individual 2-V cells are connected together to form a typical 125-Vdc battery bank that has enough voltage and electrical capacity to provide the needed electrical power for a required period of time, which is specified by the safety analysis that is performed for each nuclear plant.

As part of the U.S. Nuclear Regulatory Commission (NRC) program for Nuclear Plant Aging Research (NPAR), a Phase I study of battery aging was performed and reported in NUREG/CR-4457, "Aging of Class 1E Batteries in Safety Systems of Nuclear Power Plants." The study concluded that significant aging effects for old batteries are growth of positive plates, loosening of active material in plates that have grown, loss of active material caused by gassing and corrosion, and embrittlement of the lead grids and straps. The results of these effects are decreased electrical capacity and decreased seismic ruggedness that, during a seismic event, can lead to decreased electrical performance or complete failure. Since batteries are susceptible to aging degradation that could cause old batteries to be vulnerable to severe seismic events, a test program, sponsored by the NRC, has been conducted to determine if it is possible for the seismic ruggedness of aged batteries in nuclear plants to be inadequate, even though the measured electrical capacity is satisfactory, as determined by tests recommended by IEEE Std 450-1987, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Storage Batteries for Generating Stations and Substations." In addition, selected alternate surveillance methods have been evaluated during the testing program to determine if any of them are likely to be more sensitive to battery degradation than the surveillance and testing methods specified in IEEE Std 450 and Regulatory Guide 1.129, "Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Nuclear Power Plants."

The batteries tested were manufactured by C&D Batteries and were obtained from a nuclear facility where they were naturally aged to 13-1/2 years. Records provided by the nuclear facility indicate that the batteries were maintained and tested in accordance with practices that are consistent with those found in IEEE Std 450. The batteries were fabricated with lead-calcium plates, and discussions with C&D personnel indicate that they were typical of batteries presently being installed in nuclear facilities. Each cell had a rated 8-hour electrical capacity of 1350 ampere-hours, was 7-5/8 in. long, 14-1/8 in. wide, 22-1/16 in. high, and weighed about 240 pounds.

The batteries were installed on a shake table using a new battery rack purchased from the battery vendor and were tested to seismic spectra that are typical of those required for safe shutdown earthquake (SSE) events in nuclear facilities in the United States. Information received from selected nuclear plants and the Electric Power Research Institute (EPRI) was used to specify the required response spectrum (RRS) for the seismic tests. The tests were conducted using four different seismic levels that were the best estimate for the RRS that encompasses 50%, 85%, 95%, and 100% of the nuclear plants in the United States. During the seismic tests, the batteries were discharged at 2% of the 3-hour rate with current and battery voltages being monitored to detect the existence of catastrophic failure. The electrical capacity of each battery was determined before and after the seismic testing.

During the preseismic, seismic, and postseismic tests, alternate surveillance and monitoring methods were employed to determine whether other methods may be more sensitive to aging-related degradation than the standard volt-ampere tests that determine the electrical capacity of batteries. The alternate monitoring methods employed were (a) measurement of internal resistance, (b) measurement of capacitance, and (c) measurement of battery polarization (comparison of battery voltages measured while increasing discharge current with those obtained with decreasing discharge current). These measurements were suggested for their capacity to provide an indication of battery condition as a result of investigations performed by the Westinghouse R&D Center for Sandia National Laboratory (SNL) in 1986.

Results of the seismic tests indicate that the capacity of the lead-calcium batteries of this design did not decrease as a result of shaking at seismic levels that include the most severe SSE levels specified for batteries in nuclear plants in the United States. In fact, the average electrical capacity (ampere–hours) of batteries tested at the 100% seismic level increased from a preseismic capacity of 96% to a postseismic capacity of 98%. The batteries did not show degradation as a result of seismic testing, except for some scrape marks on the cases caused by tie rods in the battery rack and dislodging of some fiberglass in the plate separator mats. None of these degradations decreased the electrical capacity of the batteries. The battery rack suffered some bending of structural components as a result of the most severe seismic excitation. However, the battery rack held the batteries in place at all times and performed the intended function. Posttest disassembly of selected batteries showed that some corrosion of the weld joint between the positive plates and the buss/terminal assembly had occurred as a result of the natural aging process. However, this degradation did not interfere with the seismic performance. Metallurgical examinations showed that a large grain structure existed at the weld area. The larger grain structure of the weld makes it susceptible to corrosion and would explain the observed corrosion.

The results of employing the alternate surveillance methods indicate that measurement of capacitance and internal resistance can be obtained with repeatability and may provide an indication of battery condition, if the measurements were taken over the lifetime of the battery. Polarization and discharge current interruption are two techniques that are capable of measuring internal resistance, while discharge current interruption is also capable of measuring battery capacitance. It appears that these measurements would be most useful if they could be made while the batteries were new and then repeated at regular intervals to obtain a pattern of change with time.

As a result of seismic tests on naturally–aged batteries that were 14 years old, we conclude that when batteries are maintained and operated in accordance with IEEE Std 450 and Regulatory Guide 1.129, the following may be expected of equivalently designed and manufactured lead–calcium batteries:

- Little, if any, electrical capacity will be lost as a result of seismic shaking at levels that are typical of the most severe levels required for SSE in the U.S. This finding indicates that adequate seismic ruggedness will be retained in batteries and racks of equivalent design and material to meet the requirements for the most severe SSE events.

- Some internal damage to the plate separators may be expected at the most severe seismic levels. However, this damage is not expected to prevent the batteries from providing at least 80% of rated capacity during and immediately following the most severe seismic event.

- Naturally–aged batteries may show evidence of corrosion at the joint between the positive plates and the positive plate strap (buss). In a well–made joint, this corrosion should not cause the seismic ruggedness to be inadequate for the most severe SSE events expected for the U.S. However, batteries should not be operated at elevated temperatures or charged excessively to avoid this corrosion, which could then progress rapidly enough to result in inadequate seismic ruggedness.

Because most aging mechanisms cause both decreased electrical capacity and reduced seismic ruggedness, it appears that the tests recommended by IEEE Std 450 not only provide a method of monitoring electrical capacity of current generation nuclear station batteries, but also provide an indication of adequate seismic capability when the batteries are maintained and operated in accordance with IEEE Std 450 and Regulatory Guide 1.129.

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AGING EVALUATION OF CLASS 1E BATTERIES: SEISMIC TESTING

1. INTRODUCTION

Batteries are the only installed source of electrical power to provide for monitoring of plant conditions and control of some systems of the nuclear reactor in the event of a station blackout (all offsite power is lost and the diesel generators do not start). Since batteries are susceptible to aging degradation that could cause old batteries to be vulnerable to severe seismic events, a test program was conducted to determine if it is possible for the seismic ruggedness of aged batteries in nuclear plants to be inadequate even though the electrical capacity is satisfactory. In addition, selected advanced surveillance methods were evaluated during the testing program to determine if any of them were likely to be more sensitive to battery degradation than the surveillance and testing methods required in IEEE Std 450-1987, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Storage Batteries for Generating Stations and Substations,"[1] and Regulatory Guide 1.129, "Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Nuclear Power Plants."[2] This section of the report describes some work that has been performed and the organization of this report. Note that even though the term "cell" is usually defined as a single electrical cell and "battery" refers to a number of cells connected together, the term "battery" will be used in this report to describe both a single cell and a group of connected cells.

1.1 Background

As part of the U.S. Nuclear Regulatory Commission (NRC) program for Nuclear Plant Aging Research (NPAR), a Phase I study of battery aging was performed and reported in NUREG/CR-4457, "Aging of Class 1E Batteries in Safety Systems of Nuclear Power Plants."[3] The study reviewed testing performed by others, studies that have been conducted, and reports of operational experiences.

The study concluded that significant aging effects for old batteries are growth of positive plates, loosening of active material in plates that have grown, loss of active material caused by gassing and corrosion, and embrittlement of the lead grids and straps. The results of these effects are decreased electrical capacity and decreased seismic ruggedness that, during a seismic event, can lead to decreased electrical performance or complete failure.

In general, the same aging mechanisms cause both decreased electrical capacity and reduced seismic ruggedness. These mechanisms are elevated temperature, overcharging, ac ripple, low electrolyte level, and impurities in the electrolyte. There are a few mechanisms which lead only to a decrease in seismic ruggedness because they affect the case (container) but not the components inside the battery; examples are defects caused by handling and the use of solvents to clean the cases. It appears that it is possible for the mechanisms that affect both electrical capacity and seismic ruggedness to have a greater effect on seismic ruggedness than electrical capacity.

The above conclusion is supported by research performed by Sandia National Laboratories (SNL).[4,5,6,7] Naturally aged batteries (fabricated by three different manufacturers) that were 10 to 23 years old had retained an average electrical capacity of 98%; the electrical capacity, however, dropped to an average of 72% when the batteries were subjected to seismic-fragility testing at a zero period acceleration (ZPA) of 1.5 to 1.7 g. Electrical capacity after seismic testing at a ZPA of 2 g ranged from 0% (catastrophic failure) to 87%, with the average being 32%. The capacity of new (unaged) batteries only dropped from an average capacity of 96% to an average of 85% after seismic testing at about 2 g.[8] These figures demonstrate that while aging may cause only a small decrease in electrical capacity, seismic ruggedness in certain designs could be greatly reduced. It is recognized that the tests conducted by SNL used seismic levels greater than those required for battery qualification. Yet, the tests demonstrate that it is possible for aging to have a greater effect on seismic ruggedness than on electrical capacity.

It should be remembered that seismic ruggedness is greatly influenced by battery cell design. The jar material and design, the method of attaching and supporting the plates, and control of the manufacturing processes are all major contributors to any battery's ability to withstand high levels of seismic acceleration. Since there are three manufacturers of nuclear plant batteries, caution must be used in treating the results of this program in a completely generic fashion. In addition, battery and rack must be considered as an assembly. When dynamically responsive racks are used (such as those used in this program), the stress imposed on the battery is amplified—up to five times the actual floor acceleration. Another manufacturer's rack may be more rigid or employ vertical restraints, either of which lessens the seismic stress imposed on the cells, in which case the cells need not be as robust as those mounted on a rack that is dynamically responsive.

The IEEE Std 450–1987 recommends that batteries should be replaced when the electrical capacity has decreased to 80% of rated capacity. Considering that aged batteries were observed to decrease in capacity from 98% to 72% as a result of high–level shaking, it appears that a degraded older battery with a capacity near 80% would be unable to supply the demanded electrical power as a result of shaking. The demanded power (design load) is different for each plant, but could be as high as 70% of rated capacity and yet meet the requirements of IEEE Std 485–1983, "IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations."[9]

Although batteries are now seismically qualified to the requirements of IEEE Std 535–1986, "IEEE Standard for Qualification of Class 1E Storage Batteries for Nuclear Power Generating Stations,"[10] (which requires aging to end–of–qualified–life prior to seismic testing) and are qualified for 15 to 20 years of service, actual life could be less than qualified life if their operational conditions, including maintenance practices, were more severe than the conditions for which they were qualified. These batteries could, then, be operating with adequate electrical capacity but inadequate seismic ruggedness, if seismic ruggedness decreased more rapidly than electrical capacity. Some examples of severe operating conditions are high environmental temperature, too many deep discharge cycles, overcharging, low electrolyte level, and impurities in the electrolyte. Deep discharges occur when most of the battery's ampere–hour capacity is used. Overcharging may be caused by continued charging at an excessive voltage, i.e., floating at a higher than recommended voltage. Also, the accelerated aging practices permitted in IEEE Std 535 may not fully duplicate the aging effects experienced by naturally aged batteries. Many old batteries at nuclear plants were not qualified to IEEE Std 535, and they could become vulnerable to a seismic event prior to reaching the end of their electrical life.

Standard testing and monitoring methods provided in IEEE Std 450 and Regulatory Guide 1.129 only provide for measurements of temperature, voltage, and electrical capacity as well as some visual inspections. However, these tests are not designed to detect the degradation of batteries that causes seismic vulnerability. In addition, the tests conducted by SNL did not provide information concerning the seismic ruggedness of batteries at seismic levels near those used for qualification.

1.2 Objectives

The specific objectives of this program were: (a) to determine if the seismic ruggedness of aged batteries in nuclear plants might be inadequate, even though the electrical capacity is satisfactory; and (b) to evaluate selected advanced surveillance methods to determine if any of them might be more sensitive to battery degradation than the surveillance and testing methods required in IEEE Std 450–1987 and Regulatory Guide 1.129.

Associated with these specific objectives were the general objectives of the NPAR Program as stated in NUREG–1144, Rev. 1,[11] which are to:

- Identify and characterize aging and service–wear effects associated with electrical and mechanical components, interfaces, and systems likely to impair plant safety
- Identify and recommend methods of inspection, surveillance, and condition monitoring of electrical and mechanical components and systems that will be effective in detecting significant aging effects before loss of safety function so that timely maintenance and repair or replacement can be implemented
- Identify and recommend acceptable maintenance practices that can be undertaken to mitigate the effects of aging and to diminish the rate and extent of degradation caused by aging and service wear.

1.3 Scope

The scope of the program was to provide test results that would lead to one of two conclusions: (a) batteries aged to near the end of electrical life retain adequate seismic ruggedness, and additional surveillance testing is not required; or (b) aged batteries may not retain adequate seismic ruggedness, and therefore additional surveillance testing or revised replacement criteria are recommended. In addition, the program was to provide test data that would permit the evaluation of selected advanced surveillance methods to determine if any of them would be more sensitive to battery degradation than the surveillance and testing methods required in IEEE Std 450–1987 and Regulatory Guide 1.129.

To accomplish the above scope and meet the program objectives, the following steps were performed:

1. Obtained naturally aged batteries that are representative of batteries found in nuclear plants.
2. Reviewed advanced surveillance and testing methods that have been identified. Selected the methods that were believed to be most likely to provide an indication of battery condition for further testing.
3. Reviewed seismic levels at a variety of nuclear plants to determine the range of seismic levels to utilize in the test program.
4. Prepared, reviewed, and approved a test plan that described, in detail, the tests to be conducted.
5. Performed seismic testing in accordance with the test plan.
6. Tested selected advanced surveillance methods.
7. Analyzed test data and reached conclusions.

Section 2 of this report provides a brief description of the batteries tested. The test program is described in detail in Section 3, followed by a discussion of the test results in Section 4. Finally, conclusions are discussed in Section 5.

2. DESCRIPTION OF BATTERIES TESTED

Batteries for class 1E applications at nuclear power plants are typically composed of many (60 for a 125 Vdc system) individual lead–acid storage cells that are connected together to provide the needed voltage and current for emergency situations. These cells, then, are the fundamental unit of the battery. The essential parts of the cell are two dissimilar electrodes immersed in an electrolyte held in a suitable container. The two dissimilar electrodes are composed of active material contained within a grid structure (usually referred to as a plate). The active material on both electrodes chemically combines with the electrolyte to provide the current during discharge, with the chemical reaction being reversed when the cell is being charged. If impurities are present, other reactions may occur which can cause the cell to be prematurely discharged.[12] The components of the reaction are insoluble in the electrolyte. Thus, under normal operating conditions the active materials remain in their respective positions.

The grid of a cell has two functions: first, as a support for the active material, which is not normally self supporting; and, second, as a conductor to transmit current from all parts of the active material to the plate terminal. Figure 1 shows a typical grid assembly. The plates are fused to conductors (straps) and posts at the top of the cell that transmit current from the plates to external connections to the cell. The straps are slotted to facilitate fusing of the final battery assembly. Positive plates typically hang from the positive plate straps, container side walls, or are cantilevered from the negative plates to allow for positive plate growth. The negative plates are usually supported by the negative plate straps and by feet that rest on the floor of the battery case.

The lead oxide (PbO) active material is applied to the supporting grids in the form of a puttylike paste consisting of lead powder mixed with a liquid (water, dilute sulfuric acid, or other aqueous solution), and then allowed to set and dry. The plates are formed by immersing the grids in dilute sulfuric acid and passing current through them, with opposite polarities for the positive and negative plates. The PbO is converted to PbO_2 in the positive plate and Pb in the negative plate.

Separators are installed between the plates to provide a physical separation and yet allow conduction of ions through the electrolyte between electrodes of opposite polarity. A cover completes the containment so that the electrolyte does not escape or contaminants do not enter the container. A vent is necessary to provide an opening for both the addition of electrolyte and the escape of gases formed during charging. Figure 2 is a sketch of a battery with all the essential components.[13,14]

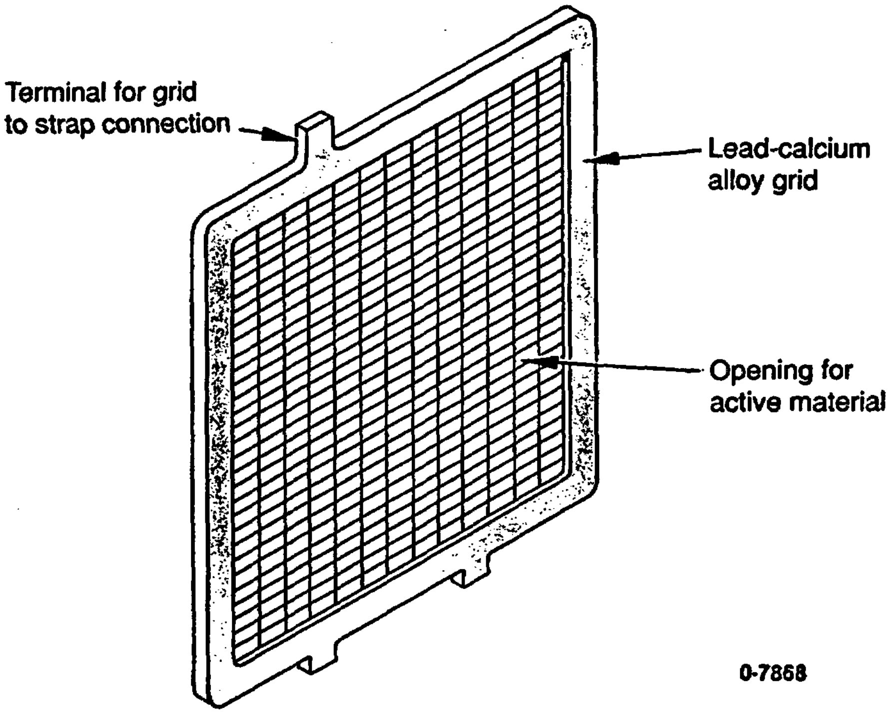


Figure 1. Typical grid assembly for a pasted plate.

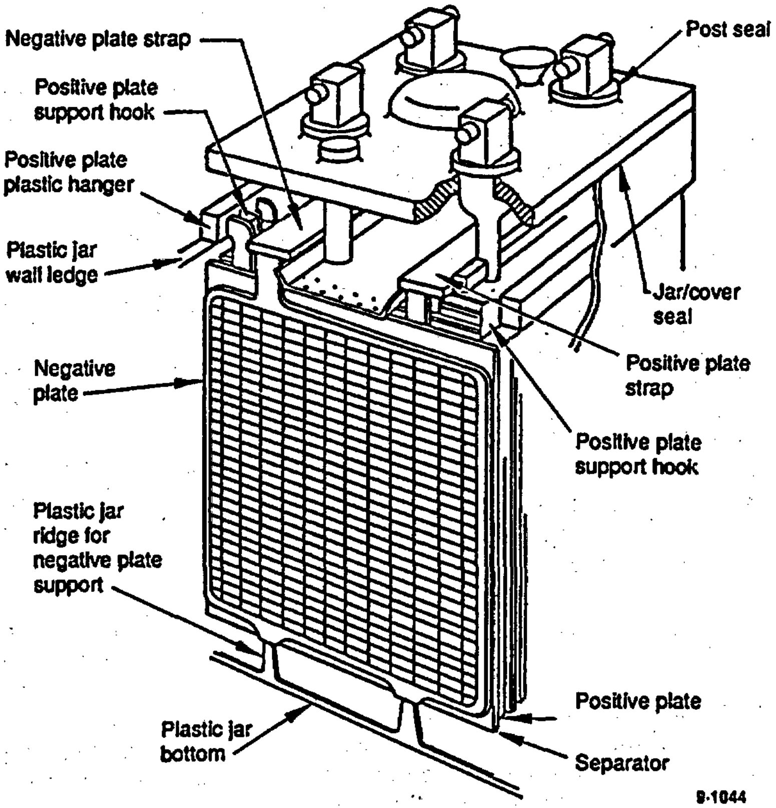


Figure 2. Typical lead–acid battery for stationary applications (taken from Reference 14).

Cells are placed in racks designed to support the cells during seismic events and are connected together in banks to form the battery. The batteries are housed in a room designed to provide a suitable environment for the battery.

The batteries tested were LCU–19 batteries similarly constructed as previously described and naturally aged at approximately 80°F to 13–1/2 years. The batteries were fabricated by C&D Batteries with lead–calcium plates, and discussions with C&D personnel indicate that they were typical of batteries presently being installed in nuclear facilities. Each battery had an 8–hour electrical capacity of 1350 ampere–hours, were 7–5/8 in. long, 14–1/8 in. wide, and 22–1/16 in. high, and weighed about 240 pounds. These batteries were obtained from a nuclear facility after they had been replaced by new batteries. A review of the records provided by the nuclear facility indicates that they were maintained and tested in accordance with practices that are consistent with those in IEEE Std 450. Figure 3 is a photograph of one of these batteries.

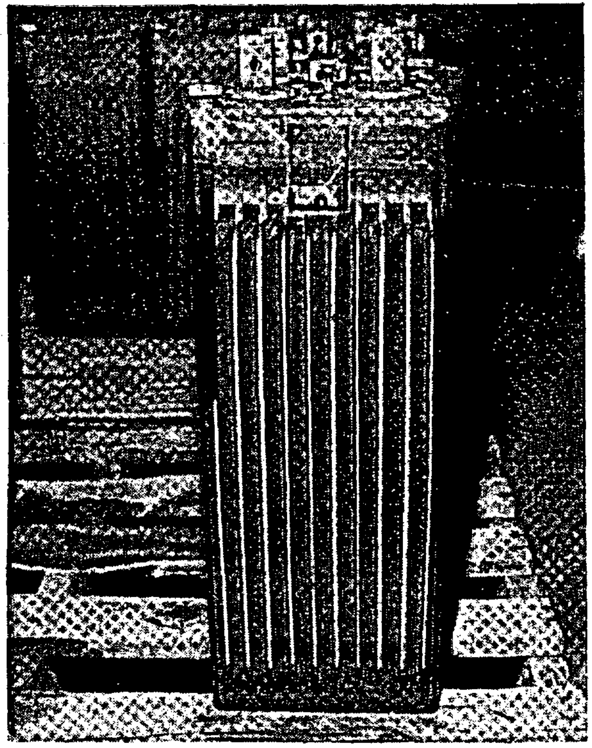


Figure 3. Typical battery obtained from a nuclear facility for seismic testing.

3. TEST PROGRAM

The basic strategy of the test program was to obtain naturally aged batteries, determine the electrical capacity of those batteries, perform seismic testing at a level that is representative of the levels required for qualification, evaluate selected advanced surveillance and monitoring methods, perform postseismic capacity tests, and analyze the test results. A test plan, "Test Plan for Determining Seismic Ruggedness of Aged Stationary Batteries in Nuclear Power Plants," December 13, 1988, was prepared and reviewed by the NRC Technical Monitor. The test plan is included as Attachment A of this report. Subsequently, a Test Specification, ES–51235, "Seismic Testing of Naturally Aged Stationary Batteries,"[15] was issued to describe the testing program to prospective test facilities. The following paragraphs describe details of the various aspects of the test program.

3.1 Battery Selection

Batteries were selected for testing based on a combination of availability and specific characteristics. The specific characteristics were chosen to describe batteries that were naturally aged, currently acceptable according to the criteria of IEEE Std 450, and of a design that is typical of batteries currently being installed in nuclear plants. It was also recognized that "ideal" batteries may not be readily located. Since the only naturally aged batteries available were old batteries being replaced, they could very well be unacceptable according to IEEE Std 450 or of a design that is no longer used in nuclear plants. The desired characteristics are discussed in the following paragraphs.

Lead components should be fabricated with lead–calcium alloy. Nearly all batteries currently being installed have components made of a lead–calcium alloy rather than a lead–antimony alloy. Some older batteries have components made of a lead–antimony alloy, but their numbers are decreasing with time, as they are being replaced with new lead–calcium batteries. The use of aged batteries with components made of a lead–calcium alloy will permit the test results to apply more directly to batteries presently being installed.

Batteries should be at least 10 years old. The purpose of the program is to evaluate the seismic ruggedness of aged batteries. In addition, the testing performed by SNL utilized batteries that were at least 10 years old. The use of batteries that are at least 10 years old will provide test data obtained from naturally aged batteries and will also provide test data that can be compared to test data obtained by SNL.

Batteries should be of a flat plate design. Batteries currently being installed in nuclear plants are nearly all of the flat plate design. In addition, the majority of the older batteries that remain in nuclear plants are also of the flat plate design.

The capacity of the batteries should be about 85%. The objective of the program is to test naturally aged batteries that are approaching their end of life. The end of life with respect to electrical capacity has been identified by IEEE Std 450 as 80% of rated capacity. For this reason, batteries with a capacity smaller than and much larger than 80% are not desired.

Batteries should be from more than one manufacturer. The test results will have a more general application if batteries from more than one manufacturer are tested. It is desirable to obtain batteries from each of the three primary suppliers of nuclear power plant batteries (Exide, GNB, and C&D Batteries).

With the help of the Electric Power Research Institute (EPRI), who utilized the services of CFA, Inc., twelve batteries were obtained from the Arkansas Power and Light Company Arkansas Nuclear One (ANO) nuclear facility. These batteries were in good condition, and plant records indicated they had an electrical capacity of about 88%. The batteries were naturally aged (to 13–1/2 years) C&D LCU–19 batteries and were fabricated with lead–calcium plates. Discussions with C&D personnel indicated that they were typical of batteries presently being installed in nuclear facilities. Each battery had a rated 8–hour electrical capacity of 1350 ampere–hours, was 7–5/8 in. long, 14–1/8 in. wide, and 22–1/16 in. high, and weighed about 240 pounds. The batteries had been installed about September 1, 1974, and were removed about April 1988. Subsequent charging and testing of the batteries at the Idaho National Engineering Laboratory (INEL) showed that they had electrical capacities ranging from 92% to 98%, with an average capacity of 95%. A review of ANO test data obtained with the batteries indicated that they were well maintained according to practices consistent with those found in IEEE Std 450. Visual inspections at the INEL showed the batteries to be in good condition with no evidence of significant aging effects. Figure 3 is a photograph of one of the batteries that is typical of all twelve.

3.2 Test Configuration

Batteries were placed on the shake table in a two-step rack, purchased from the battery manufacturer (C&D Batteries), that has been seismically qualified for use in nuclear plants. The batteries were loaded in the rack and the rack attached to the shake table according to the manufacturer's instructions to simulate the way batteries are mounted in a nuclear facility. The manufacturer's instructions for assembling the batteries into the rack called for a 1/2-in. styrofoam spacer between each battery or simulated battery. Subsequent discussions with the manufacturer indicated that most nuclear facilities use material provided by the manufacturer or a nonflammable material that is compressible, but not as compressible as the styrofoam. Apparently most facilities used plywood until about 20 years ago, but since then have changed to a compressible material such as styrofoam or something similar.

The battery rack was mounted to two 4 x 46 x 3/4 in. carbon steel bars, using eight 1/2-13 Grade 5 bolts torqued to 75 foot-pounds. The bars were then welded to the shake table during the final installation. Figure 4 is a photograph of the batteries assembled in the rack and mounted on the shake table. Because a standard rack is designed to hold twelve batteries and the batteries were tested in groups of four, eight simulated batteries were built and installed to fill and load the rack as if it were filled with twelve batteries. The simulated batteries were fabricated of a combination of wood and steel to provide a solid unit of the same size and weight that had about the same center of gravity as the actual batteries. Figure 5 is a photograph of a simulated battery. As a result of discussions with the manufacturer of the batteries and battery rack, the four batteries were located at the end of the top step to subject them to the maximum accelerations. Initially, the simulated batteries were not interconnected to simulate the straps that interconnect the battery posts. However, prior to testing at the most severe seismic level, the simulated batteries were interconnected as shown in Figure 6.

3.3 Seismic Test Spectra

The batteries were subjected to seismic tests to determine how much electrical capacity would be lost as a result of shaking during a seismic event. The twelve batteries were divided into three groups of four batteries each. The first group was tested at both the lowest and highest seismic levels. The other two groups were tested at only one level of excitation to minimize fatigue effects that could bias the results. The groups were tested at the different levels described in the following paragraph.

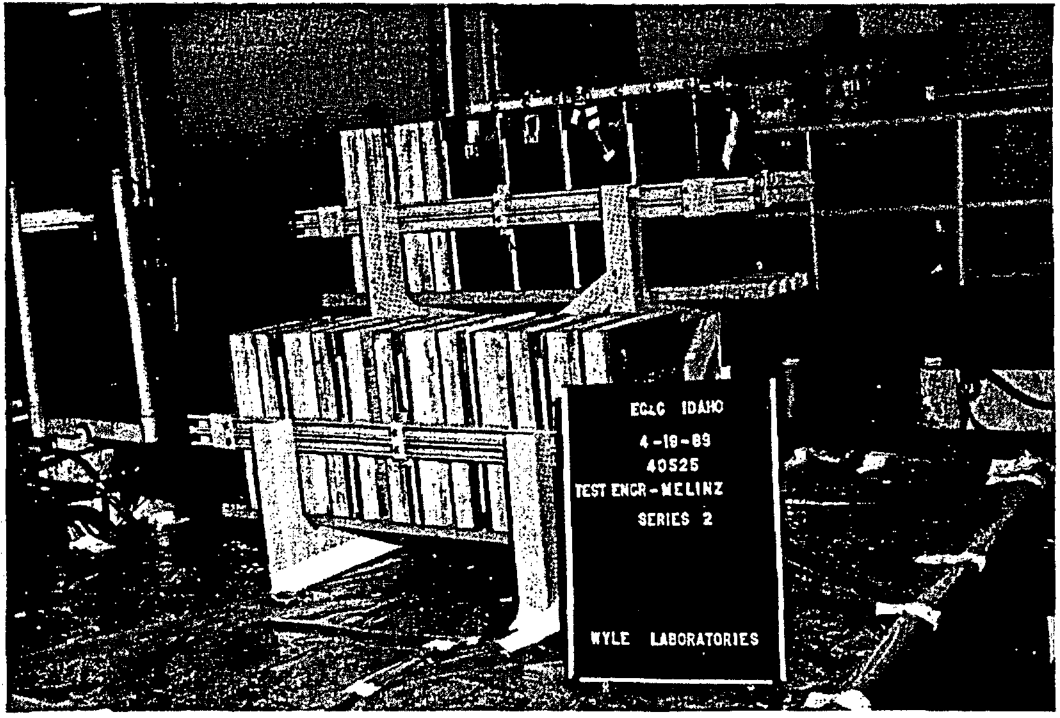


Figure 4. Batteries and rack assembled on the shake table.

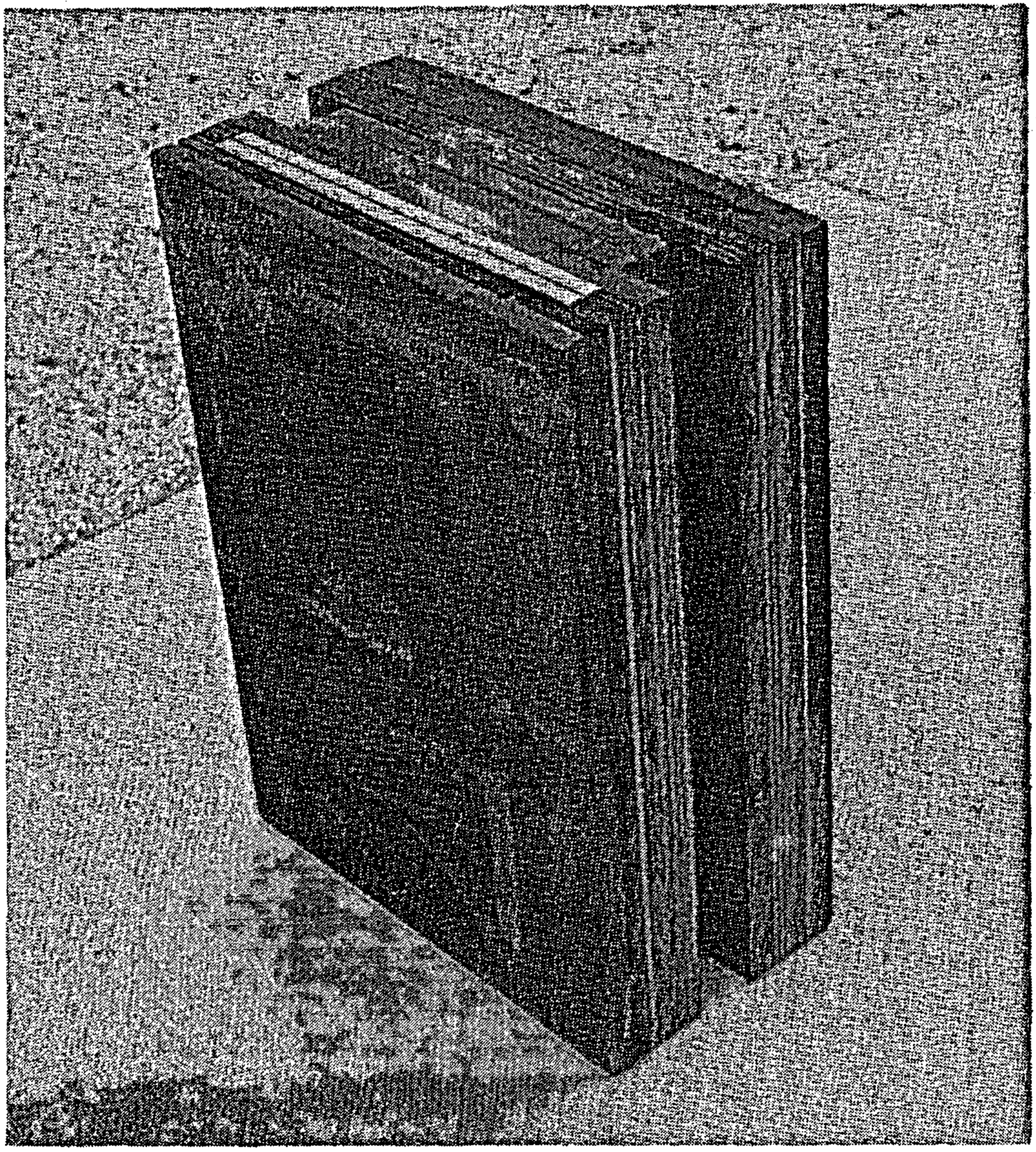


Figure 5. Simulated battery.

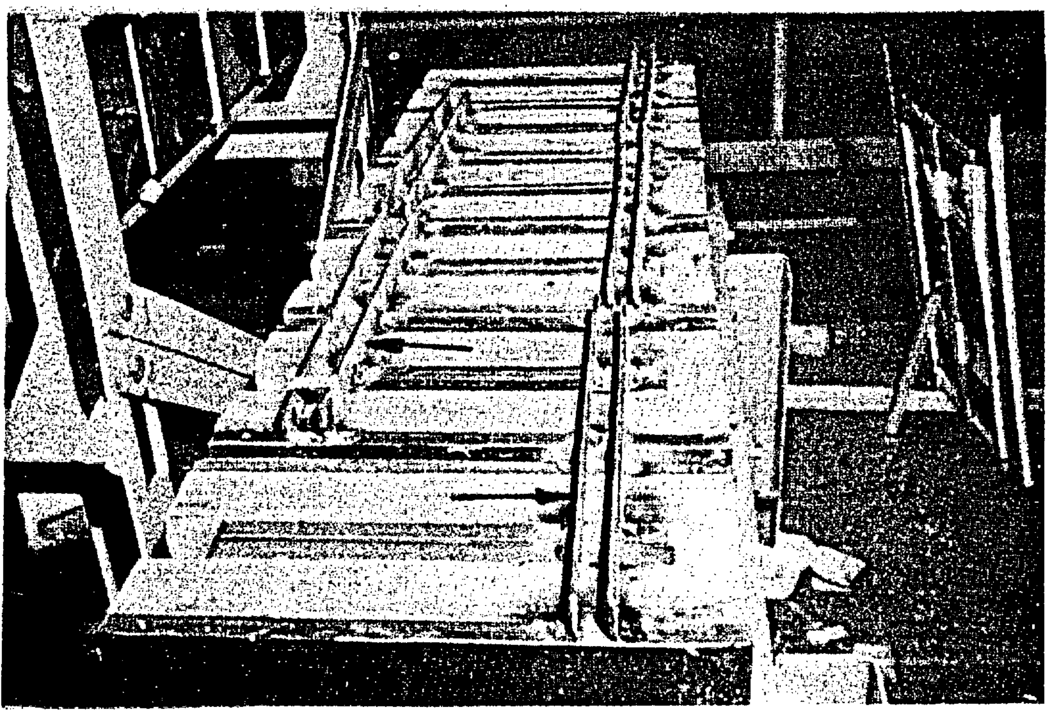


Figure 6. Simulated battery interconnected.

All batteries were tested using required response spectra (RRS) typical of the RRS for batteries in nuclear plants. Four levels of excitation were utilized, as shown in Figure 7. These curves are based on actual RRS curves received from various nuclear facilities located throughout the United States and on information received from EPRI showing the safe shutdown earthquake (SSE) levels for each nuclear plant in the United States. The curves selected use a damping factor of 2% and are the best estimates of excitations that encompass the RRS for batteries in 50%, 85%, 90 to 95%, and 100% of the nuclear plants in the U.S. In addition, the 95% level is a modification of a curve published in an EPRI report, NP-5223, "Generic Seismic Ruggedness of Power Plant Equipment,"[16] known as the GERS (Generic Equipment Ruggedness Spectrum) for batteries. This curve represents a level of seismic ruggedness for which there is a high degree of confidence that the batteries can endure and yet provide rated electrical capacity. The EPRI GERS curve, which is based on a damping value of 5%, was modified to approximate a 2% damping curve by increasing the peak excitation by a factor of 1.36. This value was obtained by calculating the ratio of the peak excitation for 2% to the peak excitation at 5% damping found in Regulatory Guide 1.60, "Design Response Spectra For Seismic Design of Nuclear Power Plants."[17]

The RRSs in each of the two horizontal directions (in a three-axis system) were equal, and the vertical/horizontal input ratio was between 1.0 and 0.67. The excitation for the seismic testing was random in nature with 2% damping. This value of damping has been specified by some nuclear plants and was representative for structures in IEEE Std 344-1975.[18] Since IEEE Std 344 states that an earthquake of magnitude 6.0 or higher on the Richter scale may persist for 15 to 30 seconds with the major energy content usually occurring in the first 5 or 10 seconds, the duration of each test was about 30 seconds.

3.4 Battery Handling

Batteries were handled and shipped with precautions to assure that no damage would be caused or that any existing degradation would not be aggravated. Manufacturer's instructions were followed, which included the procurement and use of a lifting sling designed specifically to lift the batteries. The batteries were shipped by air-ride-van from ANO to the INEL and between the INEL and the test facility (Wyle Laboratory, Huntsville, Alabama) to minimize the possibility of damage in transit from large impact forces or vibrations.

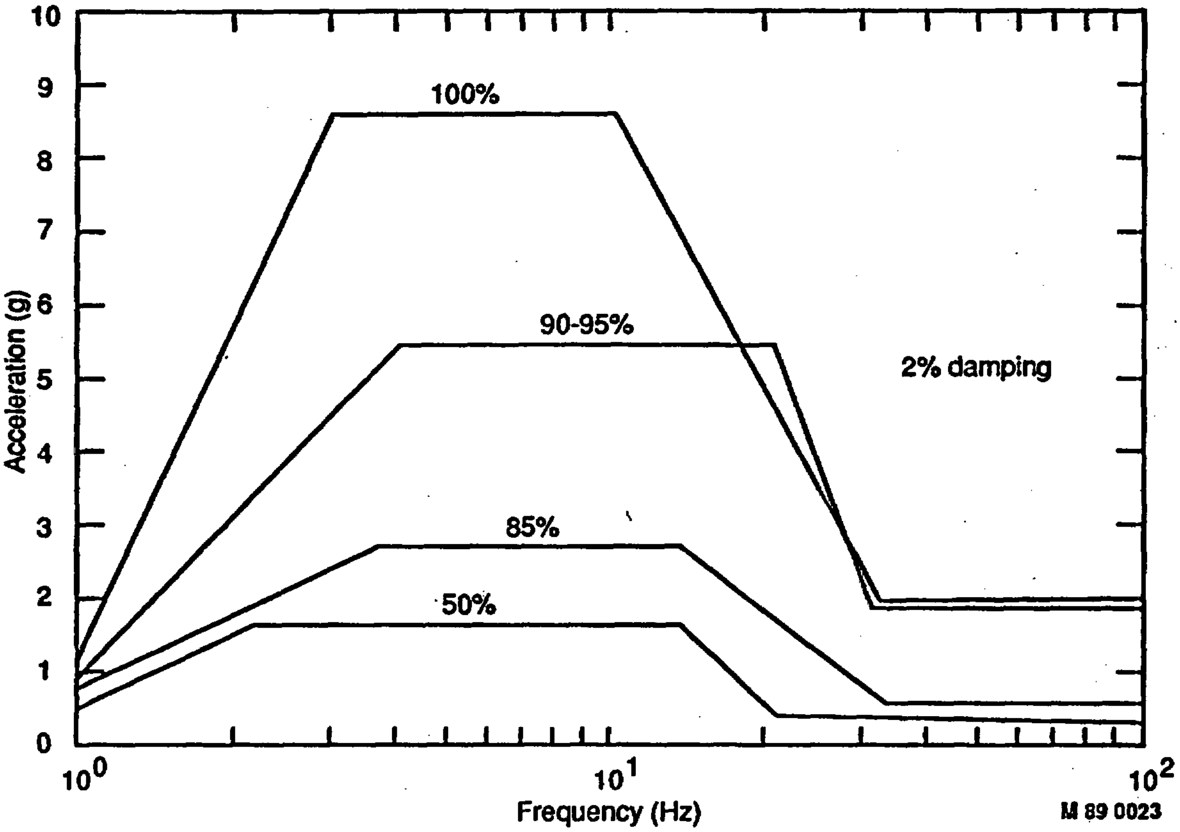


Figure 7. Required response spectra for seismic testing.

3.5 Battery Testing

Batteries were tested to determine their condition at each step of the program and to evaluate selected advanced surveillance methods. The tests to determine battery condition are standard tests prescribed in IEEE Std 450.

Visual examinations: After the batteries were received at INEL or at the test facility they were inspected for proper electrolyte level, leaks, excess sediment, broken parts, cracks, crazing, and damage that was obviously caused during transit. The batteries were photographed, with special attention given to abnormalities. The visual examinations were also performed after each level of seismic testing. No batteries were damaged during transit, and all twelve completed the entire test program.

Preseismic tests: After receipt at INEL the batteries were charged and subjected to a stand test and capacity tests to verify that they were acceptable for seismic testing. Batteries were charged at the manufacturer's recommended rate until specific gravity readings, corrected for temperature, stabilized. Batteries were then placed on a 2–week stand test at room temperature to verify that they would hold a charge. Batteries whose voltage had fallen below 2.03 V (beginning at about 2.07 V) or whose specific gravity had fallen more than 0.005 g/cm^3 (beginning at 1.207 g/cm^3) would have been considered defective. All batteries passed this test. To establish their capacity, batteries were discharged at the 3–hour rate, as provided in Paragraph 6 of IEEE Std 450–1987. The capacity tests were repeated two times at the INEL to verify that capacity remained constant (variability).

The capacity tests were repeated at the test facility to verify that the batteries had not degraded as a result of shipping.

Seismic testing: Seismic testing was performed in accordance with the referenced test plan and test specification. The test procedures are documented in Wyle Laboratories test report, 40525–1, "Seismic Simulation Test Program on Twelve Naturally–Aged LCU–19 Batteries," included in this report as Attachment B. For this testing the seismic levels specified in Figure 7 were used as the RRS. The batteries were shaken with a triaxial shake table. IEEE Std 344–1975 states that when a biaxial table is used, the equipment is to be shaken at two or four different orientations about the vertical axis (two, if the inputs are uncorrelated or random, and four, if the inputs are not random). However, as this was a research program and not a qualification program, repetitious biaxial shaking could have produced different results from single-event triaxial shaking because of the effects of fatigue. Accelerometers were placed on selected batteries during the seismic test sequence so response of the batteries could be compared with the input to the shake table, the response of the shake table, and the response of the battery rack.

Prior to the seismic shaking, the battery rack with eight simulated batteries and four batteries installed was subjected to low level (0.2 g) shaking to identify resonant frequencies for the rack and batteries. A single-axis sine sweep test was performed from 1 to 35 Hz in each of the three orthogonal axes. The sweep rate was one octave per minute.

During the seismic tests, batteries were discharged at 2% of the 3-hour rate, with current and battery voltages monitored to detect catastrophic failure. This rate is consistent with the rate recommended by IEEE Std 535-1986, paragraph 8.3.1.1(2).[10] Any battery that did not continuously provide at least 1.75 V would have been considered to have failed and not subjected to further testing. At all levels of seismic testing, battery voltages remained above 1.75 V.

For the seismic tests the batteries were divided into three groups with four batteries in each group. The groups were selected to provide the same average capacity for each group. The battery groups, their capacities, and the corresponding seismic levels are shown in Table 1.

Figures 8, 9, and 10 show the configuration of the batteries and simulated batteries on the rack for Groups 1, 2, and 3, respectively.

Seismic data (test response spectra, battery rack response, and battery response) were recorded on magnetic tape and plotted on paper by the test facility. The electrical response of the batteries was recorded by INEL personnel on a PC-based data acquisition system that stored the data on a 10 Mb disk and produced plots of the data. The sequence of activities at the test facility is shown in Table 2.

Postseismic tests: The batteries were visually inspected after seismic testing and before shipping back to the INEL, and capacity of the batteries was determined by discharging at the 3-hour rate. After the 3-hour discharge, the batteries were recharged to prepare them for return to the INEL.

At the INEL selected batteries were disassembled and examined for evidence of significant degradation as a result of either the seismic testing or the natural aging process. Battery condition was documented with both written descriptions and photographs. Results of the posttest examinations, the preseismic capacity tests, and the postseismic tests were compared to determine the adequacy of the seismic ruggedness of the batteries.

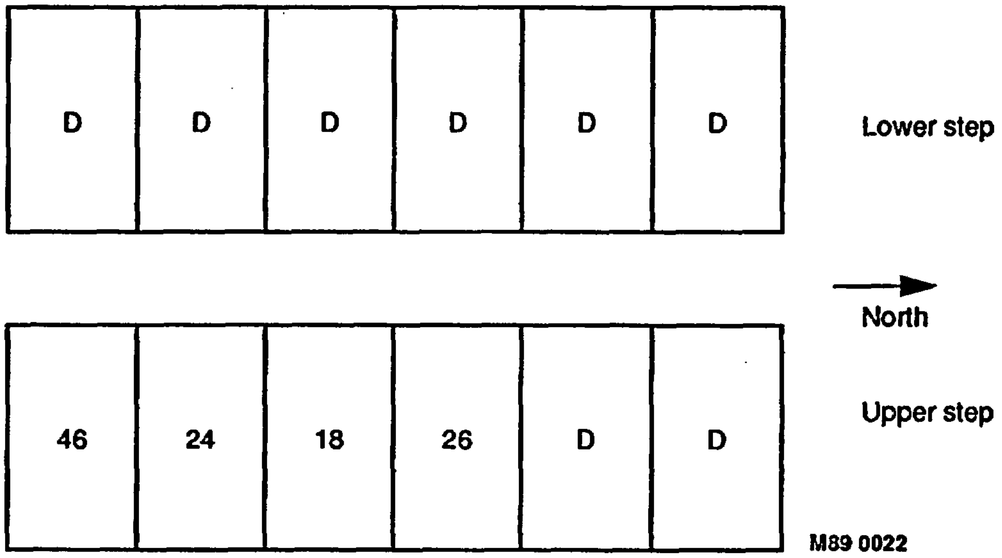
Testing of alternate surveillance methods: During the preseismic, seismic, and postseismic tests, alternate surveillance or monitoring methods that may be more sensitive to aging related degradation were tested. The alternate monitoring methods tested were (a) measurement of internal resistance, (b) measurement of capacitance, and (c) measurement of battery polarization (comparison of battery voltages measured while increasing discharge current with those obtained with decreasing discharge current). These measurements were suggested to provide an indication of battery condition in NUREG/CR-4533, "Program to Analyze the Failure Mode of Lead-Acid Batteries."[19] The report is a result of investigations performed by the Westinghouse R&D Center for SNL in 1986. The results of these alternate monitoring methods were compared to the electrical and seismic conditions of the batteries as determined by the standard tests. The objective of these measurements was to determine if one or more of them could provide a more sensitive measurement of aging degradation than the standard volt-ampere tests that determine the electrical capacity of batteries. The specific tests performed are described in the following paragraphs:

1. A polarization test in which fully charged batteries were discharged at increasing currents to 450 amperes and then decreasing currents back to zero. The current was increased or decreased in 50 ampere steps, with each step held a minimum of 1 minute to allow the battery voltage to stabilize. At each step battery voltage and current were recorded. The voltage for increasing currents was then compared to the voltage with decreasing currents.

Table 1. Battery groups, capacities, and seismic levels for testing

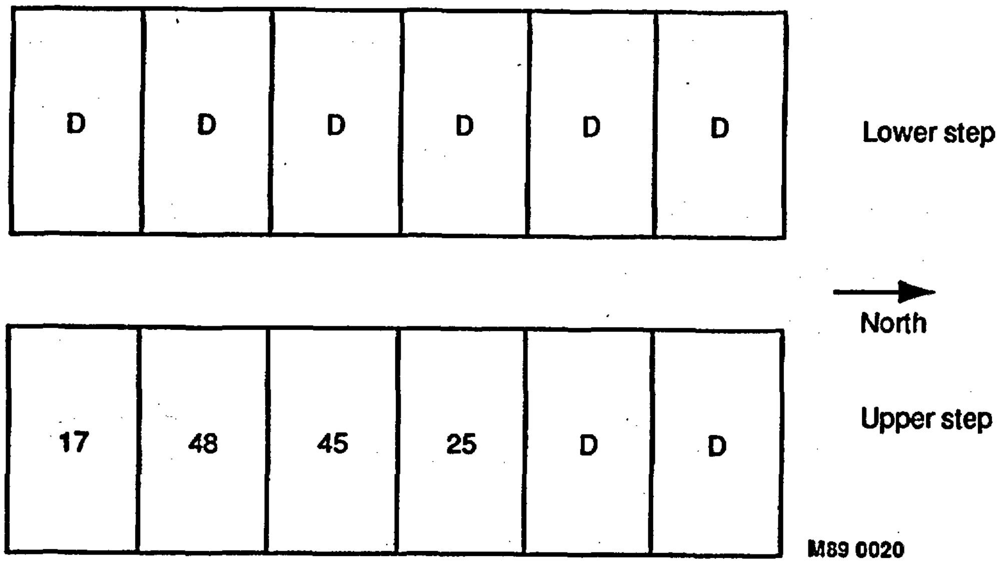
Group 1 50 and 100% Seismic Levels		Group 2 85% Seismic Level		Group 3 95% Seismic Level	
Battery No.	Electrical Capacity[a] (%)	Battery No.	Electrical Capacity[a] (%)	Battery No.	Electrical Capacity[a] (%)
18	92/93	17	97/96	23	94/96
24	94/97	25	94/96	29	93/99
26	97/94	45	98/99	30	94/96
46	96/98	48	92/94	47	98/98
Average	95/96	Average	95/96	Average	95/97

a. Capacities are electrical capacity in percent, INEL/Wyle.



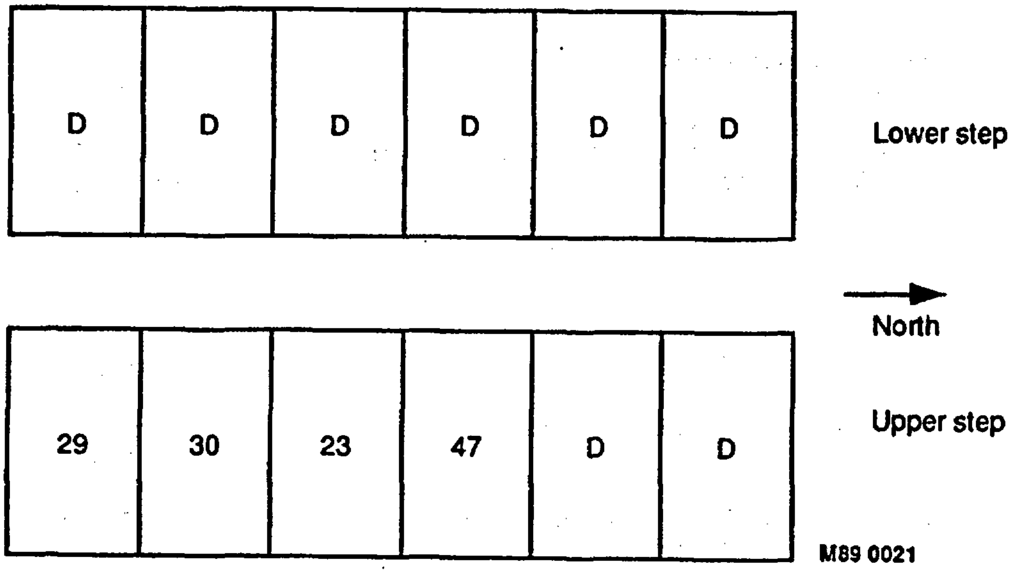
Notes:
1. D is simulated battery
2. Accelerometer installed on top of #24

Figure 8. Configuration for Group 1.



Notes:
1. D is simulated battery
2. Accelerometer installed on top of #48

Figure 9. Configuration for Group 2.



Notes:
1. D is simulated battery
2. Accelerometer installed on top of #30

Figure 10. Configuration for Group 3.

Table 2. Sequence of events at the test facility

	Activity	Performer
1.	Batteries and equipment arrive at Test Facility	INEL
2.	Verify capacity of batteries and recharge	INEL
3.	Verify alternate surveillance measurements	INEL
4.	Install battery rack on shake table (may be done during 2 and 3)	Test Facility
5.	Install first group of batteries and simulated batteries on battery rack. Electrically connect the batteries together	Test Facility and INEL
6.	Connect discharger and battery performance data acquisition system to the batteries	INEL
7.	Connect seismic related data acquisition	Test Facility
8.	Perform exploratory test and first level of seismic tests	Test Facility and INEL
9.	Remove first group of batteries and install the second group (includes 6 and 7)	Test Facility and INEL
10.	Perform second level of seismic tests	Test Facility and INEL
11.	Remove second group of batteries and install the third group (includes 6 and 7)	Test Facility and INEL
12.	Perform third level of seismic test	Test Facility and INEL
13.	Remove third group of batteries and install the first group (includes 6 and 7)	Test Facility and INEL
14.	Perform fourth level of seismic test	Test Facility and INEL
15.	Remove batteries and simulated batteries from rack and rack from the shake table	Test Facility
16.	Determine electrical capacity, recharge, and perform alternate surveillance measurements on all batteries	INEL

2. An instantaneous interruption of a 50 ampere discharge current. When the current is interrupted, the battery voltage experiences a step increase and then an exponential increase. The step increase in voltage in combination with the instantaneous decrease in current provides a measure of the internal ohmic resistance of the battery. The time constant of the exponential, in combination with the internal resistances of the battery, provides a measure of the capacitance of the battery. The parallel plates separated by a dielectric form a capacitor. Changes in the internal resistance and capacitance are believed to indicate the existence and kind of degradation that has occurred.

3. A step increase in charge current of 4 amperes. The transient also produces a step change and an exponential change in battery voltage that indicates internal resistance and capacitance of the batteries.

4. TEST RESULTS

The test results are described in three sections. The first section presents the results that relate to measurements that describe the seismic ruggedness of the batteries. The second section presents the results of the posttest disassembly and analysis of the batteries, and the third section describes the results of the advanced inspection and monitoring methods.

4.1 Seismic Test Results

As described in Section 3, battery condition was determined before and after seismic testing to determine whether seismic shaking caused the batteries to experience a decrease in electrical capacity. In addition, the seismic levels, battery discharge current, and battery voltage were monitored during the seismic tests to verify the level of seismic shaking and to monitor the performance of the batteries as the shaking occurred. Table 3 shows a summary of the seismic test results.

The actual, or test response spectra (TRS), accelerations for the various seismic levels are shown in the Wyle Laboratories test report, Attachment B. The accelerations for the 50% level are shown on pages B–57 through B–65; the 85% level on pages B–69 through B–77; the 95% level on pages B–81 through B–89; and the 100% level on pages B–93 through B–101. In addition the results of the frequency sweeps performed to determine the resonant frequencies are shown on pages B–47 through B–52. The magnitude of the vertical acceleration was always less than the horizontal acceleration, with the vertical usually about 70% of the horizontal. The data for the TRS contain significant scatter, 70 to 85% at the peak acceleration. Since the TRS was ranged to envelop the RRS closely, the lower values of the scatter are approximately equal to the RRS, and the upper values are greater than the RRS. The ZPA values for the TRS are consistently greater than the ZPA for the RRS. Because the shake table actuating system is a real, mechanical system, it generates some high frequencies with magnitudes greater than those input to the system by the controller. The effects are caused, in part, by tolerances in mechanical linkages, ringing in the hydraulic system, and inertia of the hydraulic system and the mechanical components. The results produced are typical of those expected from large, high capacity shake tables.

Results of the frequency sweeps, with the Group 1 batteries and simulated batteries installed, show that the resonant frequencies were about 12 Hz front to back (east–west), 9 Hz side to side (north–south), and 25 to 30 Hz vertical. This means that the peak horizontal accelerations during the seismic test occurred at frequencies that included the resonant frequency for the assembly and should have produced maximum accelerations for the batteries. In general, the vertical resonant frequencies were just higher than the frequency corresponding to the peak of the RRS and TRS curves. The above values for resonant frequencies are consistent with experience reported in EPRI report NP–5223, "Generic Seismic Ruggedness of Power Plant Equipment," May 1987.

A review of the data in Table 3 shows that the batteries did not experience a decrease in electrical capacity as the seismic level increased. In fact, the electrical capacity appears to have increased as a result of the 100% level shaking. Discussion with the battery manufacturer indicated that this effect agrees with their experience. It is believed that the high level shaking created many small fractures in the active material, which provides a larger surface area to the electrolyte, resulting in more efficient electrolyte penetration into the relatively thick plates.

During each seismic level of testing, the batteries were discharged at 2% of the 3–hour rate (7 amperes) with battery voltages and current being monitored. Plots of the battery voltages are shown on pages B–125 through B–128 of the Wyle test report (Attachment B). During the seismic tests, there were no anomalies in the batteries' performance. Large variations in voltage did occur near the beginning of the 100% level test, but since these occurred on all four batteries at the same time, they are believed to have been caused by the measurement and data acquisition system or by a poor connection in the discharge circuit rather than a fault in the batteries. Analysis of the discharge current data showed that the current did not vary during the 100% level seismic test.

After each level of testing the batteries and battery rack were inspected for damages. Except for scrape marks on battery cases caused by the battery rack tie rods and loosening of fiberglass from the mats used for plate separators, no battery damage was observed. Some loss of electrolyte did occur in the 100% level test as a result of loosening of the seal between the cover and jar. However, this loss was not enough to reduce the capacity of the batteries. Bending of some battery rack parts was observed after the 100% level test; however, the battery rack successfully held the batteries and performed as required for SSE events (equipment must be held in place and equipment must

Table 3. Summary of seismic test results

	Electrical Capacity (%)			Acceleration (g)			
				RRS		TRS	
Battery Number	Preseismic INEL	Preseismic WYLE	Postseismic WYLE	Peak	ZPA	Peak	ZPA
	Group 1 – 50% level			1.68	0.27	3.1[a]	0.8
18	92	93	95				
24	94	97	94				
26	97	94	96				
46	96	98	98				
Average	95	96	96				
	Group 2 – 85% level			2.67	0.55	5.0[a]	1.5
17	97	96	100				
25	94	96	93				
45	98	99	97				
48	92	94	97				
Average	95	96	97				
	Group 3 – 95% level			5.44	1.84	9.3[a]	3.0
23	94	96	93				
29	93	99	93				
30	94	96	96				
47	98	98	96				
Average	95	97	95				
	Group 1 – 100% level			8.5	2.0	15.0[a]	6.0
18	92	93	95				
24	94	97	98				
26	97	94	99				
46	96	98	100				
Average	95	96	98				

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a. Data point with the largest magnitude. The TRS, or actual data, contains significant scatter. The lowest points at the peak are approximately equal to the RRS up to 20 Hz.

function as required, but some structural damage is permitted). Batteries 25 and 45 from the 85% level, 23 and 47 from the 95% level, and 18 and 26 from the 100% level tests all showed scrape marks from rubbing on the upper tie rod of the battery rack. The scrape marks became more evident as seismic levels increased, but in no case were they severe enough to cause the battery case to leak or crack. All batteries subjected to 100% level tests had fiberglass, dislodged from the separator mat, lying on the inside of the battery case. However, this degradation did not cause the batteries to malfunction during shaking or to have reduced electrical capacity. Figure 11 shows a battery with scrape marks that are typical of the observed damage, and Figure 12 shows a battery with fiberglass lying on the inside of the case. Figure 13 shows typical damage to the battery rack. Additional photographs are shown on pages B–41 through B–44 of the Wyle test report (Attachment B). The following battery rack damage was observed after the 100% level test:

- The cross braces were bent
- The lower tie rod broke
- The inside vertical supports sustained significant buckling.

The battery rack was tested at the 100% level with only simulated batteries installed to verify the shake table control settings. Results of that test indicated a potential for battery rack damage. To minimize the likelihood of battery rack damage, some precautionary measures were taken before performing the 100% level test with batteries installed. These measures include the following activities:

- The battery rack was completely emptied, and all bolts were retorqued.
- The simulated batteries and batteries were reinstalled according to the manufacturer's instructions.
- Straps were welded to the top of the simulated batteries (pages B–38 and B–39 of Wyle test report, Attachment B). As a result of conversations with the battery manufacturer, it was decided that this design would simulate how batteries are installed in the rack.

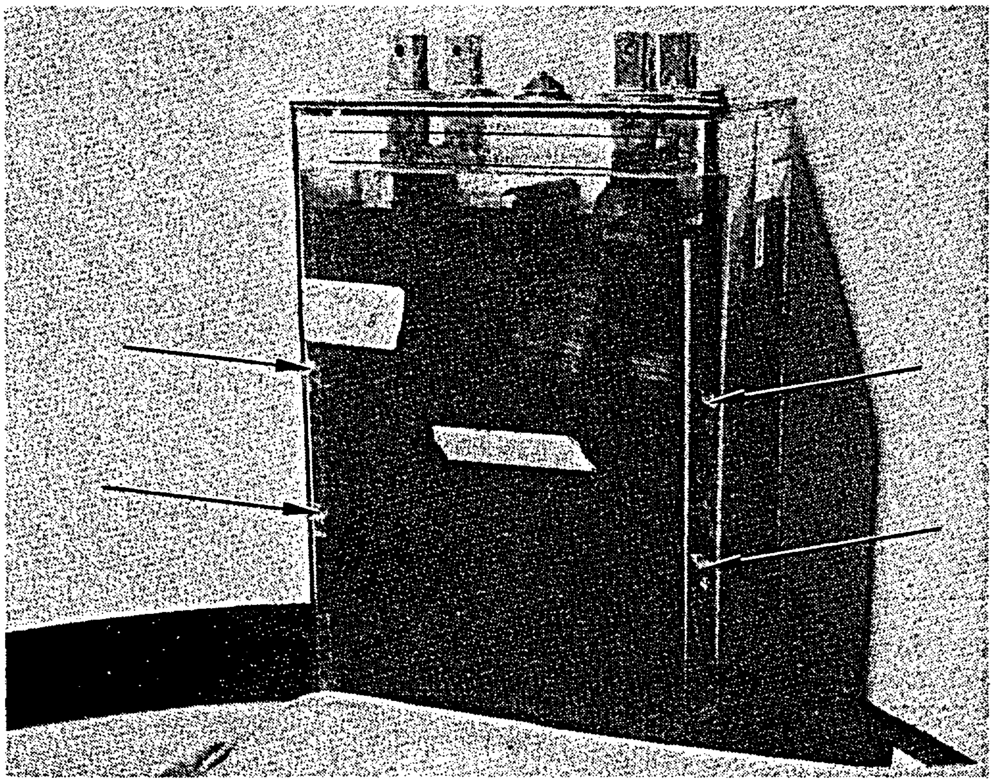

Figure 11. Scrape marks on battery caused by the battery rack tie rods.

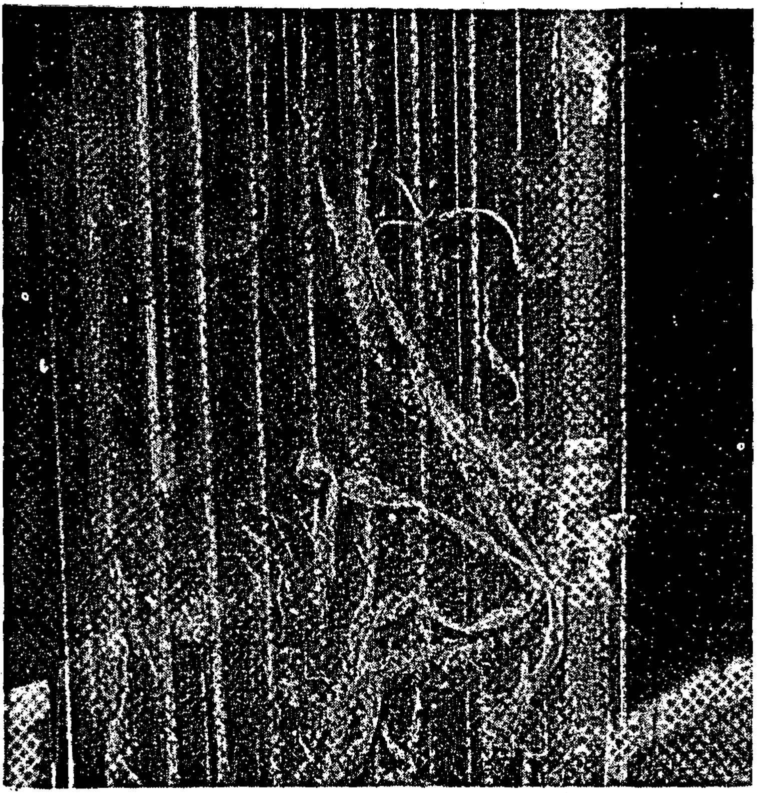

Figure 12. Fiberglass dislodged from separator (100% seismic level).

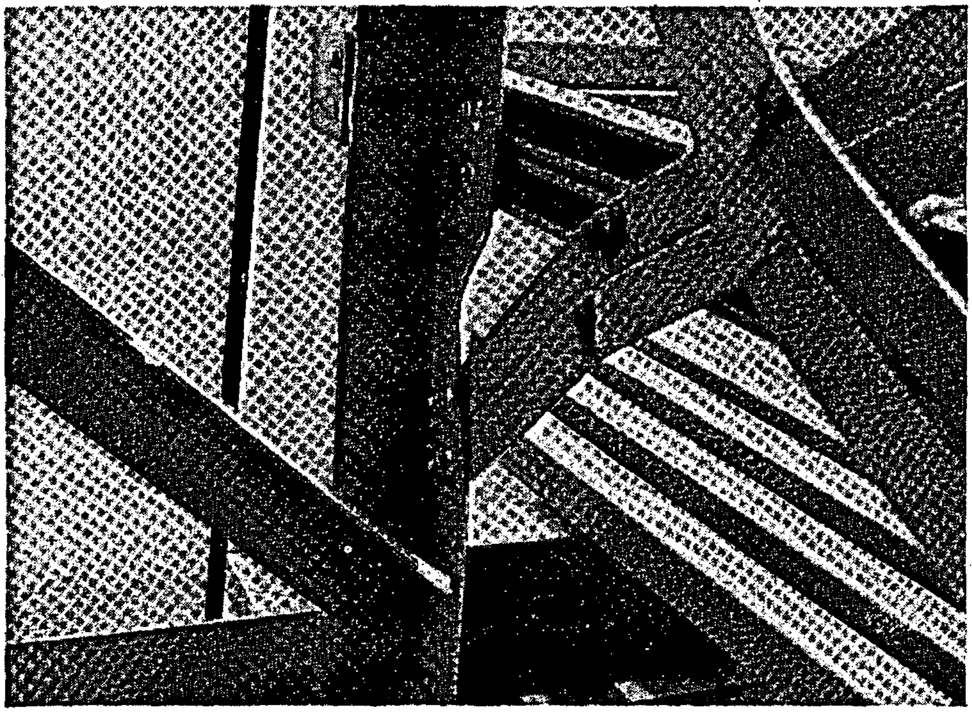

Figure 13. Typical battery rack damage after 100% seismic level.

4.2 Results of Posttest Disassembly

After the seismic tests had been performed, two batteries were disassembled at the INEL to determine if additional evidence could be found of degradation due to either natural aging or the seismic testing. Two batteries, 25 and 26, where chosen for the disassembly. One of these batteries (No. 25) was tested at the 85% level and the other (No. 26) at the 100% level. Both batteries were located in the same position on the battery rack, were scraped by the battery rack tie rods, and were at the interface between the simulated batteries and the actual batteries. In addition, both batteries should have been exposed to identical environmental conditions, since they would have been located adjacent to each other while being used by ANO.

After discussions with the battery manufacturer, the joint between the battery case and cover was broken and the battery terminals, cover, and internals were withdrawn as a unit by lifting from the battery posts. One negative and one positive plate from each battery were cut from the upper busses and examined. As the battery internals were withdrawn, the dislodged fiberglass in No. 26 became very apparent, as shown in Figure 14; no evidence of dislodged fiberglass was apparent for No. 25, as shown in Figure 15. Dislodging of the fiberglass, then, was caused by the 100% level seismic shaking. Except for the scrape marks caused by the battery rack tie rods and the dislodged fiberglass, no other degradation caused by the seismic testing was apparent. The color of the plates was as expected for an aged battery, metal colored for the negative plates and black lead-oxide colored for the positives. About the same amount of sediment was found on the bottom of the cases in both batteries. The amount of sediment was small (not more than 1/8 in. thick) and was not indicative of excessive oxidation or sluffing of lead-oxide.

After being cut from the busses, the positive and negative plates were inspected for evidence of degradation and measured to determine if significant growth had occurred as a result of aging. The negative plates were in generally good condition. The grid structure was not broken, the active material was not loose, and the general appearance was good. Although some evidence of loss of active material was evident, all grid locations contained active material. Figure 16 shows a negative plate with some loss of active material. The positive plates were in good condition with some loss of active material, no loose active material was apparent, and there was no significant bowing of the plate caused by

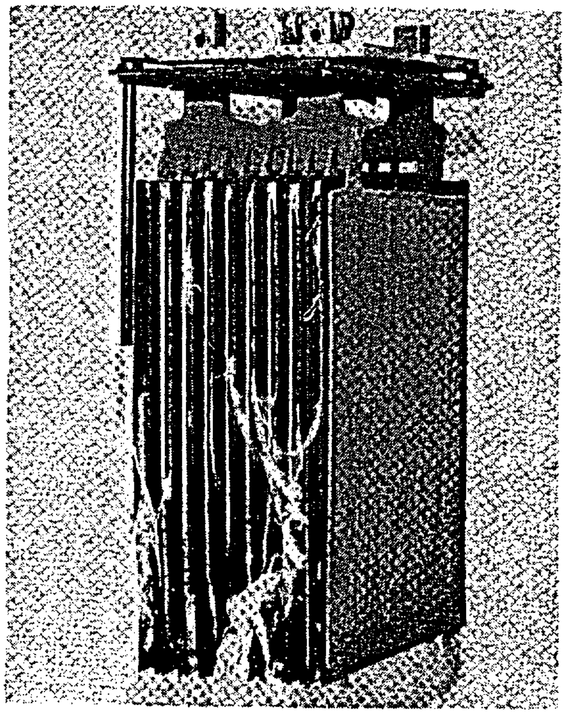

Figure 14. Dislodged fiberglass evident as Battery 26 is being disassembled.

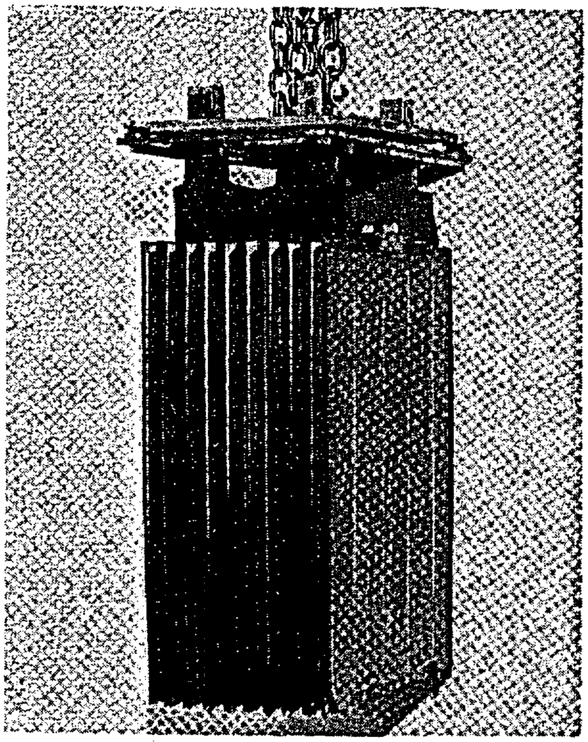

Figure 15. Battery 25 with no dislodged fiberglass.

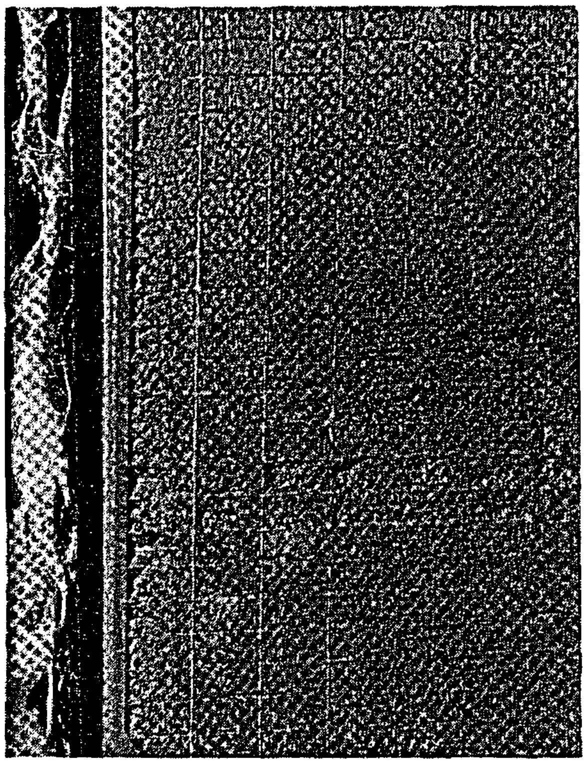

Figure 16. Naturally aged negative plate from Battery 26.

swelling. Figure 17 shows a positive plate. The plates were measured to compare with the specified dimensions. The negative plates did not show evidence of significant dimensional changes, while the dimensions of the positive plates grew about 2%. Discussions with the battery manufacturer indicate that this amount of growth is expected for naturally aged batteries that have been operated under normal conditions for 14 years. The average dimensions for the positive and negative plates are shown in Table 4.

The attachment of the plates to the busses was tested by attempting to pull the tang welded to the buss. Each plate has a tang at the top to permit the plate to be welded to the buss. This tang was cut during the disassembly process. Attempts to pull off the negative tang resulted in bending the tang about 90 degrees, indicating that the attachment was still good. Because the lead in the negative plates does not oxidize, it was still soft and pliable. Attempts to pull off the positive tang resulted in breaking the tang off without significant effort and without bending the tang. This indicates that the positive lead was more brittle, and the connection not as strong. This observation was true for both batteries. Visual examinations showed that the weld area of the positive plates appeared to have corroded, with about half of the weld area being corroded. This effect is shown in Figures 18 and 19 for Batteries 25 and 26. Since this effect is about the same for both batteries, it appears to be an aging-related degradation or a result of the manufacturing process rather than a result of the seismic testing. Because the plates are welded from the back of the strap, it is difficult to get complete back-to-front fusion without melting the tangs.

It should be noted that even though the weld area was degraded, it was strong enough to withstand the most severe seismic level required for U.S. nuclear plants. What is not known is whether this corrosion was progressing at a rate that could have caused degraded seismic performance while electrical capacity, as determined by the IEEE Std 450 criteria, was still satisfactory. In addition it is not known whether this corrosion could have progressed significantly faster had the batteries been operated in a more severe environment, such as at a higher temperature or with more charging. If so, under different conditions the same batteries might not have had the seismic ruggedness that they exhibited during these tests.

Metallographic examination of the weld area was performed to investigate the characteristics of the weld. Results indicate that where fusion occurred, the weld joints were good, some surface cracks or laps in the fusion zone were present, and the grain structure was as expected for a weld of lead components. The surface cracks in the fusion zone should not have a noticeable effect on the strength of the weld. Figure 20 is a micrograph of the weld showing a small crack, and Figure 21 shows the interface of the weld and parent material. There are no discontinuities at the interface, which indicates that the fusion is good. The larger grain structure can be expected, since lead has a low melting point and a low recrystallization temperature. However, the larger grain structure of the fused zone made it susceptible to corrosion and would explain the observed corrosion pattern.

4.3 Evaluation of Advanced Surveillance and Monitoring Methods

As previously described in Section 3.5, advanced surveillance methods were tested to determine if any could be more sensitive to age-related degradation than the traditional voltage-vs-time discharge tests. The tests performed were (a) measurement of internal resistance, (b) measurement of capacitance, and (c) measurement of battery polarization (comparison

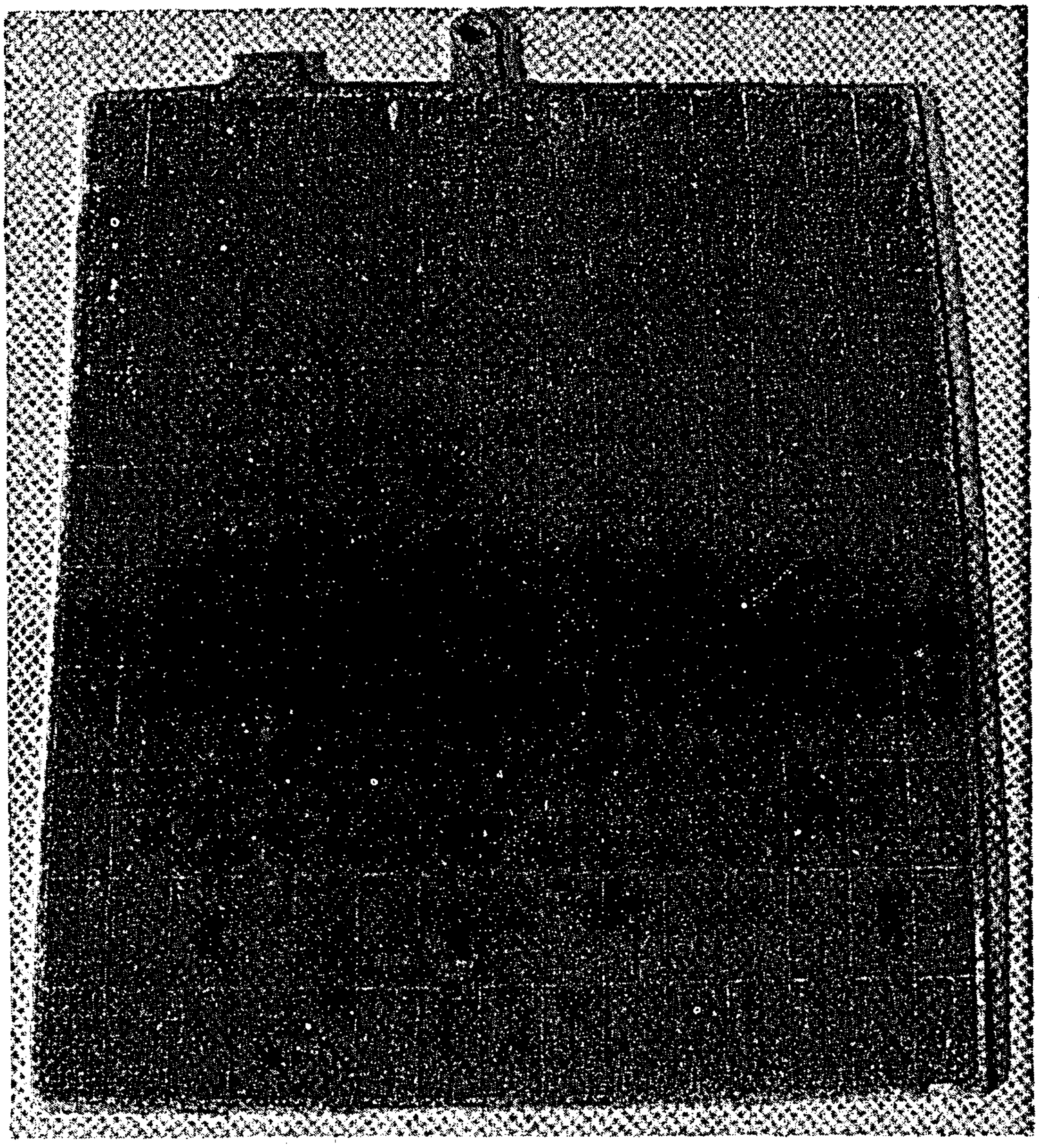

Figure 17. Naturally aged positive plate from Battery 25.

Table 4. Dimensions for negative and positive plates

	Width (in.)	Length (in.)	Thickness (in.)
Negative plates			
Specification	12	15	0.130
Battery 25	11.979	15.029	0.136
Battery 26	11.932	15.001	0.137
Positive plates			
Specification	12	15	0.312
Battery 25	12.236	15.311	0.320
Battery 26	12.245	15.306	0.321

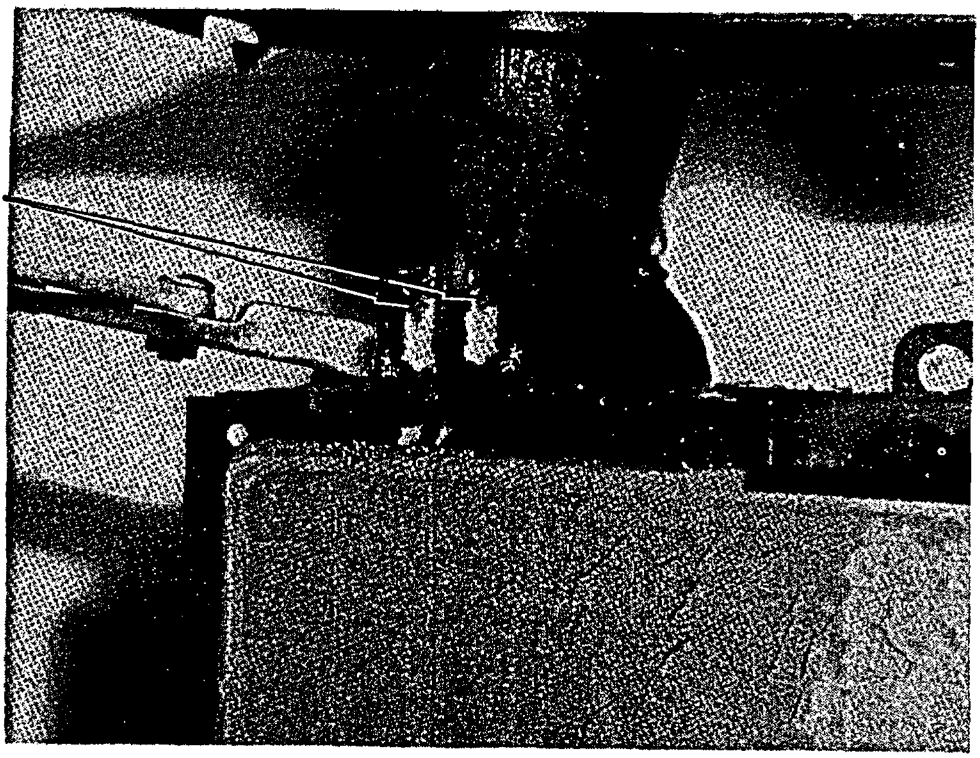
Degraded area of the weld

Figure 18. Degraded weld area for positive plate of Battery 25.

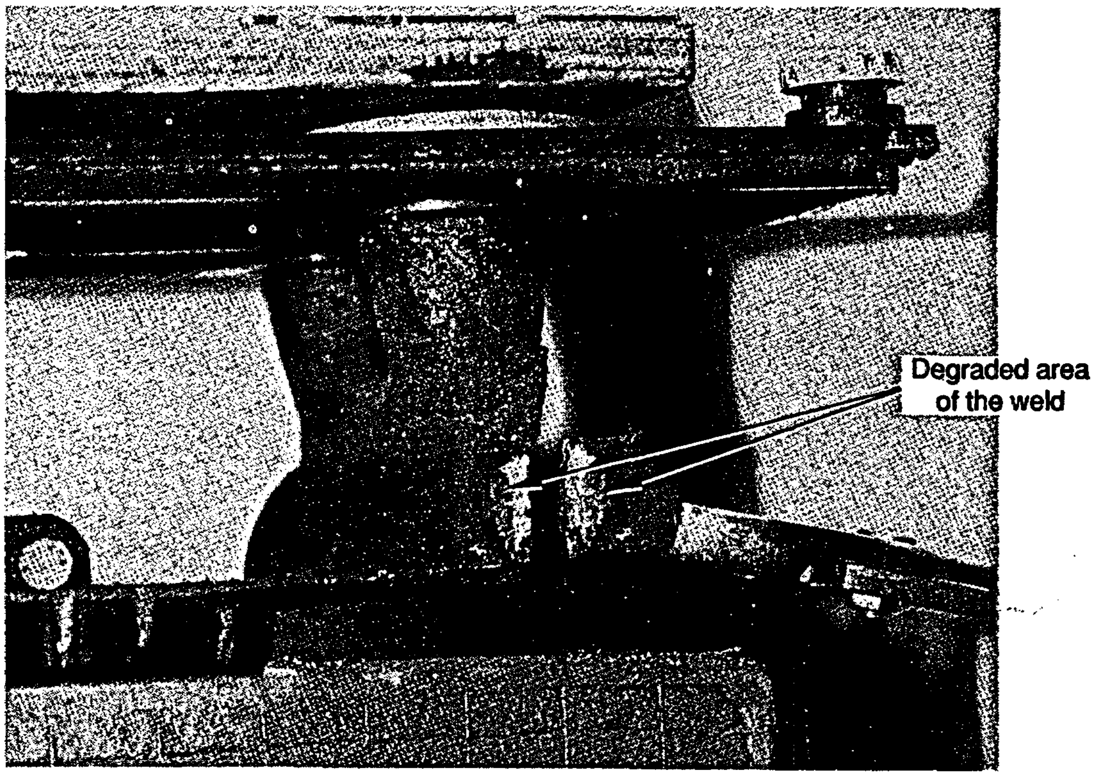

Figure 19. Degraded weld area for positive plate of Battery 26.

Figure 20. Micrograph of weld.

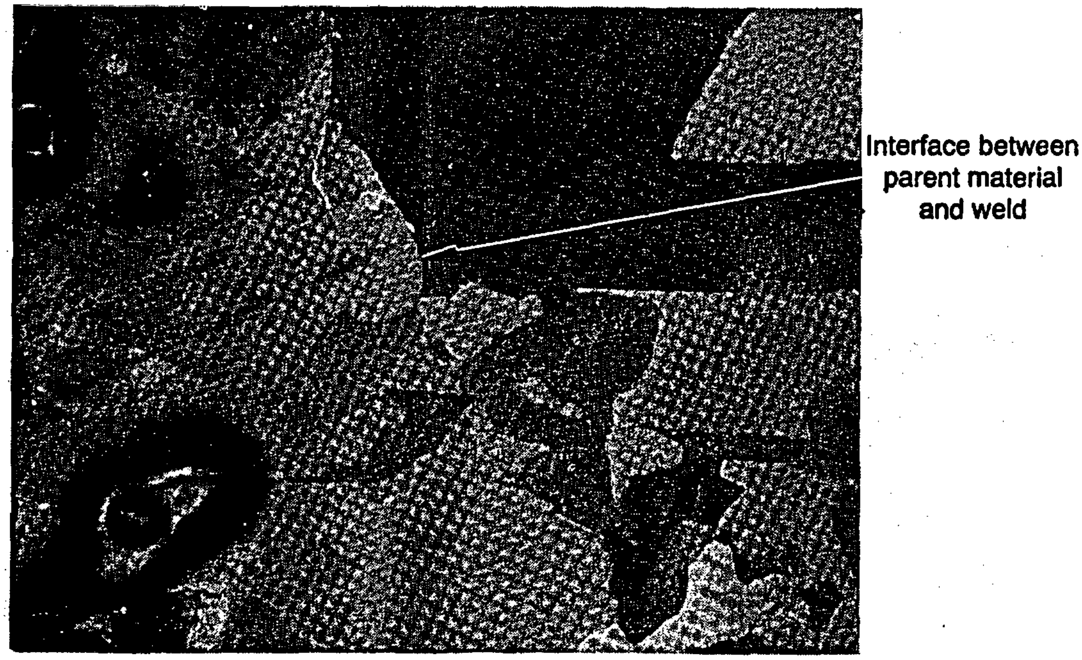

Figure 21. Micrograph showing the interface of weld and parent material.

of battery voltages measured while increasing discharge current with those obtained while decreasing discharge current). Two techniques were tested to measure internal resistance and capacitance: (a) a step increase in charging current with step and exponential voltages being measured and (b) a step decrease in discharge current with the same measurements. A more detailed description of the circuits and equations utilized are presented as a part of Attachment A.

The step decrease in discharge current involved rapidly decreasing the discharge current from 50 to 0 amperes. As can be seen in Figure 22, the step decrease in current occurred in less than 0.4 millisecond. Figure 23 shows the step rise and the subsequent exponential rise in battery voltage. The voltage data were recorded with a data acquisition system in which the data were filtered at 10 Hz, which corresponds to a rise time of about 0.035 seconds. Since the shortest time constants observed in the battery voltage were about 0.3 seconds, the filtering did not introduce noticeable error.

Analysis of the data utilized an equivalent circuit for a battery, as shown in Figure 24. The equivalent circuit assumes that the battery contains ohmic resistance primarily caused by the lead components, a reaction resistance associated with the electrochemical reaction between the electrolyte and the plates, a voltage caused by the electrochemical reaction, and capacitance related to the parallel plates separated by a dielectric material (acid and separator). It is important to recall that the electrochemical voltage is dependent upon the strength of the acid, the composition of the active material in the plates, and the temperature of the battery. During charging and discharging, all of these factors are changing, hence the voltage in the battery is changing.

To solve for the reaction resistance and capacitance, it was necessary to fit the data to an exponential curve and determine the time constant and final voltage. Attempts were not successful to fit the exponential portion of the data to a curve with a single time constant, and the data appear to be composed of multiple time constants. The use of three time constants provided a reasonably good fit to the data. Examples of the data and the curve fit for 20 and 200 second time durations are shown in Figures 25 and 26. Note that the starting voltage of the battery has been subtracted so that the voltage is zero at time = 0 seconds. The equation used is

$$E = (1 - \mathrm{Exp}{-t/T_s})[E_s + E_m(1 - \mathrm{Exp}{-t/T_m}) + E_l(1 - \mathrm{Exp}{-t/T_l})].$$

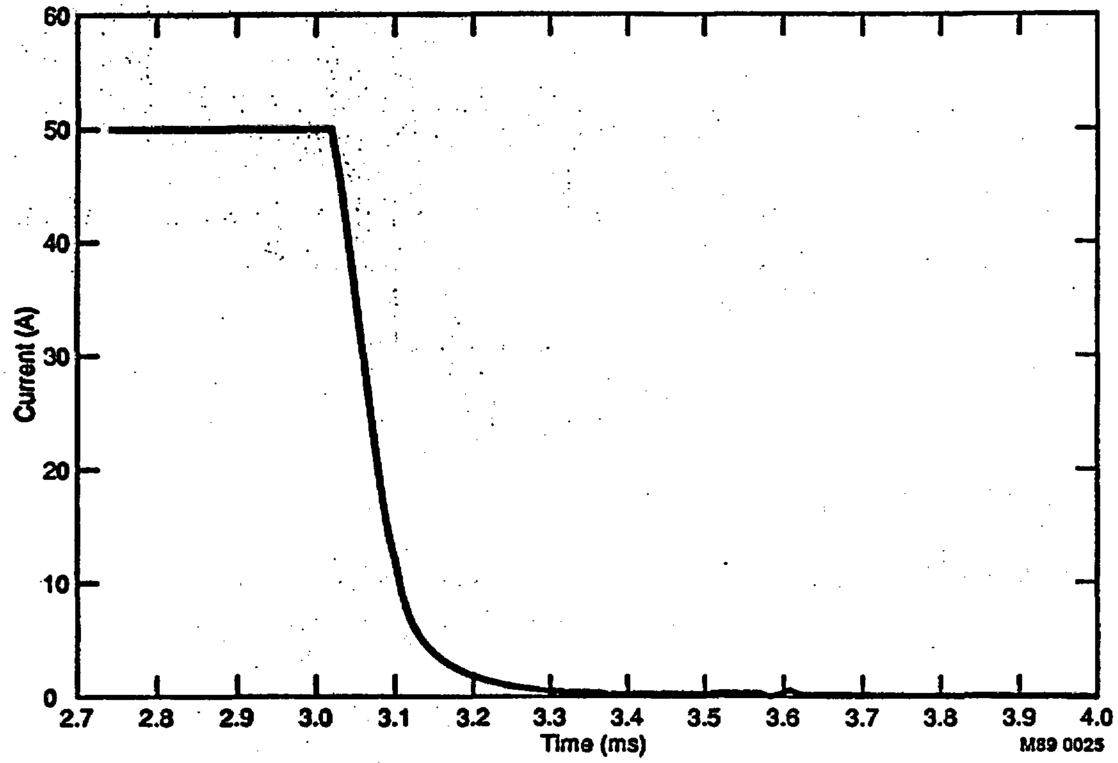

Figure 22. Step decrease in discharge current.

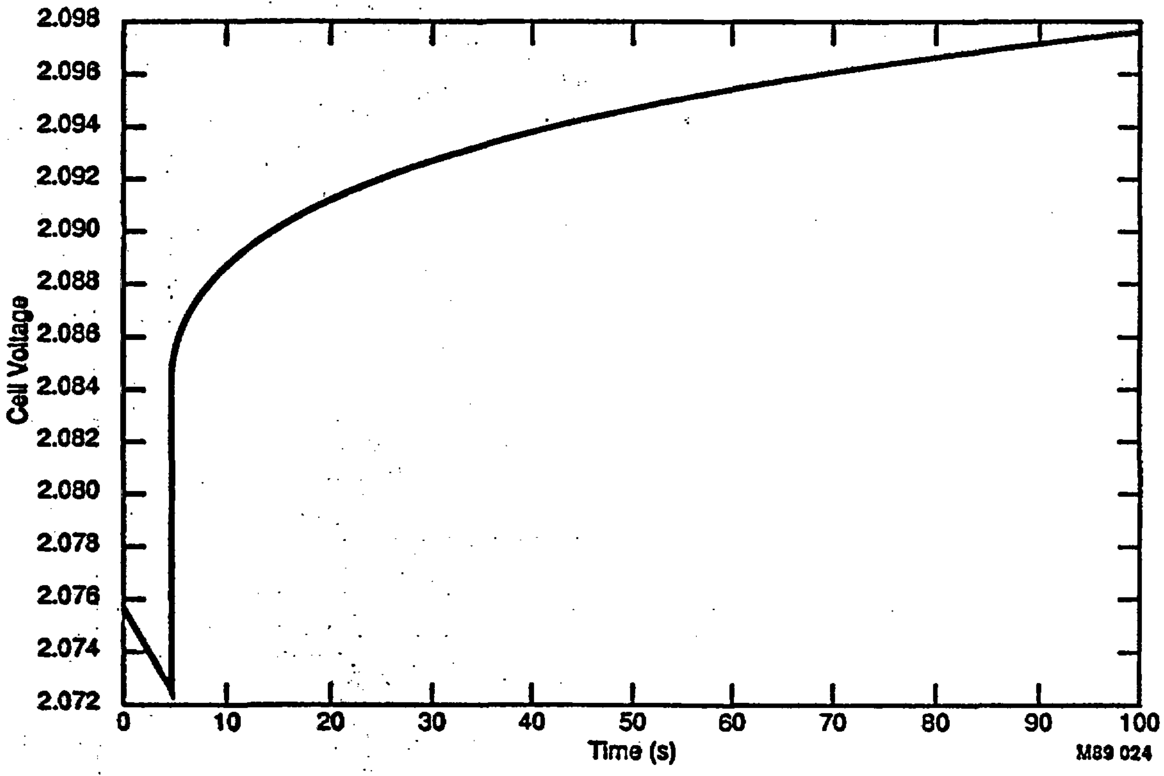

Figure 23. Battery voltage in response to step decrease in discharge current.

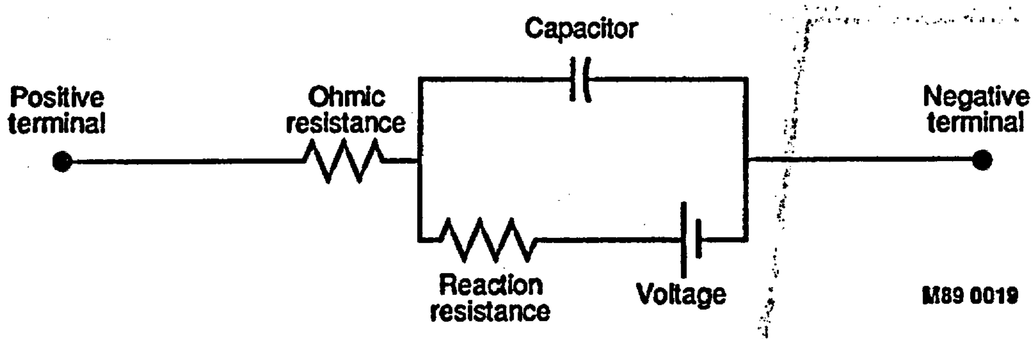

Figure 24. Equivalent battery circuit.

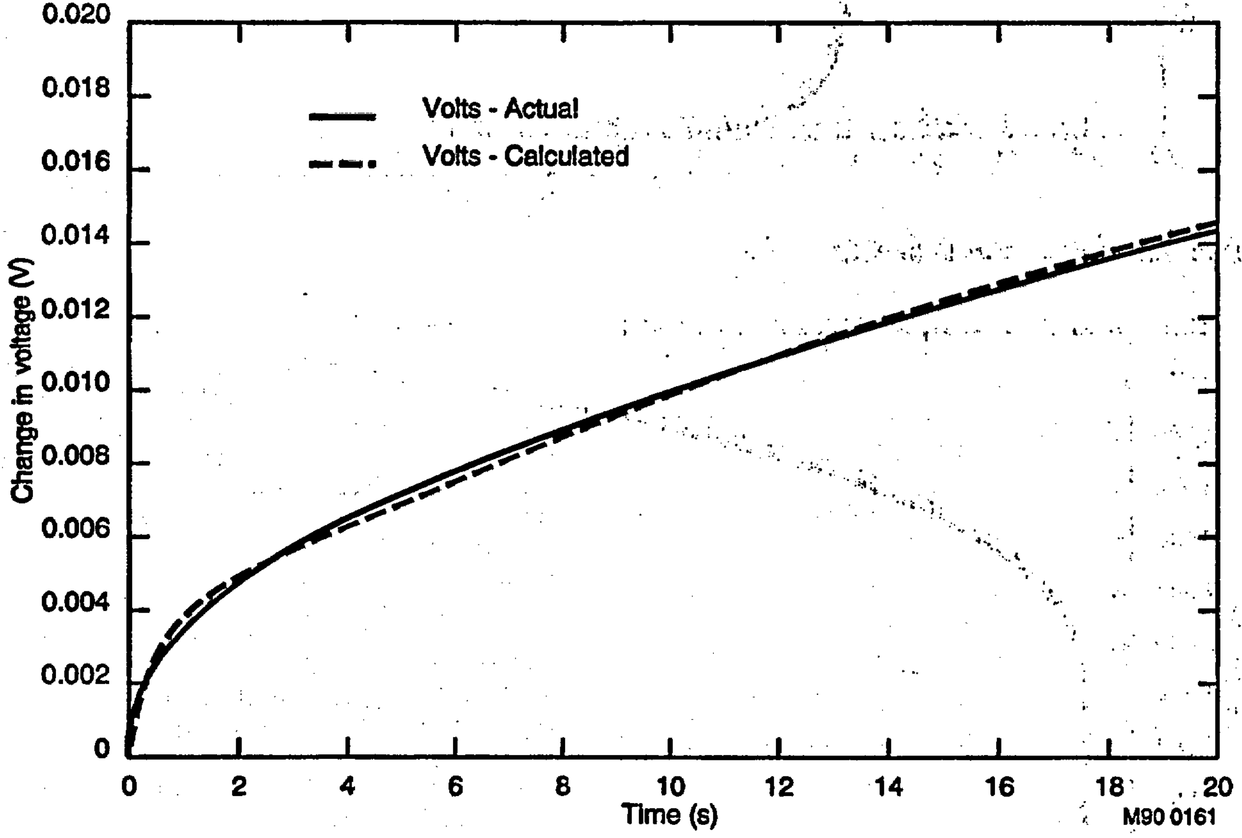

Figure 25. 20-second plot of data and curve fit.

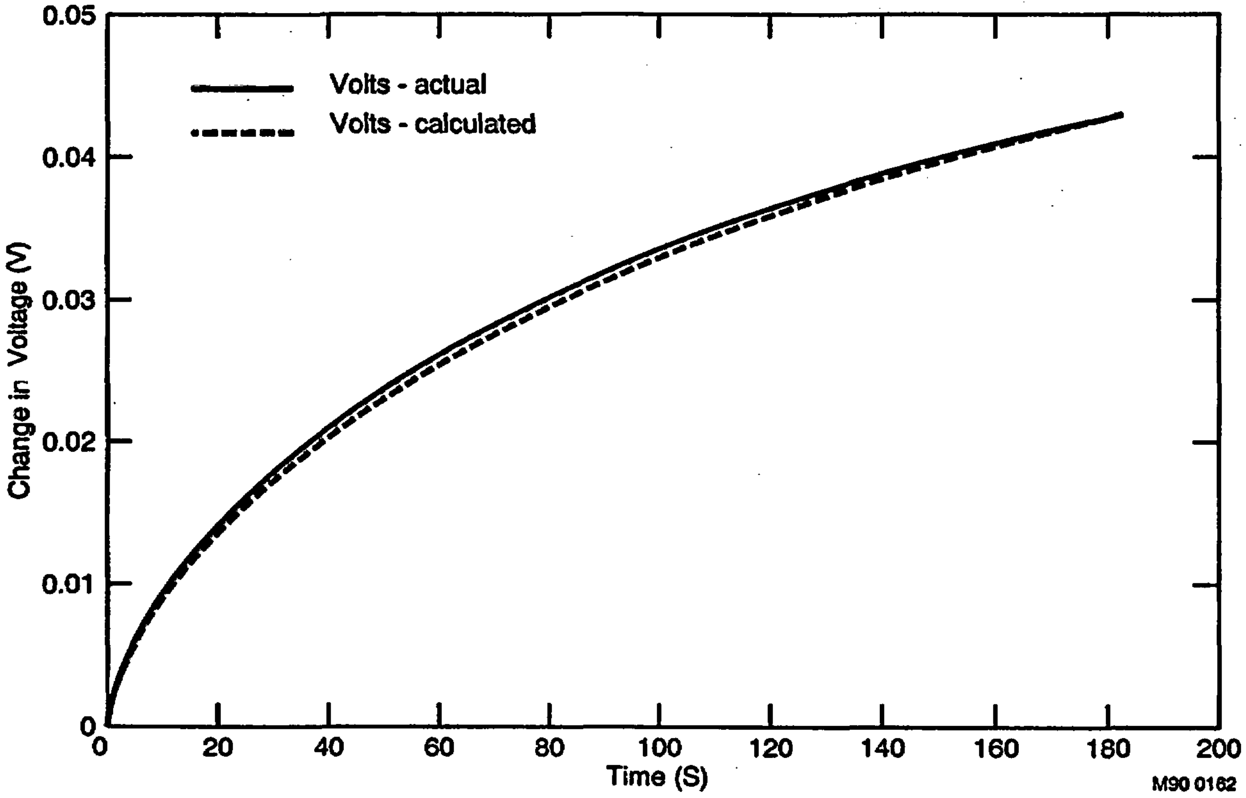

Figure 26. 200-second plot of data and curve fit.

where

E = voltage of the capacitor (with the starting voltage subtracted)

E_s = initial charging voltage for the capacitor

E_m = charging voltage for the capacitor associated with the medium value time constant

E_l = charging voltage for the capacitor associated with the long time constant

T_s = short time constant

T_m = medium time constant

T_l = long time constant.

This equation describes the charging of a capacitor at a time constant of T_s to a changing voltage that begins at E_s and exponentially increases to a final voltage of $E_s + E_m + E_l$. The exponentially increasing voltage increases with the time constants T_m and T_l.

An exact physical interpretation of the various parameters in the equation is not known. However, it is believed that E_s and T_s are associated with the capacitor and the reaction resistance, while the other parameters are associated with a change, over time, in the electrochemically generated voltage. Because the battery had been discharged prior to the current interruption, the electrolyte at the surface of the plates was being depleted, and as a result, the electrochemically generated voltage decreased. Even though the electrolyte at the surface was replenished by the large volume of electrolyte in the battery, it remained at a value lower than the larger volume while the battery was being discharged. When the discharging was interrupted, the electrolyte at the surface continued to be replenished, and the electrochemically generated voltage rose too. The rate of rise depended on the rate at which the electrolyte at the surface of the plates was replenished. This replenishment was a result of both diffusion and convection, both of which gave rise to exponential functions. In addition, the temperature also was changing as a result of the discharge current, and this, too, caused the voltage to change. The value of these time constants, then, could provide an indication of the physical condition of the separators or any other component that affects the mixing of the electrolyte.

The internal ohmic resistance, reaction resistance, and capacitance are calculated from the value of the step change in current and voltage, the voltages obtained from the curve fit, and the time constants of the curve fit. The ohmic resistance is determined from the step change in voltage and current. The reaction resistance and capacitance are determined by the values of the step change in current, the initial charging voltage, and the short time constant. Tables 5, 6, and 7 show the results of the discharge interruption tests performed at the INEL and at Wyle prior to the seismic tests and the tests performed at the INEL after the seismic tests. A comparison of these results shows that there is no significant difference in the results between tests or as a result of the seismic testing.

Tables 5, 6, and 7 also show some results from the polarization tests conducted at the INEL before and after the seismic testing. The polarization tests were conducted by increasing discharge current in 50–ampere steps from 0 to 450 amperes and then decreasing the current in 50–ampere steps to 0 in a continuous process without breaks. The current was held at each step for about 1 minute while both current and voltage were recorded for each battery. Because of limitations in the discharge equipment, the polarization tests were conducted on two groups of six batteries each. Figure 27 shows the current and voltage history for one of the batteries; the others were very similar. Figure 28 shows a polarization plot for one of the batteries that is a graph of voltage–vs–current. As can be seen, after the initial drop in voltage, the voltages for increasing currents are not much different than for decreasing currents. This pattern is expected for a battery in good condition. During the postseismic polarization test, it was observed that the batteries in one group of six all had a slightly different pattern of voltage–vs–current, shown in Figure 29. An investigation of the difference showed that the batteries with the different pattern were discharged the same day they were charged. All the other polarization tests were perfomed at least one day after charging. The six batteries with different postseismic polarization results were Nos. 18, 23, 24, 26, 46, and 47. The resistances of these batteries as calculated from the polarization tests also showed a different pattern and slightly higher values. A review of Table 7 shows that the order of higher to lower resistance is reversed and the values averaged about 18% higher. The batteries affected were from one group of six and were not limited to a single level of seismic testing. Therefore, the difference in results is believed to be entirely a result of less time between charging and testing. The importance of consistent time between charging and testing is clearly demonstrated. A comparison of Tables 3 and 5 shows that the batteries all behaved about the same during the polarization tests.

A step change in charge current from 0 to 4 amperes was also performed at the INEL prior to the seismic tests. The results of these tests were very inconsistent from battery to battery and provided no useful results. It appears that this test is extremely sensitive to the state of charge, and the effort required to obtain consistent results would make the test impractical. Therefore, the test was not repeated for the batteries after the seismic testing.

The results of the discharge current interruption and polarization tests were compared with those obtained by the Westinghouse R&D Center and reported in Reference 19. The batteries tested by Westinghouse were also large and naturally aged. A comparison of the Westinghouse results and the INEL results are:

	Ohmic Resistance (milliohm)	Reaction Resistance (milliohm)	Capacitance (F)
Westinghouse	0.39	7.86	1100
INEL	0.25	0.06	6417

While the ohmic resistance and capacitance are similar, the reaction resistance is quite different. The difference probably is due to the way reaction resistance was determined. Westinghouse determined reaction resistance by noting differences in float voltage resulting from different float currents. The INEL test determined reaction resistance by utilizing a component of the exponential rise in voltage during the discharge current interruption test. The reaction resistance during float when gassing is occurring could very well be much higher than during discharge when little if any gassing is occurring.

In summary, advanced surveillance methods were tested, and their results are consistent with the capacity tests recommended by IEEE Std 450 in that all showed no degradation in the batteries as a result of seismic testing. The results of the polarization and discharge current interruption tests indicate that these tests provide consistent results and may be useful as an indication of battery condition. Because there was no definite correlation between the absolute values of resistance or capacitance and electrical capacity, it appears that, for the results to be useful, the tests would have to be repeated as the batteries age to establish a pattern for each battery. Finally, these tests are sensitive to the state–of–charge of the battery, and a consistent practice must be established concerning charging and the time elapsed between charging and testing.

Table 5. Summary of battery test data preseismic tests at INEL, March 22, 1989

Battery Number	Electrical Capacity (%)	Current Step (A)	Voltage Step (V)	Internal Resistance (milliohm)	E_s (V)	E_m (V)	E_l (V)	T_s (s)	T_m (s)	T_l (s)	Reaction Resistance (milliohm)	Capacitance (F)	Polarization Internal Resistance Increasing/Decreasing[a] (milliohm)
17	97.00	50.10	0.01961	0.391	0.0035	0.012	0.047	0.38	24.0	210	0.0698	5439.4	0.14/0.20
18	92.00	50.14	0.01457	0.291	0.0030	1.008	0.059	0.40	20.0	220	0.0598	6685.3	0.15/0.21
23	94.00	50.14	0.01796	0.358	0.0042	0.016	0.039	0.50	27.5	305	0.0837	5969.0	0.15/0.19
24	94.00	50.14	0.01479	0.295	0.0030	0.009	0.055	0.30	20.0	214	0.0598	5014.0	0.16/0.21
25	94.00	50.12	0.01648	0.329	0.0035	0.013	0.051	0.25	26.5	217	0.0698	3580.0	0.15/0.21
26	97.00	50.10	0.01451	0.290	0.0037	0.015	0.043	0.42	24.5	250	0.0738	5687.0	0.15/0.21
29	93.00	50.13	0.01823	0.364	0.0030	0.012	0.052	0.40	26.5	233	0.0598	6684.0	0.15/0.21
30	94.00	50.15	0.01403	0.280	0.0040	0.015	0.033	0.25	18.2	239	0.0797	3134.4	0.16/0.21
45	98.00	50.14	0.01362	0.272	0.0030	0.013	0.030	0.22	16.0	194	0.0598	3676.9	0.17/0.22
46	96.00	50.13	0.01379	0.275	0.0022	0.014	0.042	0.16	29.0	185	0.0438	3645.8	0.13/0.19
47	98.00	50.10	0.01378	0.275	0.0030	0.012	0.054	0.40	25.0	245	0.0598	6680.0	0.15/0.20
48	92.00	50.13	0.01309	0.261	0.0030	0.012	0.042	0.40	18.5	192	0.0598	6684.0	0.15/0.20

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[a] Resistance is calculated between 450 and 350 amperes for both ascending and descending discharge rates.

Table 6. Summary of battery test data preseismic tests at WYLE, April 14, 1989

Battery Number	Electrical Capacity (%)	Current Step (A)	Voltage Step (V)	Internal Resistance (milliohm)	E_s (V)	E_m (V)	E_l (V)	T_s (s)	T_m (s)	T_l (s)	Reaction Resistance (milliohm)	Capacitance (F)	Polarization Internal Resistance Increasing/Decreasing (milliohm)
17	96.00	50.28	0.01164	0.232	0.0030	0.011	0.045	0.30	20.0	310.0	0.0597	5028.0	—[a]
18	93.00	50.210	0.01179	0.235	0.0030	0.011	0.045	0.30	19.0	320.0	0.0597	5021.0	N/A
23	94.00	50.51	0.01159	0.229	0.0024	0.011	0.040	0.30	23.0	340.0	0.0475	6313.8	N/A
24	97.00	50.09	0.01171	0.234	0.0030	0.011	0.038	0.30	20.0	300.0	0.0599	5009.0	N/A
25	96.00	50.57	0.01146	0.227	0.0025	0.011	0.045	0.28	24.0	325.0	0.0494	5663.8	N/A
26	94.00	50.38	0.01179	0.234	0.0030	0.011	0.045	0.30	20.0	310.0	0.0595	5038.0	N/A
29	99.00	50.88	0.01311	0.258	0.0028	0.011	0.048	0.30	21.0	310.0	0.0550	5451.4	N/A
30	96.00	50.56	0.01175	0.232	0.0030	0.012	0.048	0.30	22.0	330.0	0.0593	5056.0	N/A
45	99.00	50.56	0.01114	0.220	0.0027	0.011	0.053	0.30	23.0	310.0	0.0534	5617.8	N/A
46	98.00	49.92	0.01129	0.226	0.0027	0.011	0.045	0.30	25.0	310.0	0.0541	5546.7	N/A
47	98.00	51.53	0.01124	0.218	0.0027	0.011	0.047	0.30	23.0	310.0	0.0524	5725.6	N/A
48	94.00	50.33	0.01155	0.229	0.0030	0.012	0.042	0.30	19.0	330.0	0.0596	5033.0	N/A

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a. Polarization tests were not performed at this step.

Table 7. Summary of battery test data postseismic tests at WYLE, April 23, 1989

Battery Number	Electrical Capacity (%)	Current Step (A)	Voltage Step (V)	Internal Resistance (milliohm)	E_s (V)	E_m (V)	E_l (V)	T_s (s)	T_m (s)	T_l (s)	Reaction Resistance (milliohm)	Capacitance (F)	Polarization Internal Resistance Increasing/Decreasing[a] (milliohm)
Group 1 – 50% and 100% Seismic Levels													
18	95.00	50.02	0.01193	0.238	0.0028	0.011	0.044	0.30	22.0	350.0	0.0560	5359.8	0.20/0.15
24	98.00	50.01	0.01191	0.238	0.0028	0.011	0.047	0.31	23.0	350.0	0.0560	5536.8	0.22/0.16
26	99.00	49.85	0.01251	0.251	0.0028	0.012	0.052	0.40	27.0	350.0	0.0562	7121.9	0.21/0.15
46	100.00	50.03	0.01210	0.242	0.0028	0.012	0.052	0.40	29.0	330.0	0.0560	7147.0	0.19/0.15
Group 2 – 85% Seismic Level													
17	100.00	50.09	0.01196	0.239	0.0028	0.012	0.037	0.40	23.0	350.0	0.0559	7155.4	0.12/0.17
25	93.00	50.02	0.01278	0.255	0.0030	0.011	0.040	0.39	20.0	330.0	0.0600	6502.5	0.14/0.17
45	97.00	50.02	0.01246	0.249	0.0030	0.013	0.042	0.40	22.0	330.0	0.0600	6669.3	0.13/0.17
48	97.00	50.07	0.01242	0.248	0.0030	0.011	0.037	0.40	20.0	320.0	0.0599	6675.8	0.12/0.16
Group 3 – 95% Seismic Level													
23	93.00	49.85	0.01245	0.250	0.0030	0.011	0.030	0.40	17.0	185.0	0.0602	6646.5	0.21/0.12
29	93.00	50.11	0.01492	0.298	0.0033	0.012	0.049	0.40	23.0	280.0	0.0659	6073.6	0.13/0.17
30	96.00	50.02	0.01404	0.281	0.0033	0.012	0.042	0.40	20.0	250.0	0.0660	6063.0	0.13/0.17
47	96.00	50.02	0.01256	0.251	0.0033	0.012	0.039	0.40	22.0	220.0	0.0660	6063.6	0.20/0.14

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[a] Polarization resistance calculated between 450 and 350 amperes for ascending and descending discharge rates.

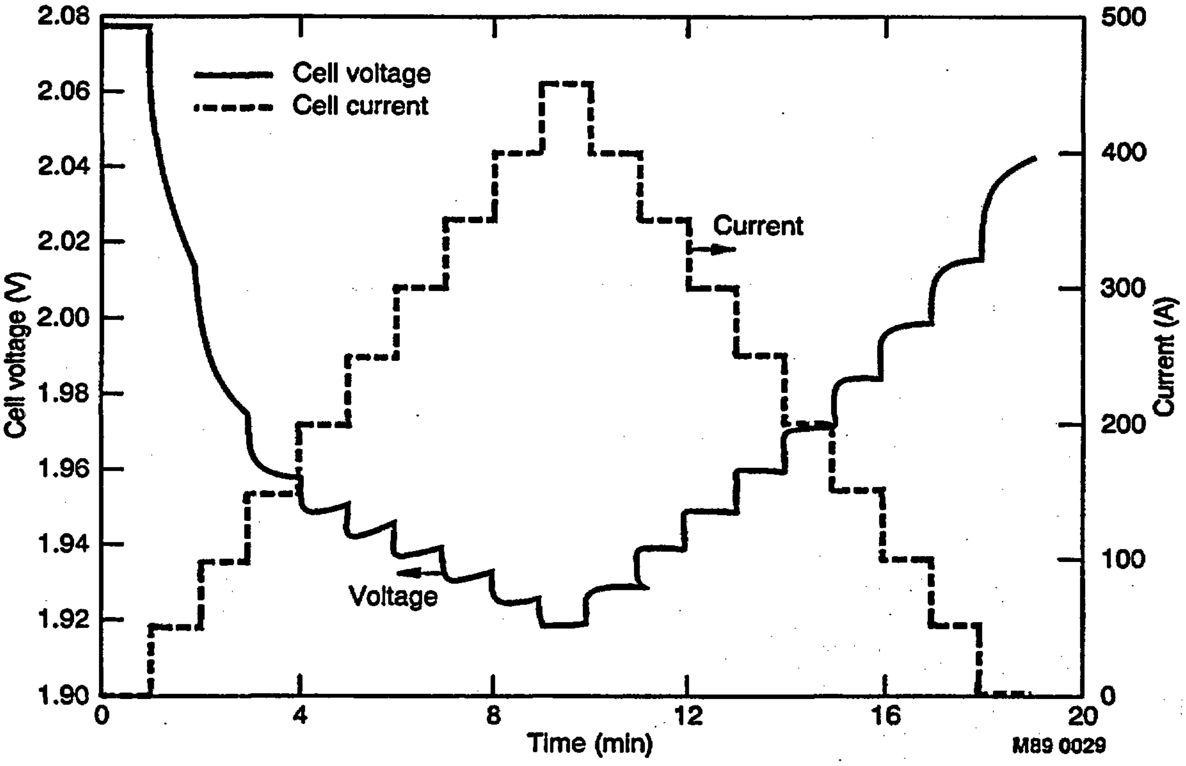

Figure 27. Polarization test current and voltage vs time.

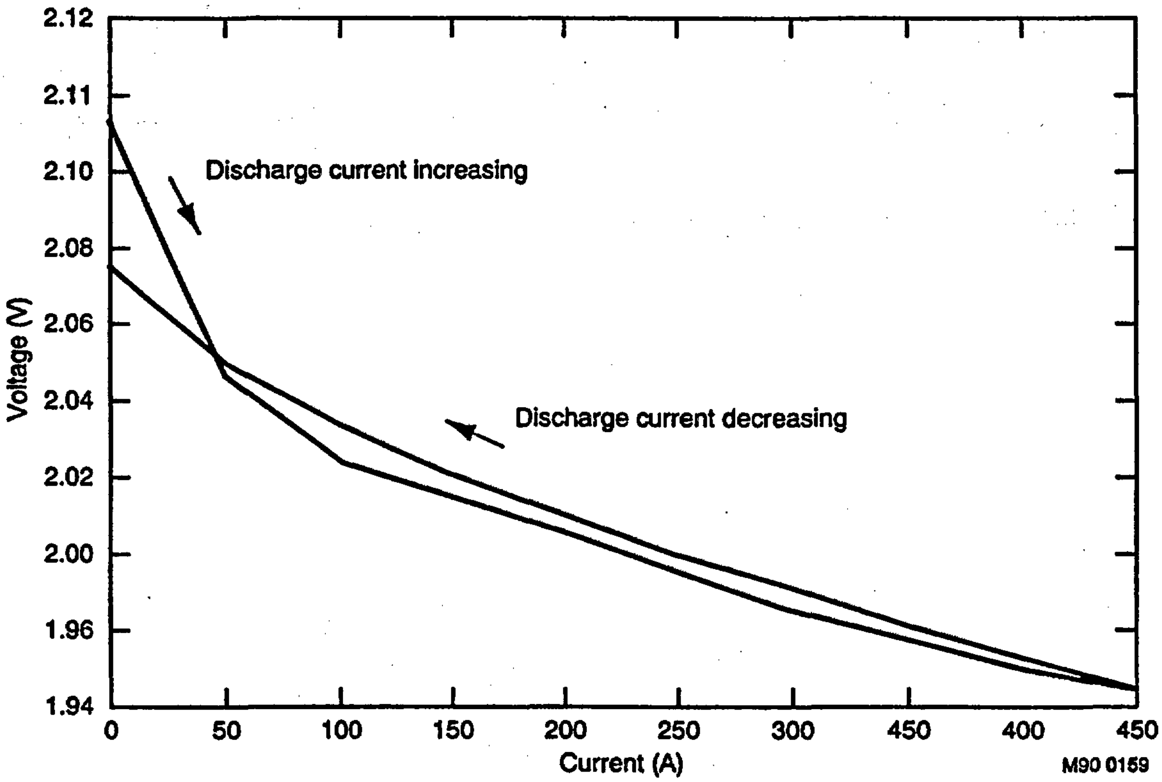

Figure 28. Expected pattern for polarization test voltage vs current.

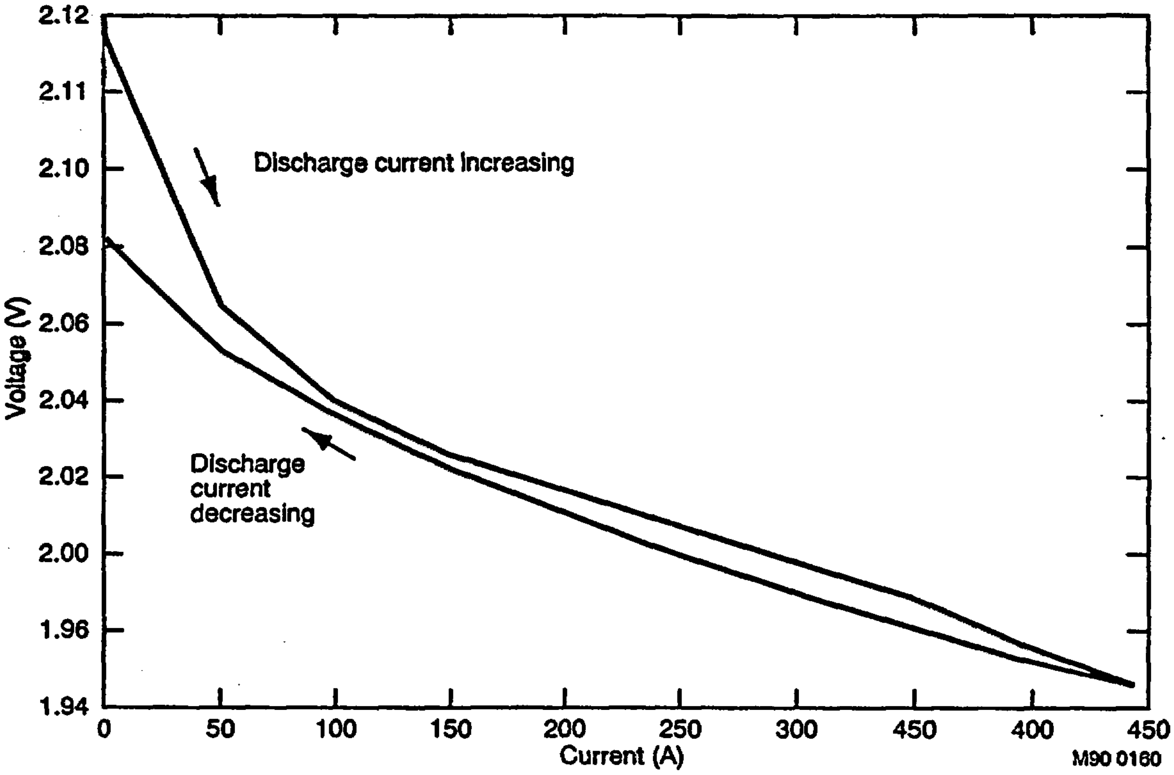

Figure 29. Different pattern for polarization test voltage vs current.

5. CONCLUSIONS

Batteries are the only installed source of electrical power to provide for monitoring of plant conditions and control of some systems of the nuclear reactor in the event of a station blackout (all offsite power is lost and the diesel generators do not start). Since batteries are susceptible to aging degradation that could cause old batteries to be vulnerable to severe seismic events, a test program was conducted to determine if it is possible for the seismic ruggedness of aged batteries in nuclear plants to be inadequate even though the electrical capacity is satisfactory. Selected advanced surveillance methods were evaluated also to determine if any of them are likely to be more sensitive to battery degradation than the surveillance and testing methods required in IEEE Standards and Regulatory Guides.

The testing program began with a review of SSE seismic levels specified for batteries at selected nuclear plants and a review of advanced surveillance methods that have been identified. A test plan was prepared and approved that described in detail the proposed testing program, including specification of the seismic levels and the advanced surveillance methods that would be utilized. Testing was then performed, and the results support conclusions and recommendations presented in the following paragraphs.

As a result of seismic tests on naturally–aged batteries that were 14 years old, we conclude that when batteries are maintained and operated in accordance with IEEE Std 450 and Regulatory Guide 1.129, the following may be expected of equivalently designed and manufactured lead–calcium batteries:

- Little, if any, electrical capacity will be lost as a result of seismic shaking at levels that are typical of the most severe levels required for SSE in the U.S. This finding indicates that adequate seismic ruggedness will be retained in batteries and racks of equivalent design and material to meet the requirements for the most severe SSE events.
- Some internal damage to the plate separators may be expected at the most severe seismic levels. However, this damage is not expected to prevent the batteries from providing at least 80% of rated capacity during and immediately following the most severe seismic event.
- Naturally–aged batteries may show evidence of corrosion at the joint between the positive plates and the positive plate strap (buss). In a well–made joint, this corrosion should not cause the seismic ruggedness to be inadequate for the most severe SSE events expected for the U.S. However, batteries should not be operated at elevated temperatures or charged excessively to avoid this corrosion, which could then progress rapidly enough to result in inadequate seismic ruggedness.

Because most aging mechanisms cause both decreased electrical capacity and reduced seismic ruggedness, it appears that the tests recommended by IEEE Std 450 not only provide a method of monitoring electrical capacity of current generation nuclear station batteries, but also provide an indication of adequate seismic capability when the batteries are maintained and operated in accordance with IEEE Std 450 and Regulatory Guide 1.129.

Advanced surveillance methods that measure the internal resistance and capacitance of batteries did not detect any degradation as a result of seismic testing. These results are consistent with the results of the surveillance methods of IEEE Std 450. The results of polarization and discharge current interruption tests indicate that these tests provide consistent results and may be useful as an indication of battery condition. In addition, it appears that, for the results to be useful, the tests would have to be repeated as the batteries age so that a pattern for each battery (cell) could be established. Finally, these tests are sensitive to the state–of–charge of the battery, and a consistent practice must be established concerning charging and the time elapsed between charging and testing. These tests are not fully developed, and it appears that significant time and effort would be required to obtain and analyze the data.

To assure that adequate seismic ruggedness is maintained, it is recommended that continued attention be given to the operating conditions and maintenance practice for batteries in nuclear plants. Conditions such as elevated temperature and excessive charging have the potential to substantially reduce seismic ruggedness as batteries age.

Because the batteries tested in this program were maintained and operated in accordance with IEEE Std 450, Regulatory Guide 1.129, and the manufacturer's recommendations, these test results are applicable only to batteries operated under similar conditions. For batteries operated at conditions outside of those recommended in IEEE Std 450, advanced monitoring methods that can detect degraded seismic ruggedness should be developed, or revised replacement criteria should be implemented.

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ATTACHMENT A

TEST PLAN FOR DETERMINING SEISMIC RUGGEDNESS OF AGED STATIONARY BATTERIES IN NUCLEAR POWER PLANTS

TEST PLAN FOR DETERMINING SEISMIC RUGGEDNESS OF AGED STATIONARY BATTERIES IN NUCLEAR POWER PLANTS

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DECEMBER 13, 1988

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CONTENTS

TEST PLAN FOR DETERMINING SEISMIC RUGGEDNESS OF AGED STATIONARY BATTERIES IN NUCLEAR POWER PLANTS

1. INTRODUCTION

This testing program will be used to determine if it is possible for the seismic ruggedness of aged batteries in nuclear plants to be inadequate even though the electrical capacity is satisfactory. The test program will concentrate on the seismic ruggedness of batteries that have aged until they are nearing their end of electrical life as determined by IEEE Std 450-1987, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Storage Batteries for Generating Stations and Substations", and the qualification requirements provided in IEEE Std 535-1986, "IEEE Standard for Qualification of Class 1E Storage Batteries for Nuclear Power Generating Stations". Program results are expected to lead to one of two conclusions: 1) batteries aged to near end of electrical life retain adequate seismic ruggedness and additional surveillance testing is not required; or 2) aged batteries may not retain adequate seismic ruggedness and therefore additional surveillance testing or revised replacement criteria are recommended.

The following program describes the test configuration, test sequence to be followed, and the data analysis that will be used to evaluate the seismic ruggedness of aged batteries. Note that even though the term "cell" is usually defined as a single electrical cell and "battery" refers to a number of cells connected together, the term "battery" will be used in this document to describe both a single cell and a group of connected cells.

2. BACKGROUND

As part of the USNRC program for Nuclear Plant Aging Research (NPAR), a Phase I study of battery aging was performed and reported in NUREG/CR-4457, "Aging of Class 1E Batteries in Safety Systems of Nuclear Power Plants." The study reviewed testing performed by others, studies that have been conducted, and reports of operational experiences.

A review of the study shows that the significant aging effects for aged batteries are growth of positive plates, loosening of active material in plates that have grown, loss of active material caused by gassing and corrosion, and embrittlement of the lead grids and straps. The results of these effects are decreased electrical capacity and decreased seismic ruggedness which, during a seismic event, can lead to decreased electrical performance or complete failure. In general, the same aging mechanisms cause both decreased electrical capacity and reduced seismic ruggedness. These mechanisms are elevated temperature, over charging, ac ripple, low electrolyte level, and impurities in the electrolyte. There are a few mechanisms which lead to only a decrease in seismic ruggedness because they affect the case (container) but not the components inside the battery; examples are defects caused by handling and the use of solvents to clean the cases. It appears that it is possible for the mechanisms which affect both electrical capacity and seismic ruggedness to have a greater effect on seismic ruggedness than electrical capacity.

This conclusion is supported by research performed by Sandia National Laboratories (SNL). Naturally aged batteries that were 10 to 23 years old with an average electrical capacity of 98% were subjected to seismic-fragility testing. Electrical capacity after testing at a zero period acceleration (ZPA) of 1.5 to 1.7 g ranged from 13% to 110% with the average being 72%. Electrical capacity after seismic testing at a ZPA of 2 g ranged from 0% (catastrophic failure) to 87% with the average being 32%. The capacity of new (unaged) batteries with an average capacity of 96% decreased to an average of 85% after seismic testing at about 2g. It is recognized that the tests conducted by SNL used seismic levels greater than those required for battery qualification. Yet the tests do demonstrate that it is possible for aging to have a greater effect on seismic ruggedness than electrical capacity.

IEEE Std 450-1987, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Storage Batteries for Generating Stations and Substations", recommends that batteries be replaced when the electrical capacity has decreased to 80% of rated capacity. Considering that aged batteries were observed to decrease in capacity from 98% to 72% as a result of high level shaking, it seems possible that an aged battery that had degraded until its capacity was near 80% could experience a large enough decrease in capacity as a result of shaking that it would no longer be able supply the demanded electrical power. The demanded power (design load) is different for each plant. However, IEEE Std 485-1983, "IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations", recommends that the design load be no greater than 70% of the battery's rated capacity.

Although batteries are now qualified to the requirements of IEEE Std 535-1986, "IEEE Standard for Qualification of Class 1E Storage Batteries for Nuclear Power Generating Stations", (which requires aging to end-of-qualified-life prior to seismic testing) and are qualified for 15 to 20 years of service, actual life could be less than qualified life if their operational conditions, including maintenance practices, were more severe than the conditions for which they were qualified. These batteries could, then, be operating with adequate electrical capacity but inadequate seismic ruggedness if seismic ruggedness decreased more rapidly than electrical capacity. Some examples include high environmental temperature, too many deep discharge cycles, overcharging, low electrolyte level, and impurities in the water. Also, the accelerated aging practices permitted in IEEE-535 may not fully duplicate the aging effects experienced by naturally aged batteries. Many old batteries at nuclear plants were not qualified to IEEE-535 and they could become vulnerable to a seismic event prior to reaching the end of their electrical life.

Standard testing and monitoring methods provided in IEEE-450 and RG 1.129, "Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Nuclear Power Plants", only provide for measurements of temperature, voltage, and electrical capacity as well as some visual inspections. However, these tests are not designed to detect the degradation of batteries that causes seismic vulnerability. In addition, the tests conducted by SNL did not provide information concerning the seismic ruggedness of batteries at seismic levels near those used for qualification. Therefore testing will be performed at realistic seismic levels to determine if it is possible for the seismic ruggedness of aged batteries in nuclear plants to be inadequate even though the electrical capacity is satisfactory.

3. SELECTION OF BATTERIES

Batteries will be selected for testing based on a combination of availability and specific characteristics. It is necessary to use batteries that have been aged in a nuclear power plant. Since nuclear power plants will be replacing batteries that are either old, have degraded performance characteristics, or unsatisfactory for their use, it may be difficult to locate ideal batteries for this testing program. However, the batteries that are selected will be aged to near the end of their expect life and whose electrical capacity is still acceptable. The desired characteristics are discussed in the following paragraphs.

Batteries with lead-calcium alloy are desired. Nearly all batteries currently being installed have components made of a lead-calcium alloy rather than a lead-antimony alloy. Some older batteries have components made of a lead-antimony alloy but their numbers are decreasing with time as they are being replaced with new lead-calcium batteries. The use of aged batteries with components made of a lead-calcium alloy will permit the test results to more directly apply to batteries presently being installed. However the test results are expected to have applicability to batteries with flat plates and lead-antimony components.

Batteries are to be at least 10 years old. The purpose of the program is to evaluate the seismic ruggedness of aged batteries. In addition, the testing performed by SNL utilized batteries that were at least 10 year old. The use of batteries that are at least 10 years old will provide for test data obtained from naturally aged batteries and will also provide for test data that can be compared to test data obtained by SNL.

Batteries are to be of a flat plate design. Batteries currently being installed in nuclear plants are nearly all of the flat plate design. In addition, the majority of the older batteries that remain in nuclear plant are also of the flat plate design.

The capacity of the batteries should be about 85%. The objective of the program is to test naturally aged batteries that are approaching their end of life. The end of life with respect to only electrical capacity has been identified as 80% of rated capacity by IEEE Std 450. For this reason batteries with a capacity smaller than and much larger than 80% are not desired. Naturally aged batteries that have high electrical capacities will also be considered if they are readily available.

Batteries should be from more than one manufacturer. The test results will have a more general application if batteries from more than one manufacturer are tested. It is desirable to obtain batteries from each of the three primary suppliers of nuclear power plant batteries (Exide, GNB, and C&D). Twelve naturally aged LCU-19 batteries, manufactured by C&D Batteries, that are 13 1/2 years old have been obtained. These batteries, as well others that may be obtained which meet the above requirements, will be used in this test program.

4. USE OF MANUFACTURER'S DATA

Data similar to what will be obtained in this program should have been obtained by manufacturers of batteries who have qualified them for use in nuclear power plants. In the process of qualifying batteries to IEEE Std 535, testing is preformed to determine the electrical capacity after the aging process but before the seismic testing and then again after seismic testing. While manufacturer's data will have been obtained with batteries that have been artificially aged and capacities were probably greater than 85%, the data should provide an indication of the the loss of capacity that should be expected of an aged battery that is subjected to seismic loads. Battery manufacturers will be contacted in an effort to determine the data that has been obtained and its availability. Manufacturers may consider this data proprietary and be reluctant to share it with us.

5. TEST SEQUENCE

The basic strategy of the test program is to obtain naturally aged batteries, determine the electrical capacity of those batteries, perform seismic testing at a level that is representative of those required for qualification, perform post seismic capacity tests, and analyze the test results. The following test procedures will be used for the testing of naturally-aged batteries to identify seismic ruggedness.

5.1 Tests and Inspections Before Shipment

If possible batteries will be subjected to tests and inspections before shipment to aid in the selection of batteries that are in a degraded state but which have acceptable electrical capacity as defined by IEEE Std 450. Tests and inspections will include capacity tests, terminal voltage, specific gravity of the electrolyte, and visual evidence of internal degradation. All shipments will be performed according the manufacturer's recommendations.

5.2 Receiving Inspection

As naturally-aged batteries are received, they will be inspected for proper electrolyte level, leaks, excess sediment, broken parts, cracks, crazing, and damage that was obviously caused during transit. All batteries will be photographed with special attention given to abnormalities. The condition of all batteries, as determined above, will be documented for subsequent analysis. Those batteries that were obviously damaged during transit will not be exposed to seismic tests but may be used for other tests including disassembly, chemical analysis, and for information purposes. Those batteries that pass the receiving inspection will be subjected to standard capacity tests as described in the following section.

5.3 Battery Conditioning

To determine which batteries are acceptable for testing they will be charged and subjected to stand tests and capacity tests. Batteries will be charged at the manufacturers recommended rate until specific gravity readings, corrected for temperature, have stabilized. Batteries will then be placed on a 2 week stand test at room temperature to identify those that will not hold a charge. Batteries whose voltage has fallen below 2.13 volts or whose specific gravity has fallen more than 0.005 gm/cc will be considered defective. If the battery manufacturer indicates that a different acceptance criteria is appropriate, it will be used. To establish capacity the batteries will be discharged at the 3 hour rate as provided in paragraph 6 of IEEE Std 450-1987. As batteries reach 1.75 volts they will be removed from the circuit to keep them from being reversed. A maximum of 3 discharge tests will be performed to establish whether capacity is increasing, decreasing or remaining constant (variability). Any battery that does not stabilize or whose capacity is less than 80% of rated will be considered defective. Defective batteries may be utilized for disassembly, scoping tests, etc. and some may be utilized in the subsequent testing programs.

The condition of each battery at each stage of conditioning will be documented and changes will be photographed.

5.4 Artificial Aging of Batteries

There are no plans to artificially age batteries to be tested by this test plan. However, if artificial aging becomes necessary it will be accomplished according to the procedure for accelerated aging that is provided by IEEE Std 535.

5.5 Seismic Testing

Batteries will be subjected to seismic tests to determine how much electrical capacity could be lost as a result of shaking during a seismic event. The twelve batteries will be divided into three groups of four batteries each. Each group will be tested at only one level of excitation to minimize fatigue effects which could bias the results, and each group will have a different level as described below.

All batteries will be tested using required response spectra typical of the required spectra for batteries in nuclear plants. Three levels of excitation will be utilized as described by Figures 1, 2, and 3. These curves are based on information received from some utilities, use a damping factor of 2%, and are the best estimates of excitations that encompass the required response spectra for batteries in 50%, 85%, and 90 to 95% of the nuclear plants. In addition, Figure 3 is a modification of a curve published in an EPRI report, NP-5223, "Generic Seismic Ruggedness of Power Plant Equipment", known as the GERS (Generic Equipment Ruggedness Spectrum) for batteries. This curve represents a level of seismic ruggedness for which there is a high degree of confidence. The EPRI GERS curve, which is based on a damping value of 5%, was modified to approximate a 2% damping curve by increasing the peak excitation by a factor of 1.36. This value was obtained by calculating the ratio of the peak excitation for 2% to the peak excitation at 5% damping found in Regulatory Guide 1.60, "Design Response Spectra For Seismic Design of Nuclear Power Plants". Figure 4 is an overlay of Figures 1, 2, and 3. The response spectra in each of the two horizontal directions (in a three axis system) will be equal and the vertical/horizontal input ratio will be in the range of 1.0 to 0.67. The excitation for the seismic testing will be random in nature with two percent damping. This value of damping has been specified by some nuclear plants and is representative of those provided for structures in IEEE Std 344-1975. IEEE Std 344-1975 states that an earthquake of magnitude 6.0 or higher on the Richter scale may persist for 15 to 30 seconds with the major energy content usually occurring in the first 5 or 10 seconds. Therefore, the duration of each test will be about 30 seconds.

A triaxial shake table will be used. IEEE Std 344-1975, "IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations", states that when a biaxial table is used the equipment is to shaken at 2 or 4 different orientations about the vertical axis (2 if the inputs are uncorrelated, random, and 4 if the inputs are not random). However, this is a research program and not a qualification program, and repetitious biaxial shaking may not yield the same results as single event triaxial shaking. Therefore, a triaxial table will be used.

Batteries will be placed on the shake table in a two step rack, purchased from the battery manufacturer, that has been seismically qualified for use in a nuclear plant. The batteries will be loaded in the rack and the rack attached to the shake table according to the manufacturers instructions. This will simulate the way batteries are mounted in a nuclear facility. Figure 5 shows a sketch of how the batteries will be mounted on the shake table. Because the rack is designed to hold twelve batteries and batteries will be tested in groups of four, eight dummy batteries will be built and installed to fill the rack and load it as if it were filled with twelve batteries. The dummy batteries will be solid and of the same size , weight, and with about the same center of gravity as the actual batteries. The four batteries will be located in the center of the top step to subject them to the maximum accelerations.

The batteries will be discharged at 2% of the 3 hour rate, with current and battery voltages being monitored, while being seismically tested to detect the existence of catastrophic failure. Figure 6 shows a sketch of the electrical circuit. This rate is consistent with the rate recommended by IEEE Std 535-1986 Paragraph 8.3.1.1(2). Any battery that fails to continuously provide at least 1.75 volts will be considered to have failed and will not be subjected to further testing. After each level of seismic testing the capacity of the batteries will be determined by discharging at the 3 hour rate. After the 3 hour discharge the batteries will be recharged.

Accelerometers will be placed on the rack mounted batteries during the seismic test sequence so batteries' response can be compared to the input to the shaker table.

Visual inspection, photographs, and a written description of the batteries at each phase of the seismic testing will be accomplished.

5.6 Testing of Alternate Surveillance Methods

During the pre seismic tests, section 5.2, and the seismic tests, section 5.5, alternate surveillance or monitoring methods that may be more sensitive to aging related degradation will be tested. The alternate monitoring methods are: 1) measurement of internal resistance, 2) measurement of capacitance, and 3) measurement of battery polarization (comparison of battery voltages measured while increasing discharge current with those obtained with decreasing the discharge current). These measurements were suggested as being able to provide an indication of battery condition in NUREG/CR-4533, "Program to Analyze the Failure Mode of Lead-Acid Batteries." The report is a result of investigations performed by the Westinghouse R&D Center for SNL in 1986. The results of these alternate monitoring methods will be compared to the electrical and seismic conditions of the batteries as determined by the standard tests. The objective of these measurements is to determine if one or more of them are more sensitive to aging degradation than the standard volt-ampere tests that determine the electrical capacity of batteries. A more detailed discussion of the alternate surveillance methods and the techniques for performing them is provided in appendix A.

5.7 Post Test Examinations and Data Analysis

Selected batteries that have failed (either catastrophically or by failing to provide 80% of rated capacity) will be disassembled and examined to determine cause of failure. It is expected that the failure mode will be one that has been anticipated, however, failure mode will be verified. Battery condition will be documented with both written descriptions and photographs. Results of the post test examinations, the pre seismic capacity tests, and the post seismic tests will be compared to determine the adequacy of the seismic ruggedness of the batteries.

6.0 REPORT OF TEST RESULTS

A NUREG/CR report will be written describing the test program, the test results, and conclusions reached.

7.0 ESTIMATED COST

The estimated cost to perform these tests is $216K

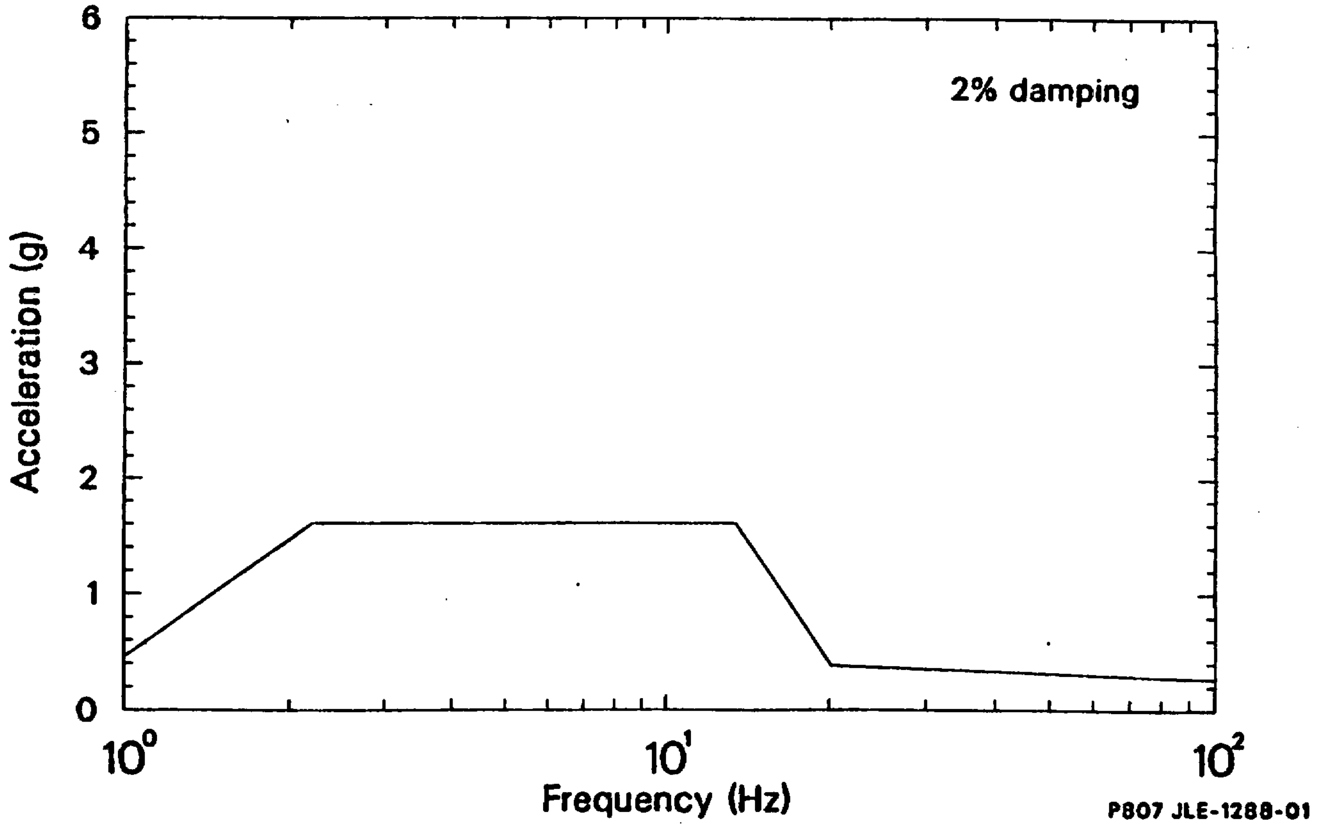


Figure 1 Required Response Spectra For Seismic Testing That Encompasses about 50% of The Nuclear Plants

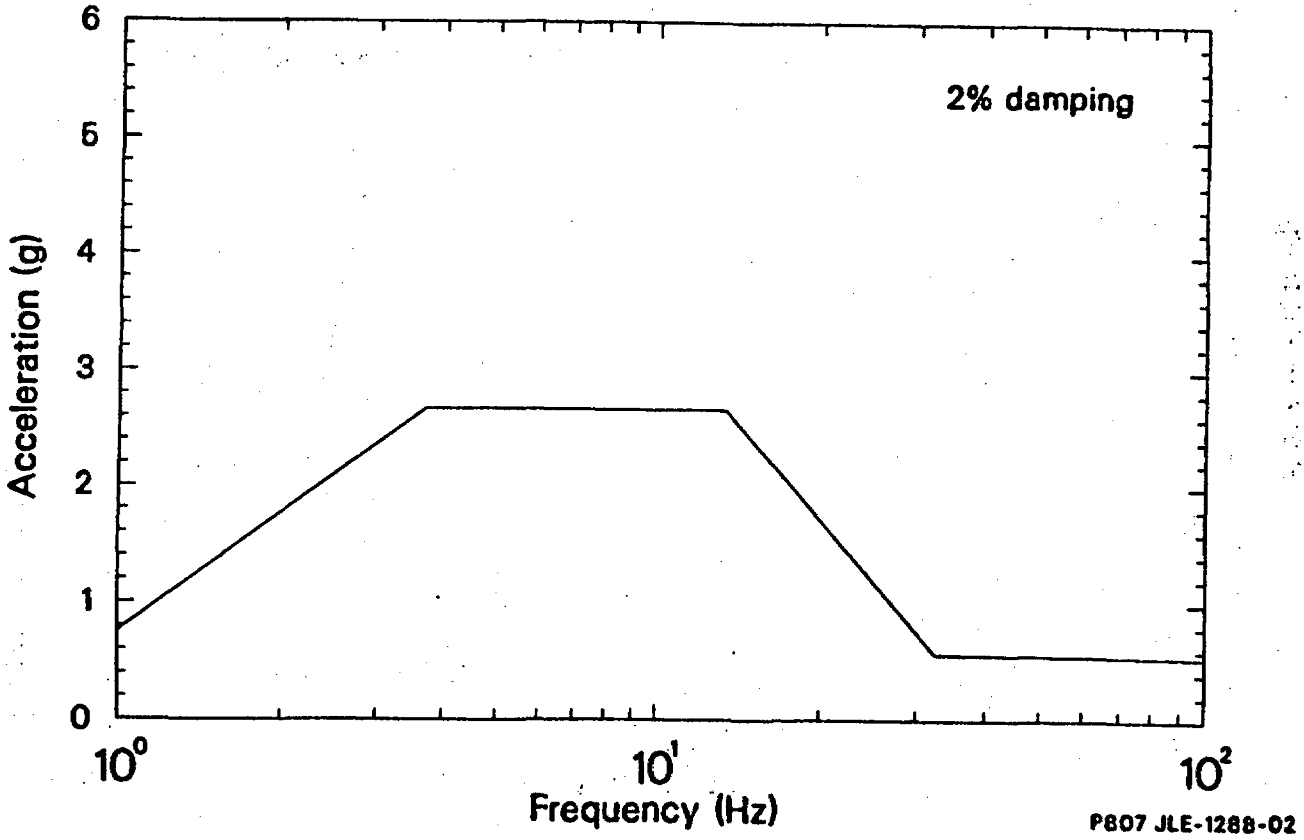


Figure 2 Required Response Spectra For Seismic Testing That Encompasses about 85% of The Nuclear Plants

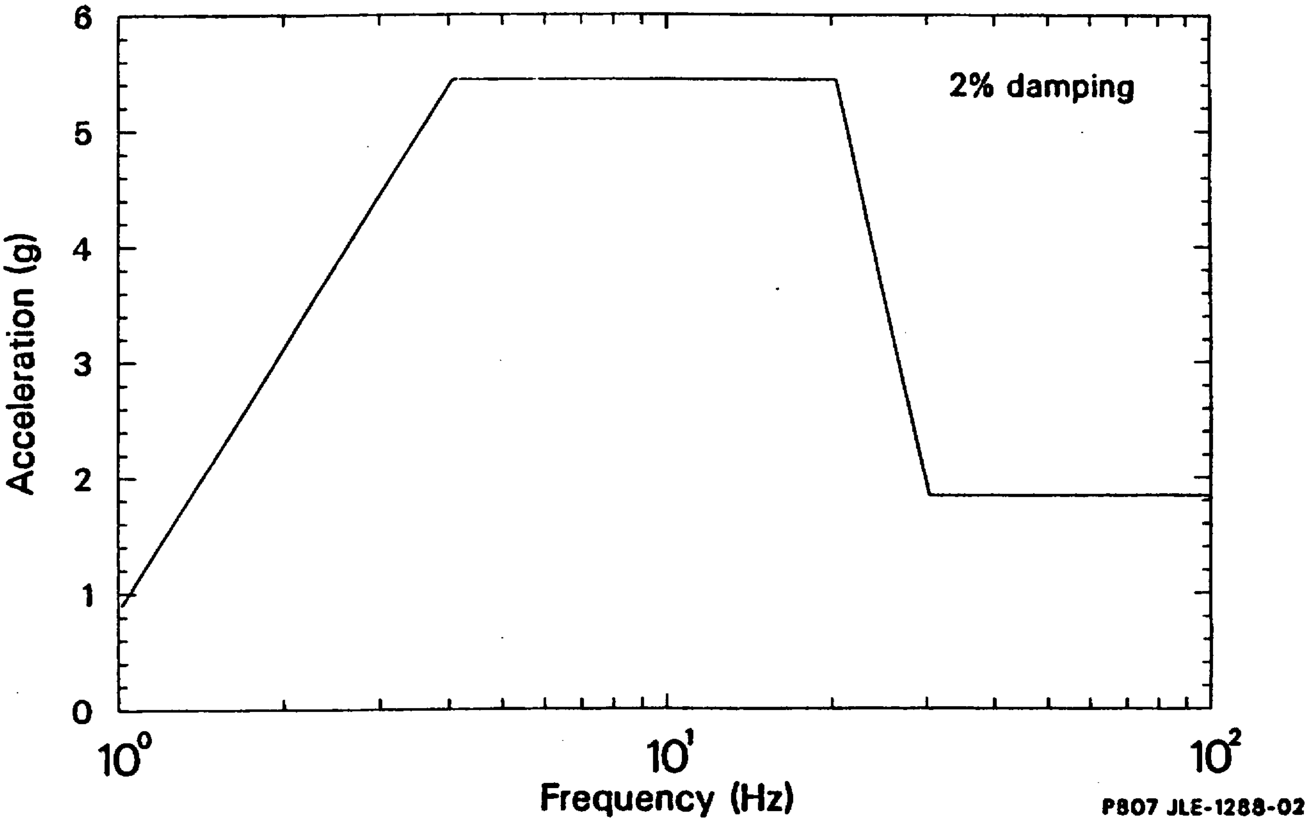


Figure 3 Required Response Spectra For Seismic Testing That Encompasses 90 to 95% of The Nuclear Plants

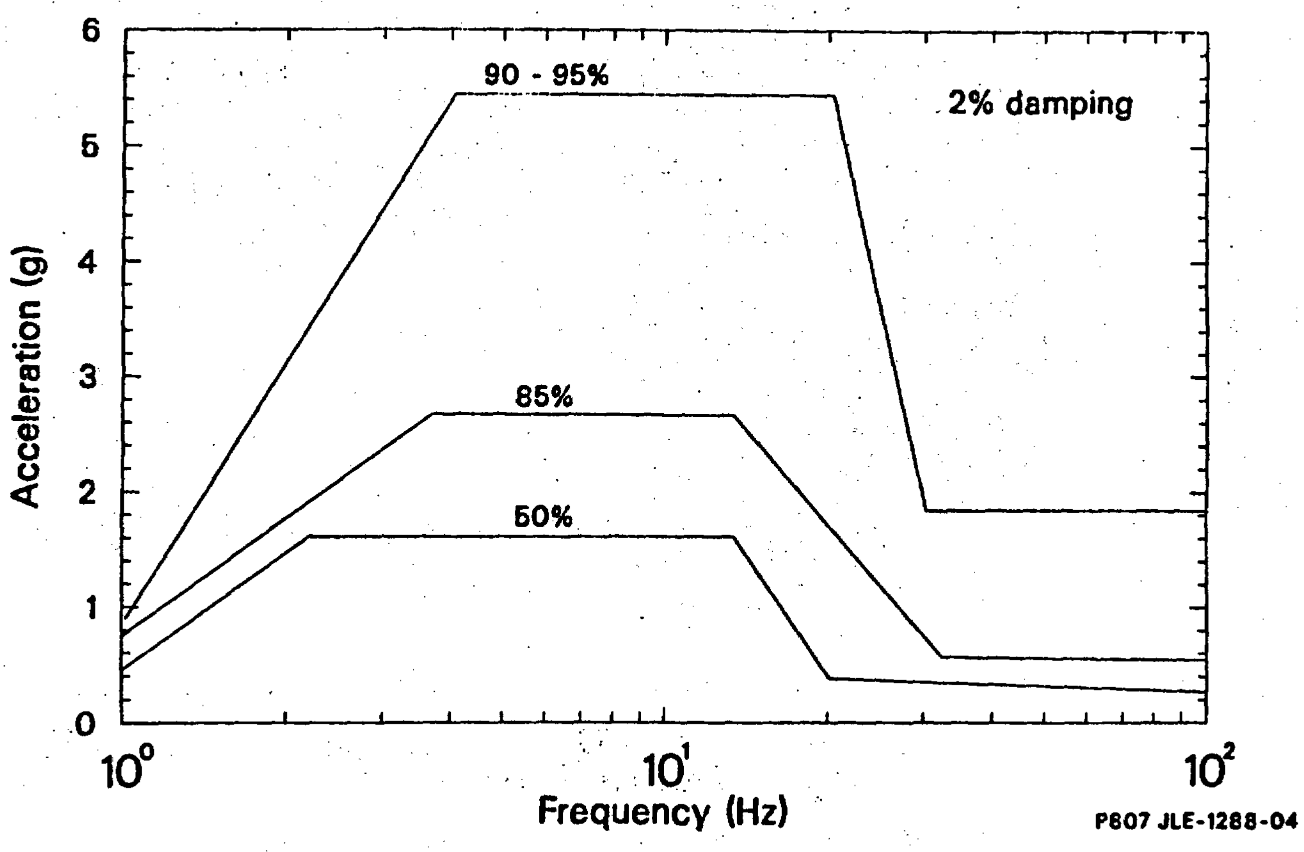
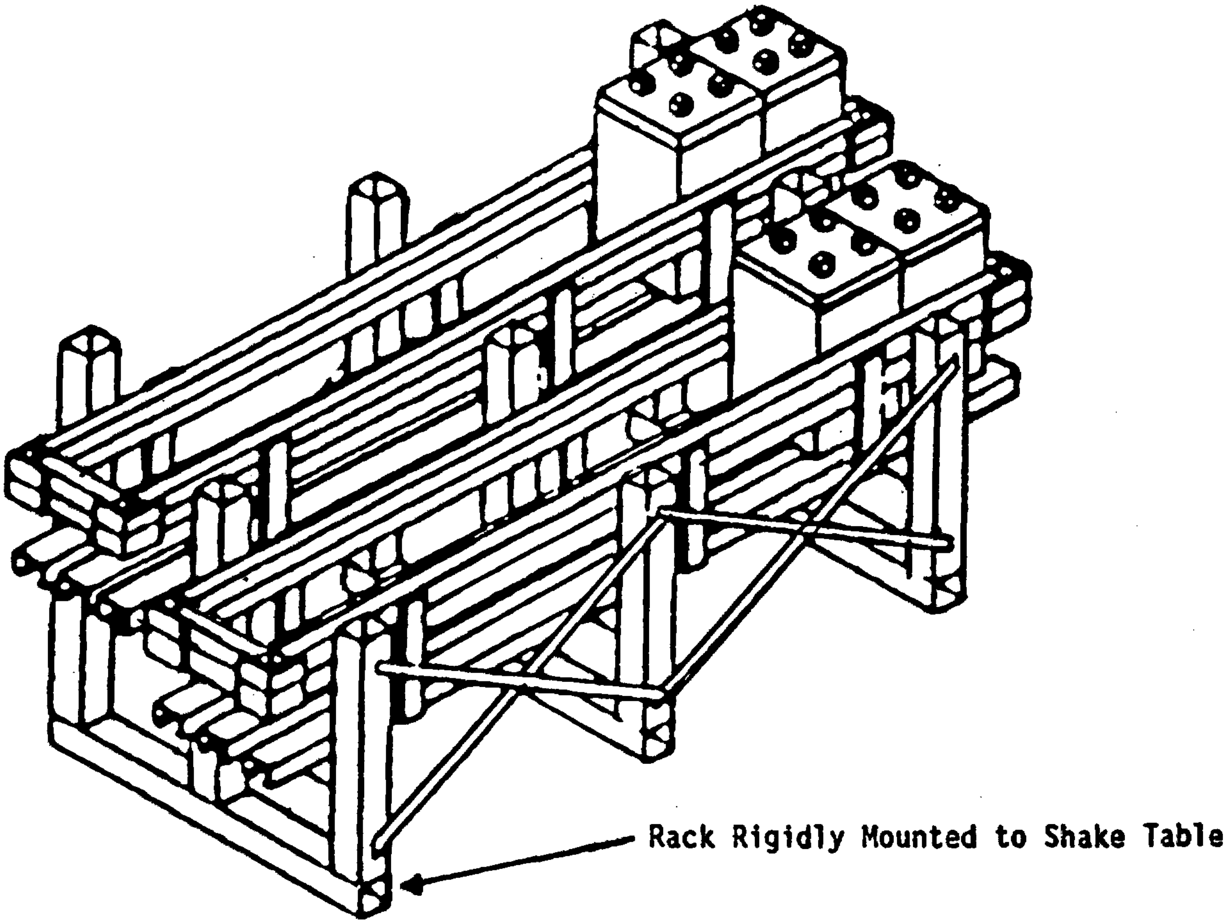


Figure 4 Overlay of 50%, 85%, and 90 to 95% Required Response Spectra Curves



Notes:

1. Rack is to be attached to the table according to manufacturer's instructions.
2. Locate four C&D LCU-19 batteries, that form a single group, in the center of the top step. Fill the remainder of the rack with dummy batteries supplied by the INEL.
3. Install batteries and dummies according to the battery/rack manufacturer's instructions.

Figure 5 Sketch of Battery Mounting Configuration

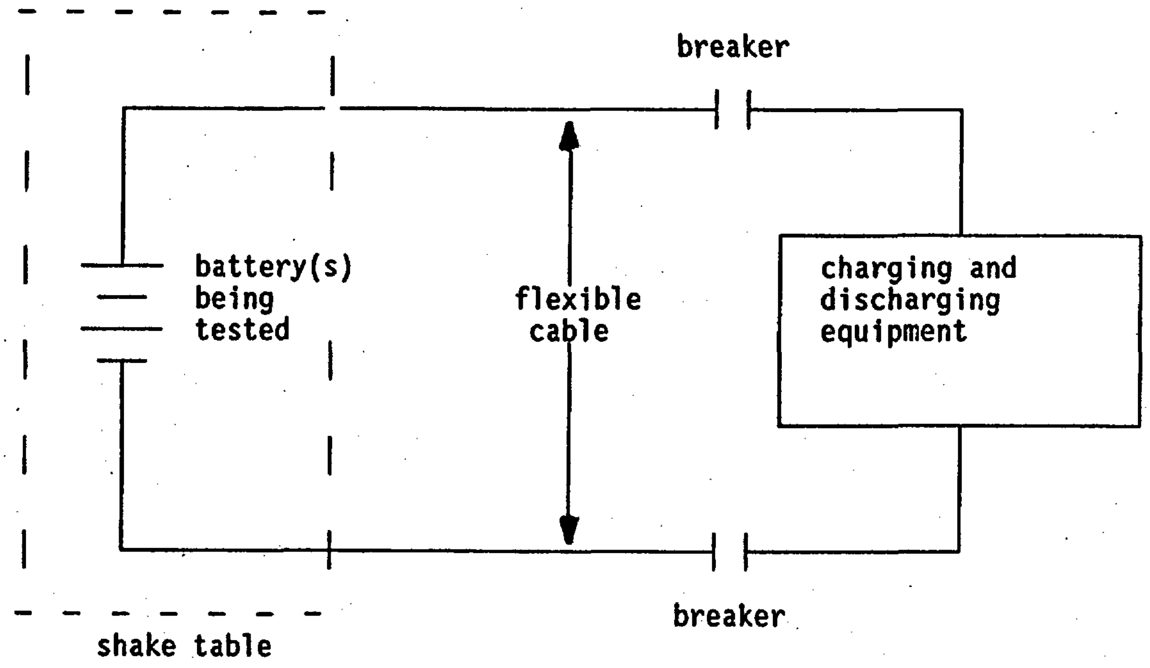


Figure 3 Sketch of Circuit For Shake Table Tests

APPENDIX A

POTENTIAL ALTERNATE SURVEILLANCE OR MONITORING METHODS FOR BATTERIES

POTENTIAL ALTERNATE SURVEILLANCE OR MONITORING METHODS FOR BATTERIES

INTRODUCTION

Some proposed alternate surveillance or monitoring methods that may be more sensitive to aging related degradation are discussed in the following paragraphs. The methods discussed are 1) measurement of internal reistance, 2) measurement of capacitance, and 3) measurement of cell polarization (increase and then decrease the discharge rate, and compare the cell voltages obtained). These measurements were suggested as being able to provide an indication of cell condition by the Westinghouse R&D Center in NUREG/CR-4533, "Program to Analyze the Failure Mode of Lead-Acid Batteries". The study was performed by Westinghouse for Sandia National Laboratory as a result of research being conducted for the NRC. The following describes specific types of degradation that may be detected with the measurement of capacitance and resistance.

> "A lower than expected capacitance will probably be indicative of a failure mode involving shedding, plugging of pores due to morphological changes, or exfoliation from the current collector grid.
>
> The electronic resistance of the cell is interpreted as a measure of the condition of the current collector grids, the integrity of the busses, and the attachment of the active material to the grid. A high electronic resistance as measureed by a current interruption technique, would indicate failure by the above modes rather than by those which would be indicated by a low measured capacitance."

The slope and shape of the polarization curve provides additional indication of cell condition. The slope of the curve is another indication of the internal resistance while shape indicates general condition. A nearly linear shape suggests that the cell is under reistance control, which is expected for a cell that is fully charged and in good condition.

MEASUREMENT OF CAPACITANCE AND RESISTANCE

The equivalent circuit of Figure A-1 was used by the Westinghouse R&D Center for their analysis and is also used for this analysis.

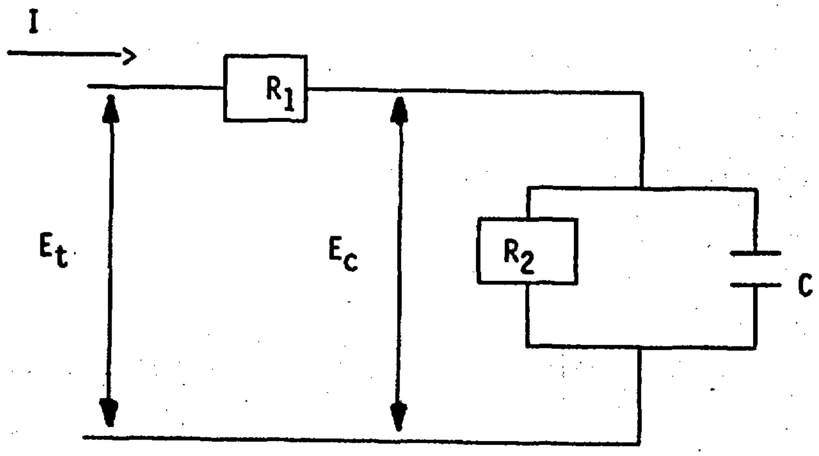


Figure A-1 Equivalent Circuit for Battery Analysis

R_1 represents the electronic reistance of the cell, R_2 the reaction resistance, and C the cell capacitance.

The following illustrates how each of the circuit paramaters can be measured.

For a step increase in current, I, of ΔI from I_0 to $I_0 + \Delta I$ the circuit equation for the voltage across R_2 is:

$$E/R_2 + CdE/dt = (I_0 + \Delta I)[u(t)]$$

Where I_0 is the current I before time, (t), = 0 and [u(t)] is the expression for a unit step at t = 0.

The solution is:

For $t \geq 0$;

$$E_c = I_0R_2 + \Delta IR_2(1 - e^{-t/R_2C})$$

And for $t < 0$;

$$E_c = I_0R_2$$

The voltage at the terminals E_t is the sum of the voltage across R_1 and E_c and is expressed as:

for $t < 0$;

$$E_t = I_0R_1 + I_0R_2 = I_0(R_1 + R_2)$$

for $t \geq 0$;

$$E_t = I_0(R_1 + R_2) + \Delta I[R_1 + R_2(1 - e^{-t/R_2C})]$$

Figure A-2 shows a graphical representation of the above expressions.

Using the previous equations the circuit elements R_1, R_2, and C can be determined as follows:

at t = 0 the instantaneous change in E_t is;

$$\Delta E_t = [(\text{voltage at } t = 0) - (\text{voltage before } t = 0)]$$

$$\Delta E_t = [I_0(R_1 + R_2) + \Delta IR_1] - [I_0(R_1 + R_2)]$$

$$\Delta E_t = \Delta IR_1$$

and so;

$$R_1 = \Delta E_t/\Delta I \qquad (1)$$

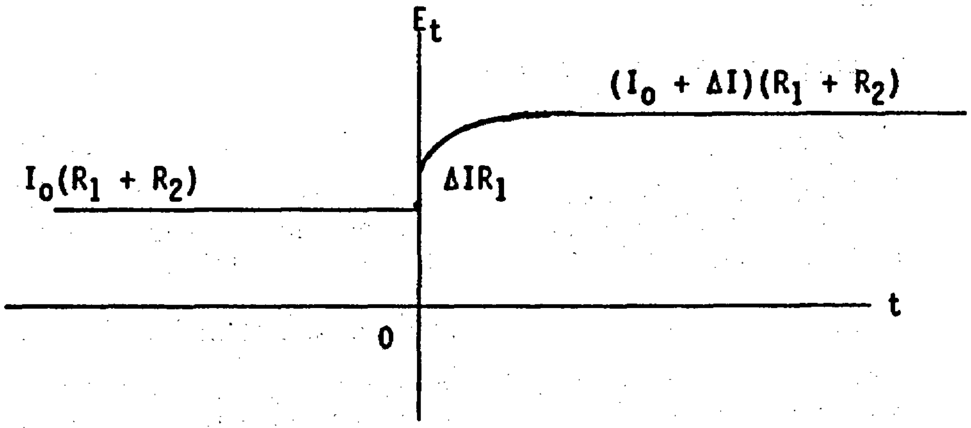


Figure A-2 Terminal Voltage Response to a Step Increase in Current at t = infinity the voltage, E_{inf}, is;

$$E_{inf} = I_o(R_1 + R_2) + \Delta I[R_1 + R_2(1 - 0)]$$

$$E_{inf} = (I_o + \Delta I)(R_1 + R_2)$$

and the change from before t =0 is;

$$\Delta E_t = [(I_o + \Delta I)(R_1 + R_2)] - [I_o(R_1 + R_2)]$$

$$\Delta E_t = \Delta I(R_1 + R_2)$$

and so;

$$R_2 = (\Delta E_t/\Delta I) - R_1 \qquad (2)$$

Note that the term ΔE_t is different in equation 2 than it is in equation 1.

since the time constant $\tau = R_2C$;

$$C = \tau/R_2 \qquad (3)$$

The Westinghouse R&D Center has stated that R_1 may also be determined by interrupting a discharge current of about 50 amperes with a high speed switch and noting the instantaneous change in voltage.

CIRCUITS FOR MEASUREMENT OF RESISTANCES, CAPACITANCE, AND POLARIZATION

Figure A-3 shows the circuit for measuring R_1, R_2, and C by using a step change of about 1 ampere in charging current. Based on information obtained by the Westinghouse R&D Center the following are the approximate values that are expected:

R_1 = 0.3 milliohm

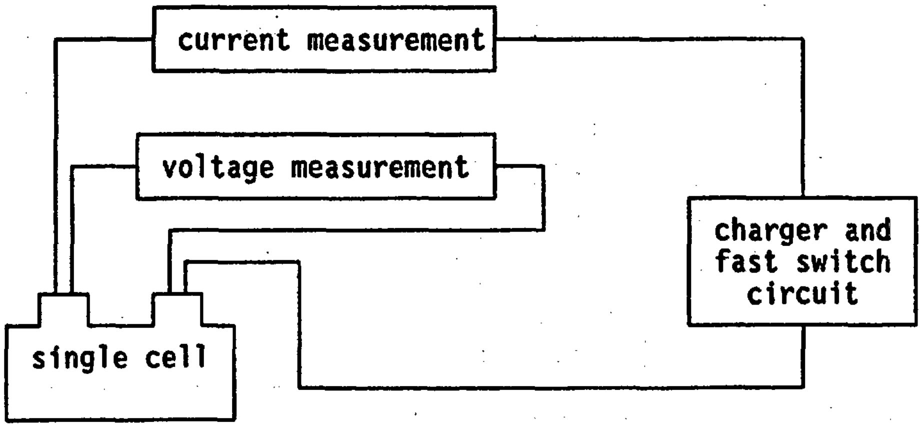
R_2 = 41 milliohm

C = 1100 farads

τ = 45 seconds

Figure A-4 shows the circuit for measuring the electronic resistance by interrupting a discharge current of about 50 amperes.

The circuit for performing the polarization tests is shown in Figure A-5. The discharge current will be increased in steps up to a current of 450 amperes and then decreased in steps to 0 amperes. Each step will be held for 1 minute and the voltage and current will be recored at the end of each 1 minute step.

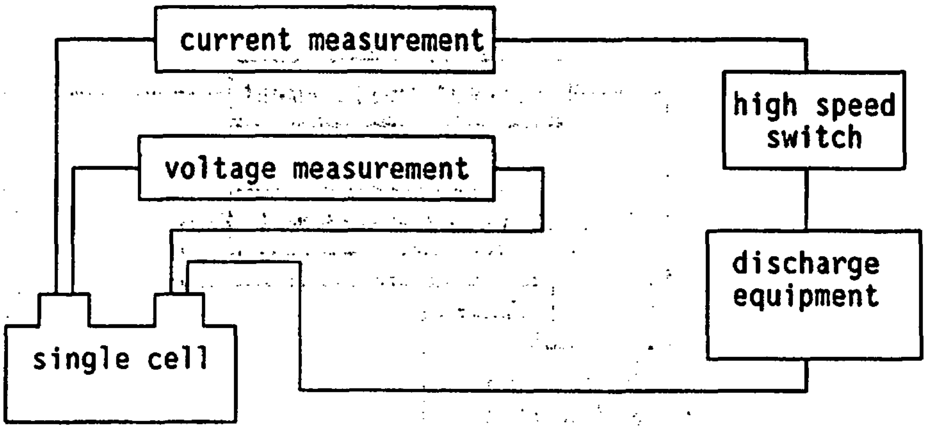


Notes: 1. Current and voltage measurements must have a response time no greater than 4 milliseconds. A 0.4 millisecond or better response is preferred.

2. The voltage measurement must be attached directly to the cell terminals to avoid measuring the contact resistance between the terminals and the external circuit.

3. The step change in charging current must occur as fast as possible. A switching speed of 0.1 millisecond is preferred.

Figure A-3 Circuit For Measuring Resistances and Capacitance with a Step Change in Charging Current

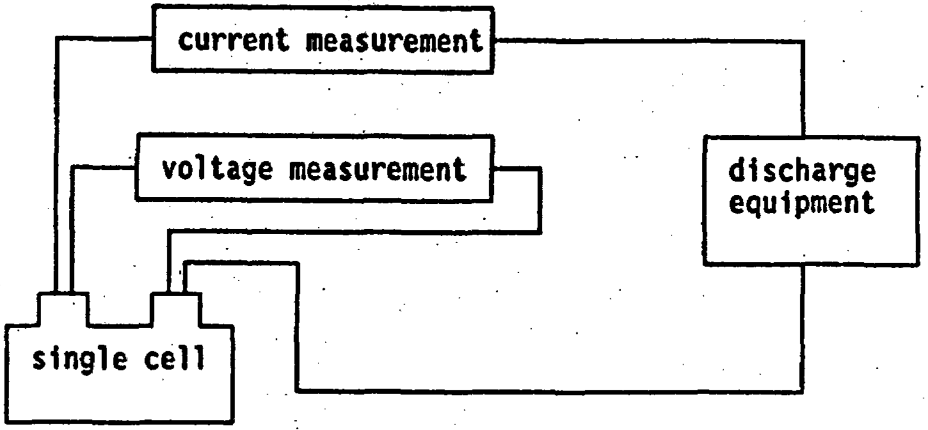


Notes: 1. Current and voltage measurements must have a response time no greater than 4 milliseconds. A 0.4 millisecond or better response is preferred.

2. The voltage measurement must be attached directly to the cell terminals to avoid measuring the contact resistance between the terminals and the external circuit.

3. The step change in discharging current must occur as fast as possible. A switching speed of 0.1 millisecond is preferred.

Figure A-4 Circuit For Measuring Resistances and Capacitance by Interrupting Discharging Current



Notes: 1. Use 50 ampere steps increasing from 0 to 450 amperes and then decreasing from 450 to 0 amperes.

2. Each step is to be held for 1 minute. Data is to recorded at the end of each 1 minute step.

Figure A-5 Circuit For Measuring Cell Polarization

ATTACHMENT B

SEISMIC SIMULATION TEST PROGRAM ON TWELVE NATURALLY-AGED C&D LCU-19 BATTERIES

SEISMIC SIMULATION TEST PROGRAM

ON

TWELVE NATURALLY-AGED
C&D LCU19 BATTERIES

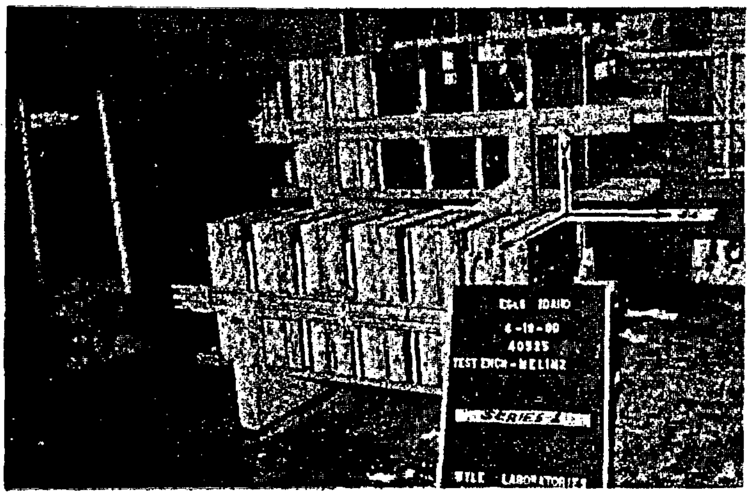
FOR

EG&G IDAHO, INC.
P. O. BOX 1625
IDAHO FALLS, IDAHO 83145

SEISMIC SIMULATION TEST PROGRAM ON TWELVE NATURALLY-AGED C&D LCU-19 BATTERIES

Prepared by Wyle Laboratories

CONTENTS



SEISMIC SIMULATION
Test Report

REPORT NO. 40525-1

WYLE JOB NO. 40525

CUSTOMER P. O. NO. C89-102280

PAGE 1 OF 156 PAGE REPORT

DATE May 19, 1989

SPECIFICATION (S)
See References in Section 7.0

1.0 CUSTOMER EG&G Idaho, Inc.

ADDRESS P. O. Box 1625, Idaho Falls, Idaho 83145

2.0 TEST SPECIMEN Twelve Naturally-Aged C&D LUC-19 Stationary Batteries

3.0 MANUFACTURER C&D Power Systems, Inc.

4.0 SUMMARY

Twelve Batteries, described in Paragraph 5.1 and hereinafter called the specimens, were subjected to a Seismic Simulation Test Program as required by the EG&G Idaho, Inc., Purchase Order Number C89-102280 and Wyle Laboratories' Seismic Test Procedure 543/40525-01/JK dated April 1, 1989, Revision A dated April 18, 1989. This test program was performed on April 18 through 21, 1989.

The test program consisted of single-axis resonance search testing and triaxial random multifrequency testing to several test levels. The specimens were interconnected and their output was monitored during the performance of the tests. Additionally, pre-seismic and post-seismic capacity checks were performed by EG&G.

It was demonstrated that the specimens possessed sufficient integrity to withstand, without compromise of structures or monitored functions, the prescribed seismic environment.

STATE OF ALABAMA }
COUNTY OF MADISON } ss.

Ala. Professional Eng.
Reg. No. 8256

Flavous R. Johnson, being duly sworn, deposes and says: The information contained in this report is the result of complete and carefully conducted tests and is to the best of his knowledge true and correct in all respects.

SUBSCRIBED and sworn to before me this ___ day of May, 1989

Virginia R. Dent
Notary Public in and for the State of Alabama at large.

My Commission expires June 12, 1991

PREPARED BY Rod Thornberry 5-22-89
L. R. Thornberry

APPROVED BY Heinrich Melinz 5-22-89
Heinrich Melinz

WYLE Q. A. R Hamilton 5-23-89 for
G. W. Hight

WYLE (101)
LABORATORIES SCIENTIFIC SERVICES & SYSTEMS GROUP
HUNTSVILLE, ALABAMA

4.0 SUMMARY (Continued)

Notice of Anomaly No. 1, located on Page 11, documents the procedural deviation that several of the datapoints of the Test Response Spectrum plots did not envelop the Required Response Spectrum.

Notice of Anomaly No. 2, located on Page 12, documents the degree of scraping (caused by the battery rack tie rods) damages to the transparent polycarbonate battery housing containers.

Table I, located on Page 13, contains descriptions of the test runs.

Figure 1, located on Page 15, shows the mounting locations of the Batteries and response accelerometers.

Figures 2 through 9, located on Pages 16 through 23, show the horizontal and vertical Required Response Spectra for the 50% Level, 85% Level, 95% Level, and the 100% Level Tests, respectively.

Photographs 1 through 5, located on Pages 25 through 27, show the test setup details of Test Series 1 (Group #1 Batteries) and response accelerometer mounting locations.

Photographs 6 and 7, located on Pages 27 and 28, pertain to Test Series 2 (Group #2 Batteries) testing.

Photographs 8 through 12, located on Pages 28 through 30, pertain to Test Series 3 (Group #3 Batteries) testing.

Photographs 13 through 17, located on Pages 31 through 33, pertain to the Bare Table Test performed prior to Test Series 4.

Photographs 18 through 27, located on Pages 33 through 38, pertain to Test Series 4 (Group #1 Batteries 100% Level) testing.

Appendix I, beginning on Page 39, contains Transmissibility plots of the specimen-mounted accelerometers from the Resonance Search Tests.

Appendix II, beginning on Page 47, contains Test Response Spectrum plots of the control and specimen response accelerometers from the Seismic Simulation Tests.

Appendix III, beginning on Page 115, contains a summary of the operational checks performed and their respective results.

Appendix IV, beginning on Page 123, contains the Instrumentation Log Sheets, Instrumentation Equipment Sheets, and Instrumentation Data Sheets.

Appendix V, beginning on Page 135, contains Wyle Laboratories' Seismic Test Procedure 543/40525-01/JK dated April 1, 1989, Revision A dated April 18, 1989.

5.0 TEST REQUIREMENT DETAILS

The test requirements are as described in Test Procedure No. 543/40525-01/JK Revision A, which is contained in Appendix V.

5.1 Specimen Description

Twelve naturally-aged (to 13-1/2 years) C&D LCU-19 Batteries, each having an electrical capacity of 1350 ampere-hours were divided in three groups of four batteries each. Each Battery is 7-5/8" long, 14-1/8" wide, and 22-1/16" high and weighs 240 pounds. The following identifies the groups and the tests which were performed.

TEST SERIES	GROUP	EG&G I.D. NOS.	PERFORMED TESTS
1	#1	18, 24, 26, 46	Resonance Search Test and 50% Level RMF Test
2	#2	17, 25, 45, 48	85% Level RMF Test
3	#3	23, 29, 30, 47	95% Level RMF Test
4	#1	18, 24, 26, 46	100% Level RMF Test

LEGEND: RMF = Random Multifrequency

Each group of four Batteries was mounted in the upper shelf of a C&D No. RD-903-5 Seismic Battery Rack Assembly (which is capable of holding 12 batteries as shown in Figure 1) according to the instructions outlined in Appendix C of EG&G Specification ES-51235.

NOTE: Since only four batteries were tested together, the remaining eight locations on the rack were filled with simulated batteries. The simulated batteries were constructed of wood and steel and had the weight and dimensions of an actual battery.

Each specimen was charged to the specified capacity prior to testing and was electrically loaded (discharged at 2% of the specified three-hour rate) during the Seismic Tests. The charge equipment and monitoring environment to perform these tasks were the responsibility of EG&G.

NOTE: All testing was performed at ambient laboratory temperatures which were within the specified 77°F ± 5°F.

5.0 TEST REQUIREMENT DETAILS (Continued)

5.2 Test Sequence

The test sequence described in Paragraph 1.3 of the Test Procedure (Appendix V) was followed for the first three test series.

EG&G decided to perform Test Series 4 after successful completion of the first three test series. Therefore, Step 1 and Steps 4 through 12 were repeated (for the Group #1 Batteries) for the 100% Test level.

5.3 Acceptance Criteria

The minimum acceptance criteria were defined as follows:

- The specimens shall retain their structural and electrical integrity during and after the Seismic Tests.
- The specimens shall be capable of performing their designed function during and after the Seismic Tests. (EG&G shall monitor the specimens as required and shall verify that the specimens operated per their design requirements.)
- Leakage due to cracked cells shall not be acceptable.

NOTE: The acceptance criteria apply to the Battery Cells only (excluding Battery Rack and dummy batteries, etc.).

6.0 TEST PROCEDURES AND RESULTS

6.1 Pre-Seismic Operational Verification

Prior to performing the Seismic Tests, all specimens were subjected to the following:

- Receipt inspection
- Electrical capacity checks by discharging at the three-hour rate
- Recharging to the required charge level
- Alternate surveillance measurements.

These tests were performed by EG&G personnel.

6.0 TEST PROCEDURES AND RESULTS (Continued)

6.2 Seismic Testing

Following successful completion of the above tests, the specimens (in groups of four) were subjected to Seismic Tests outlined in the procedures below.

6.2.1 Specimen Mounting and Orientation

The C&D Seismic Battery Rack Assembly (pre-mounted on two 4" x 46" x 3/4"-thick carbon steel bars using 1/2-13 Grade 5 bolts which were torqued to 75 foot-pounds) was placed on the Seismic Test Table such that its principal orthogonal axes were colienar with the test table's axes of excitation. The test fixture was welded* to the test table. Subsequently, the eight dummy batteries were installed. Each group of four aged Batteries (specimens) was loaded in the rack (located at one end of the top step of the rack assembly), as shown in Figure 1. Installation and tie-down of the Batteries in the rack were according to the instructions outlined in Appendix C of EG&G Specification ES-51235.

*2-Inch long 3/16" welds (on either side of each mounting bolt location) were utilized to weld the fixture to the test table.

Photographs 1 through 6 and 8 show test setup details for Test Series 1 through 3 testing.

Photographs 16 through 18 show test setup details for Test Series 4 testing.

6.2.2 Resonance Search Test Procedure (Group #1 Batteries Only)

A low-level (0.2g horizontally and vertically) single-axis Sine Sweep Test was performed from 1 to 35 Hz in each of the three orthogonal axes to establish the resonant frequencies for the equipment rack and specimens. The sweep rate was one octave per minute.

6.2.2.1 Resonance Search Test Results

Table I contains the test run descriptions for the Resonance Search Tests.

Transmissibility plots (the specimen response accelerometers divided by the control accelerometers) from the Resonance Search Tests in each test axis are contained in Appendix I.

6.0 TEST PROCEDURES AND RESULTS (Continued)

6.2 Seismic Testing (Continued)

6.2.3 Random Multifrequency Tests (All Groups)

The specimens were subjected to 30-second duration triaxial multifrequency random motion which shall be amplitude-controlled in one-third octave bandwidths spaced one-third octave apart over the frequency range of 1 to 100 Hz. Three simultaneous, but independent, random signals were used as the excitation to produce phase-incoherent motions in the vertical and two horizontal axes. The amplitude of each one-third octave bandwidth was independently adjusted in each of the three axes until the Test Response Spectra (TRS) enveloped* the Required Response Spectra (RRS) within the limitations of the test machine. The resulting table motion was analyzed by a response spectrum analyzer at 2% damping and plotted at one-sixth octave intervals over the frequency range of 1 to 200 Hz.

Each group of Batteries was subjected to one test run to the applicable test level indicated below:

Test Series	Group	Applicable RRS Curves
1	#1	Figures 2 and 3 (50% Level)
2	#2	Figures 4 and 5 (85% Level)
3	#3	Figures 6 and 7 (95% Level)
4	#1	Figures 8 and 9 (100% Level)

*Various data points on several TRS plots did not envelop the respective applicable RRS. For details, see Notice of Anomaly No. 1 and Appendix II.

NOTE 1: Bare Table Tests to shape the TRS (for each test level and test axis) to envelop the respective RRS as closely as possible were performed prior to performing any testing on the specimens.

NOTE 2: EG&G discharged the Batteries at 2% of the specified three-hour rate (and monitored the battery current and voltages) during the Seismic Tests.

6.0 TEST PROCEDURES AND RESULTS (Continued)

6.2 Seismic Testing

6.2.3.1 Random Multifrequency Test Results

It was demonstrated that the specimens (the Batteries) possessed sufficient integrity to withstand the prescribed simulated seismic environment without compromise of structures. No cracked battery cells were noted.

Descriptions of the Random Multifrequency Test runs are contained in Table I.

TRS plots of the control accelerometers for the OBE and SSE Tests at 2% damping are included in Appendix II.

NOTE: Damages to the battery rack assembly, as shown in Photographs 13 through 15, resulted from the 100% Level Bare Table Test (Test Run 7), which was performed with the battery rack fully loaded with dummy batteries. At the direction of the EG&G Technical Representative, the rack was disassembled, all bent parts were straightened. Subsequently, the rack was reassembled, all bolts were retorqued and flat bars were added to the dummy batteries (as shown in Photographs 16 and 17) prior to performing Test Series 4. Additional damages to the rack assembly resulted from Series 4 testing. Photographs 22 through 27 show the extent of these damages.

6.2.4 Specimen Response Procedure

A total of six specimen-mounted uniaxial piezoelectric accelerometers were located on the test assembly as shown in Figure 1 and Photographs 3 through 6. The placement of the accelerometers was as instructed by the EG&G Technical Representative. Magnetic tape recorders provided a record of each accelerometer's response.

6.2.4.1 Specimen Response Results

Transmissibility plots of the accelerometers from the Resonance Search Tests are contained in Appendix I.

TRS plots (filtered at 100 Hz) of the accelerometers, analyzed at 2% damping, from all full-level tests are contained in Appendix II.

6.2.5 Electrical Monitoring Procedures

The Battery performance data were acquired and stored by EG&G for all performed Functional and Seismic Tests.

6.0 TEST PROCEDURES AND RESULTS (Continued)

6.2.5.1 Electrical Monitoring Results

A summary of the EG&G-provided monitoring results is contained in Appendix III.

6.3 Post-Seismic Operational Verification

A post-seismic specimen inspection was performed on each Battery following completion of each series test. Additionally, the functional checks described in Paragraph 6.1 were repeated by the EG&G personnel.

6.3.1 Post-Seismic Operational Verification Results

It was demonstrated that the Batteries possessed sufficient functional integrity to successfully survive the imposed seismic environments.

NOTE: The post-test visual inspections (for Test Series 2, 3 and 4) revealed scrape marks on the battery housings which were caused by the battery rack tie rods (for details, see Notice of Anomaly No. 2 and Photographs 7, 10-12, and 19-21. This did not, however, affect the operability results of the specimens.

The test results for all batteries were within the specified acceptance criteria.

The EG&G-provided test results are contained in Appendix III.

7.0 REFERENCES

7.1 EG&G Idaho, Inc., Purchase Order Number C89-102280.

7.2 Wyle Laboratories' Seismic Test Procedure 543/40525-01/JK dated April 1, 1989, Revision A dated April 18, 1989.

7.3 IEEE Standard 344-1975 Specification entitled "IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

7.4 EG&G Engineering Specification ES-51235 entitled "Seismic Testing of Naturally-Aged Stationary Batteries," dated January 20, 1989.

7.5 Wyle Laboratories' (Eastern Operations) "Quality Assurance Program Manual" dated June 1988.

8.0 QUALITY ASSURANCE

All work performed on this test program was done in accordance with Wyle Laboratories' Quality Assurance Program which complies with the applicable requirements of Military Standard MIL-STD-45662A, 10 CFR 50 Appendix B, ANSI N45.2, and the "daughter" standards. Defects are reportable in accordance with the requirements of 10 CFR Part 21.

9.0 TEST EQUIPMENT AND INSTRUMENTATION

All instrumentation, measuring, and test equipment used in the performance of this test program were calibrated in accordance with Wyle Laboratories' Quality Assurance Program which complies with the requirements of Military Specification MIL-STD-45662A. Standards used in performing all calibrations are traceable to the National Institute of Standards and Technology (NIST) by report number and date. When no national standards exist, the standards are traceable to international standards, or the basis for calibration is otherwise documented.

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WYLE LABORATORIES (Eastern Operations)

NOTICE OF ANOMALY

DATE: 5/2/89

NOTICE NO: 1 P.O. NUMBER: C89-102280 CONTRACT NO: N/A
CUSTOMER: EG&G Idaho, Inc. WYLE JOB NO: 40525
NOTIFICATION MADE TO: J. Edson NOTIFICATION DATE: 4/19-21/89
NOTIFICATION MADE BY: H. Melinz VIA: Verbal

CATEGORY: ☐ SPECIMEN ☒ PROCEDURE ☐ TEST EQUIPMENT DATE OF ANOMALY: 4/19-21/89
PART NAME: All C&D LCU-19 Stationary Batteries PART NO. N/A
TEST: Random Multifrequency Tests I.D. NO. N/A
SPECIFICATION: WLTP 543/40525-01/JK, Rev. A PARA. NO. 2.4.3

REQUIREMENTS:

. . . The amplitude of each one-third octave bandwidth shall be independently adjusted in each of the three axes until the Test Response Spectra (TRS) envelop the Required Response Spectra (RRS) within the limitations of the test machine. . .

DESCRIPTION OF ANOMALY:

During the performance of the random multifrequency testing (for all test levels) several of the data points on the TRS Plot did not envelop the specified RRS.

DISPOSITION – COMMENTS – RECOMMENDATIONS:

According to the EG&G technical representative, the obtained test levels were acceptable since the test program is a R&D type in nature rather than a qualification test program and he did not want the specimens and the rack assembly exposed to any additional unnecessary testing.

NOTE: IT IS THE CUSTOMER'S RESPONSIBILITY TO ANALYZE ANOMALIES AND COMPLY WITH 10 CFR PART 21.

VERIFICATION:

TEST WITNESS: J. Edson
REPRESENTING: EG&G Idaho, Inc.
QUALITY ASSURANCE: 5-4-89
PROJECT ENGINEER: Henry Melinz 5-2-89
PROJECT MANAGER: 5/3/89
INTERDEPARTMENTAL COORDINATION:

Wyle Form WH 1066, Rev. JAN '85

Page 1 of 1

WYLE
LABORATORIES
(Eastern Operations)

NOTICE OF ANOMALY

DATE: 5/2/89

NOTICE NO: 2 **P.O. NUMBER:** C89-102280 **CONTRACT NO:** N/A
CUSTOMER: EG&G Idaho, Inc. **WYLE JOB NO:** 40525
NOTIFICATION MADE TO: J. Edson **NOTIFICATION DATE:** 4/19-21/89
NOTIFICATION MADE BY: H. Melinz **VIA:** Verbal

CATEGORY: ☒ SPECIMEN ☐ PROCEDURE ☐ TEST EQUIPMENT **DATE OF ANOMALY:** 4/19-21/89
PART NAME: Polycarbonate Transparent Container **PART NO.** N/A
TEST: Random Multifrequency Tests **I.D. NO.** N/A
SPECIFICATION: WLTP 543/40525-01/JK, Rev. A **PARA. NO.** 2.6 & 3.0

REQUIREMENTS:

. . . The specimens shall be inspected for any obvious damage following all tests.

. . . All important vibration effects shall be logged . . .

DESCRIPTION OF ANOMALY:

Post-test inspections (performed following completion of the 85%, 95%, and 100% level tests) revealed scratch and scrape marks on the transparent polycarbonate battery housing containers of the batteries located on either side of the battery rack tie rods. The severity and depth of the scratches and burrows was directly proportional to the degree of input levels.

DISPOSITION - COMMENTS - RECOMMENDATIONS:

The observed damages did not affect the operability of the specimens. However, the noted damages warrant an investigation concerning the possibility of replacing the existing rod system with an improved one. Photographs showing the extent of the noted damages on the batteries are presented in the body of the test report.

NOTE: IT IS THE CUSTOMER'S RESPONSIBILITY TO ANALYZE ANOMALIES AND COMPLY WITH 10 CFR PART 21.

VERIFICATION:

PROJECT ENGINEER: 5-2-89
TEST WITNESS: J. Edson
PROJECT MANAGER: 5/3/89
REPRESENTING: EG&G Idaho, Inc.
INTERDEPARTMENTAL COORDINATION:
QUALITY ASSURANCE: 5-4-89

Wyle Form WH 1066, Rev. JAN '85

Page 1 of 1

TABLE I

TEST RUN DESCRIPTIONS

RUN NO.	TYPE OF TEST	TEST AXIS	TEST LEVEL	ACCELERATION (g)			COMMENTS
				FBZPA	SSZPA	VZPA	
BT 1	RMF	TRI	50%	0.6	0.78	0.44	Table Only
BT 2	RMF	TRI	85%	1.1	1.5	1.0	Table Only
BT 3	RMF	TRI	95%	2.6	2.7	1.9	Table Only

PERFORMED PRE-SEISMIC OPERABILITY VERIFICATION ON ALL BATTERIES

TEST SERIES 1

1	Sine Sweep	FB	---	0.2	---	---	1 to 35 Hz
2	Sine Sweep	SS	---	---	0.2	---	1 to 35 Hz
3	Sine Sweep	V	---	---	---	0.2	1 to 35 Hz
4	RMF	TRI	50%	0.75	0.70*	0.63	See Note 1

TEST SERIES 2

5	RMF	TRI	85%	1.5	1.5	1.1	See Note 2

TEST SERIES 3

6	RMF	TRI	95%	2.5*	3.1*	2.1	See Note 2

PERFORMED POST-SEISMIC OPERABILITY VERIFICATION ON GROUP #1 BATTERIES

7	RMF	TRI	100%	5.6*	4.8*	4.2	See Note 3

TEST SERIES 4

8	RMF	TRI	100%	5.1*	5.7*	4.6	See Notes 2 and 3

*Some data points on the TRS did not envelop the RRS (reference Notice of Anomaly No. 1).

NOTE 1: Post-test inspection revealed no damages.

NOTE 2: Reference Notice of Anomaly No. 2 and Paragraph 6.3.1.

NOTE 3: Damages to the Battery Rack Assembly occurred. For details, see NOTE in Paragraph 6.2.3.1.

LEGEND:
BT = Bare Table
FB = Front-to-Back
SS = Side-to-Side
V = Vertical
ZPA = Zero Period Acceleration
RMF = Random Multifrequency
TRI = Triaxial

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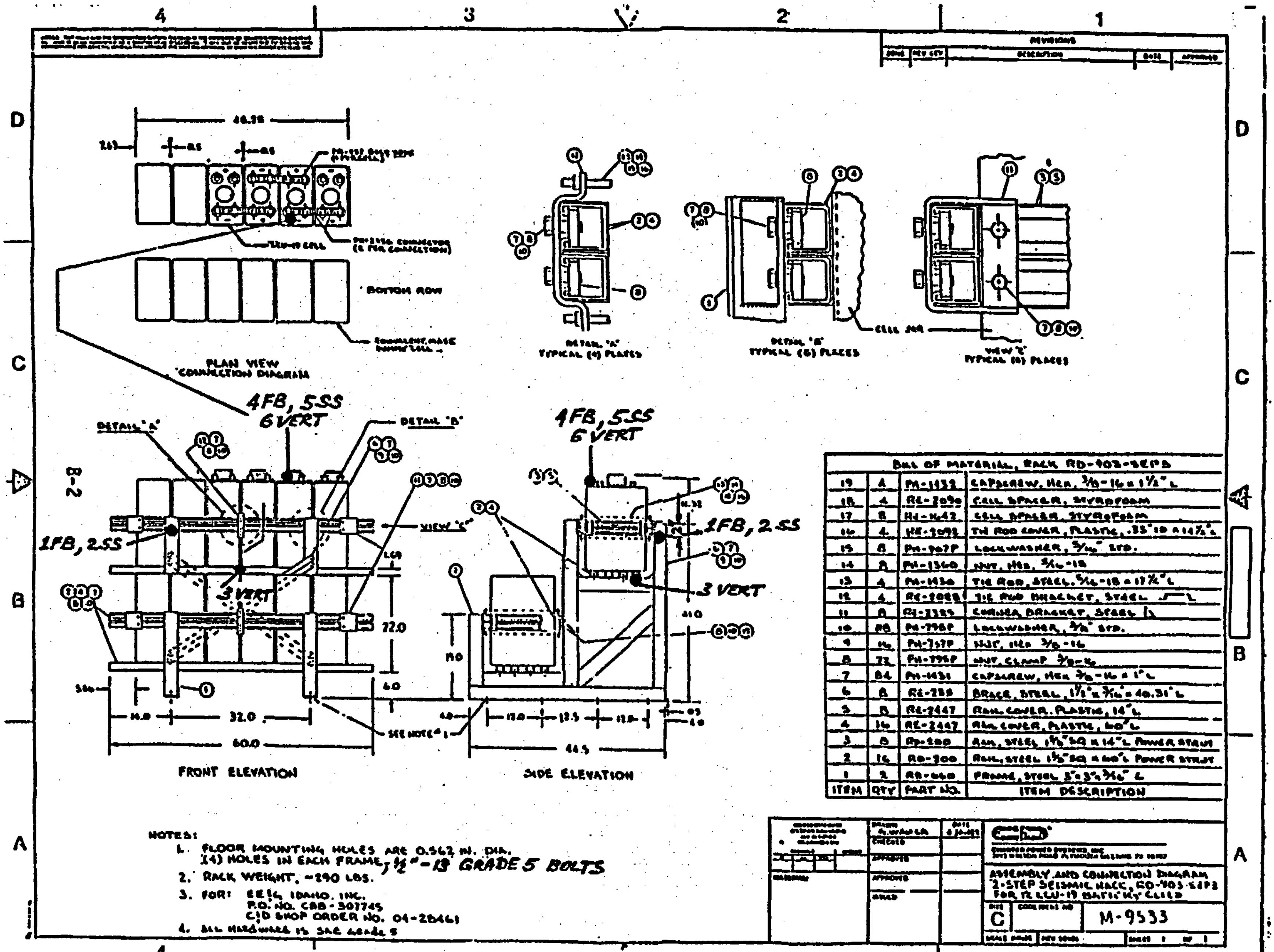

NOTES:

1. FLOOR MOUNTING HOLES ARE 0.562 IN. DIA. (4) HOLES IN EACH FRAME, ½"-13 GRADE 5 BOLTS
2. RACK WEIGHT, ~290 LBS.
3. FOR: EE&G IDAHO, INC.
   P.O. NO. C88-307745
   C&D SHOP ORDER NO. 04-28461
4. ALL HARDWARE IS SAE GRADE 5

BILL OF MATERIAL, RACK RD-903-SEPS

ITEM	QTY	PART NO.	ITEM DESCRIPTION
19	4	PH-1132	CAPSCREW, HEX, 3/8-16 x 1½" L
18	4	RE-3090	CELL SPACER, STYROFOAM
17	8	[illegible]	CELL SPACER, STYROFOAM
16	4	RE-3092	TIE ROD COVER, PLASTIC, .35" ID x 14½" L
15	8	PH-9077P	LOCKWASHER, 5/16" STD.
14	8	PH-1360	NUT, HEX, 5/16-18
13	4	PH-1430	TIE ROD, STEEL, 5/16-18 x 17¼" L
12	4	RE-2088	TIE ROD BRACKET, STEEL
11	8	RE-3323	CORNER BRACKET, STEEL
10	88	PH-796P	LOCKWASHER, 3/8" STD.
9	16	PH-757P	NUT, HEX 3/8-16
8	72	PH-795P	NUT, CLAMP 3/8-16
7	84	PH-1431	CAPSCREW, HEX 3/8-16 x 1" L
6	8	RE-233	BRACE, STEEL, 1½" x 3/16" x 40.31" L
5	8	RE-2447	RAIL COVER, PLASTIC, 14" L
4	16	RE-2447	RAIL COVER, PLASTIC, 60" L
3	8	RD-200	RAIL, STEEL, 1⅝" SQ x 14" L POWER STRUT
2	16	RD-300	RAIL, STEEL 1⅝" SQ x 60" L POWER STRUT
1	2	RD-660	FRAME, STEEL 3" x 3" x 3/16" L

ASSEMBLY AND CONNECTION DIAGRAM
2-STEP SEISMIC RACK, RD-903-SEPS
FOR 12 LCU-13 BATTERY CELLS

C
M-9533

FIGURE 1. BATTERY AND RESPONSE ACCELEROMETER MOUNTING LOCATIONS (APPLICABLE TO ALL TEST SERIES)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%

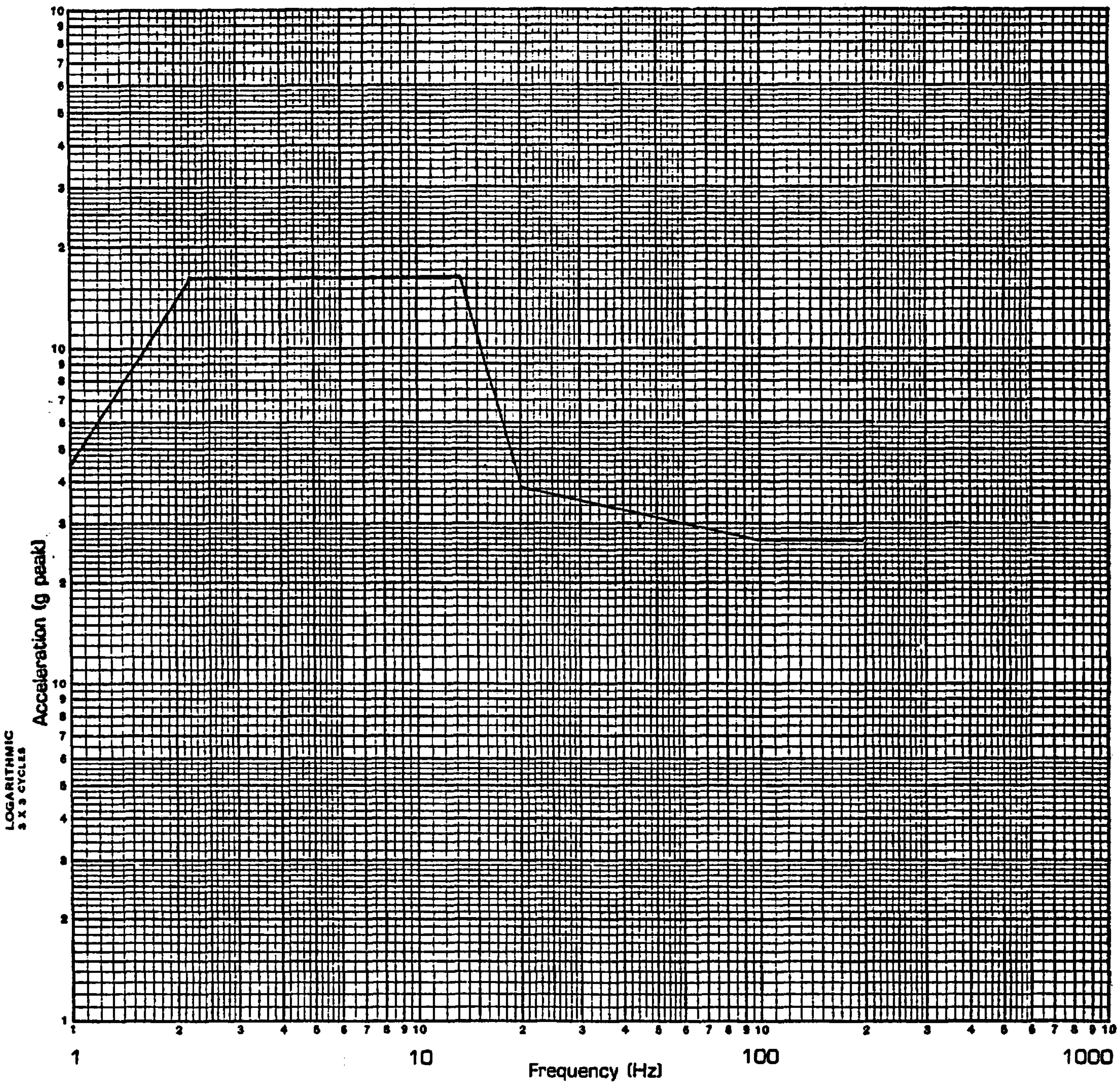

FIGURE 2. HORIZONTAL 50% LEVEL
REQUIRED RESPONSE SPECTRUM
(TEST SERIES 1, GROUP #1 BATTERIES)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%

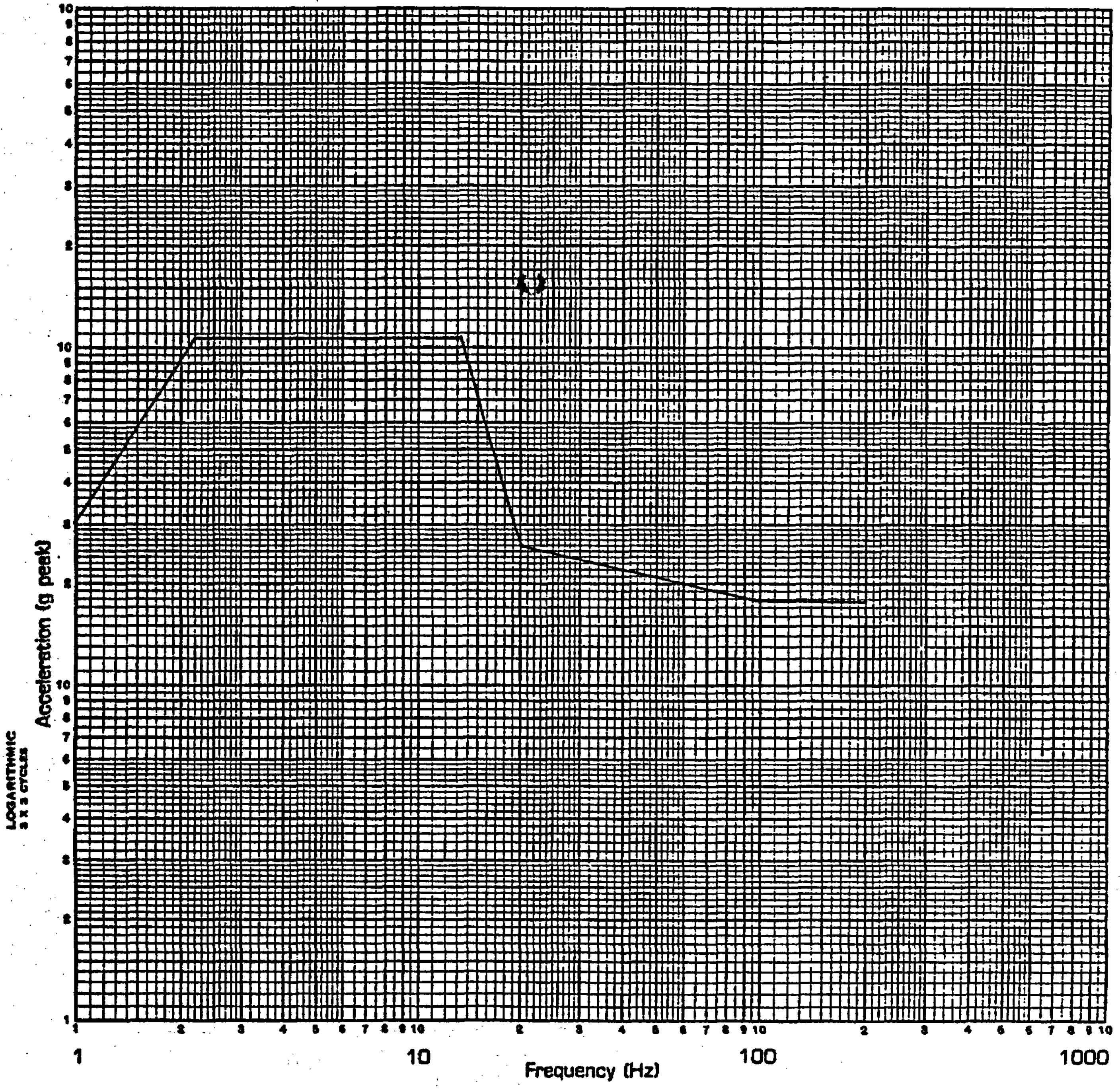

FIGURE 3. VERTICAL 50% LEVEL
REQUIRED RESPONSE SPECTRUM
(TEST SERIES 1, GROUP #1 BATTERIES)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%

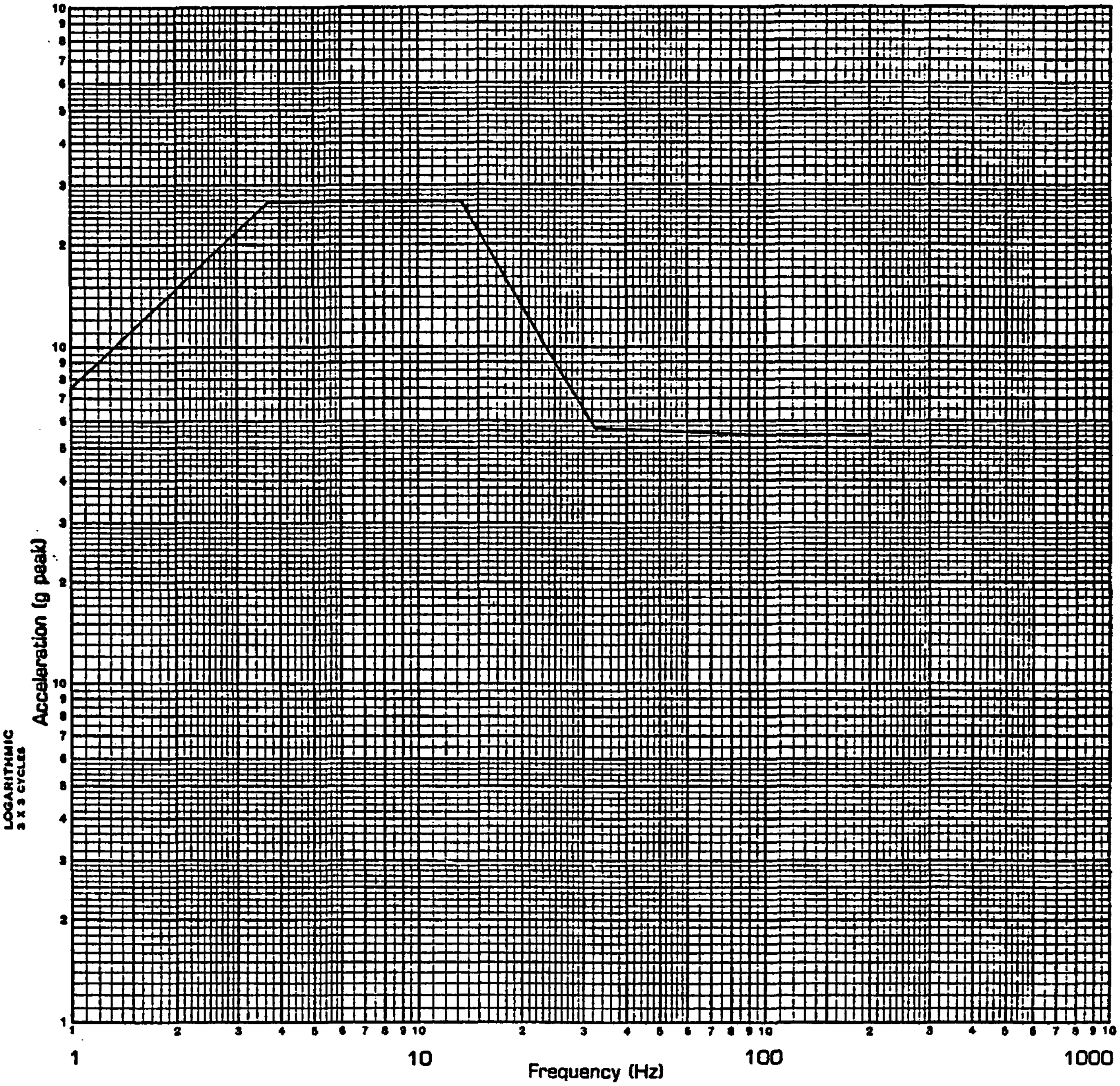

FIGURE 4. HORIZONTAL 85% LEVEL
REQUIRED RESPONSE SPECTRUM
(TEST SERIES 2, GROUP #2 BATTERIES)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%

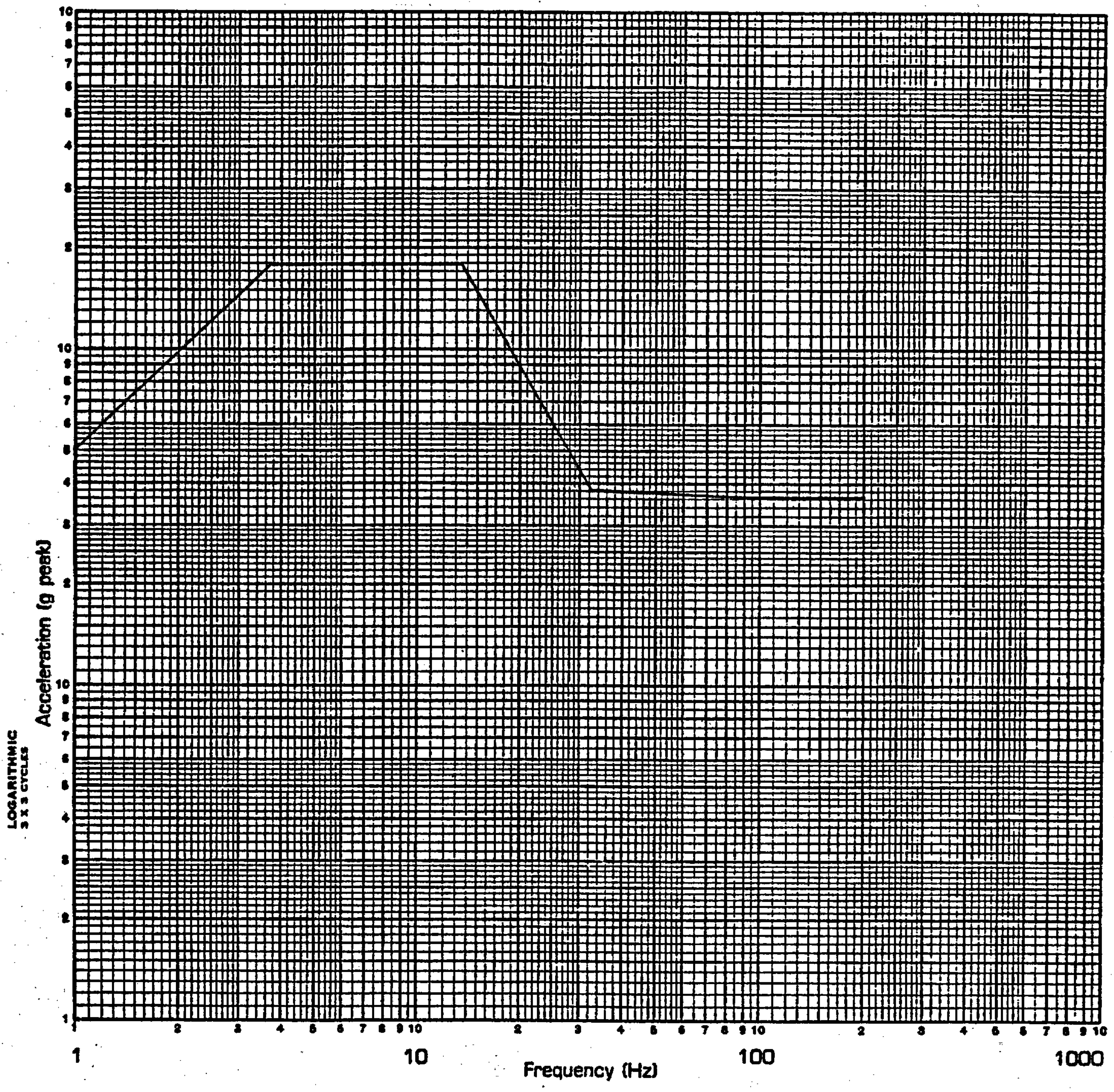

FIGURE 5. VERTICAL 85% LEVEL
REQUIRED RESPONSE SPECTRUM
(TEST SERIES 2, GROUP #2 BATTERIES)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%

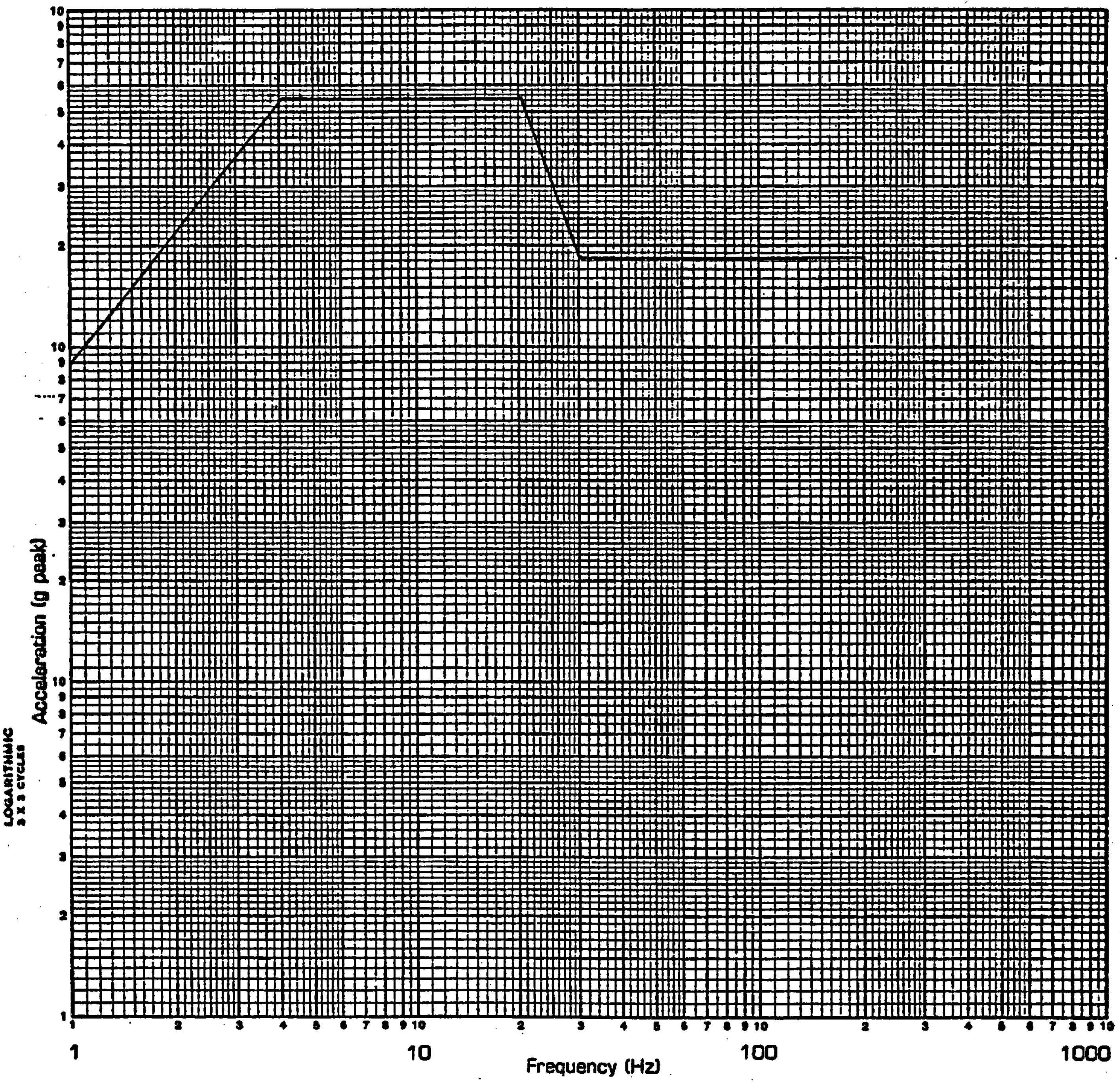

FIGURE 6. HORIZONTAL 95% LEVEL
REQUIRED RESPONSE SPECTRUM
(TEST SERIES 3, GROUP #3 BATTERIES)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%

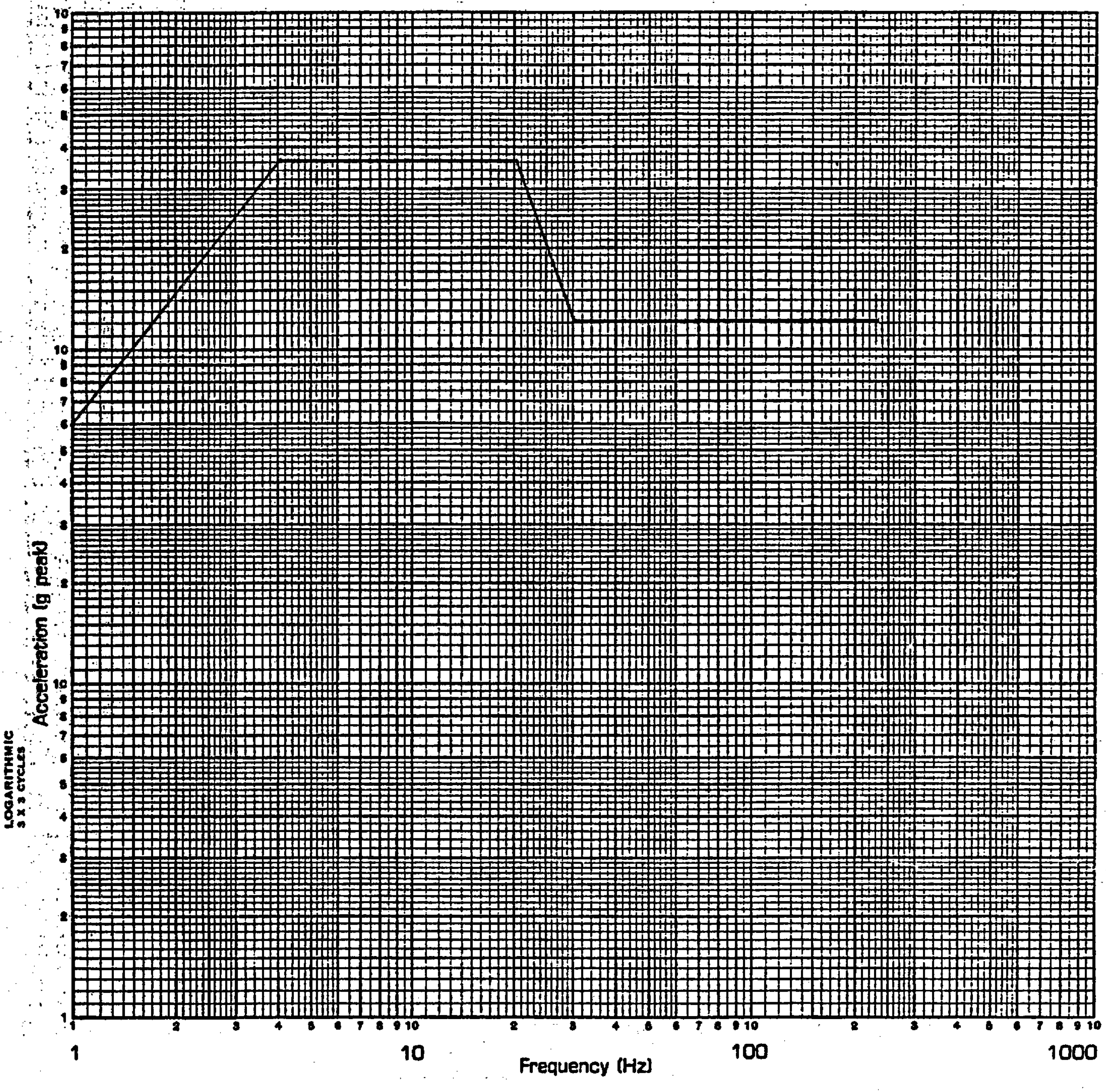

FIGURE 7. VERTICAL 95% LEVEL
REQUIRED RESPONSE SPECTRUM
(TEST SERIES 3, GROUP #3 BATTERIES)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING 2%

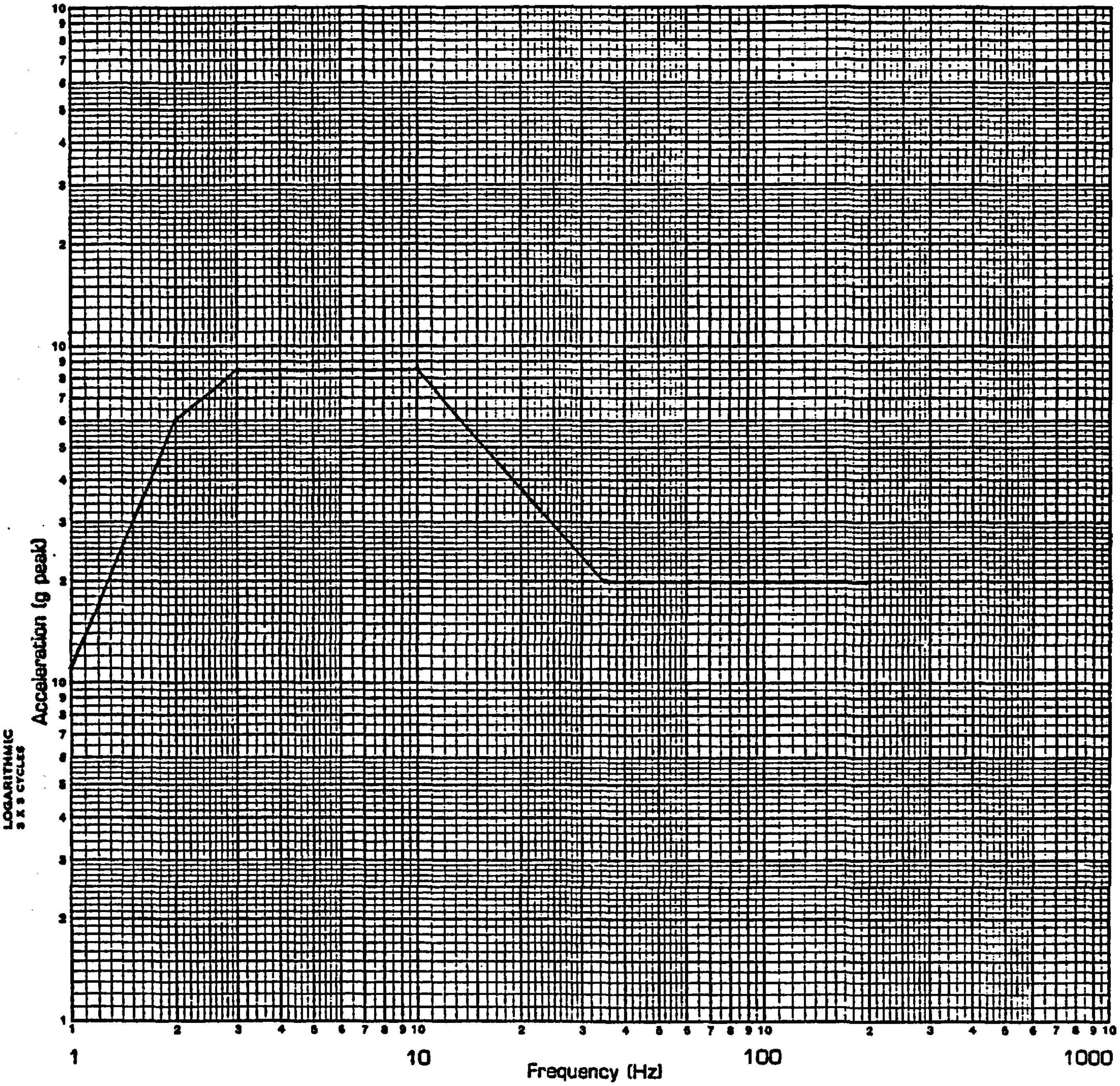

FIGURE 8. HORIZONTAL 100% LEVEL
REQUIRED RESPONSE SPECTRUM
(TEST SERIES 4, GROUP #1 BATTERIES)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000☐

DAMPING 2%

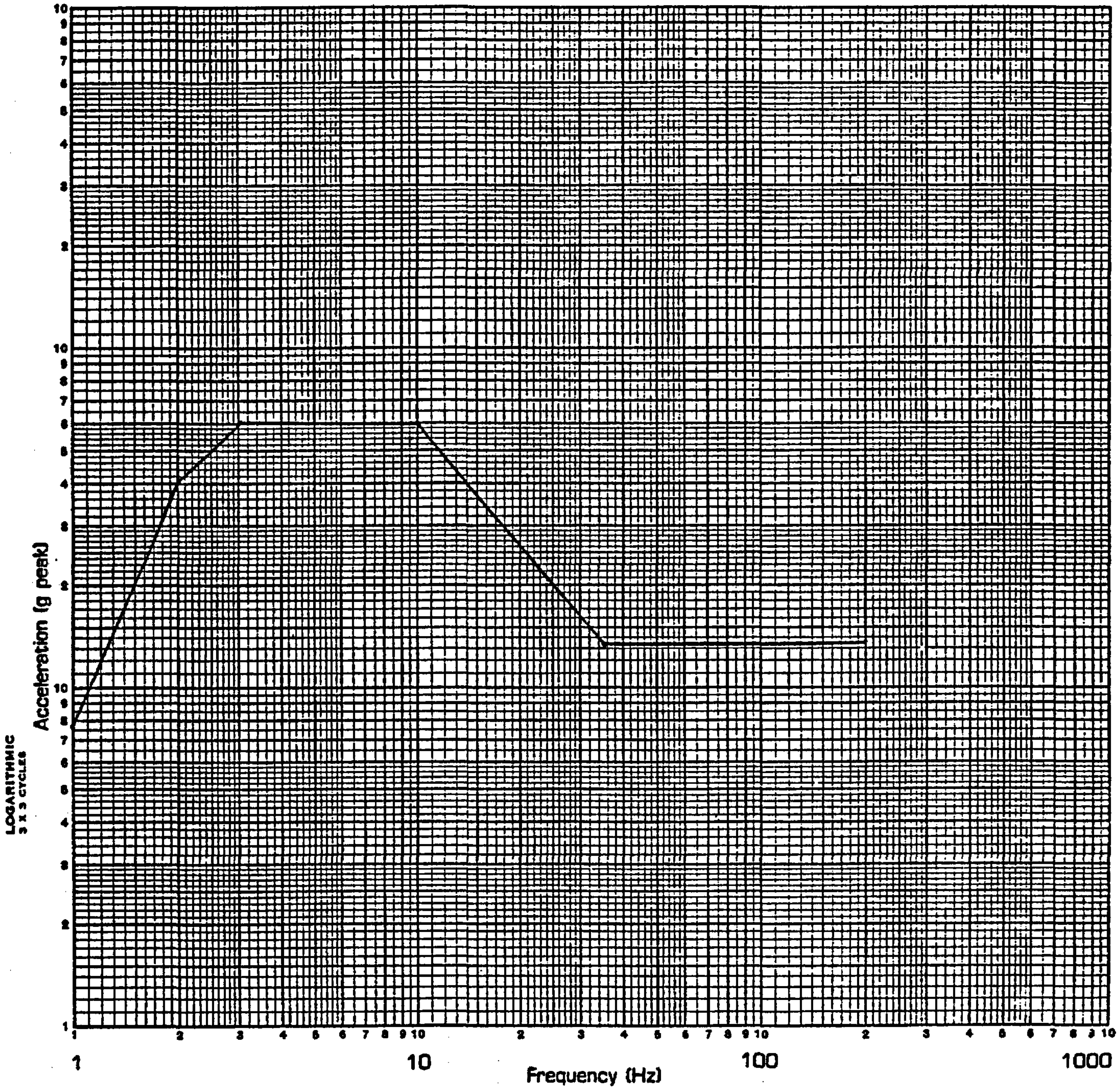

FIGURE 9. VERTICAL 100% LEVEL
REQUIRED RESPONSE SPECTRUM
(TEST SERIES 4, GROUP #1 BATTERIES)

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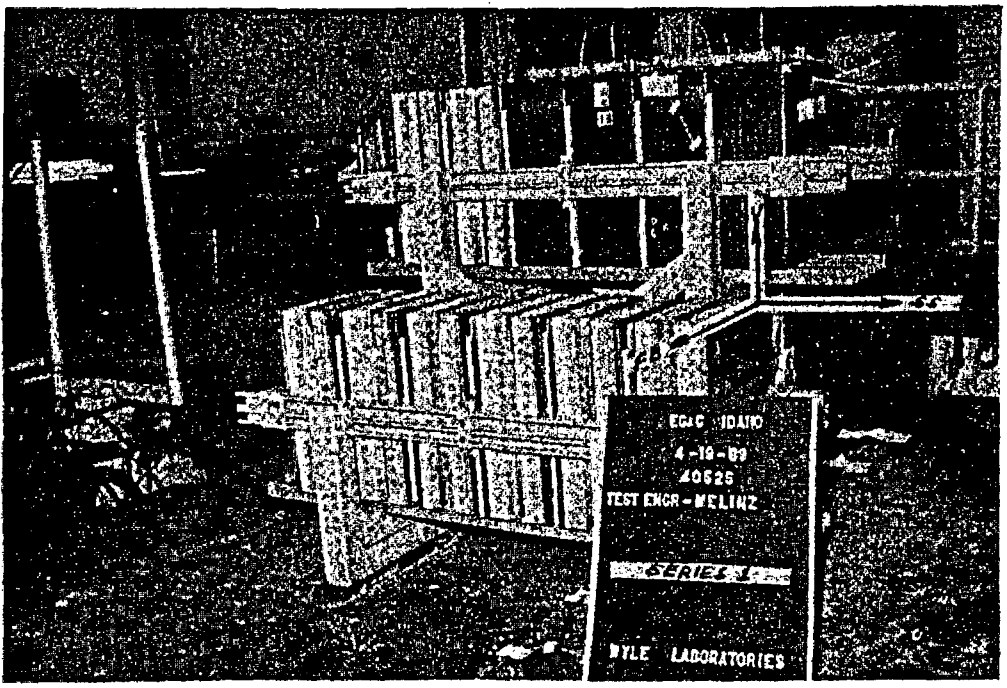
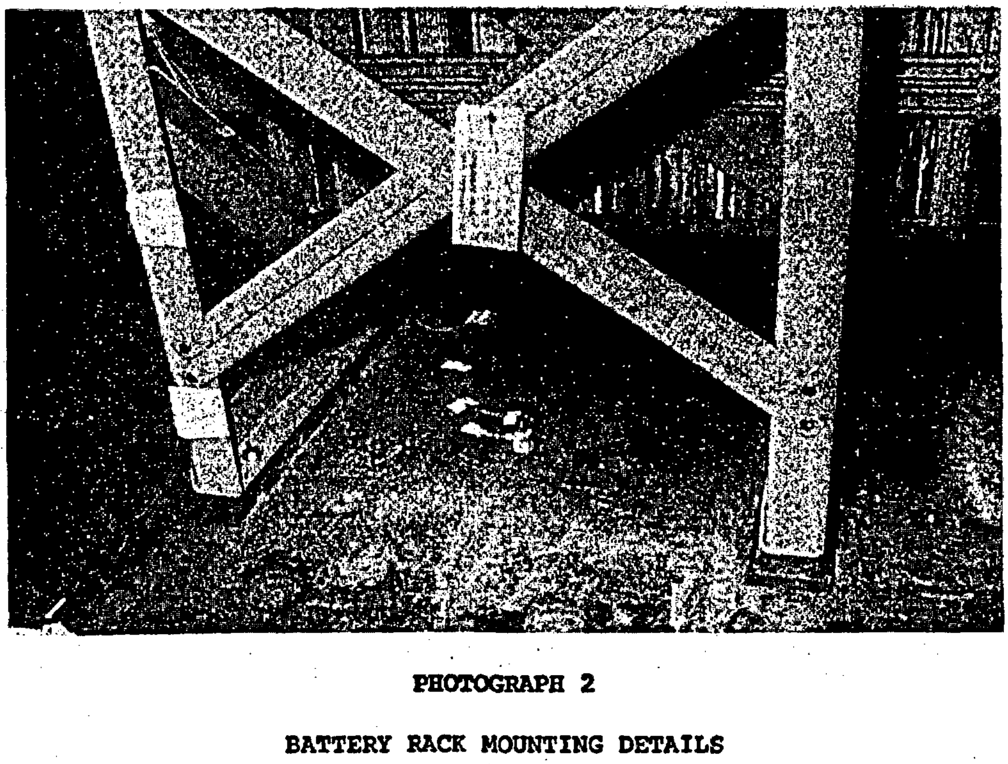


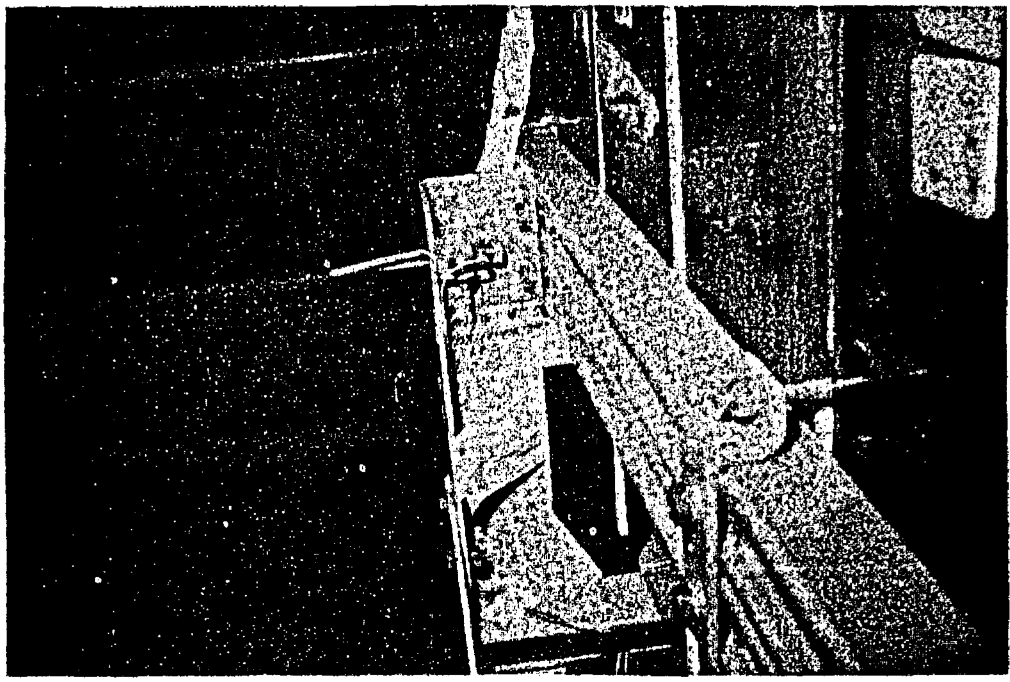
PHOTOGRAPH 1

TEST SERIES 1 TEST SETUP
GROUP #1 BATTERIES
(FROM LEFT TO RIGHT #26, #18, #24 AND #46)



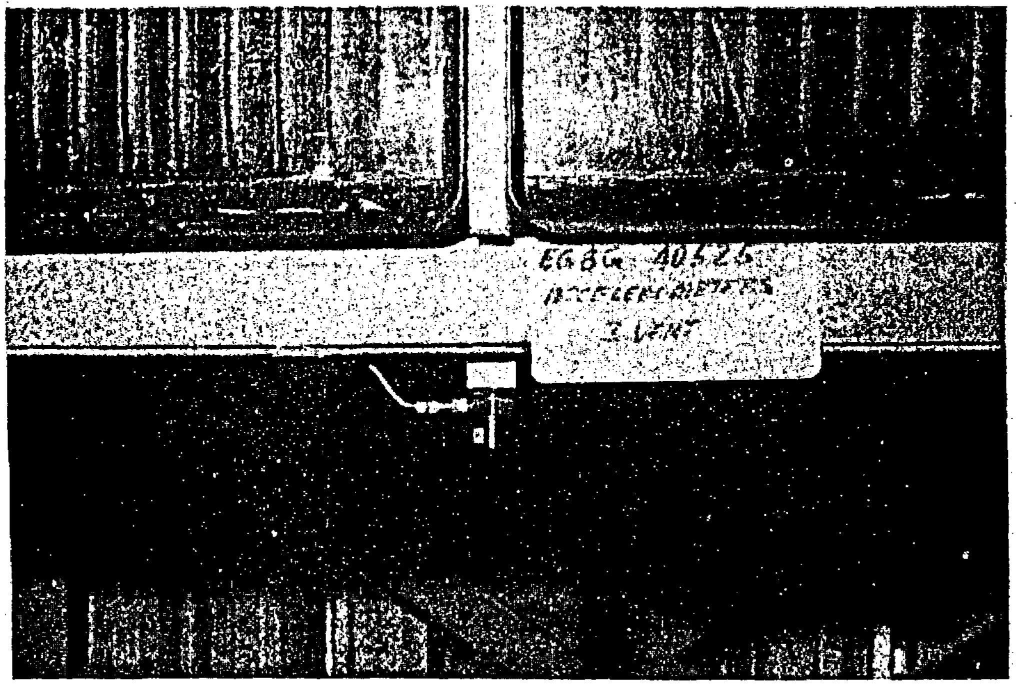
PHOTOGRAPH 2

BATTERY RACK MOUNTING DETAILS
AND
CONTROL ACCELEROMETER MOUNTING LOCATION
(THE SAME FOR ALL TEST SERIES)



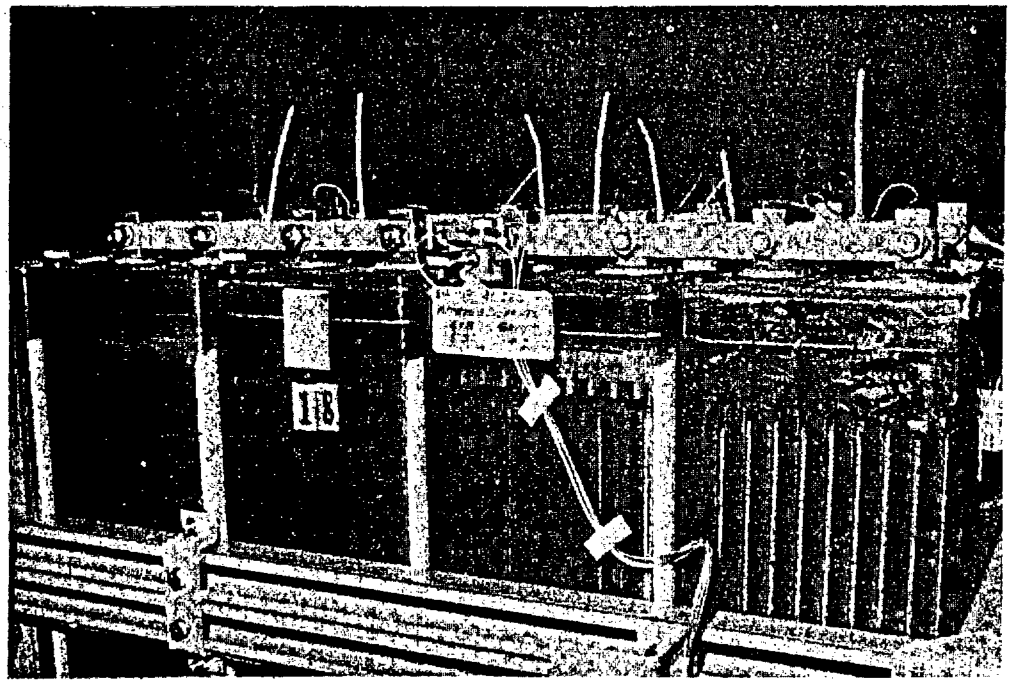
PHOTOGRAPH 3

MOUNTING LOCATION OF ACCELEROMETERS
1 FRONT-TO-BACK AND 2 SIDE-TO-SIDE
(THE SAME FOR ALL TEST SERIES)



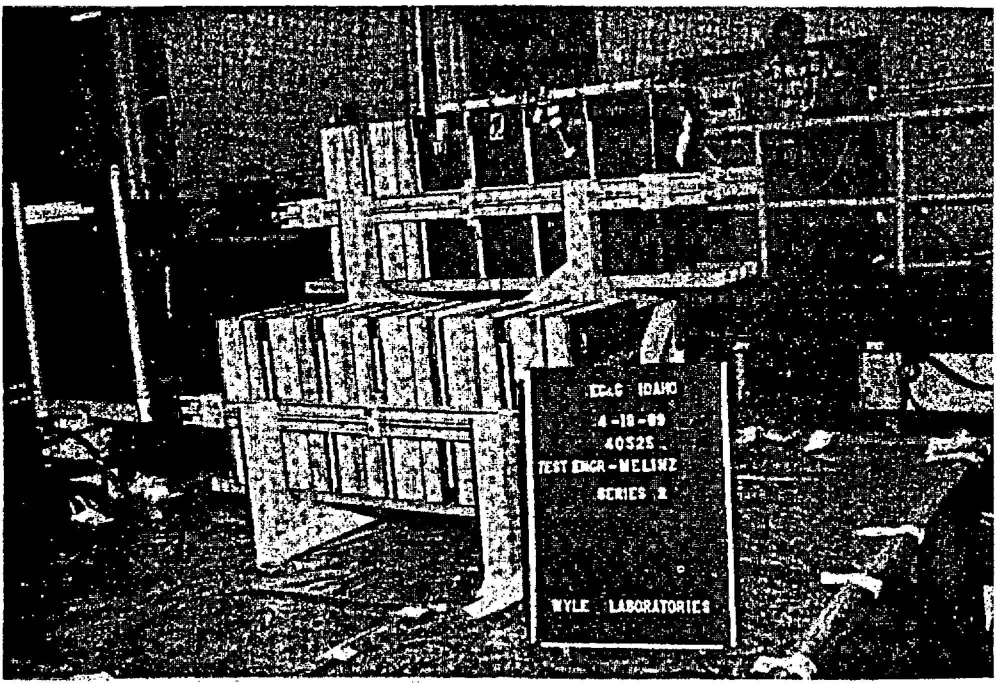
PHOTOGRAPH 4

MOUNTING LOCATION OF ACCELEROMETER
3 VERTICAL
(THE SAME FOR ALL TEST SERIES)



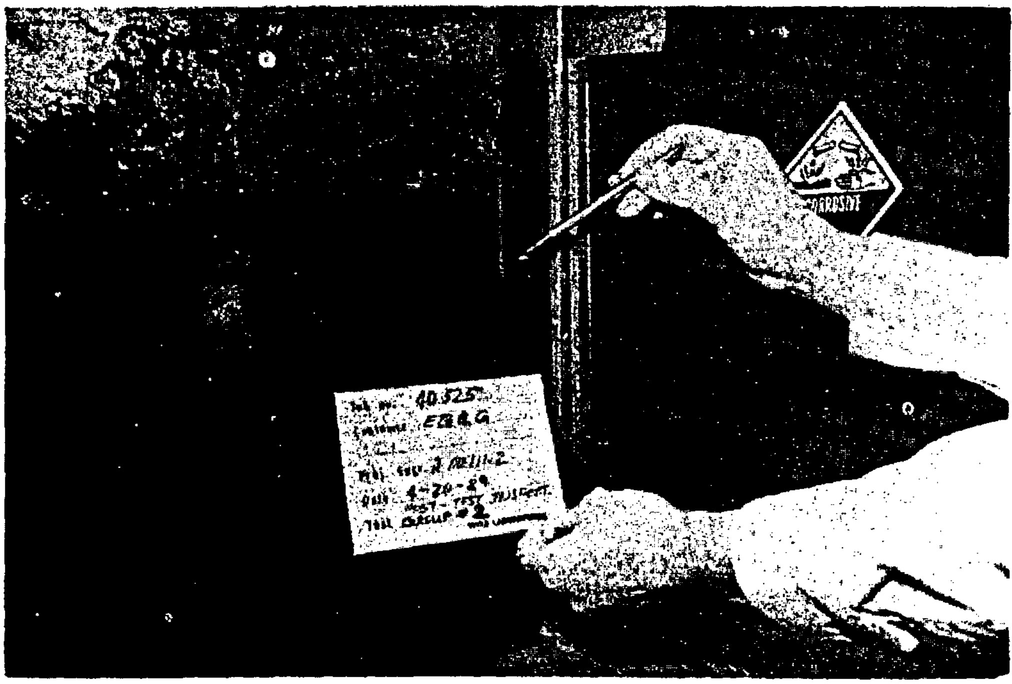
PHOTOGRAPH 5

MOUNTING LOCATION OF ACCELEROMETERS
4 FRONT-TO-BACK, 5 SIDE-TO-SIDE AND 6 VERTICAL
(THE SAME FOR ALL TEST SERIES)



PHOTOGRAPH 6

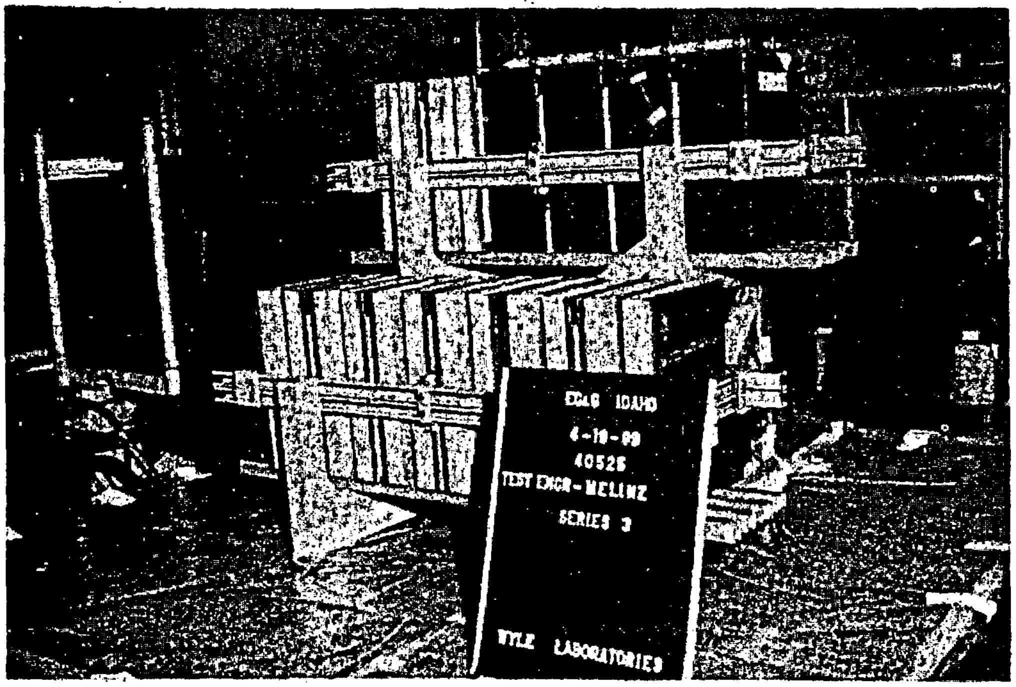
TEST SERIES 2 TEST SETUP
GROUP #2 BATTERIES
(FRONT LEFT-TO-RIGHT #25, #45, #48 AND #17)



PHOTOGRAPH 7

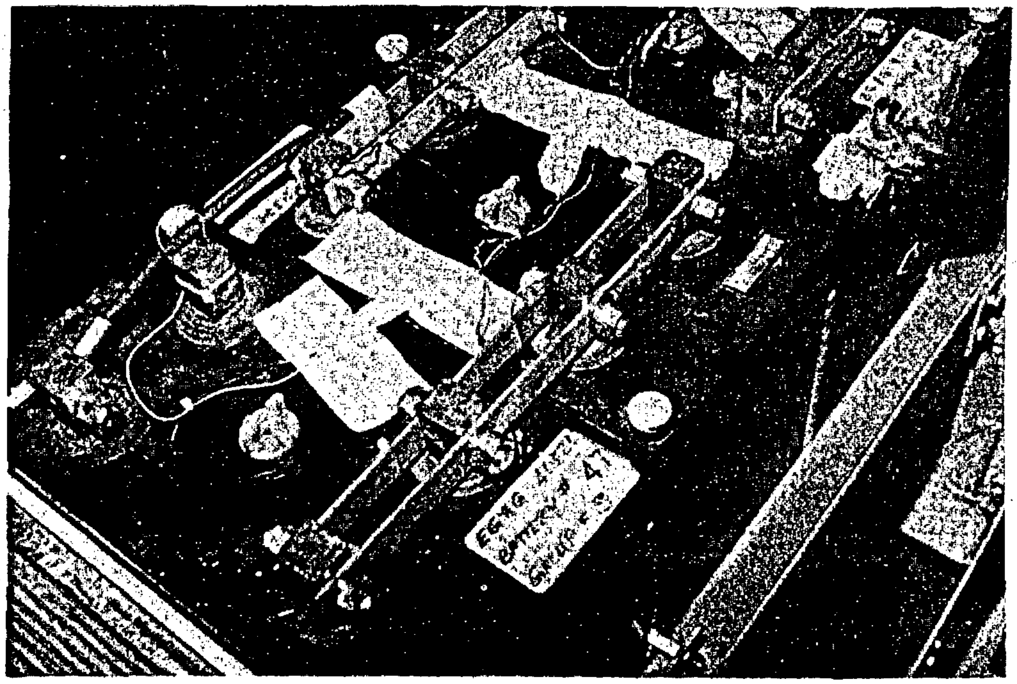
POST-TEST SERIES 2 CONDITION
OF BATTERY #45

NOTE THE EXTENT OF TIE ROD SCRAPING.



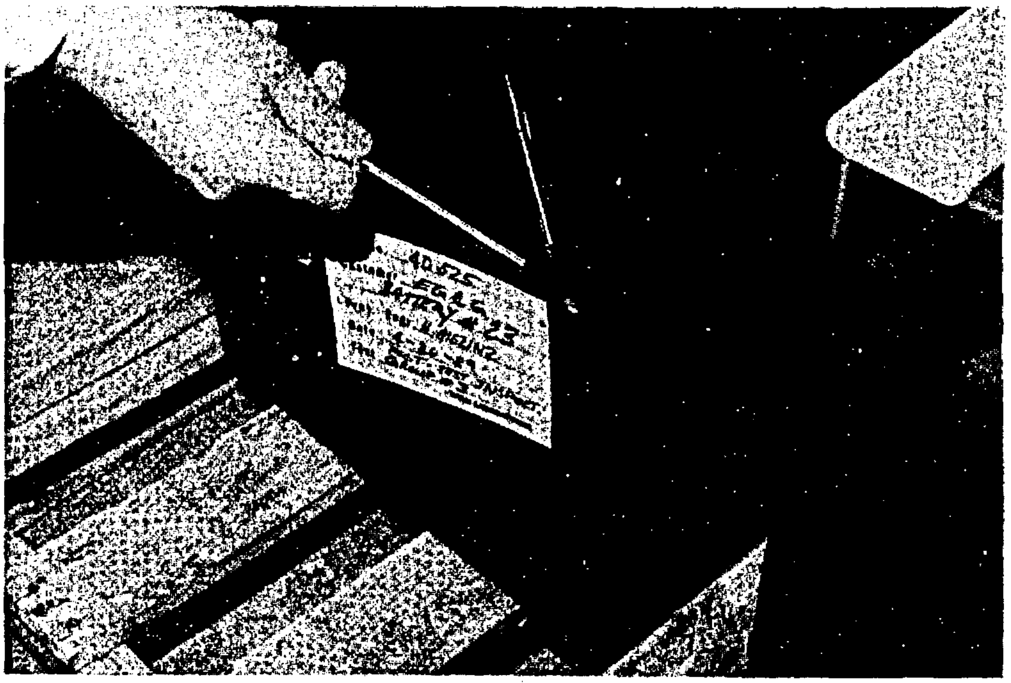
PHOTOGRAPH 8

TEST SERIES 3 TEST SETUP
GROUP #3 BATTERIES
(FROM LEFT-TO-RIGHT #47, #23, #30 AND #29)



PHOTOGRAPH 9

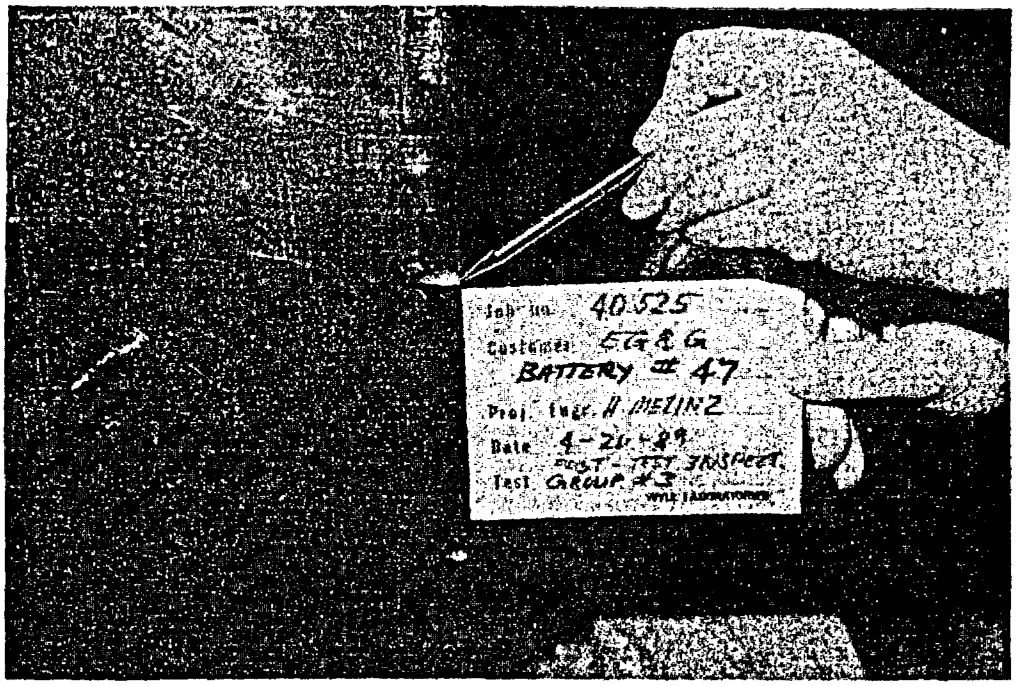
TYPICAL INTERCONNECTION PATTERN
(HERE TEST SERIES 3)



PHOTOGRAPH 10

POST-TEST SERIES 3 CONDITION
OF BATTERY #23

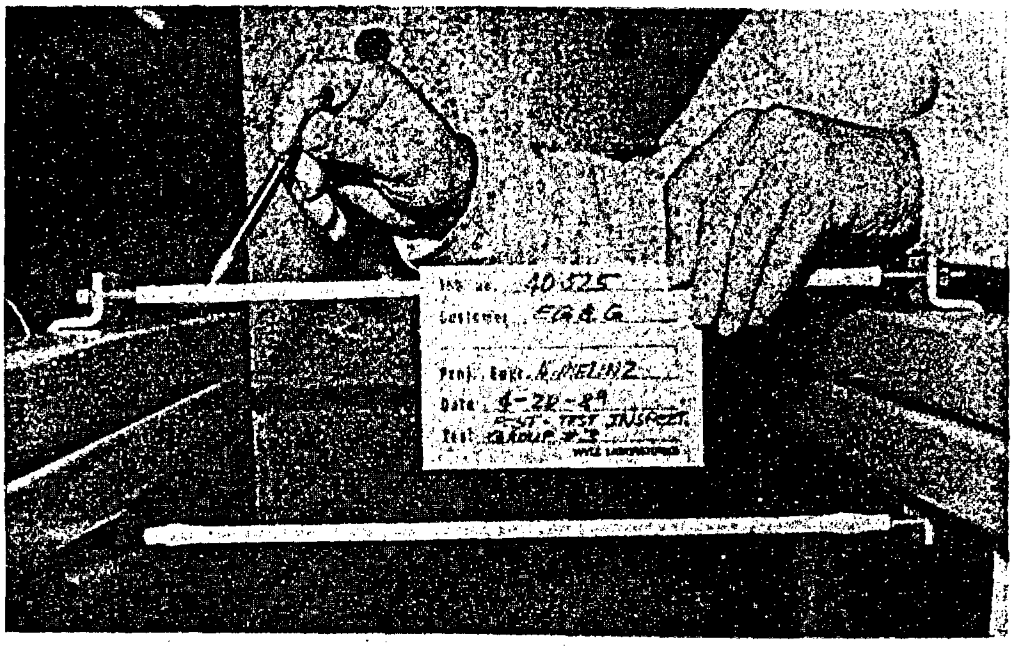
NOTE THE EXTENT OF TIE ROD SCRAPING



PHOTOGRAPH 11

POST-TEST SERIES 3 CONDITION
OF BATTERY #47

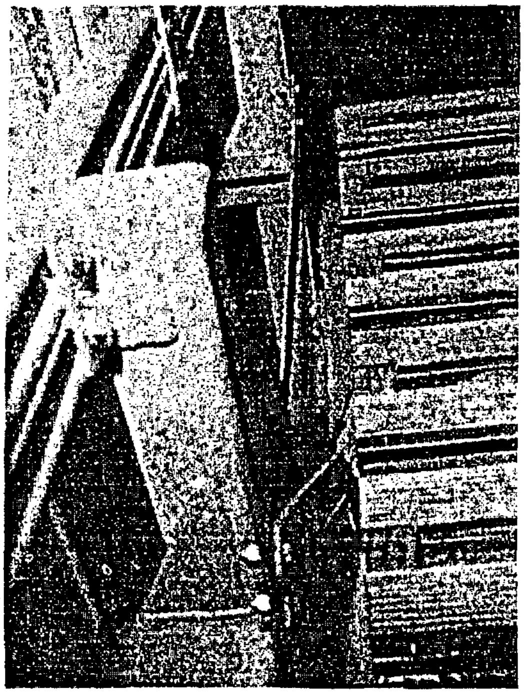
NOTE THE EXTENT OF TIE ROD SCRAPING



PHOTOGRAPH 12

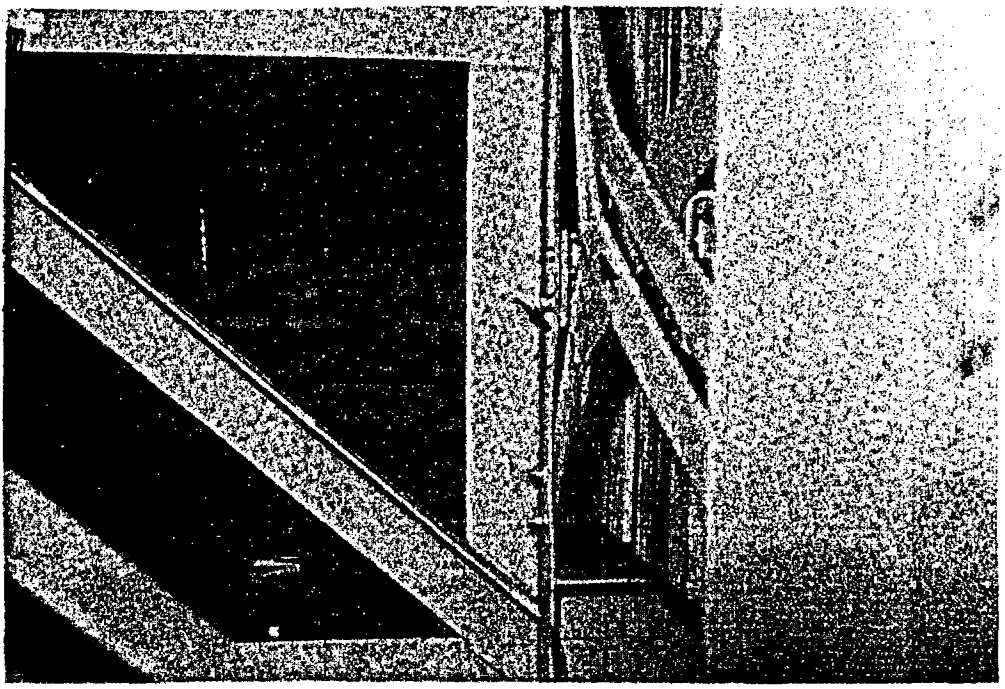
POST-TEST SERIES 3 CONDITION
OF TIE ROD SLEEVE

NOTE: DUCT TAPE WAS WOUND AROUND THE DAMAGED SLEEVE PRIOR TO TEST SERIES 4 TESTING.



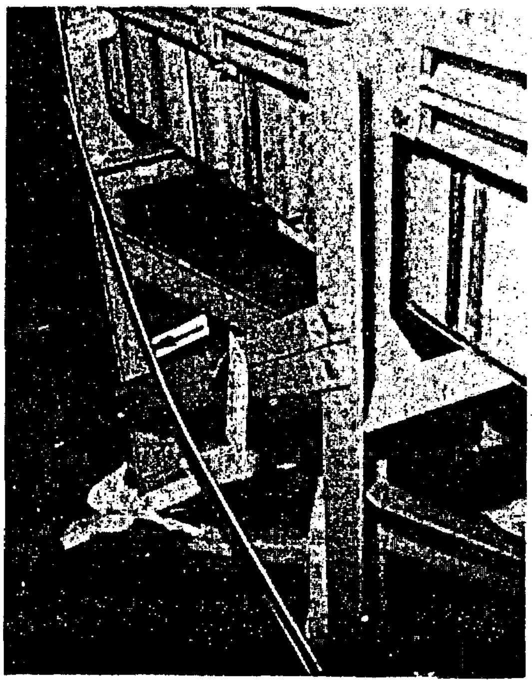
PHOTOGRAPH 13

POST-TEST RUN 7 CONDITION
OF THE BATTERY RACK CROSS BRACES
(FRONT SIDE)



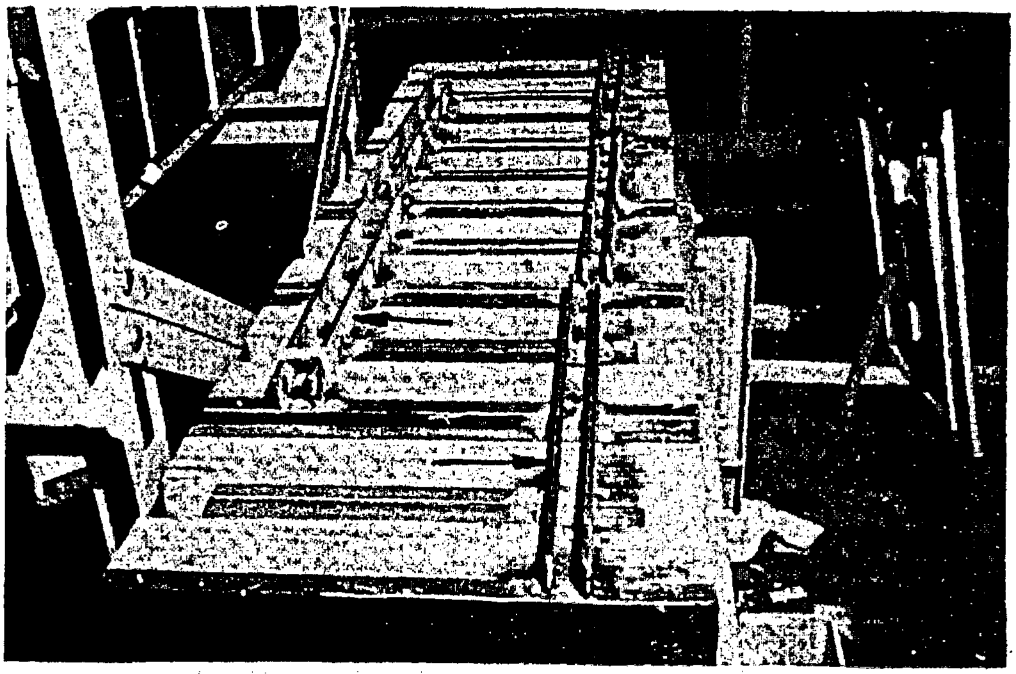
PHOTOGRAPH 14

POST-TEST RUN 7 CONDITION
OF BATTERY RACK CROSS BRACES
(FRONT SIDE)



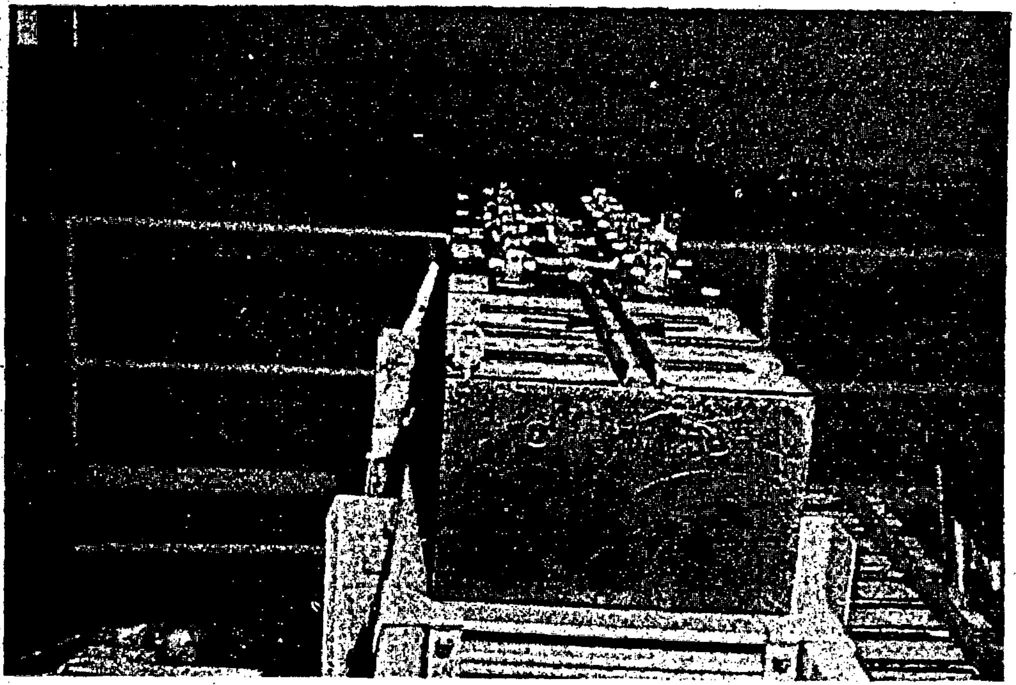
PHOTOGRAPH 15

POST-TEST RUN 7 CONDITION
OF BATTERY RACK CROSS BRACES
(REAR SIDE)



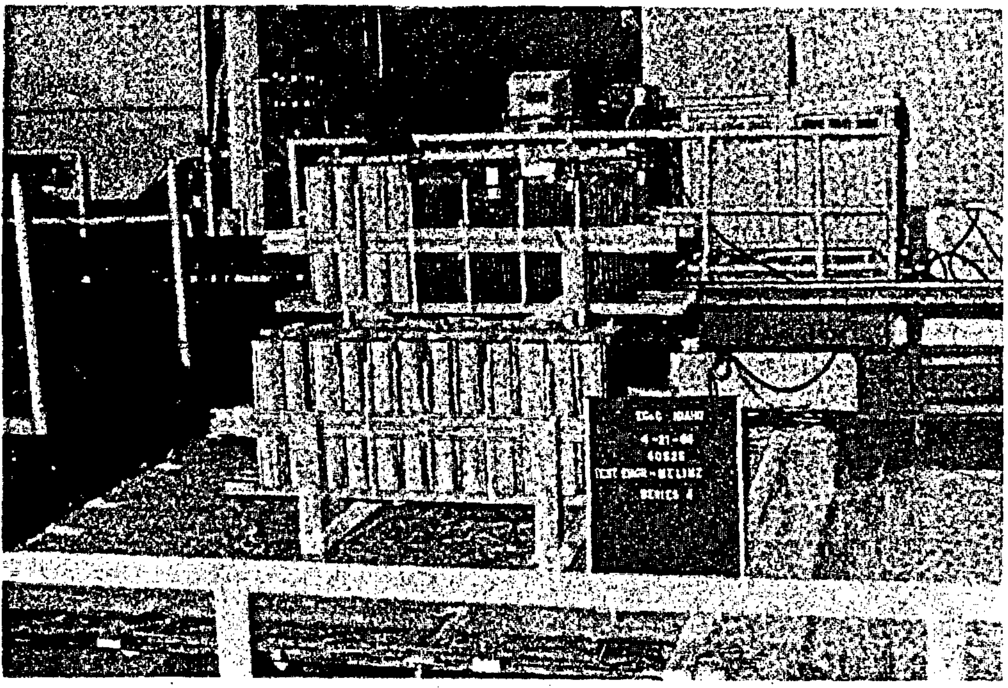
PHOTOGRAPH 16

ADDED INTERCONNECTING 1" WIDE X 3/16" THICK
CARBON STEEL FLATS TO DUMMY BATTERIES
PRIOR TO TEST SERIES 4 TESTING



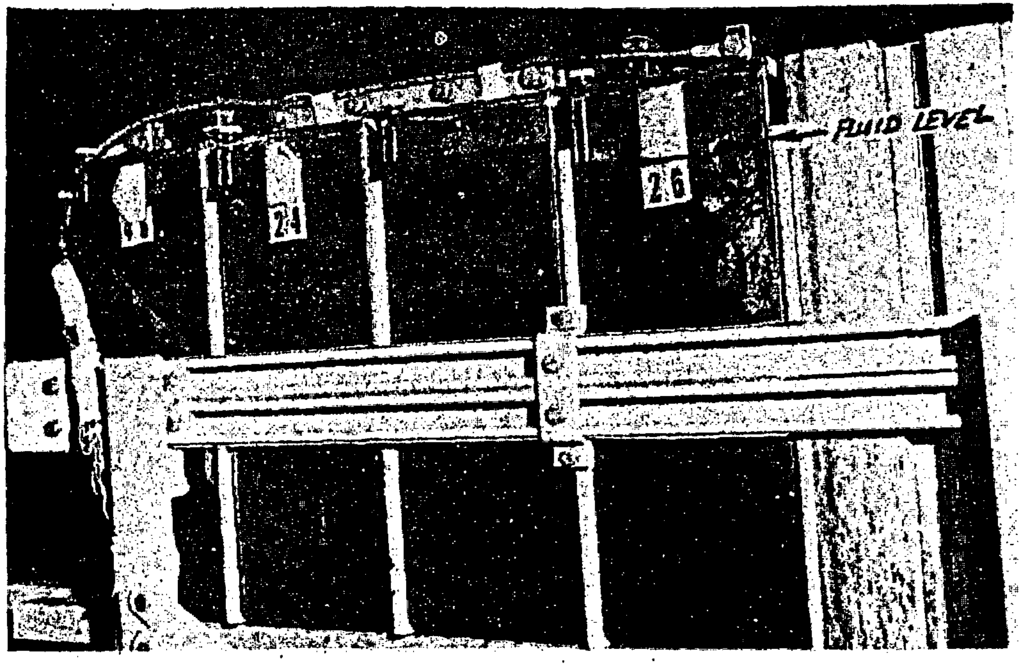
PHOTOGRAPH 17

ADDED INTERCONNECTING 1" WIDE X 3/16"
THICK CARBON STEEL FLATS TO DUMMY BATTERIES
PRIOR TO TEST SERIES 4 TESTING



PHOTOGRAPH 18

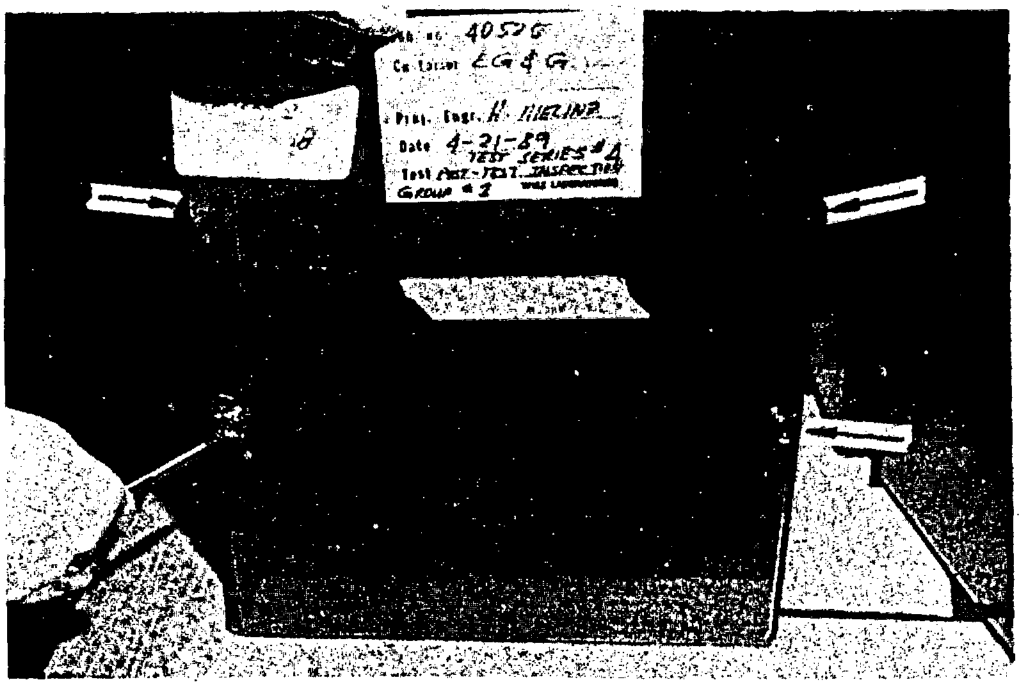
TEST SERIES 4 TEST SETUP
GROUP #1 BATTERIES
(FROM LEFT-TO-RIGHT #26, #18, #24 AND #46)



PHOTOGRAPH 19

POST-TEST SERIES 4 CONDITION OF BATTERIES

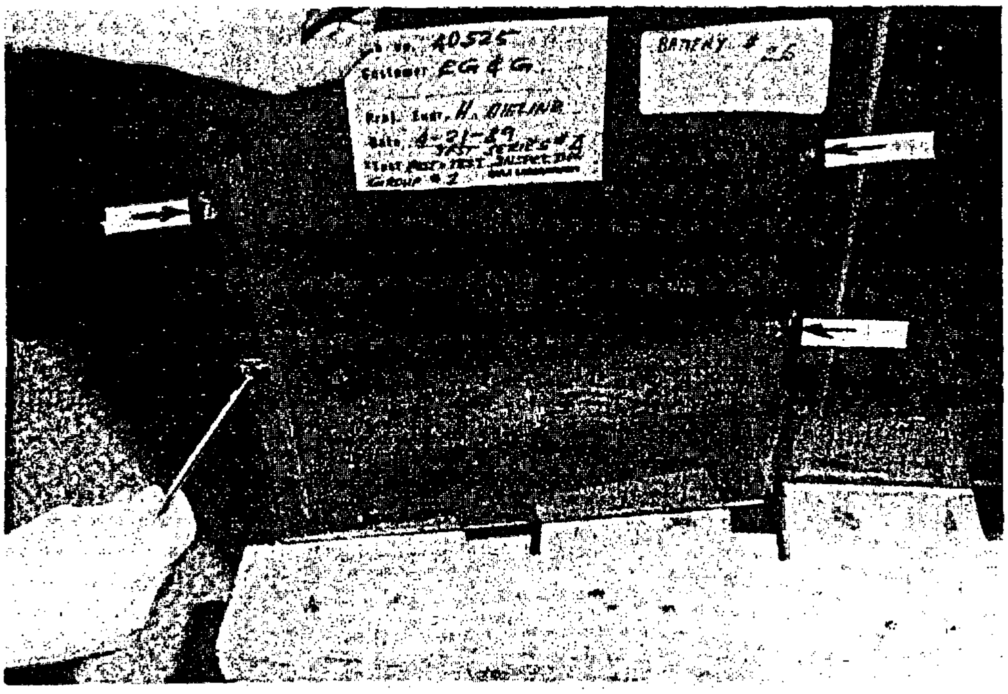
NOTE: ALL BATTERIES LOST SOME ACID THROUGH THE BREATHERS. BATTERY #26 LOST ADDITIONAL ACID THROUGH THE TOP SIDE INTERFACE. ACID LEVEL WAS APPROXIMATELY 1 INCH LOWER THAN THE OTHER BATTERIES.



PHOTOGRAPH 20

POST-SERIES 4 CONDITION OF BATTERY #18.

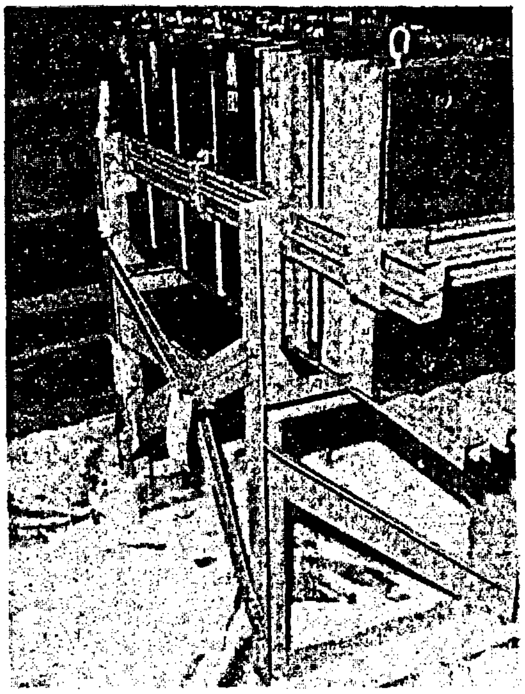
NOTE THE EXTENT OF TIE ROD SCRAPING



PHOTOGRAPH 21

POST-SERIES 4 CONDITION OF BATTERY #26

NOTE THE EXTENT OF TIE ROD SCRAPING.

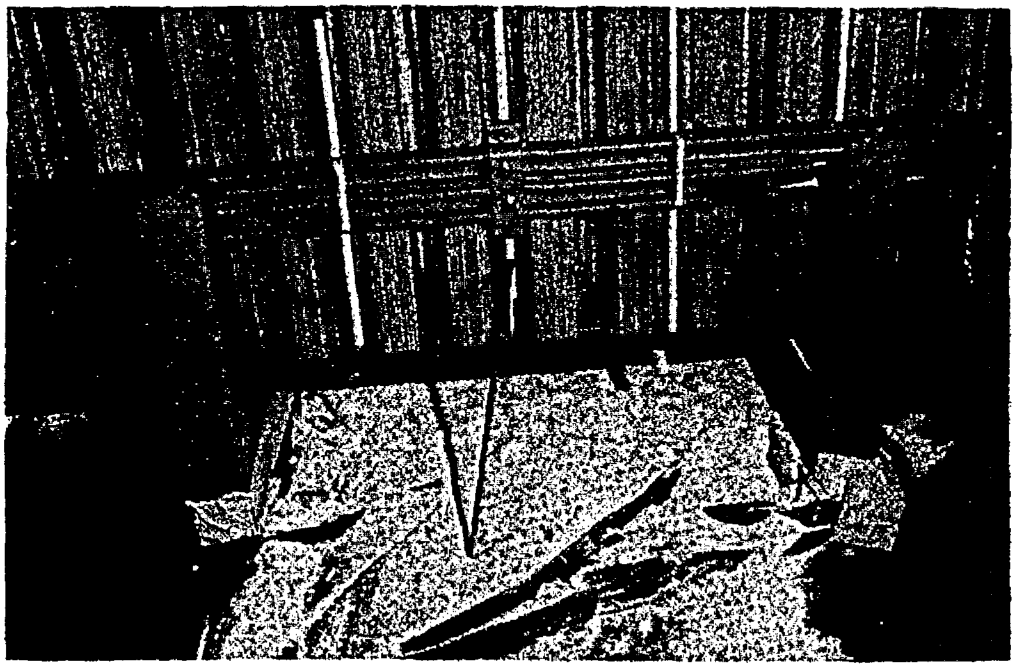


PHOTOGRAPH 22

POST-TEST SERIES 4 CONDITION
OF
BATTERY RACK ASSEMBLY

PHOTOGRAPH 23

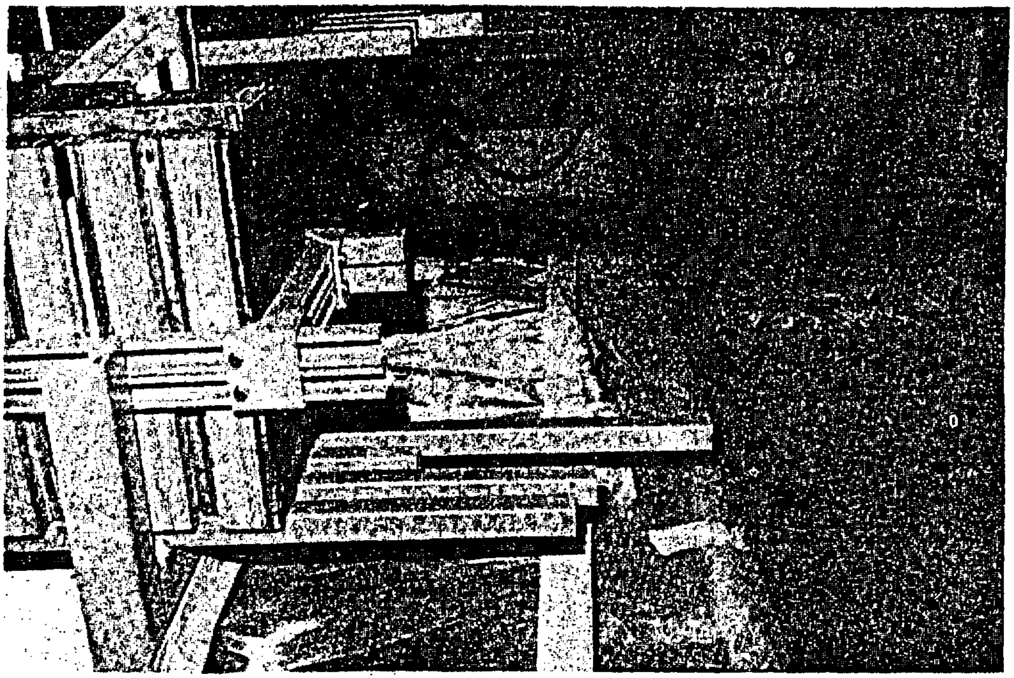
POST-TEST SERIES 4 CONDITION
OF
BATTERY RACK ASSEMBLY



PHOTOGRAPH 24

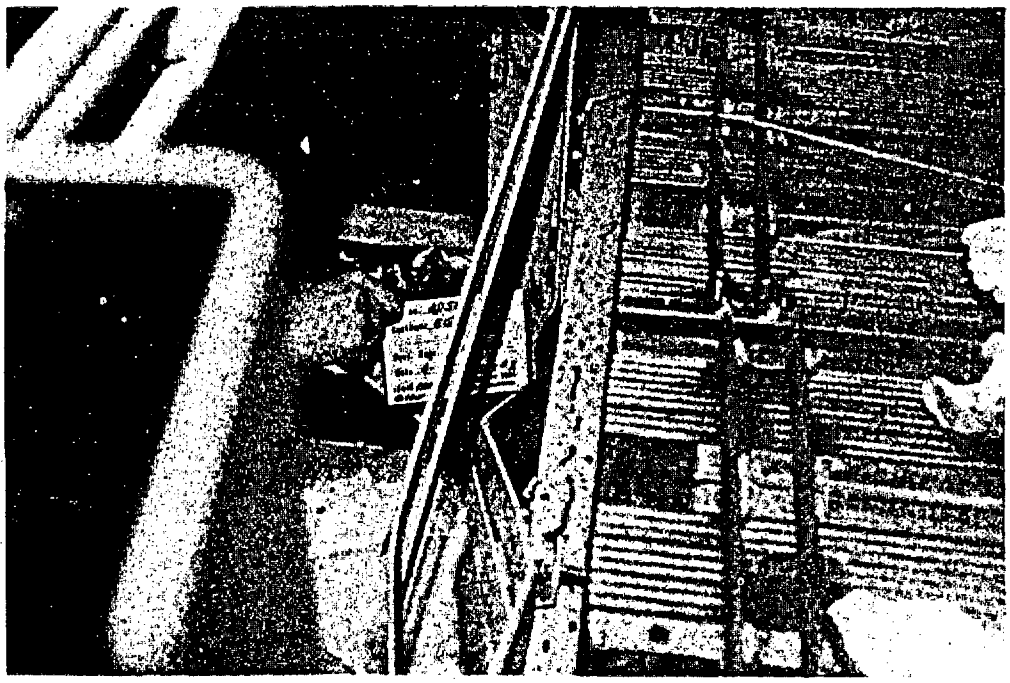
POST-TEST SERIES 4 CONDITION
OF
BATTERY RACK ASSEMBLY

NOTE BROKEN TIE ROD



PHOTOGRAPH 25

POST-TEST SERIES 4 CONDITION
OF
BATTERY RACK ASSEMBLY
(ISOLATION COVERS SLIPPED)



PHOTOGRAPH 26

POST-SERIES 4 CONDITION
OF
BATTERY RACK ASSEMBLY

PHOTOGRAPH 27

POST-SERIES 4 CONDITION
OF
BATTERY RACK ASSEMBLY

APPENDIX I

TRANSMISSIBILITY PLOTS
FOR
TEST SERIES 1 TESTING

TEST RUN	TEST AXES
1	Front-to-Back (FB)
2	Side-to-Side (SS)
3	Vertical (V)

HCA = Horizontal Control Accelerometer
VCA = Vertical Control Accelerometer

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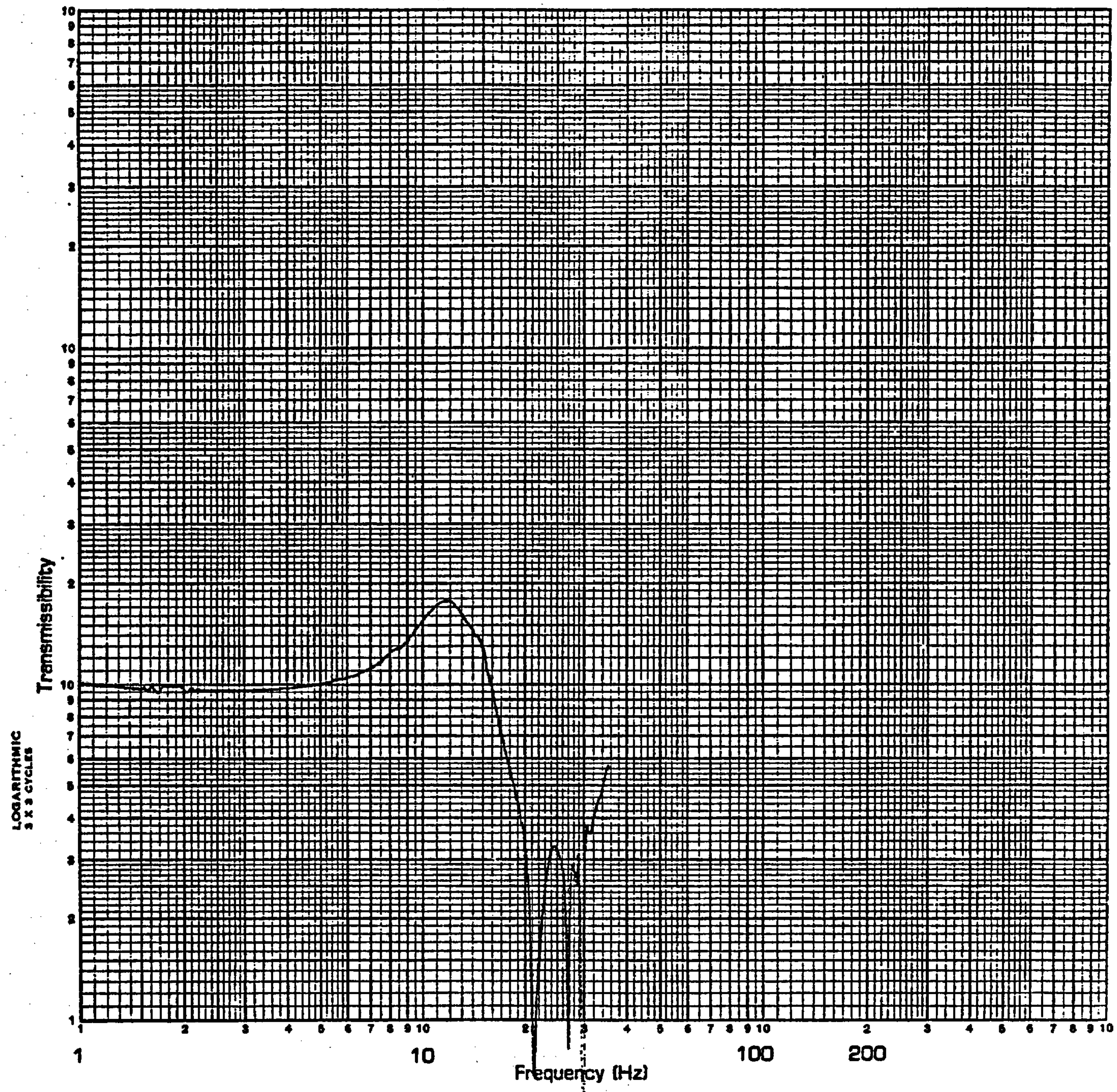
FULL SCALE TRANSMISSIBILITY

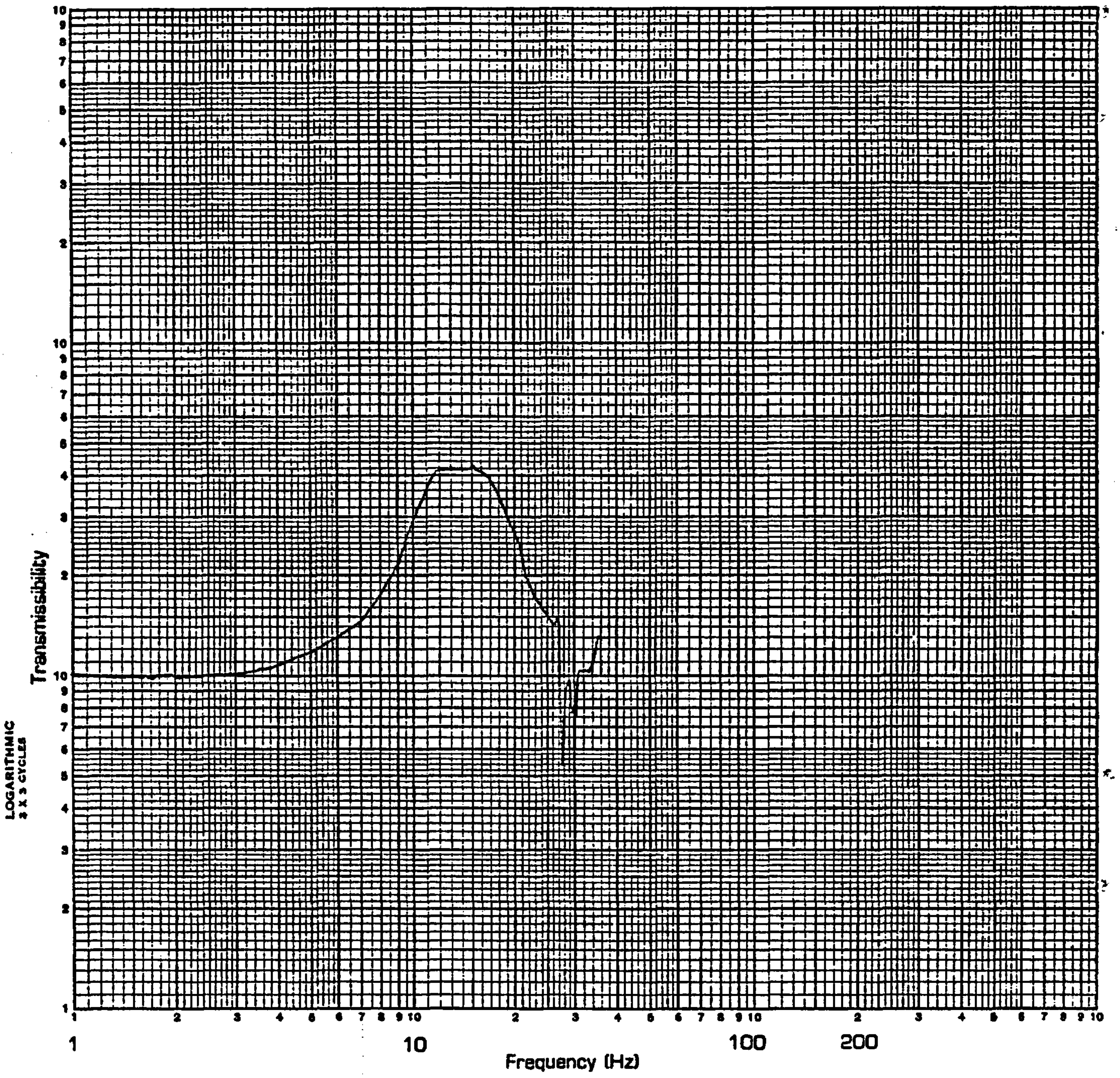
0.1 ☐ 1.0 ☐ 10 ☐ 100 ☑ 1000 ☐



SPECIMEN Rack
AXIS F-B
ACCEL. NO. 1FB NO. HCA
TEST RUN NO. 1

FULL SCALE TRANSMISSIBILITY

0.1 ☐ 1.0 ☐ 10 ☐ 100 ☒ 1000 ☐



SPECIMEN CELL #24

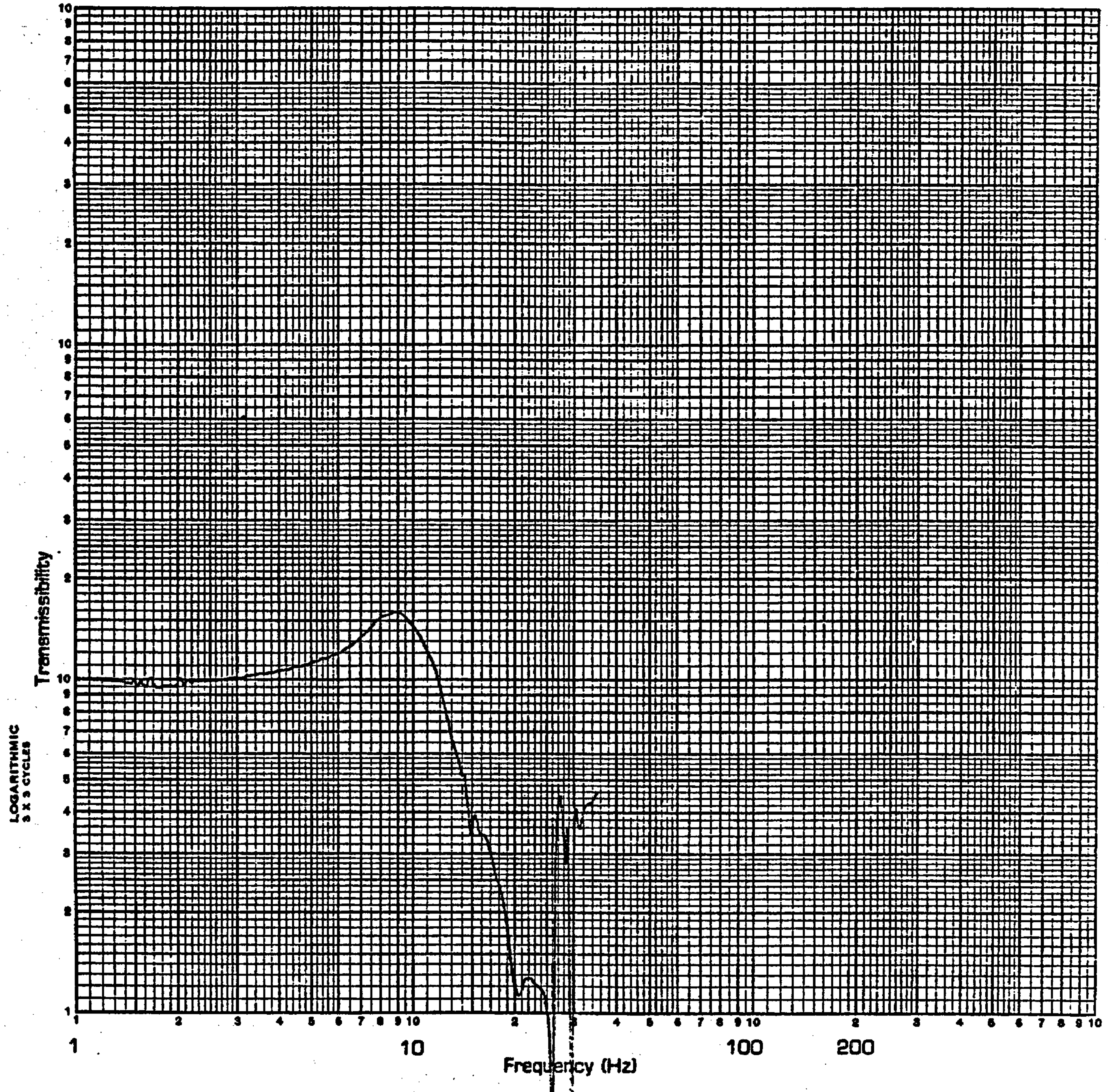
ACCEL NO. 4FB NO. HCA

AXIS F-B

TEST RUN NO. 1

FULL SCALE TRANSMISSIBILITY

0.1 ☐ 1.0 ☐ 10 ☐ 100 ☑ 1000 ☐



SPECIMEN RACK

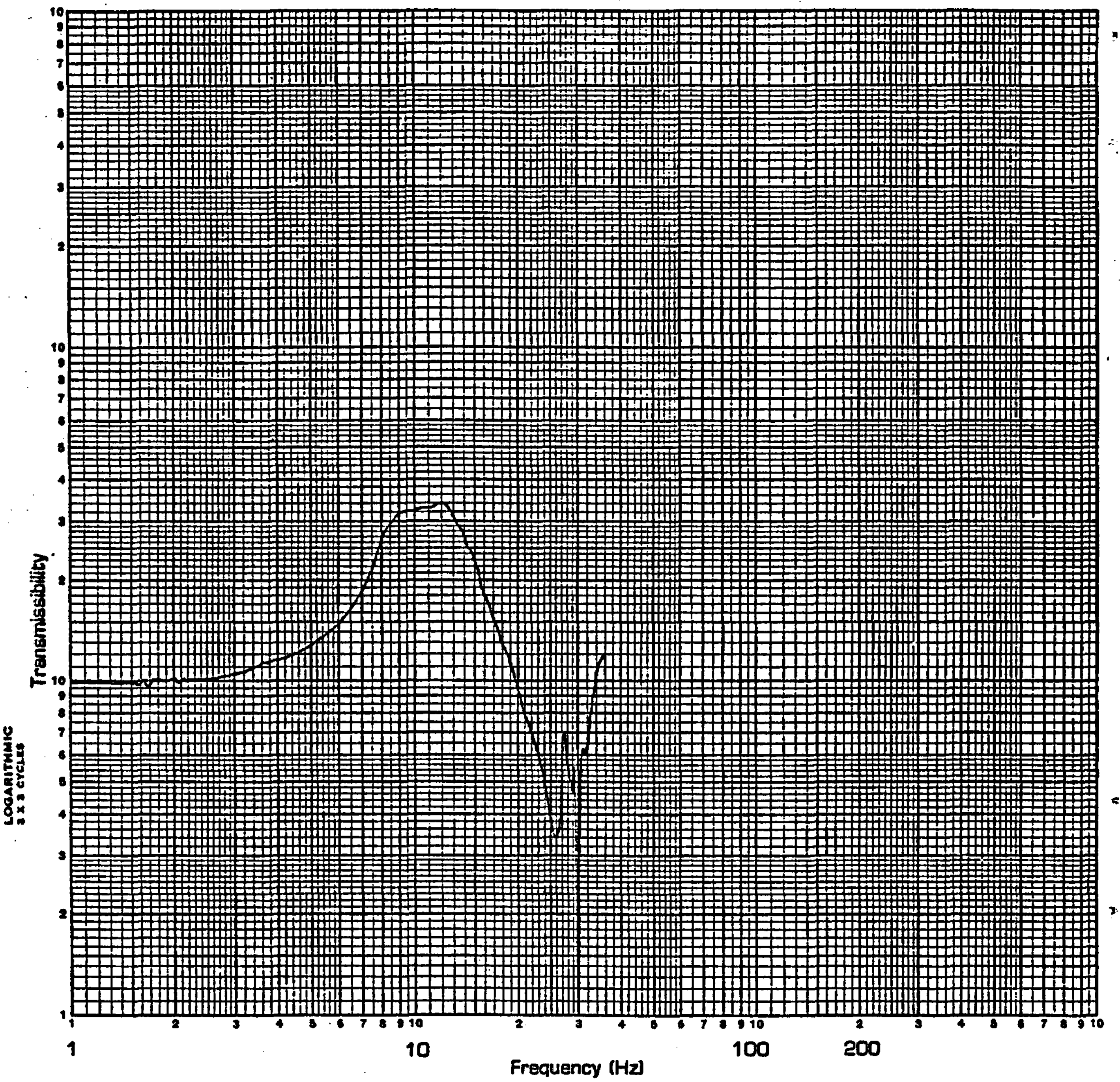
AXIS S-S

ACCEL NO. 2 SS NO. HCA

TEST RUN NO. 2

FULL SCALE TRANSMISSIBILITY

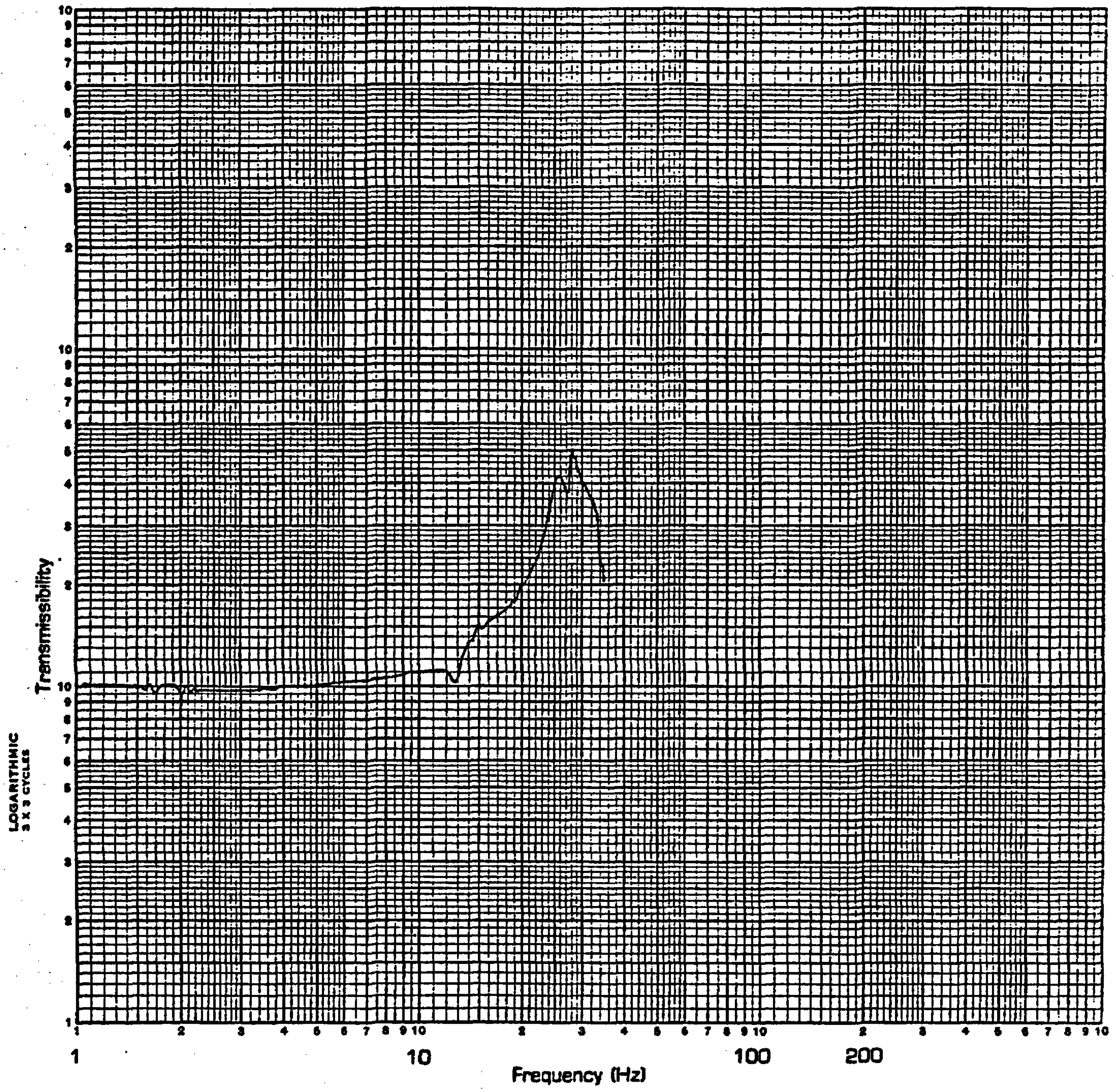
0.1 ☐ 1.0 ☐ 10 ☐ 100 ☑ 1000 ☐



SPECIMEN cell #24
ACCEL NO. 555 NO. HCA
AXIS S-S
TEST RUN NO. 2

FULL SCALE TRANSMISSIBILITY

0.1 ☐ 1.0 ☐ 10 ☐ 100 ☒ 1000 ☐



SPECIMEN RACK

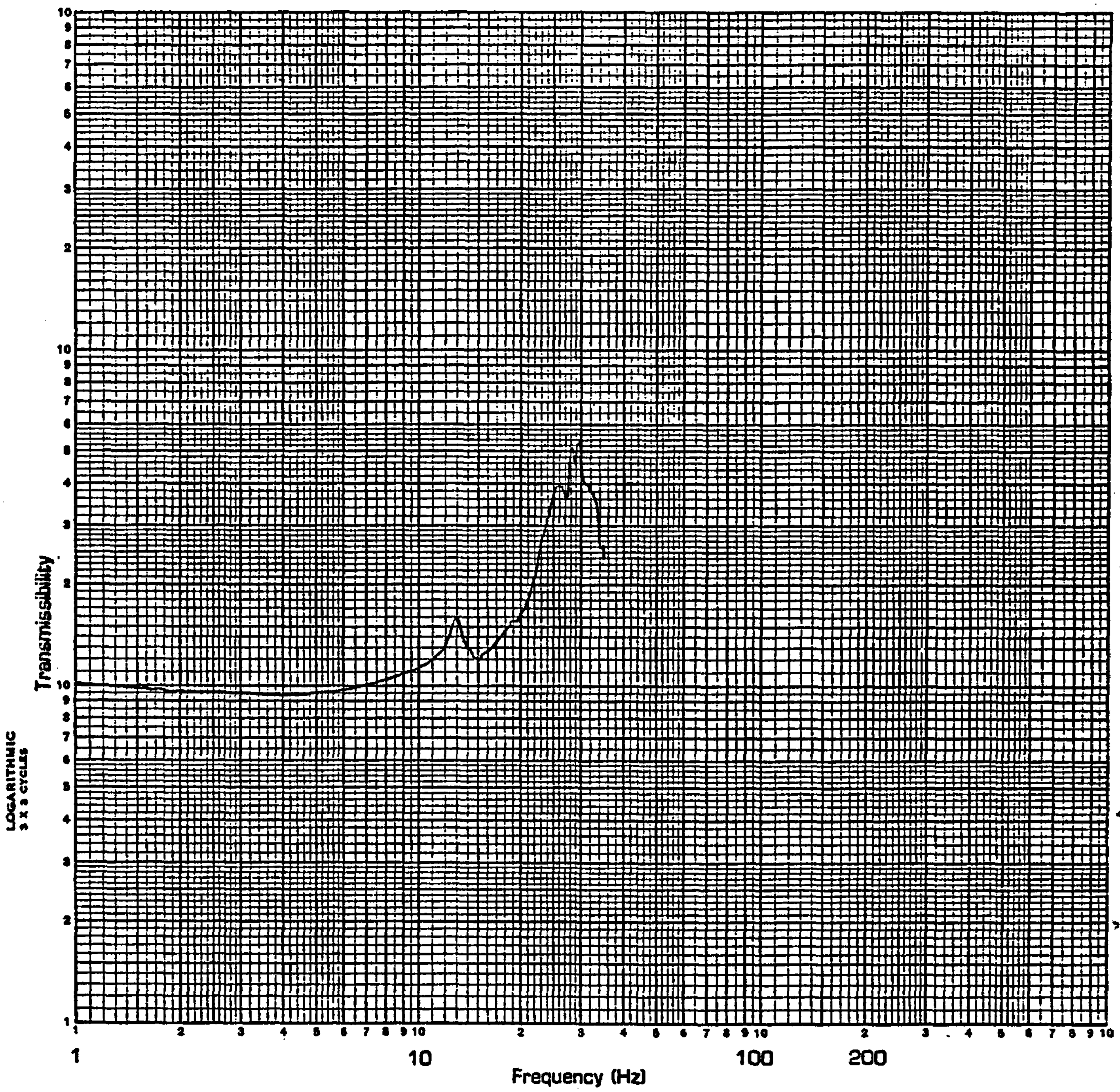
ACCEL NO. 3V NO. VCA

AXIS VERT

TEST RUN NO. 3

FULL SCALE TRANSMISSIBILITY

0.1 ☐ 1.0 ☐ 10 ☐ 100 ☒ 1000 ☐



SPECIMEN cell #24 ACCEL. NO. 6V NO. VCA

AXIS VERT TEST RUN NO. 3

APPENDIX II

TEST RESPONSE SPECTRUM PLOTS

FB = Front-to-Back
SS = Side-to-Side
V = Vertical
HCA = Horizontal Control Accelerometer
VCA = Vertical Control Accelerometer
TRI = Triaxial
OBE = Operating Basis Earthquake
SSE = Safe Shutdown Earthquake

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PART 1

PLOTS FOR TEST SERIES 1
GROUP #1 BATTERIES

TEST RUN	TEST AXES	TEST LEVEL	PLOTS @ 2% DAMPING
4	TRI	50%	Control Accelerometers and Response Accelerometers

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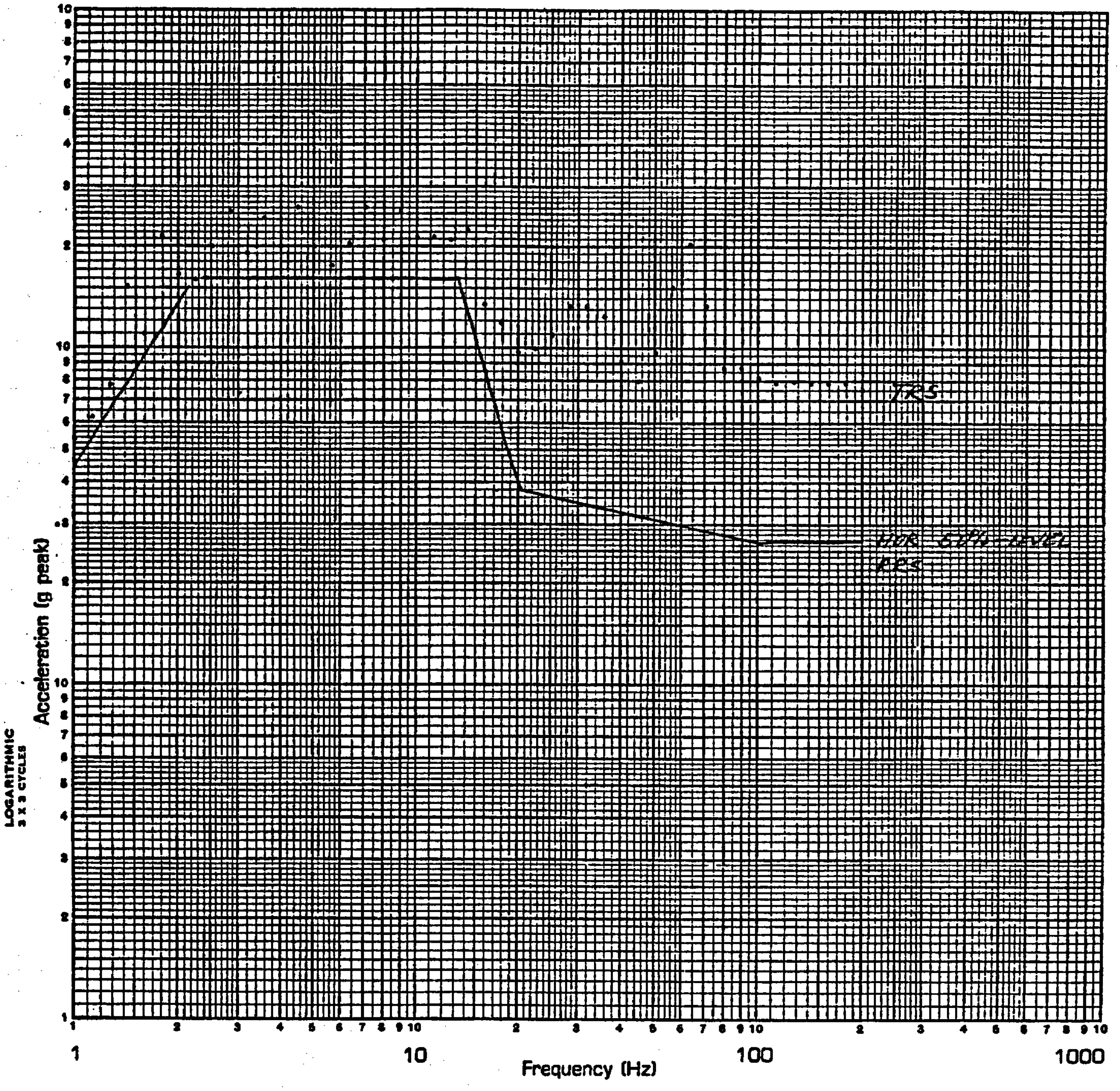
FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ——

AXIS TR1

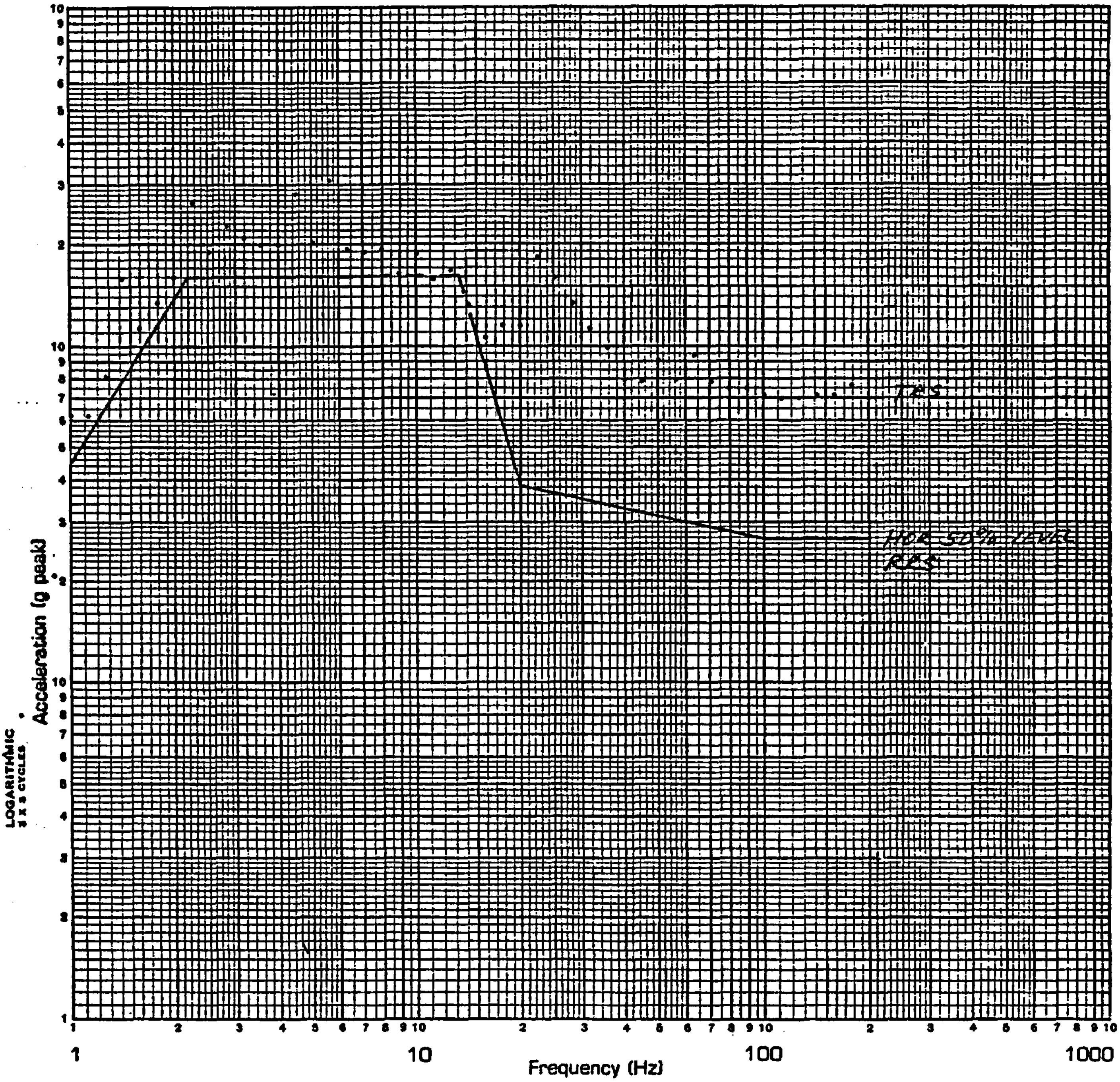
LOCATION NO. FB HCA

TEST RUN NO. 4

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN

AXIS TR1

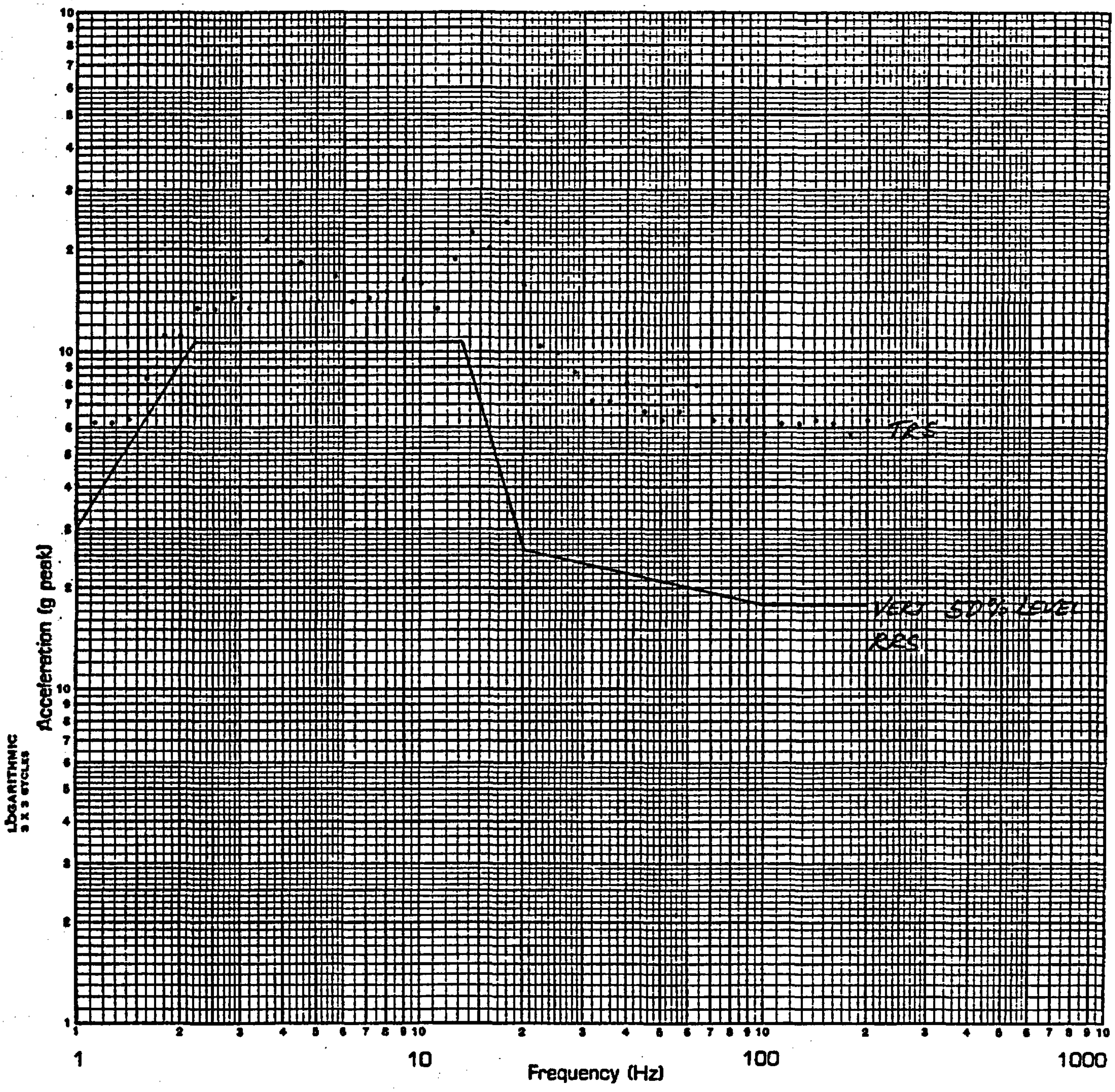
LOCATION NO. SS HCA

TEST RUN NO. 4

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ________

AXIS TR1

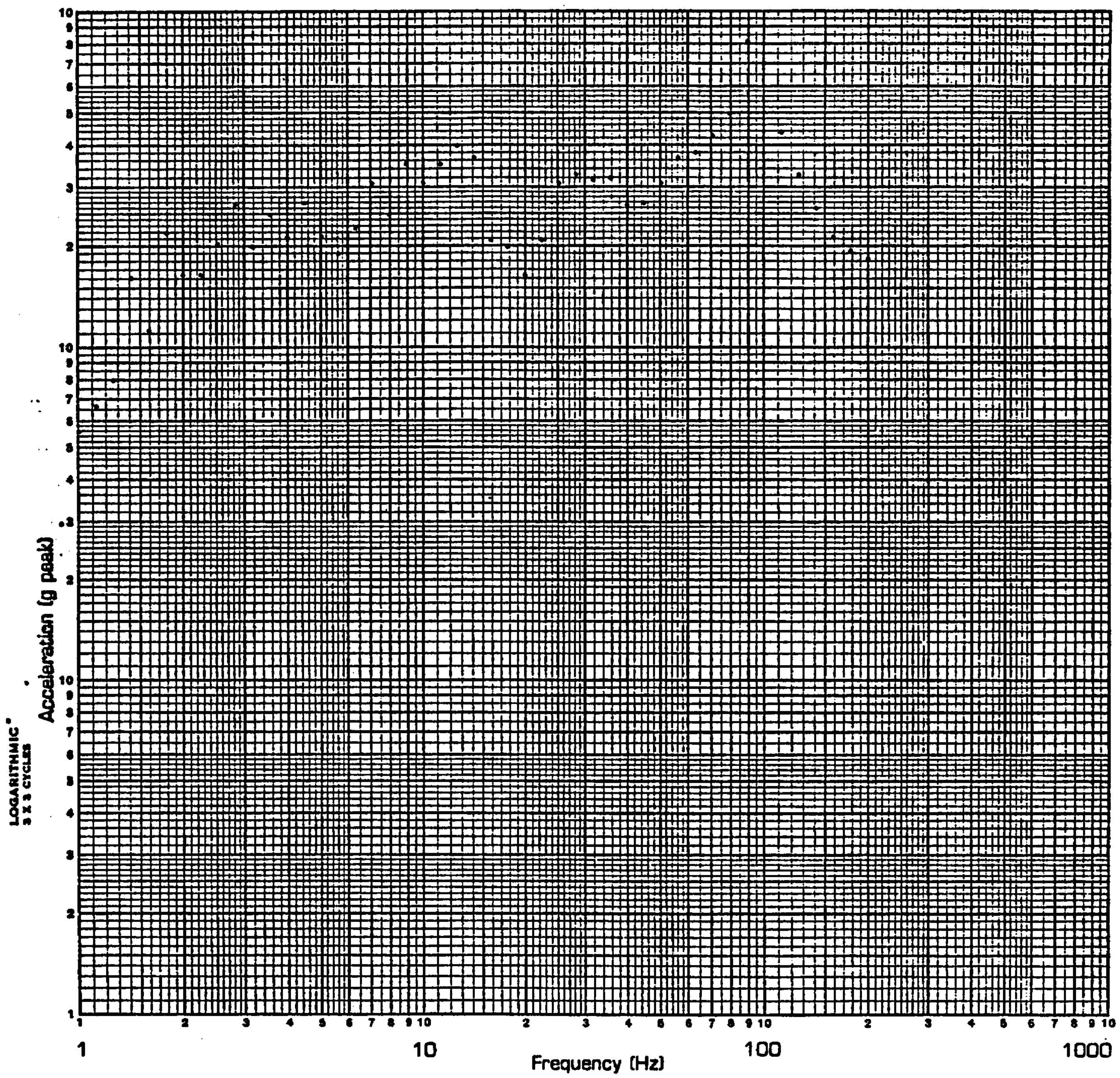
LOCATION NO. VCA

TEST RUN NO. 1

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000 ☐

DAMPING 2%

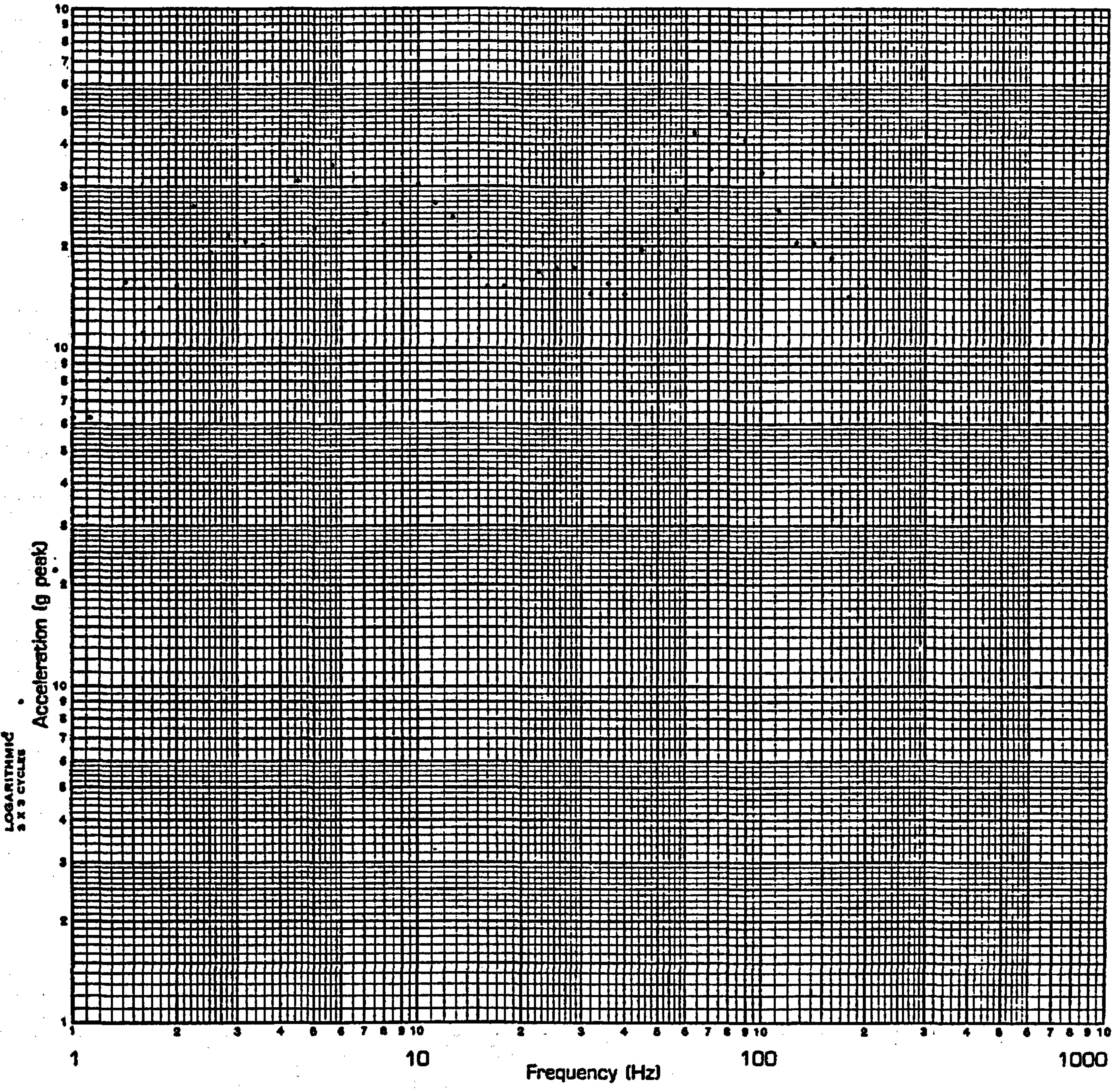


SPECIMEN RACK
LOCATION NO. 1 FB
AXIS TR1
TEST RUN NO. 4

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN Rack

LOCATION NO. 2 SS

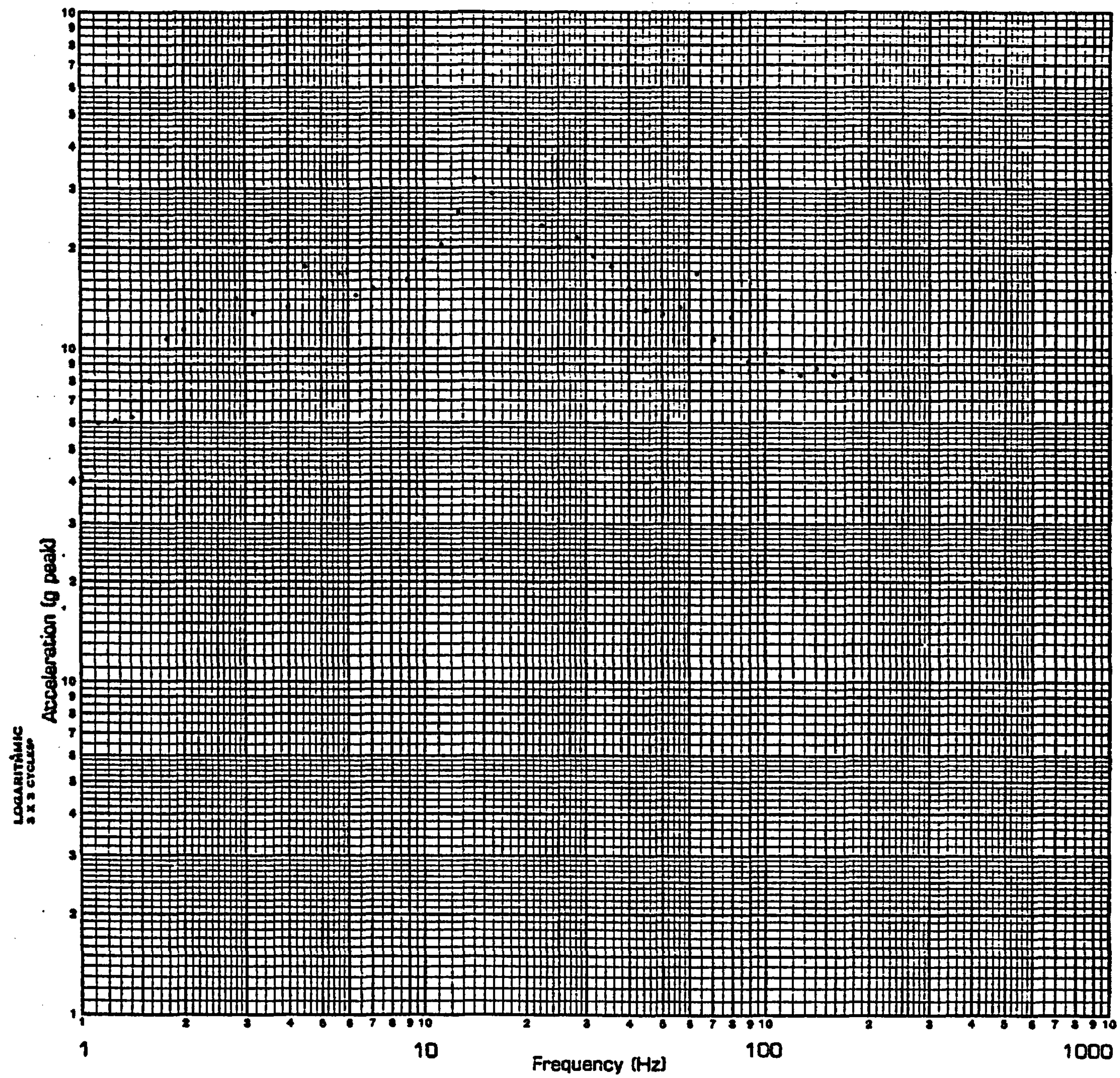
AXIS TR1

TEST RUN NO. 4

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000 ☐

DAMPING 2 %



SPECIMEN Rack

AXIS TR1

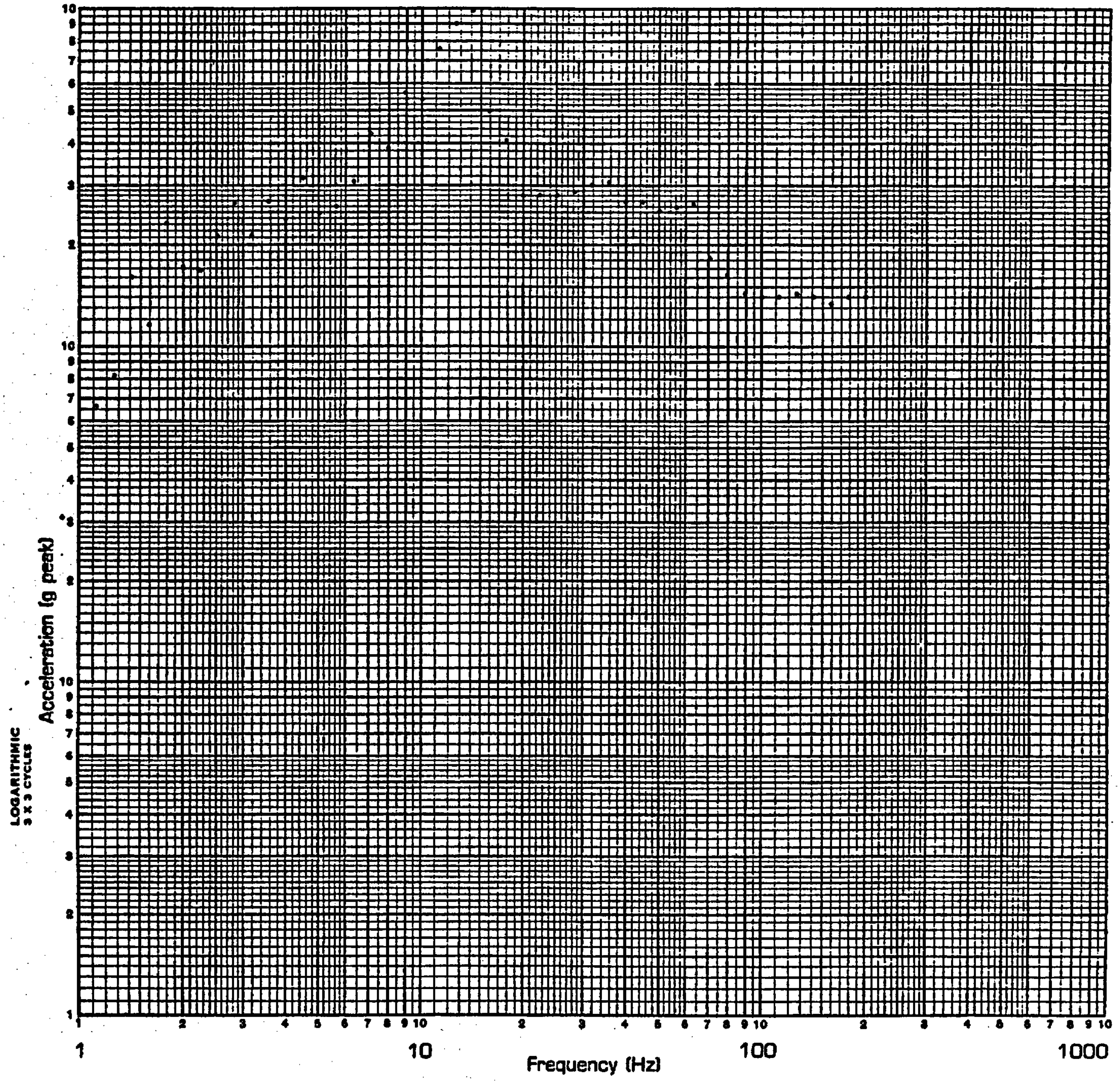
LOCATION NO. 3V

TEST RUN NO. 4

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000 ☐

DAMPING 2%



SPECIMEN CELL #24

LOCATION NO. 4 FB

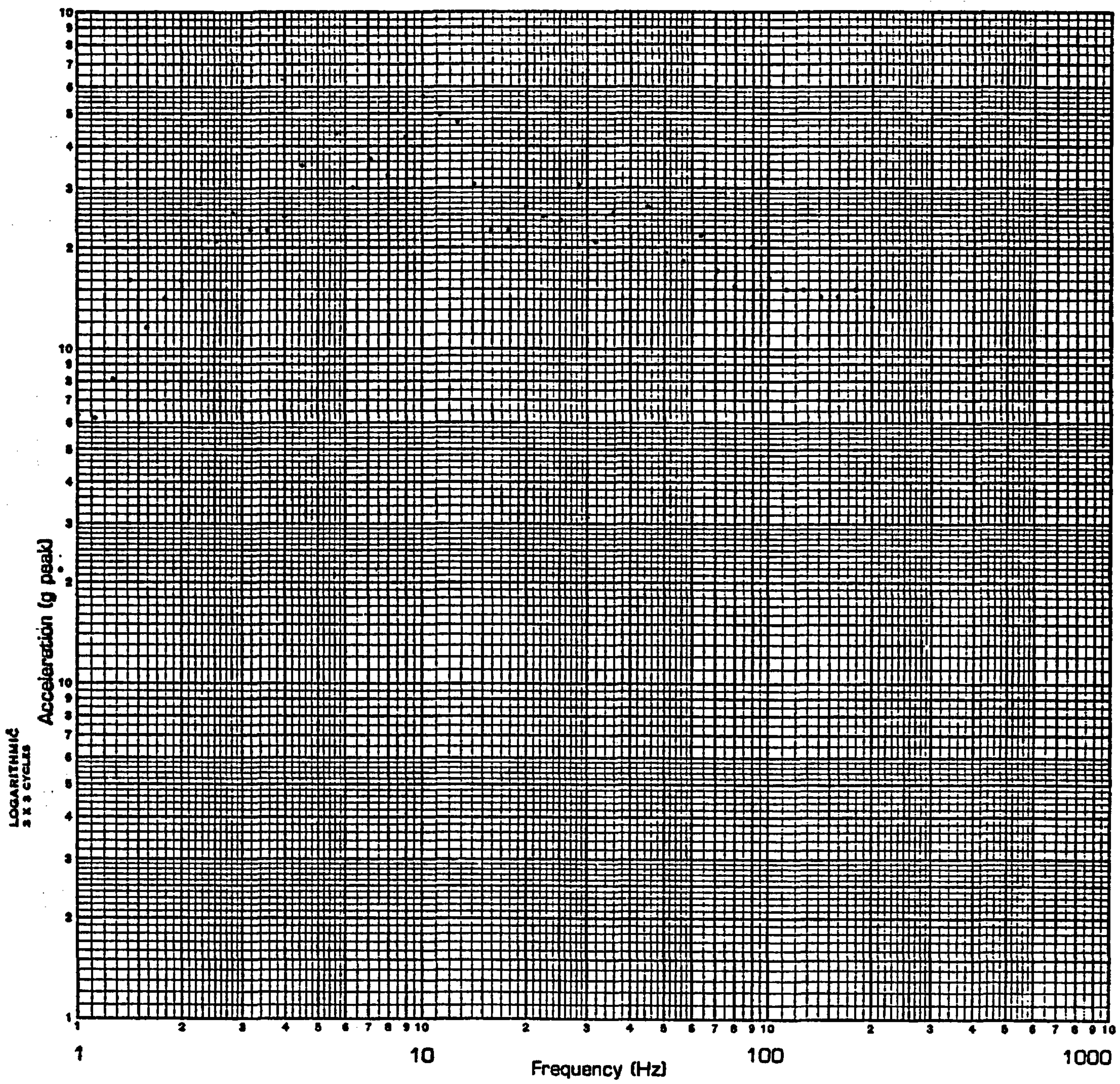
AXIS TR1

TEST RUN NO. 4

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN can #24

AXIS TR1

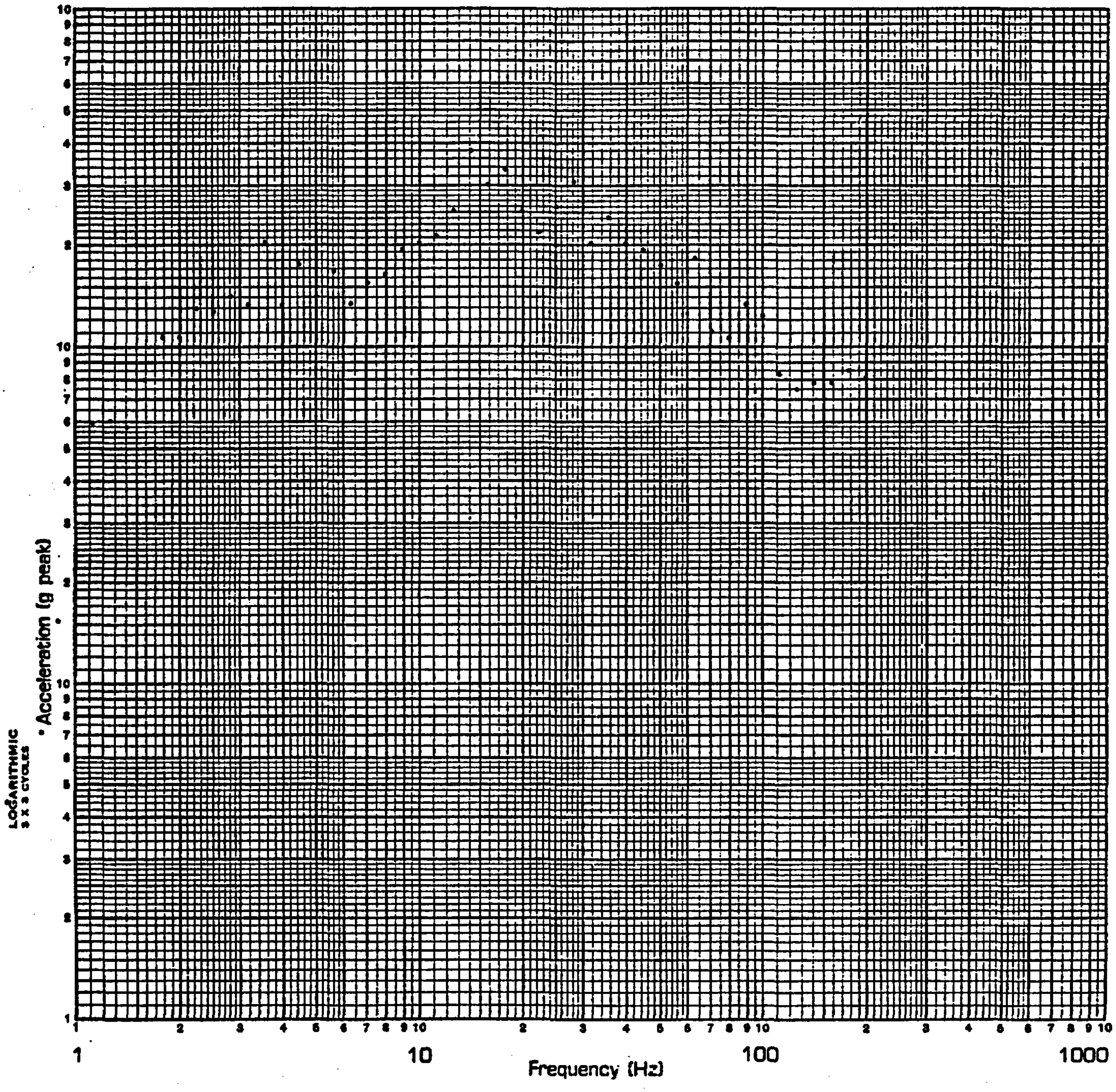
LOCATION NO. 5 SS

TEST RUN NO. 4

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN CELL #24

AXIS TR1

LOCATION NO. 6V

TEST RUN NO. 4

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PART 2

PLOTS FOR TEST SERIES 2
GROUP #2 BATTERIES

TEST RUN	TEST AXES	TEST LEVEL	PLOTS @ 2% DAMPING
5	TRI	85%	Control Accelerometers and Response Accelerometers

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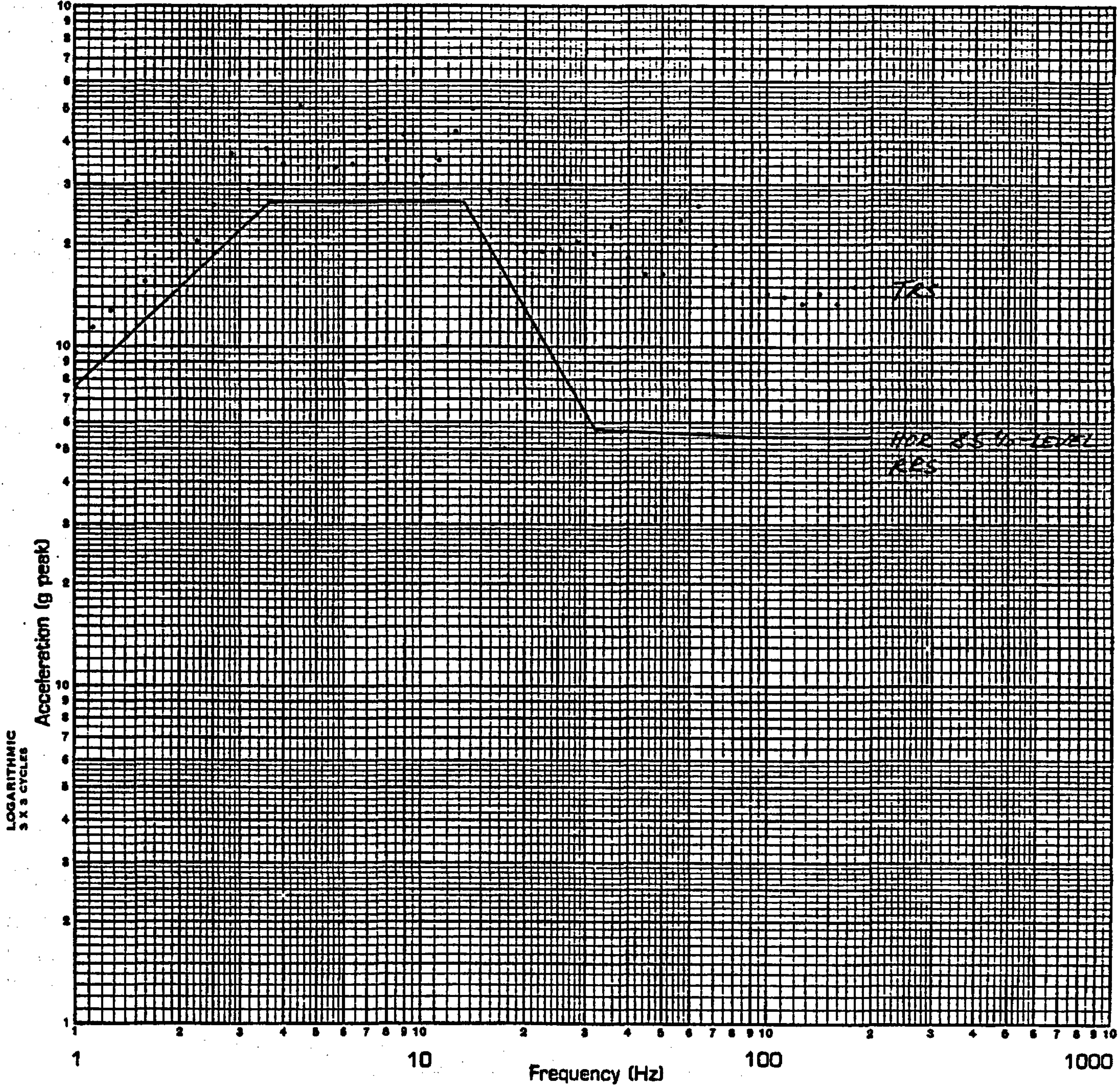
FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ______

AXIS TR1

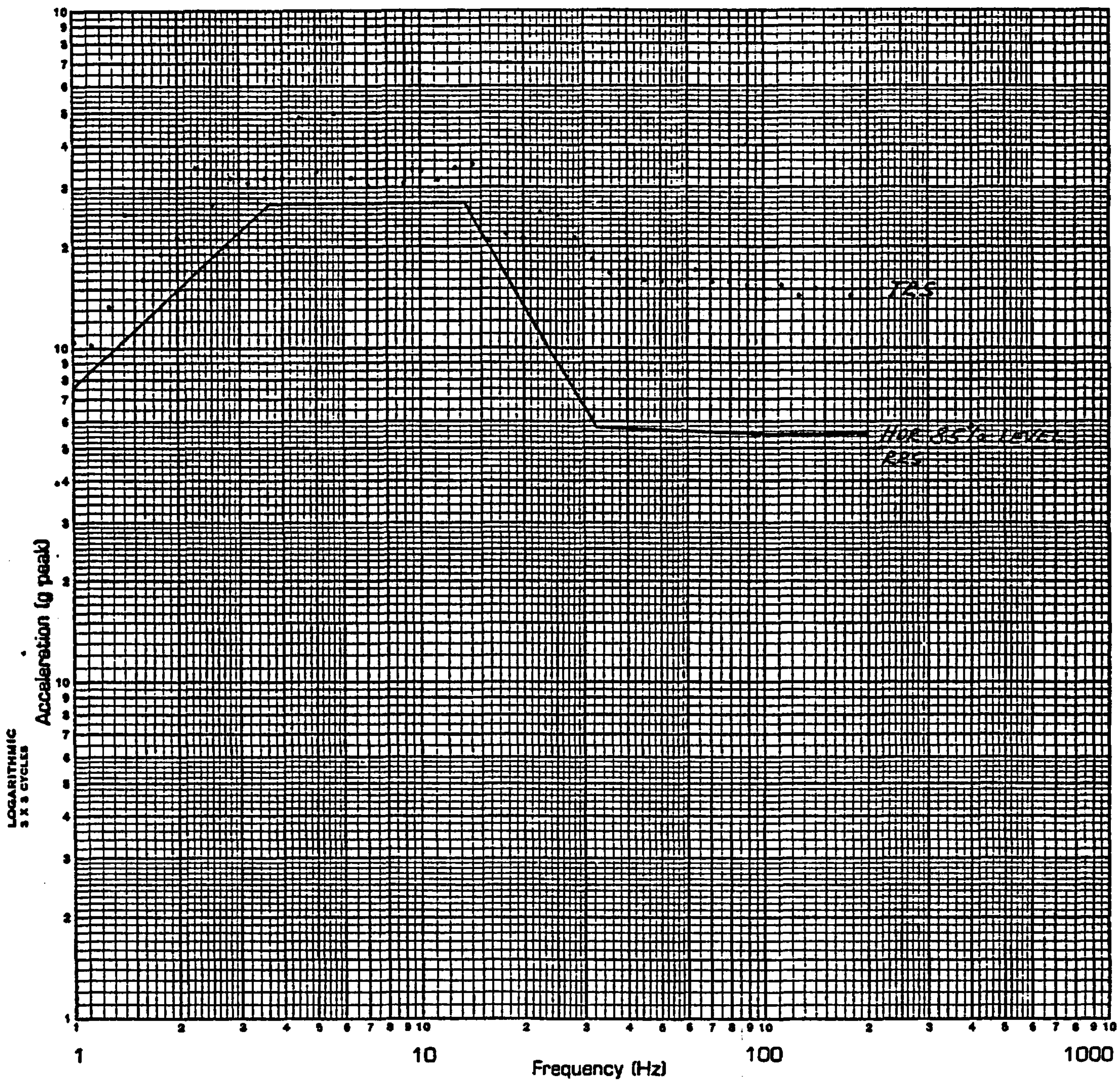
LOCATION NO. FB HCA

TEST RUN NO. 5

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ——

AXIS TR1

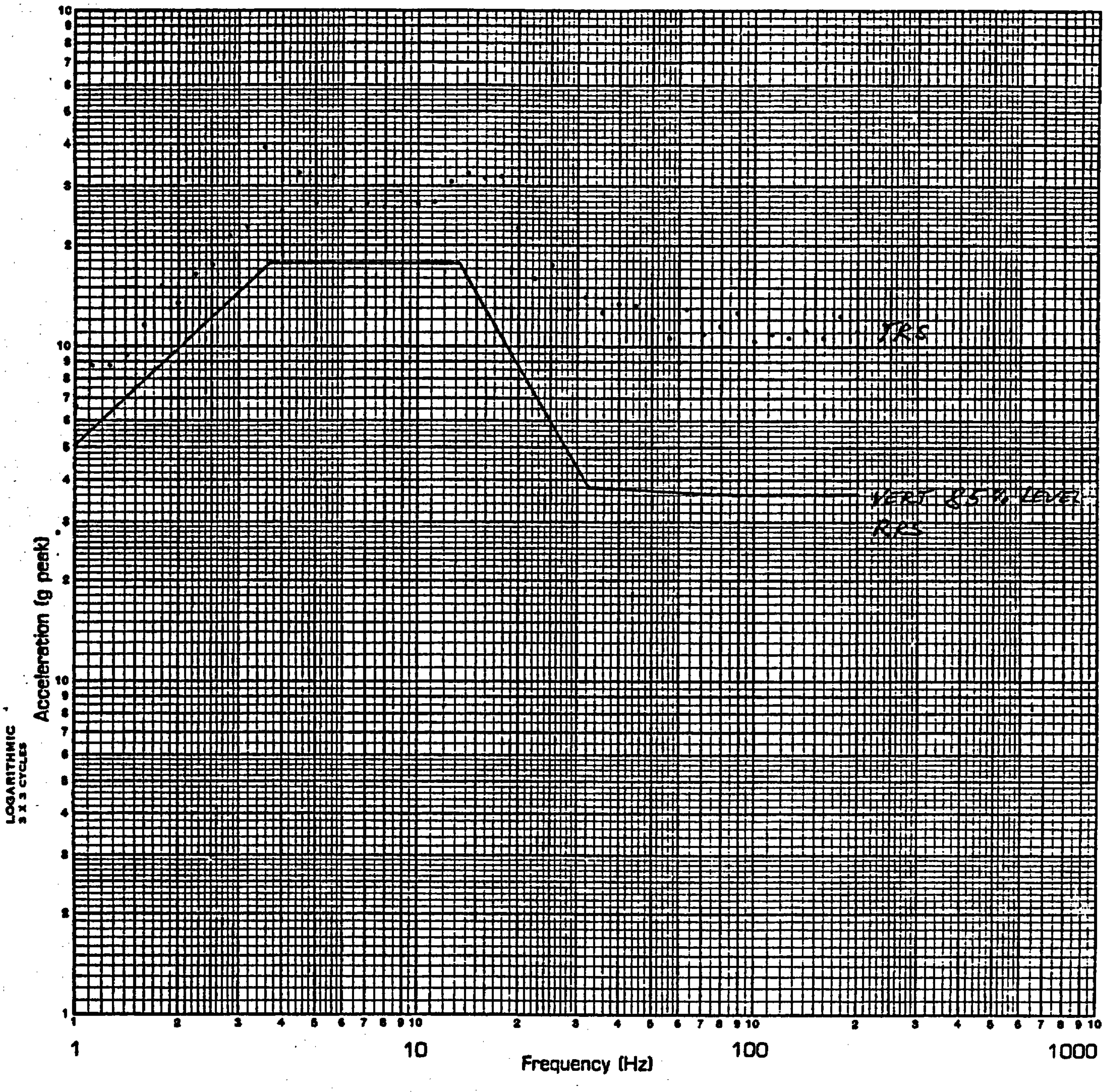
LOCATION NO. SS HCA

TEST RUN NO. 5

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ——

LOCATION NO. VCA

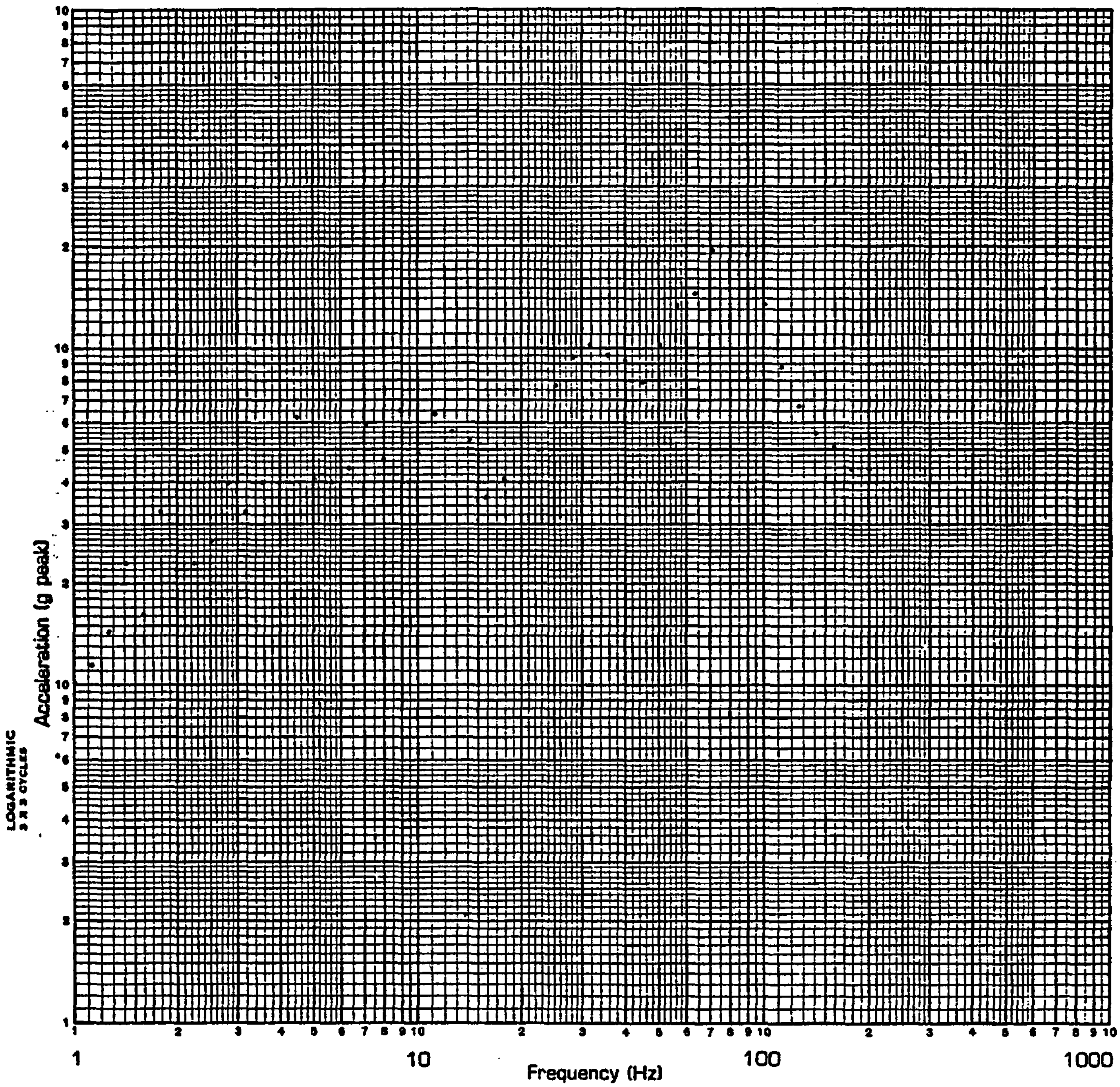
AXIS TR1

TEST RUN NO. 5

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING 2%



SPECIMEN RACK

LOCATION NO. 1FB

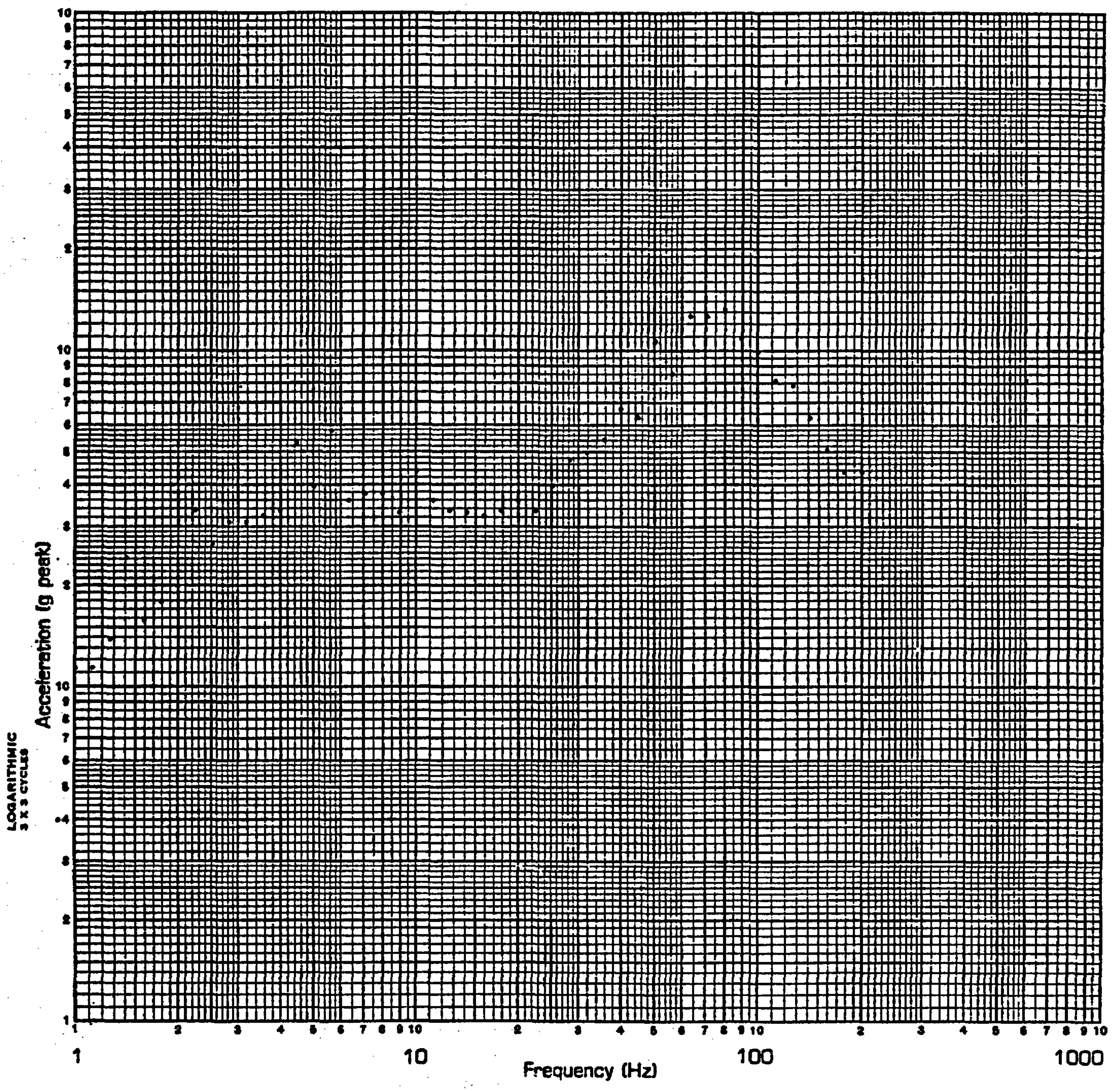
AXIS TR1

TEST RUN NO. 5

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000☐

DAMPING 2%



SPECIMEN RACK

AXIS TR1

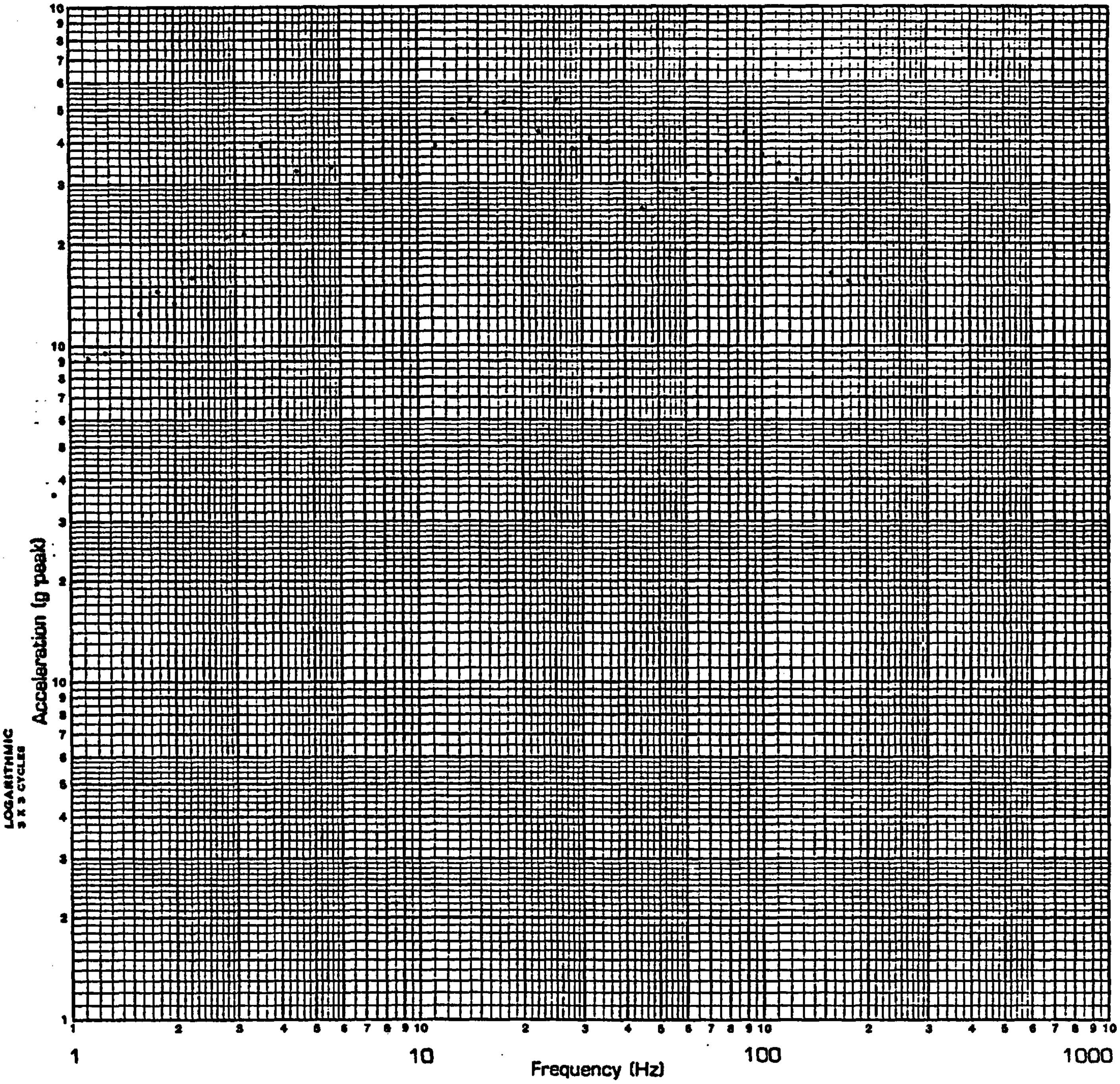
LOCATION NO. 253

TEST RUN NO. 5

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN RACK

AXIS TR1

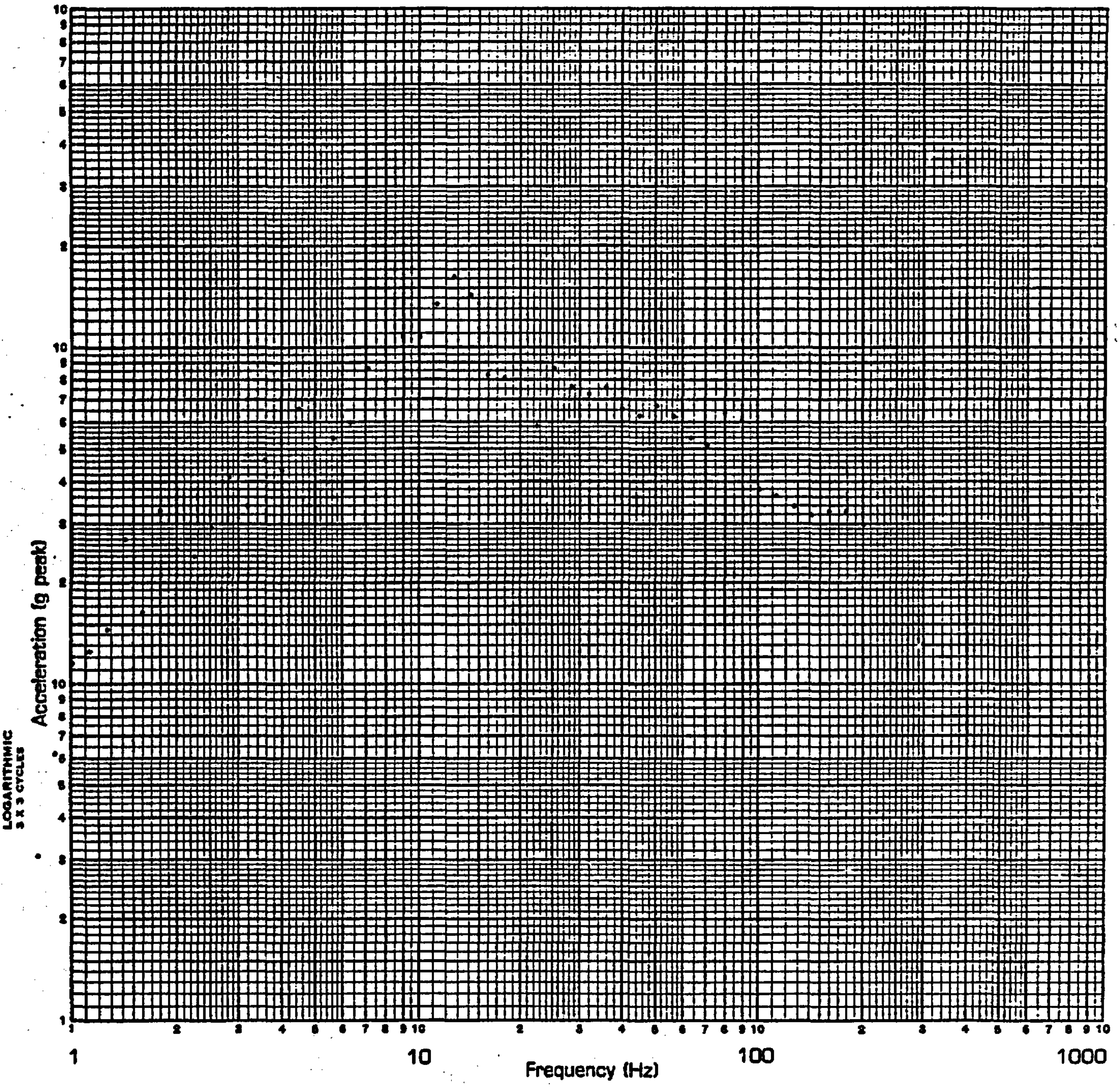
LOCATION NO. 3V

TEST RUN NO. 5

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING $\boxed{2\%}$



SPECIMEN CELL #48

AXIS TR1

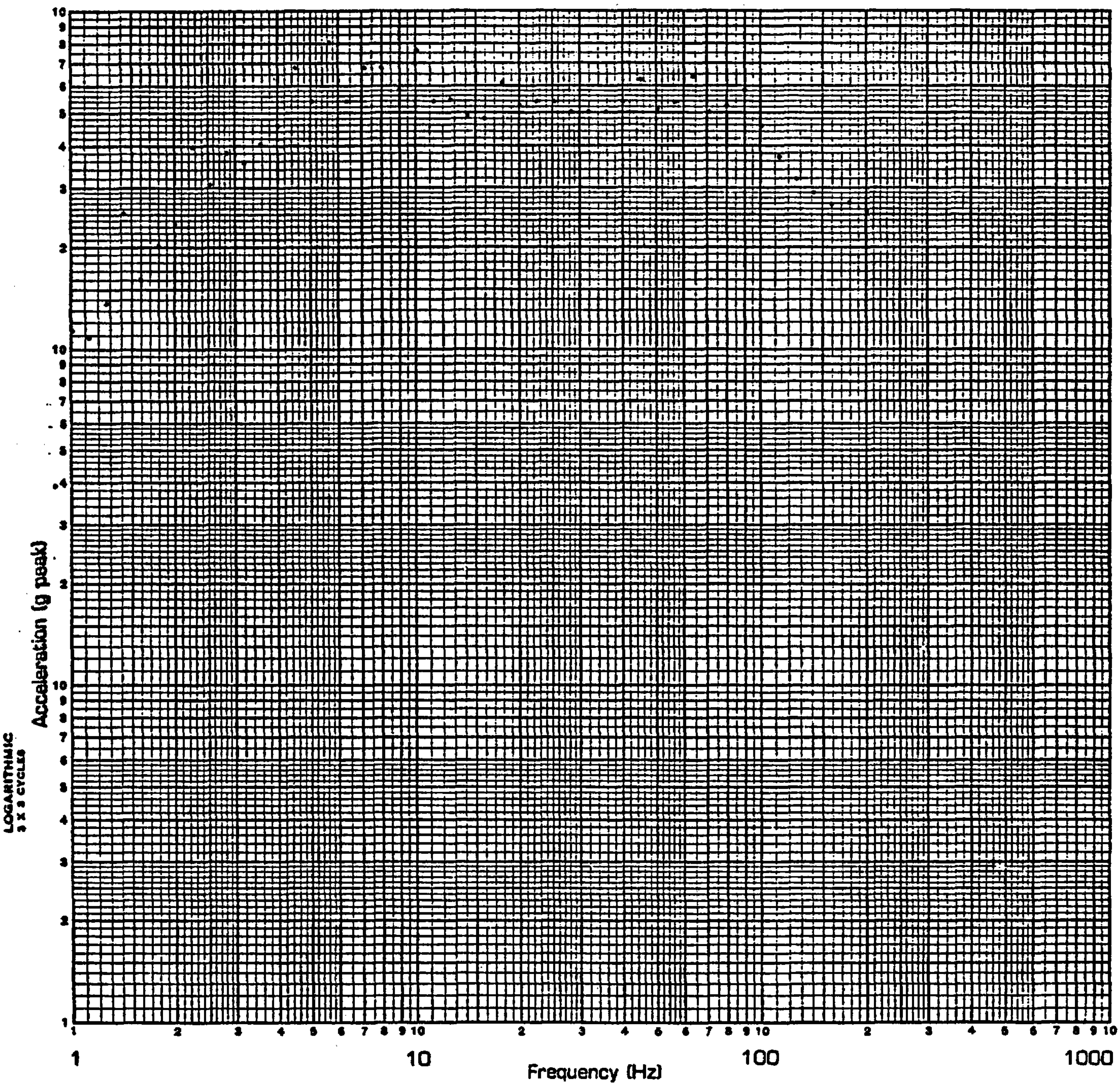
LOCATION NO. 4FB

TEST RUN NO. 5

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



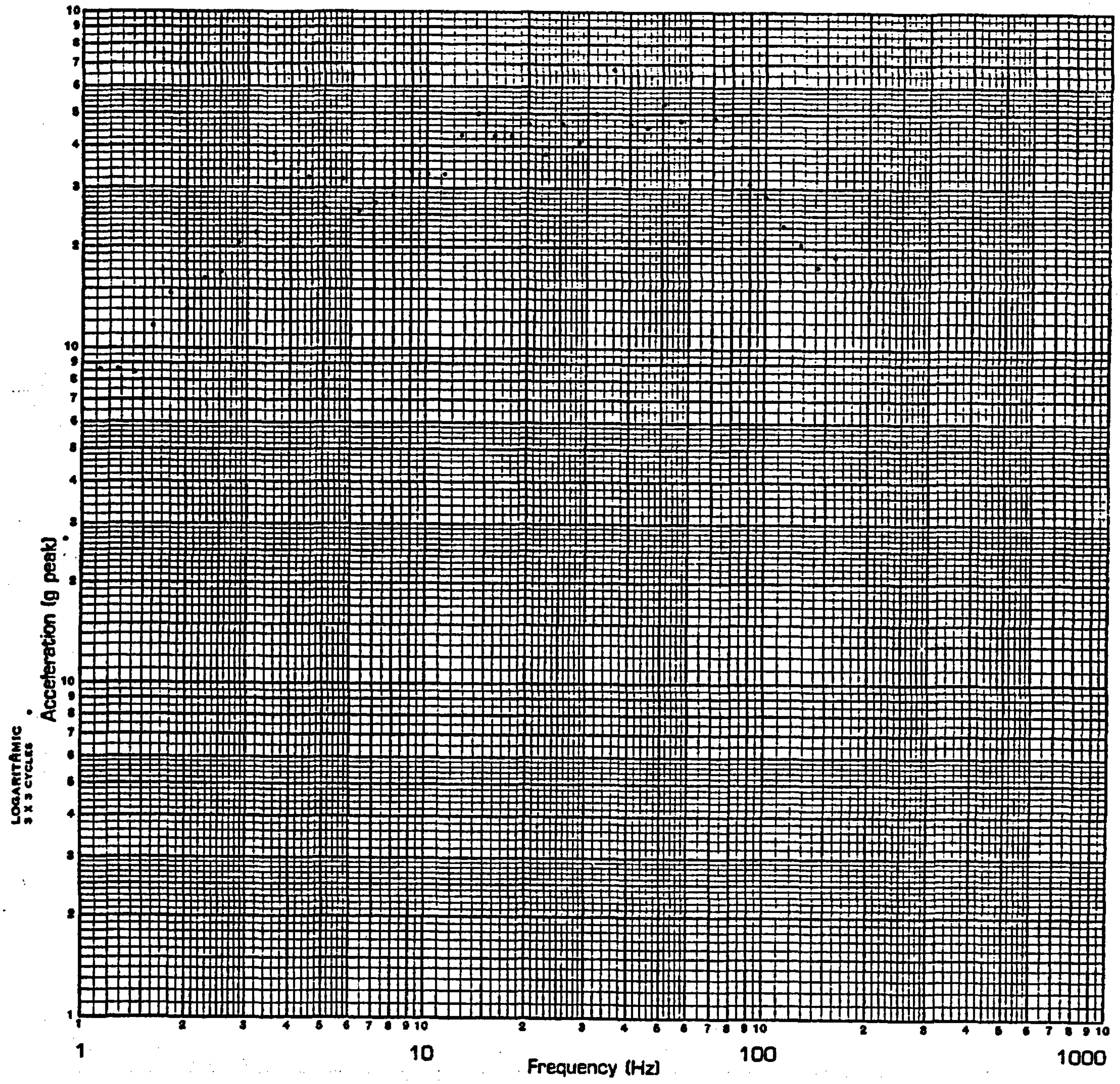
SPECIMEN cell #48 LOCATION NO. 5 SS

AXIS TR1 TEST RUN NO. 5

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000 ☐

DAMPING 2%



SPECIMEN Cell #48

AXIS TRI

LOCATION NO. 6V

TEST RUN NO. 5

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PART 3

PLOTS FOR TEST SERIES 3
GROUP #3 BATTERIES

TEST RUN	TEST AXES	TEST LEVEL	PLOTS @ 2% DAMPING
6	TRI	95%	Control Accelerometers and Response Accelerometers

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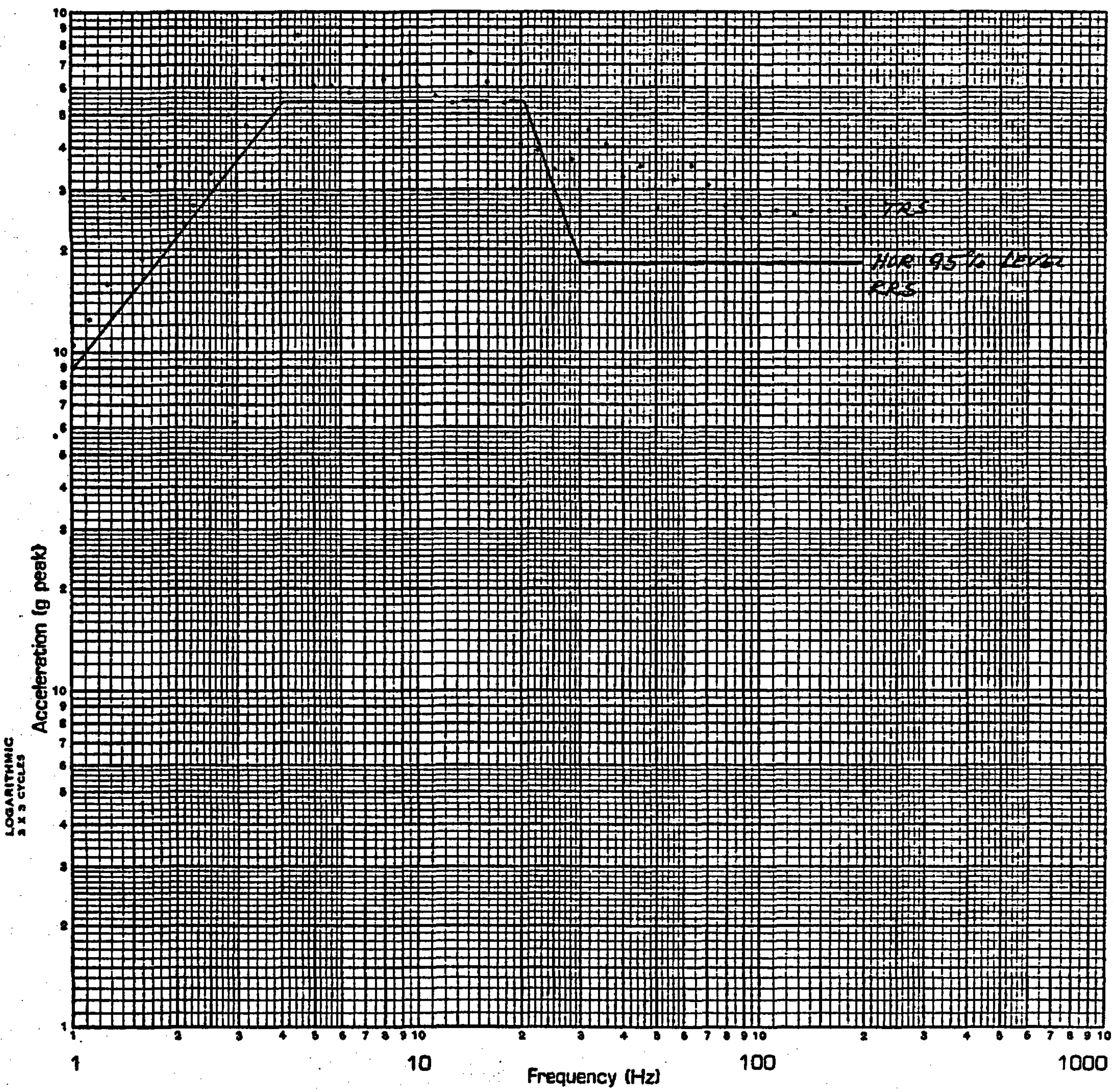
FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ——

AXIS TR1

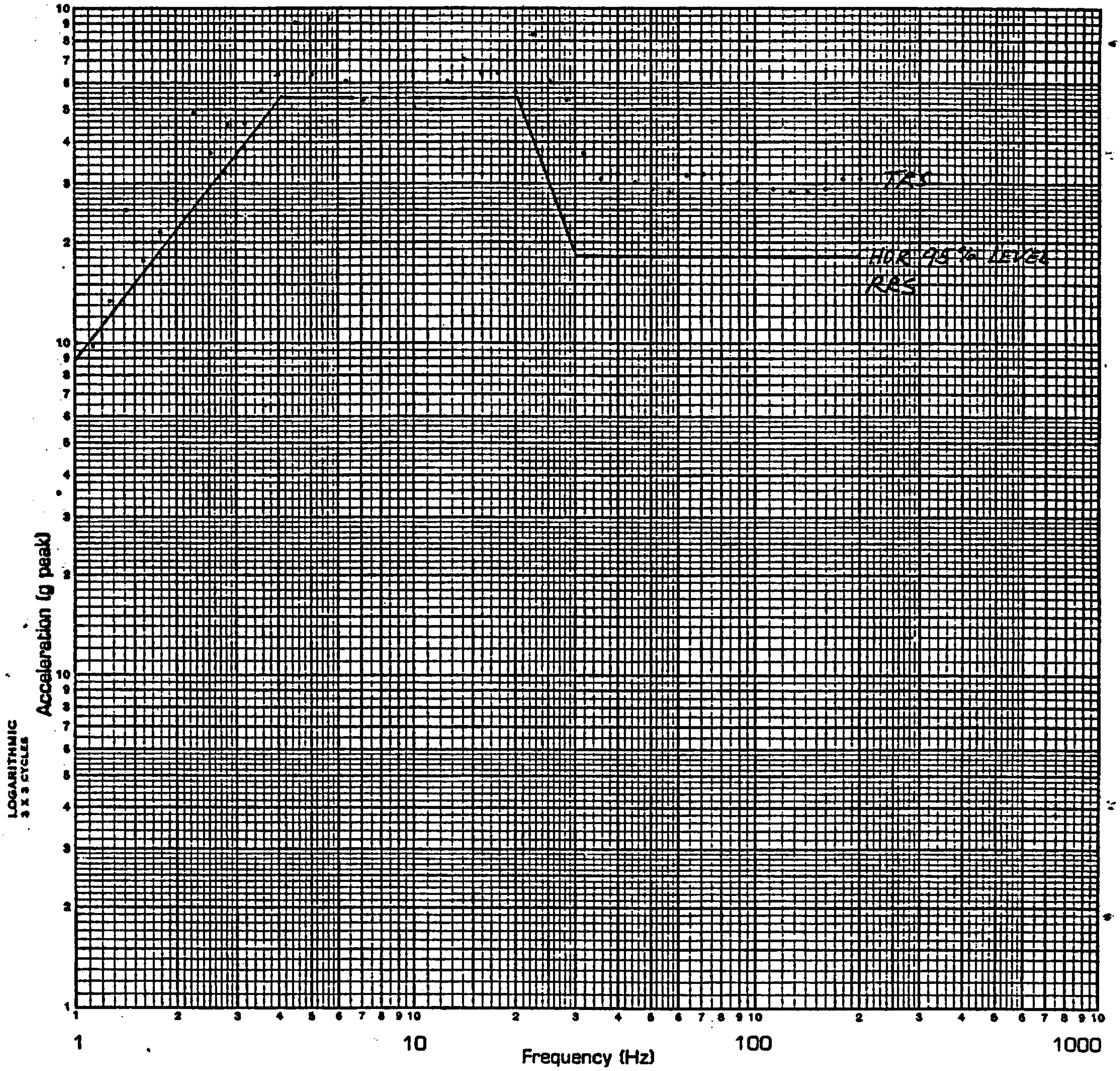
LOCATION NO. FB HCA

TEST RUN NO. 6

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ——

LOCATION NO. 53 HCA

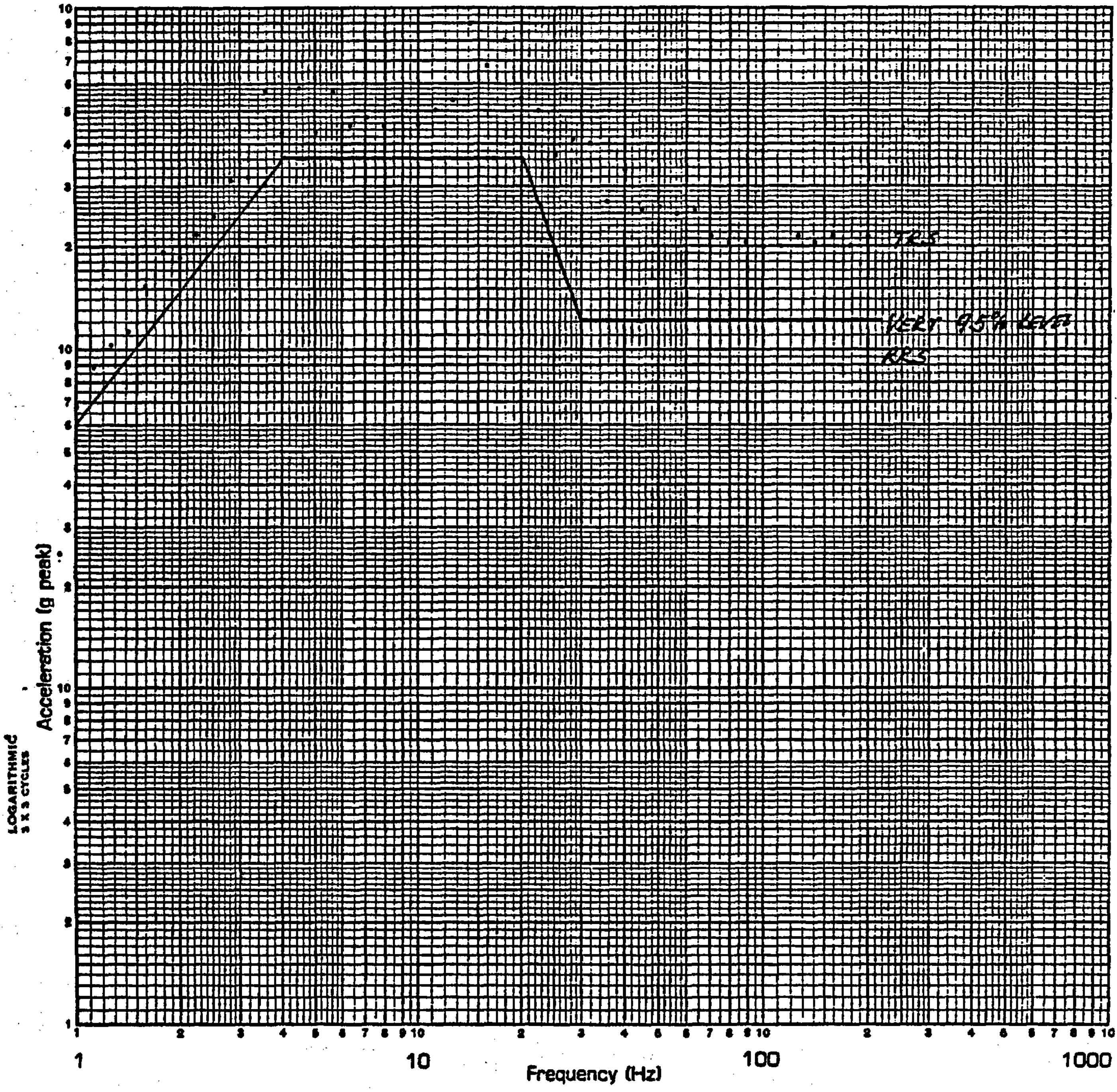
AXIS TR1

TEST RUN NO. 6

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ______

AXIS TR1

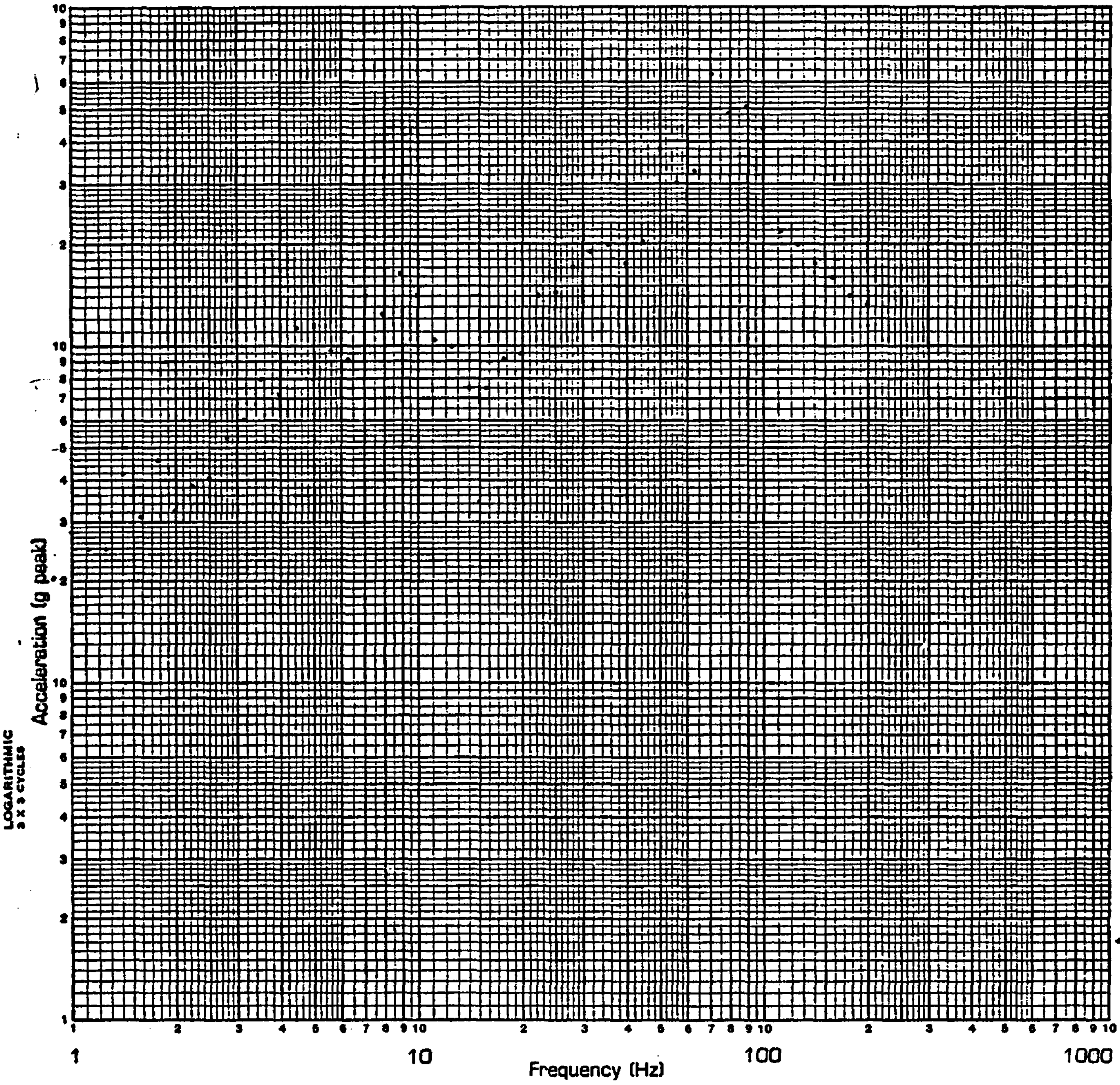
LOCATION NO. VCA

TEST RUN NO. 6

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000☐

DAMPING 2%



SPECIMEN Rack

AXIS TR1

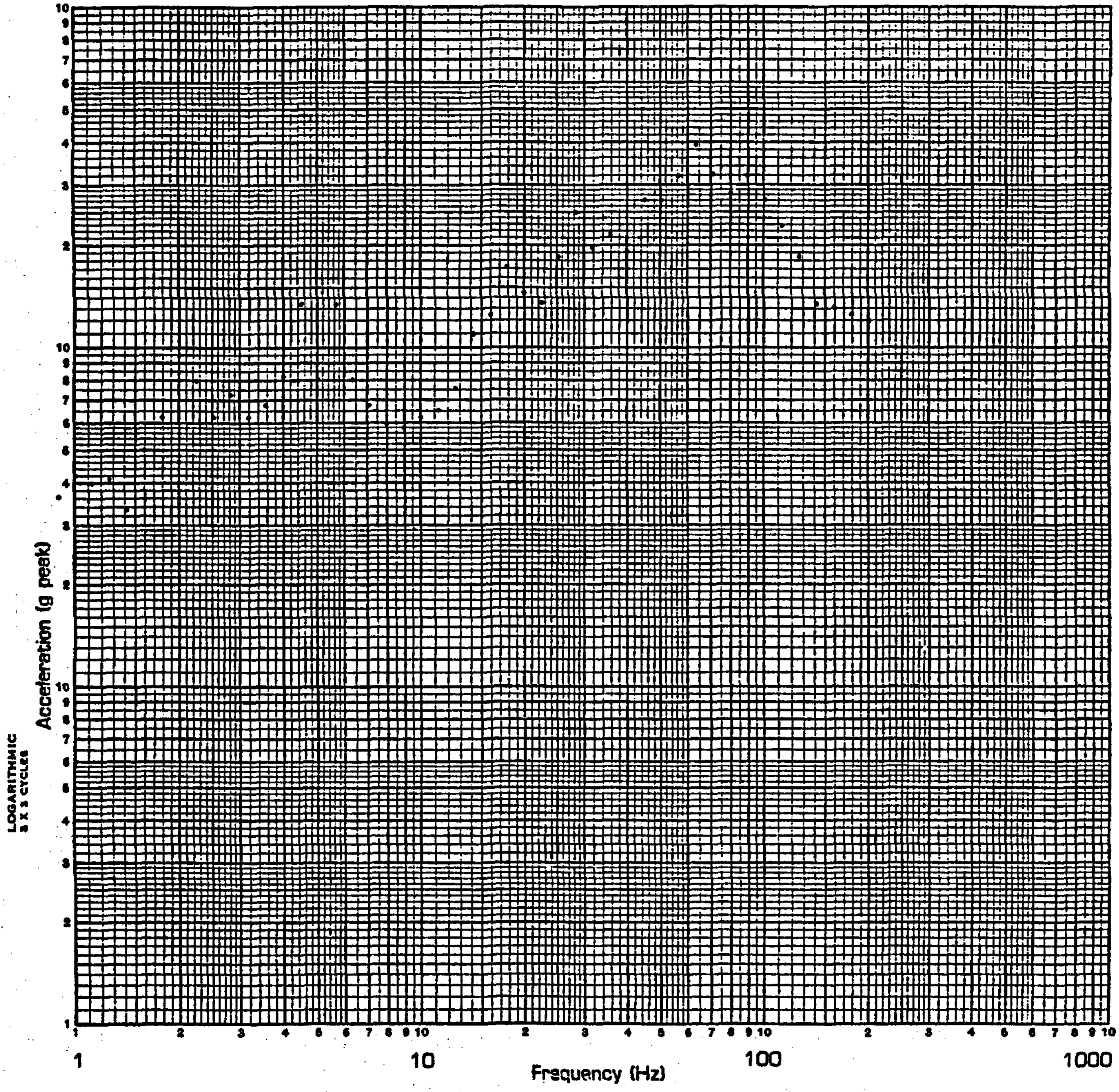
LOCATION NO. 1 FB

TEST RUN NO. 6

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000☐

DAMPING 2%



SPECIMEN RACK

AXIS TR1

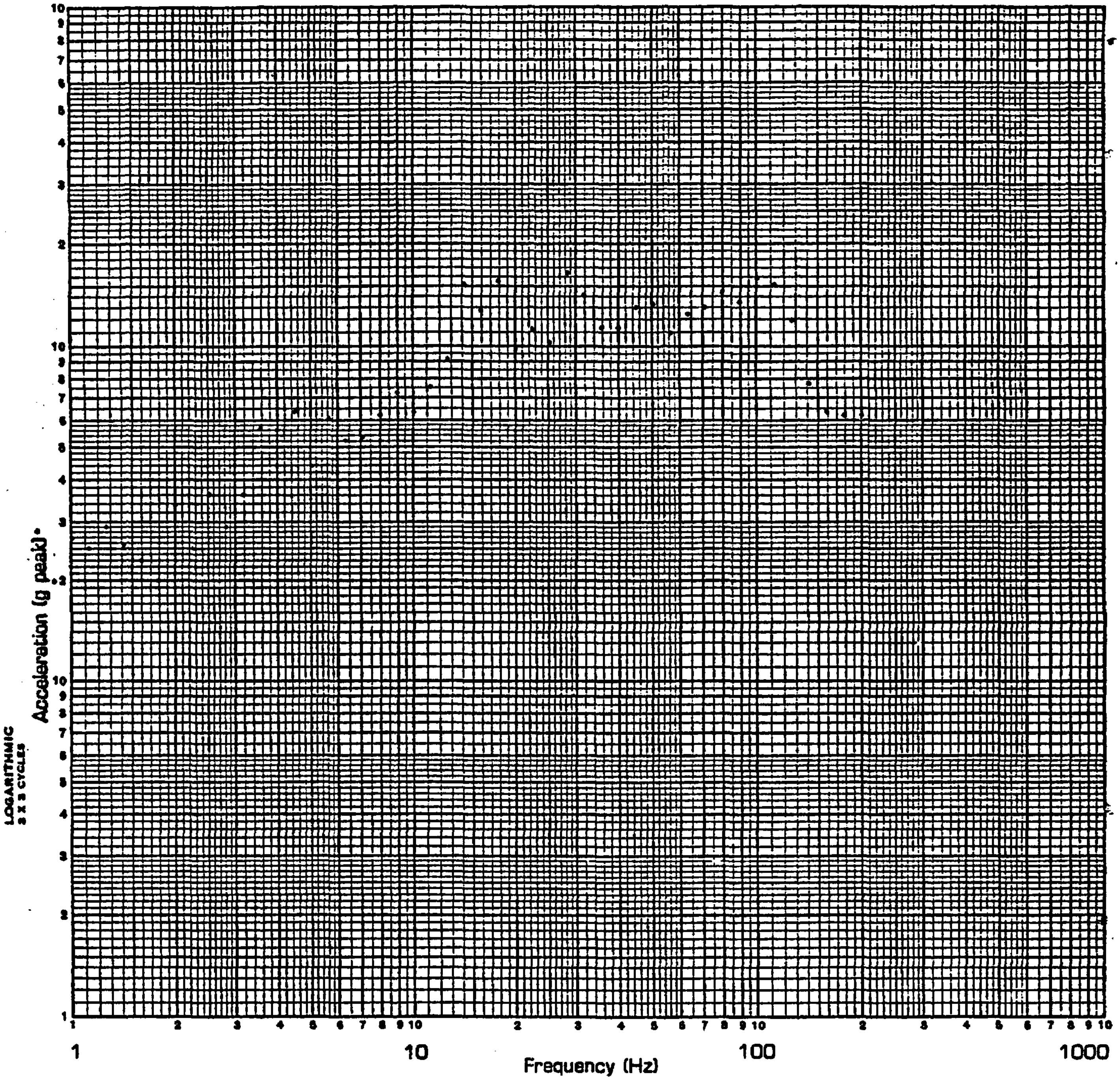
LOCATION NO. 2SS

TEST RUN NO. 6

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING $\boxed{2\%}$

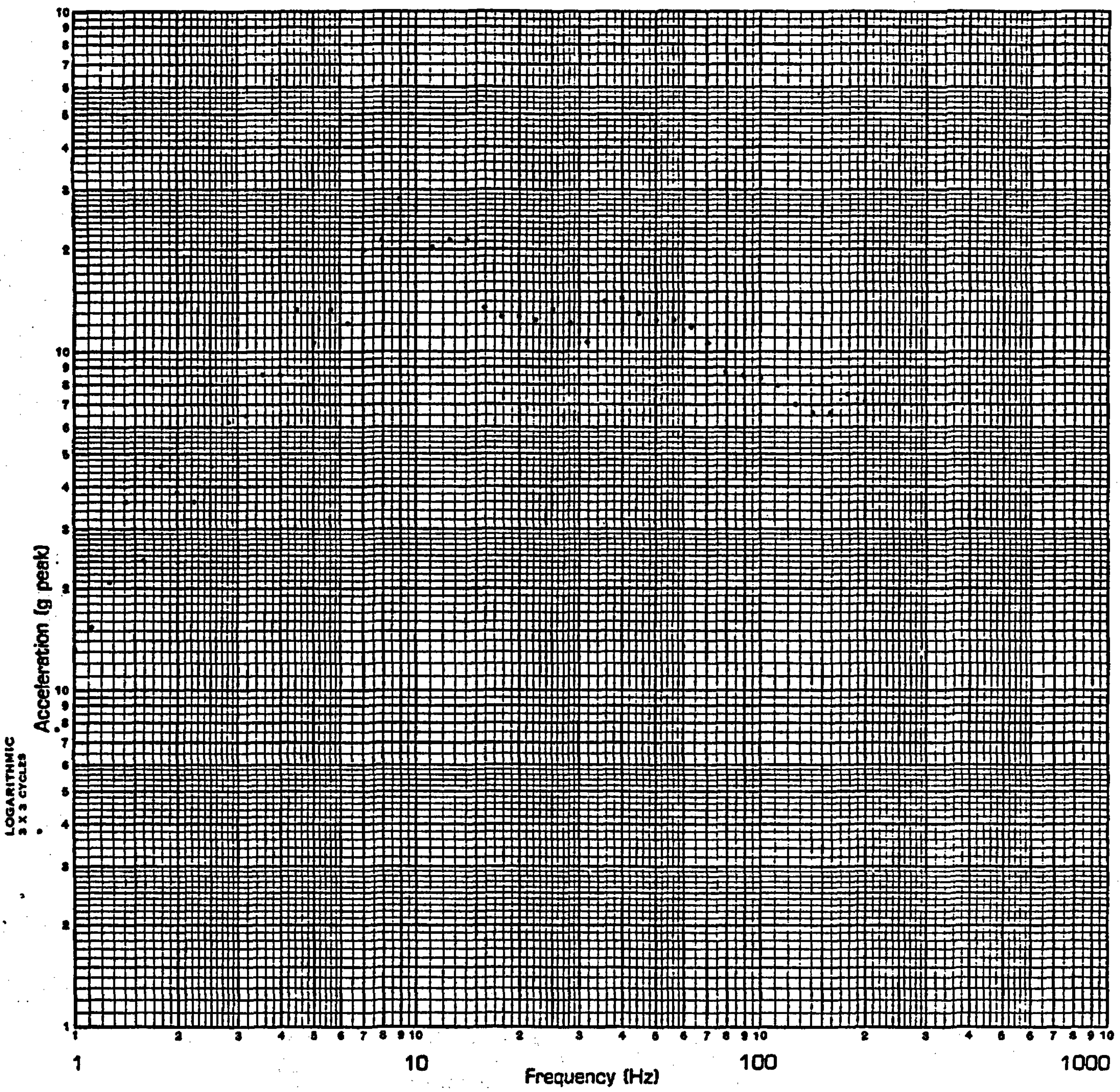


SPECIMEN RACK
AXIS TR1
LOCATION NO. 3V
TEST RUN NO. 6

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000 ☐

DAMPING 2%



SPECIMEN cell #30

LOCATION NO. 4FB

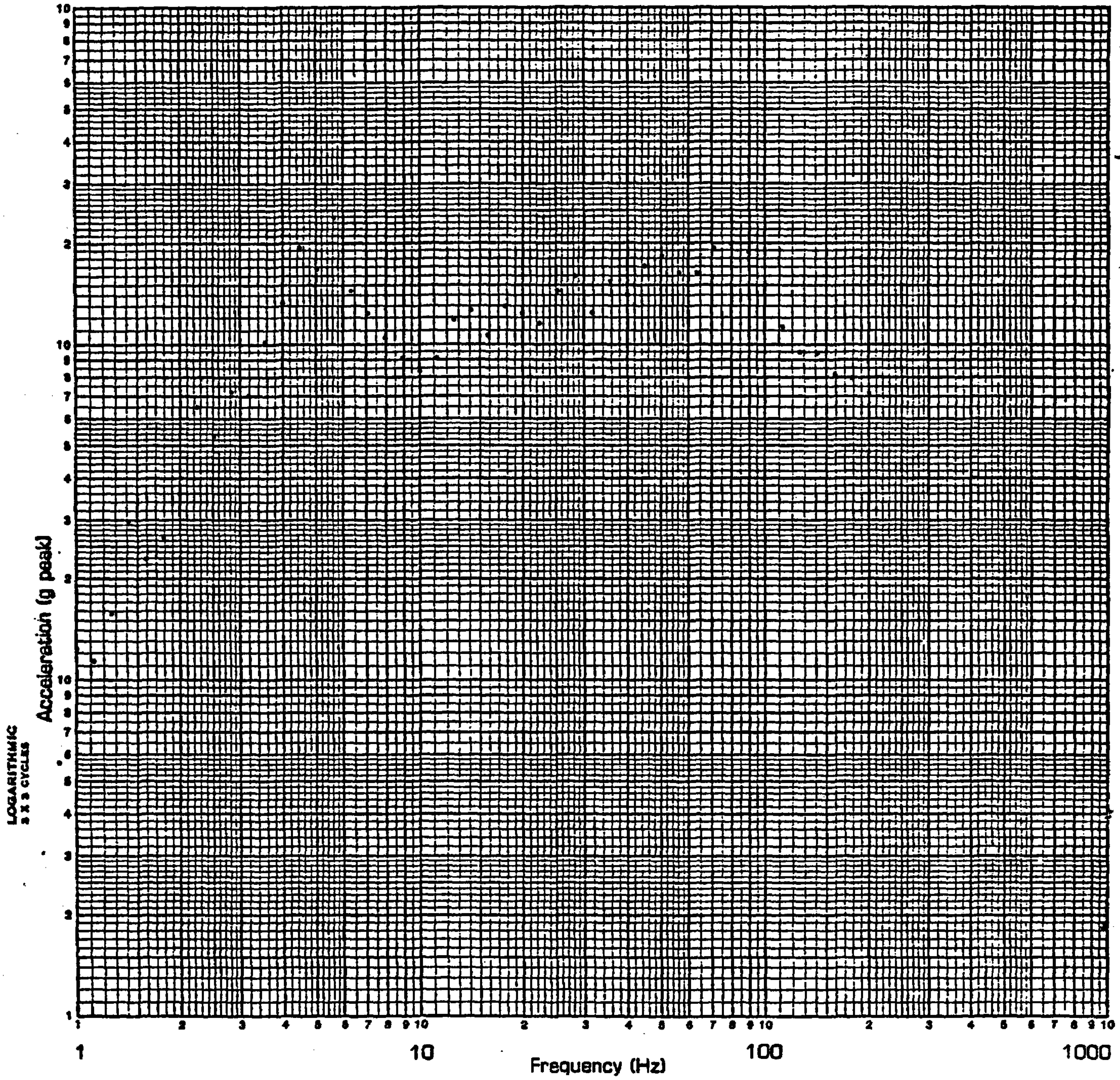
AXIS TR1

TEST RUN NO. 6

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000☐

DAMPING 2%



SPECIMEN cell #30

LOCATION NO. 5SS

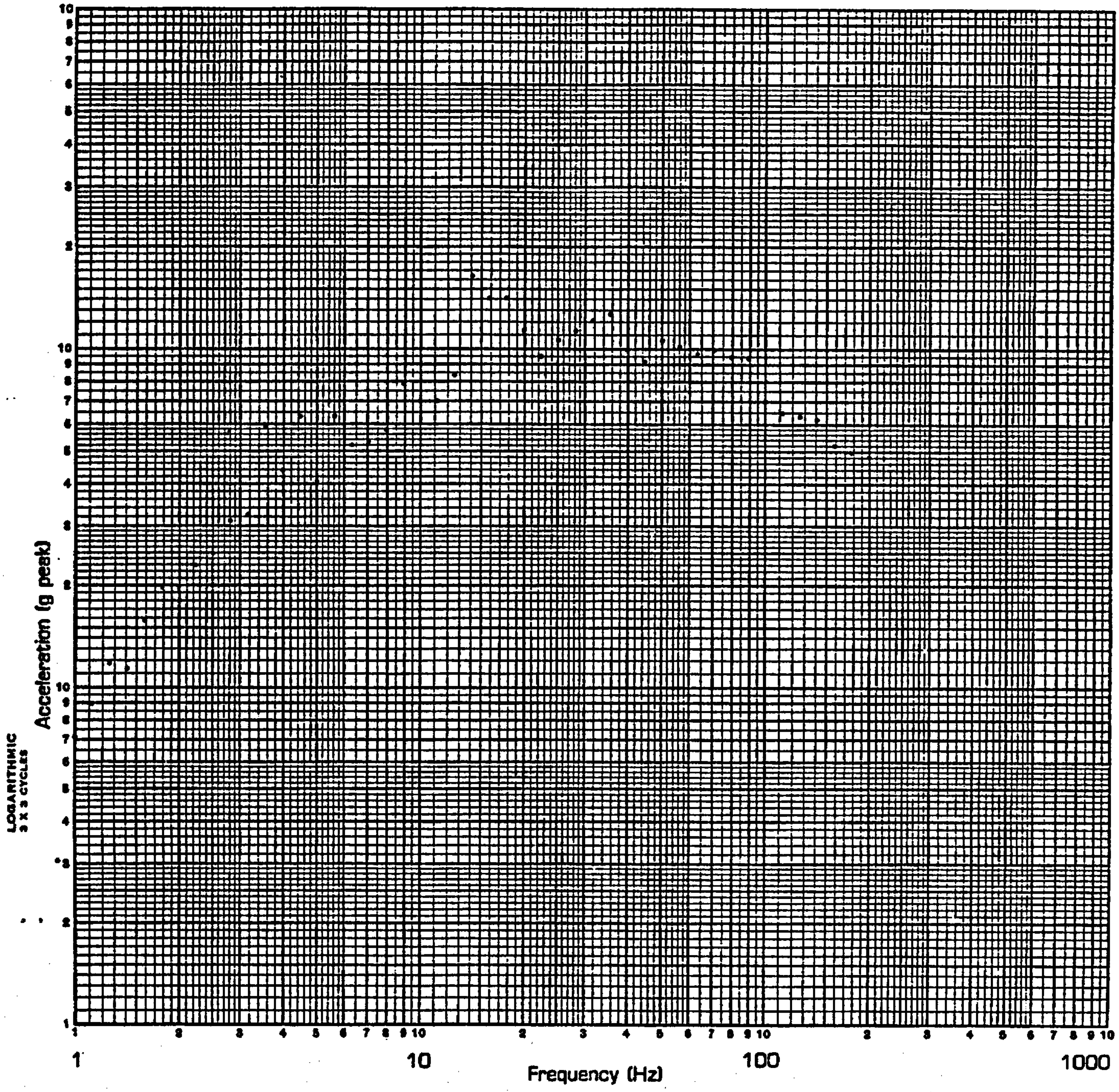
AXIS TR1

TEST RUN NO. 6

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000☐

DAMPING 2%



SPECIMEN cell #30
LOCATION NO. 6V
AXIS TR1
TEST RUN NO. 6

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PART 4

PLOTS FOR TEST SERIES 4
GROUP #1 BATTERIES

TEST RUN	TEST AXES	TEST LEVEL	PLOTS @ 2% DAMPING
8	TRI	100%	Control Accelerometers and Response Accelerometers

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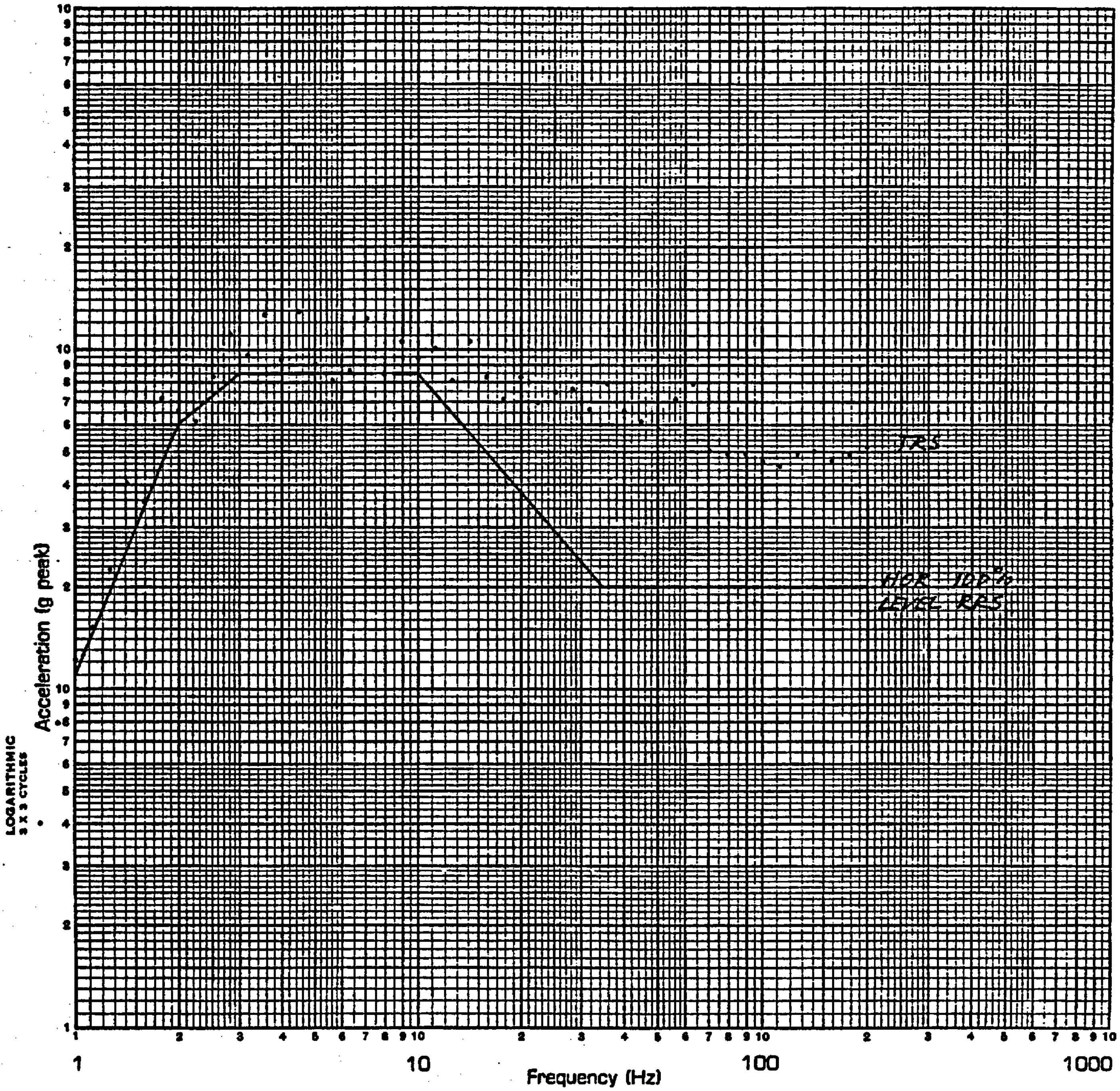
FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000☐

DAMPING 2%



SPECIMEN ______

LOCATION NO. FB HCA

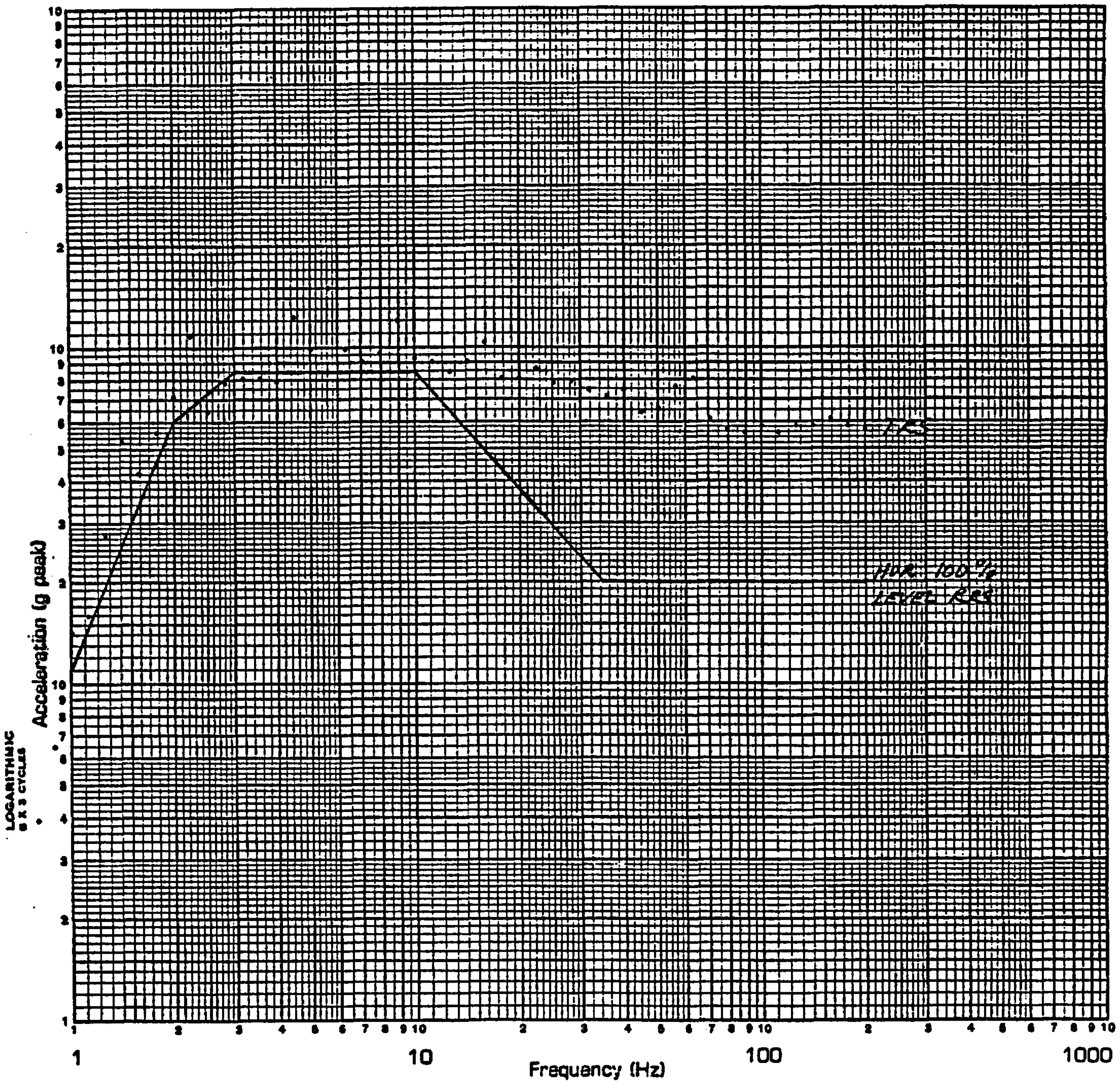
AXIS TR1

TEST RUN NO. 8

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING 2%



SPECIMEN ———

LOCATION NO. 33 HCA

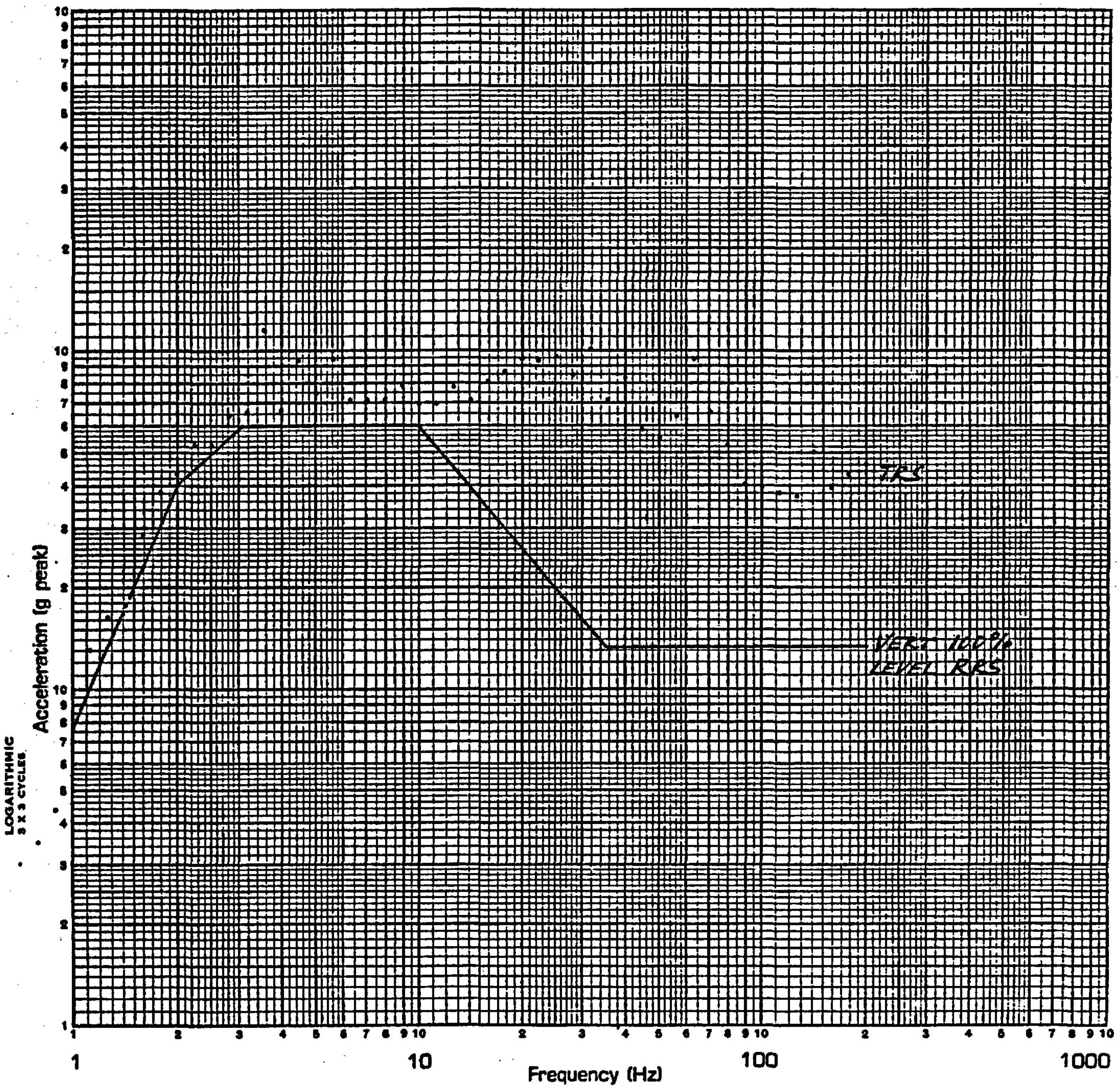
AXIS TR1

TEST RUN NO. 8

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING 2%



SPECIMEN ——

LOCATION NO. VCA

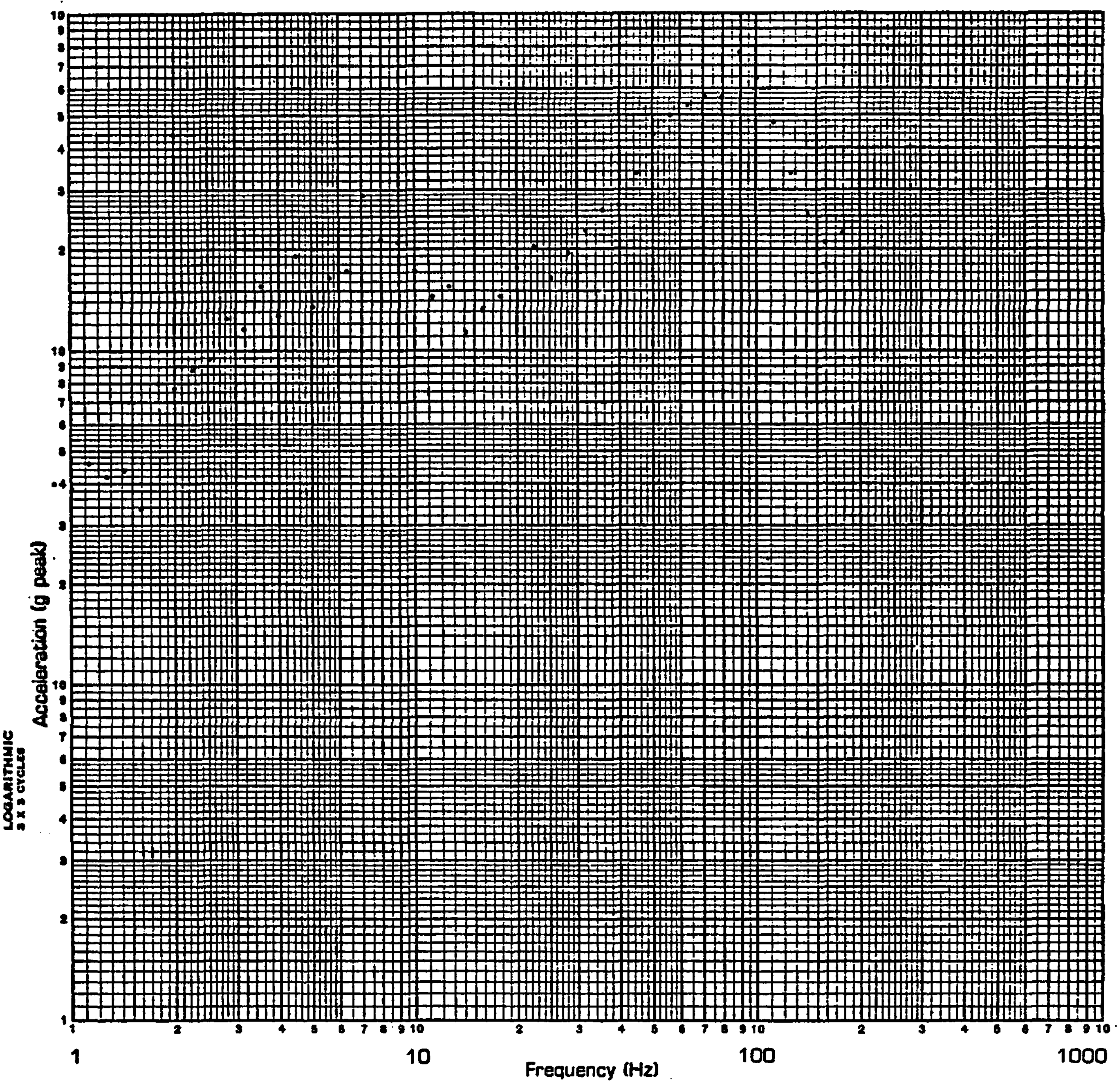
AXIS TR1

TEST RUN NO. 8

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000 ☐

DAMPING $\boxed{2\%}$



SPECIMEN RACK

AXIS TR1

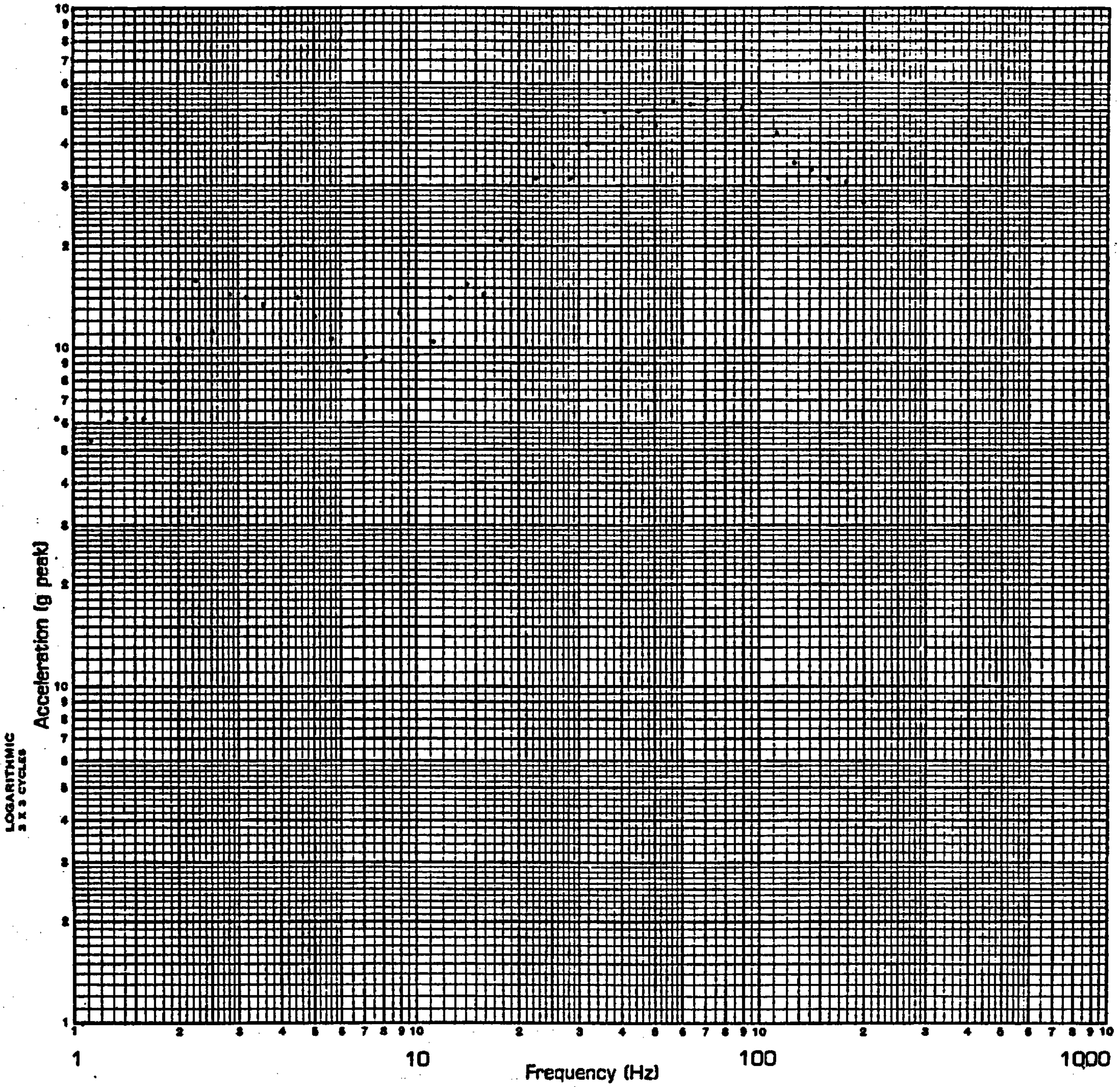
LOCATION NO. 1 FB

TEST RUN NO. 8

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING 2 %



SPECIMEN RACK

LOCATION NO. 2SS

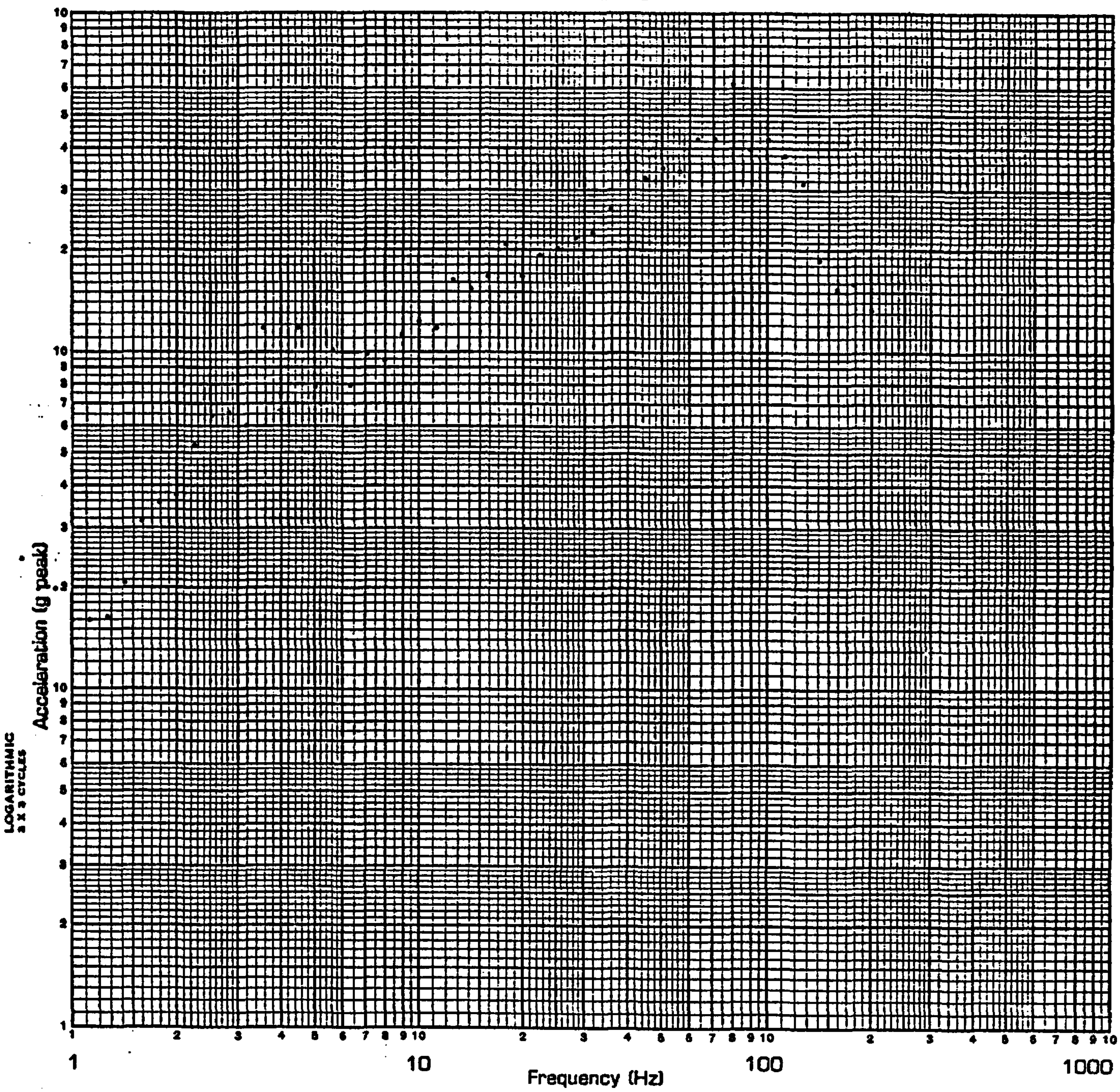
AXIS TR1

TEST RUN NO. 8

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING 2%



SPECIMEN RACK

LOCATION NO. 3V

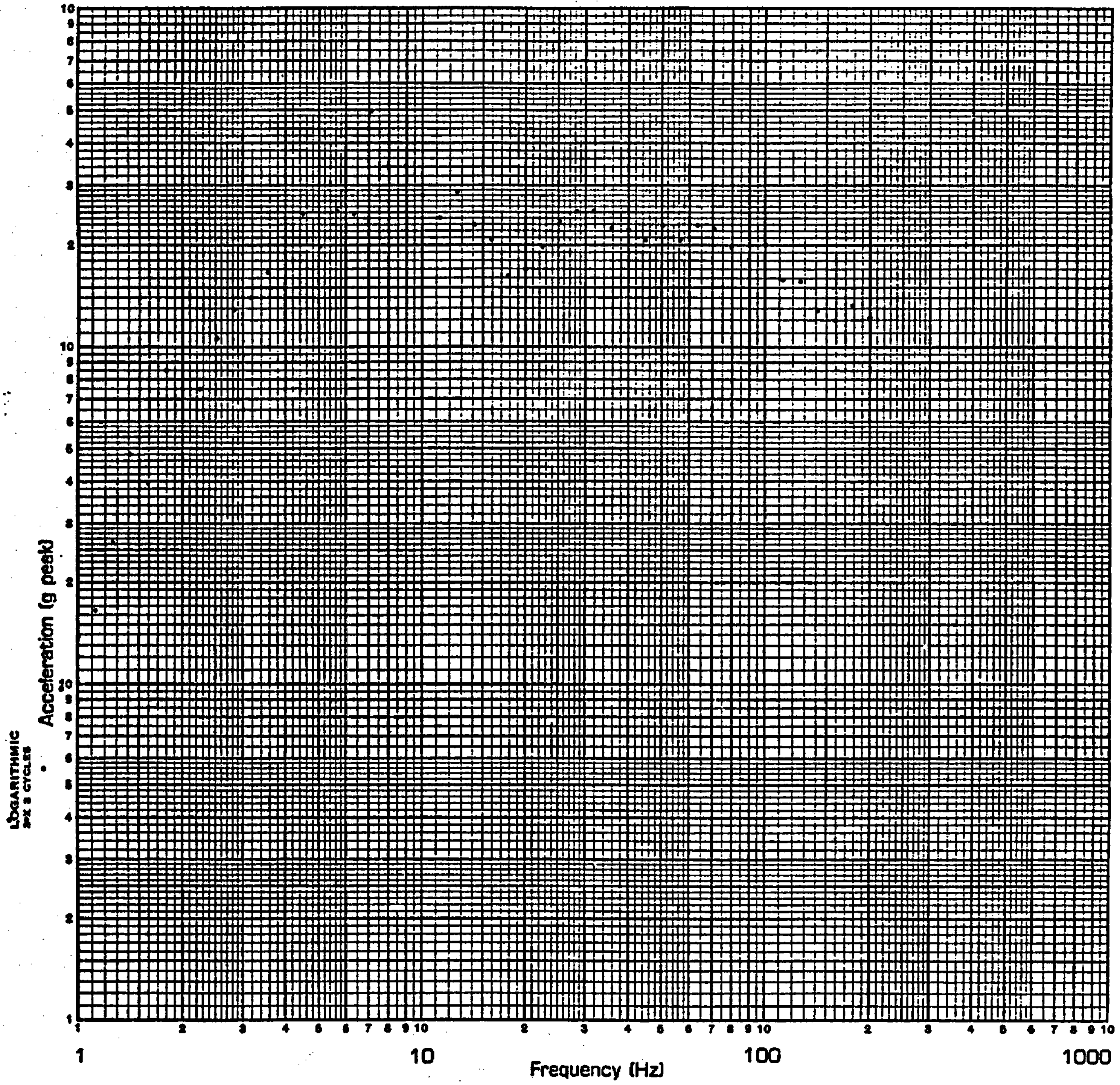
AXIS TR1

TEST RUN NO. 8

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING 2%



SPECIMEN CELL # 24

LOCATION NO. 4FB

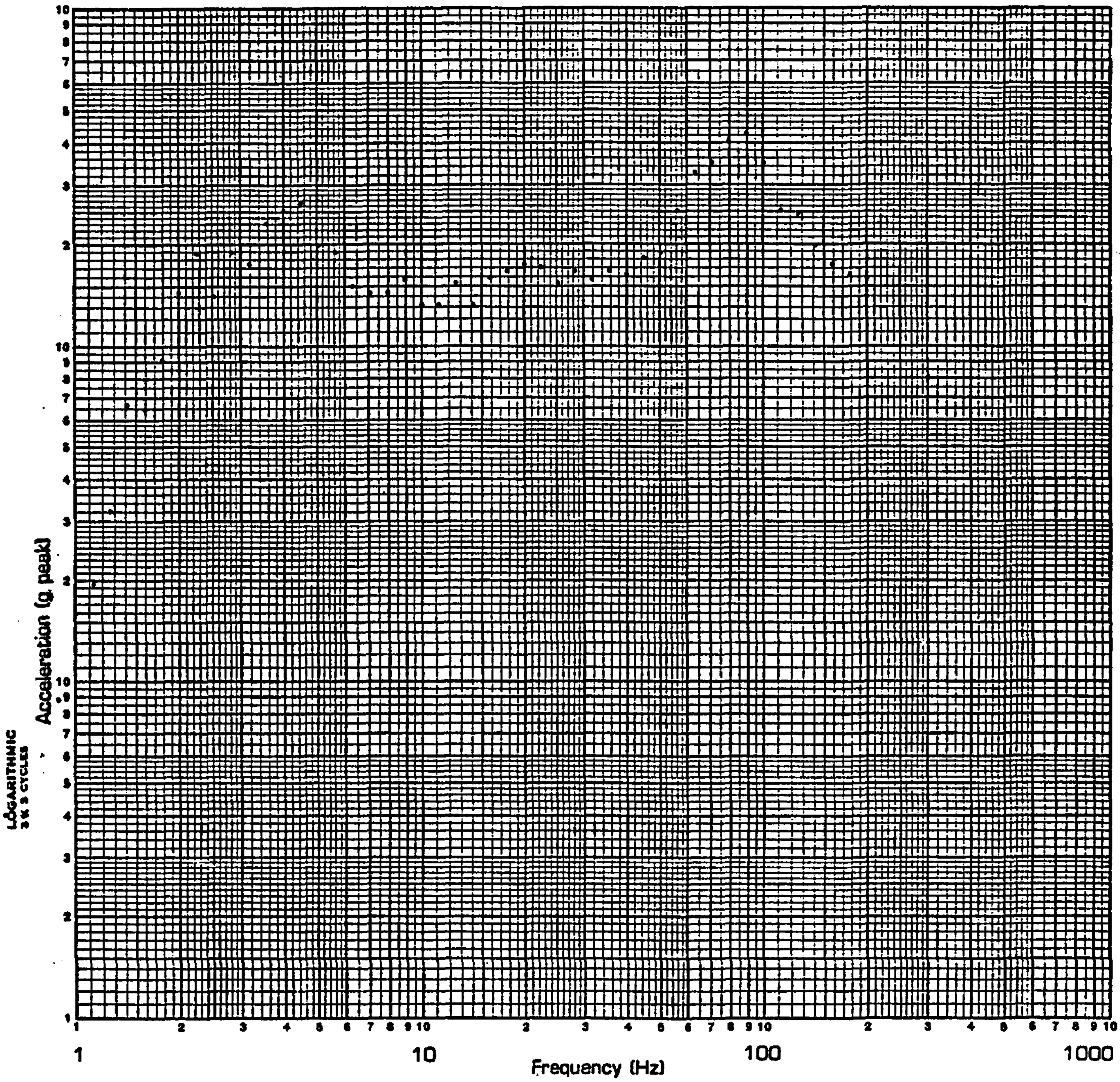
AXIS TR1

TEST RUN NO. 3

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000 ☐

DAMPING 2%



SPECIMEN CELL #24

AXIS TR1

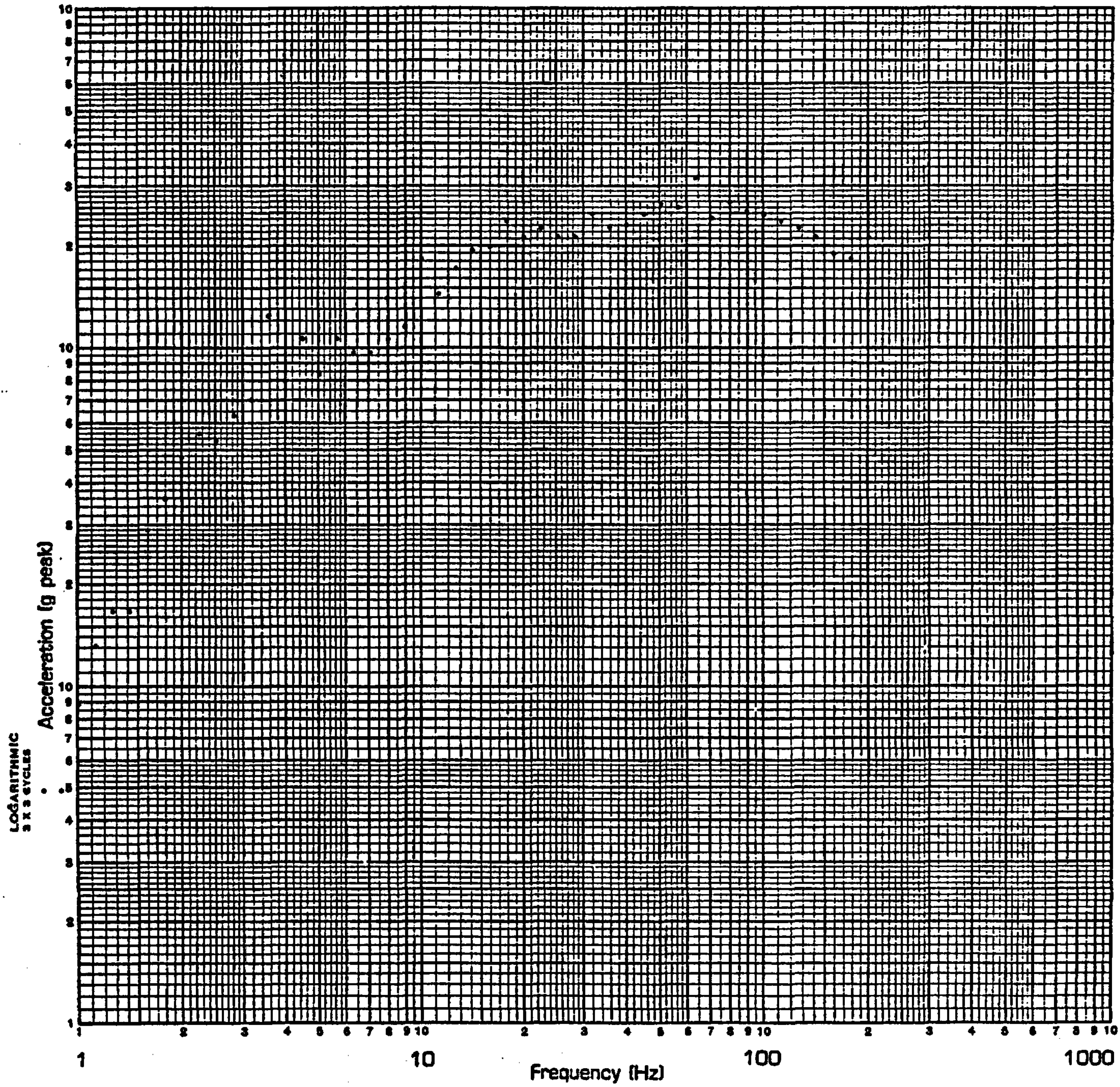
LOCATION NO. 5 SS

TEST RUN NO. 8

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 10000 ☐

DAMPING 2 %



SPECIMEN cell #24

AXIS TR1

LOCATION NO. 6 V

TEST RUN NO. 8

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PART 5

PLOTS FOR THE PERFORMED BARE TABLE TESTS

TEST RUN	TEST AXES	TEST LEVEL	PLOTS @ 2% DAMPING
BT 1	TRI	50%	Control Accelerometers
BT 2	TRI	85%	Control Accelerometers
BT 3	TRI	95%	Control Accelerometer
7	TRI	100%	Control Accelerometer

BT = Bare Table only (no rack, no dummy weights, etc.)

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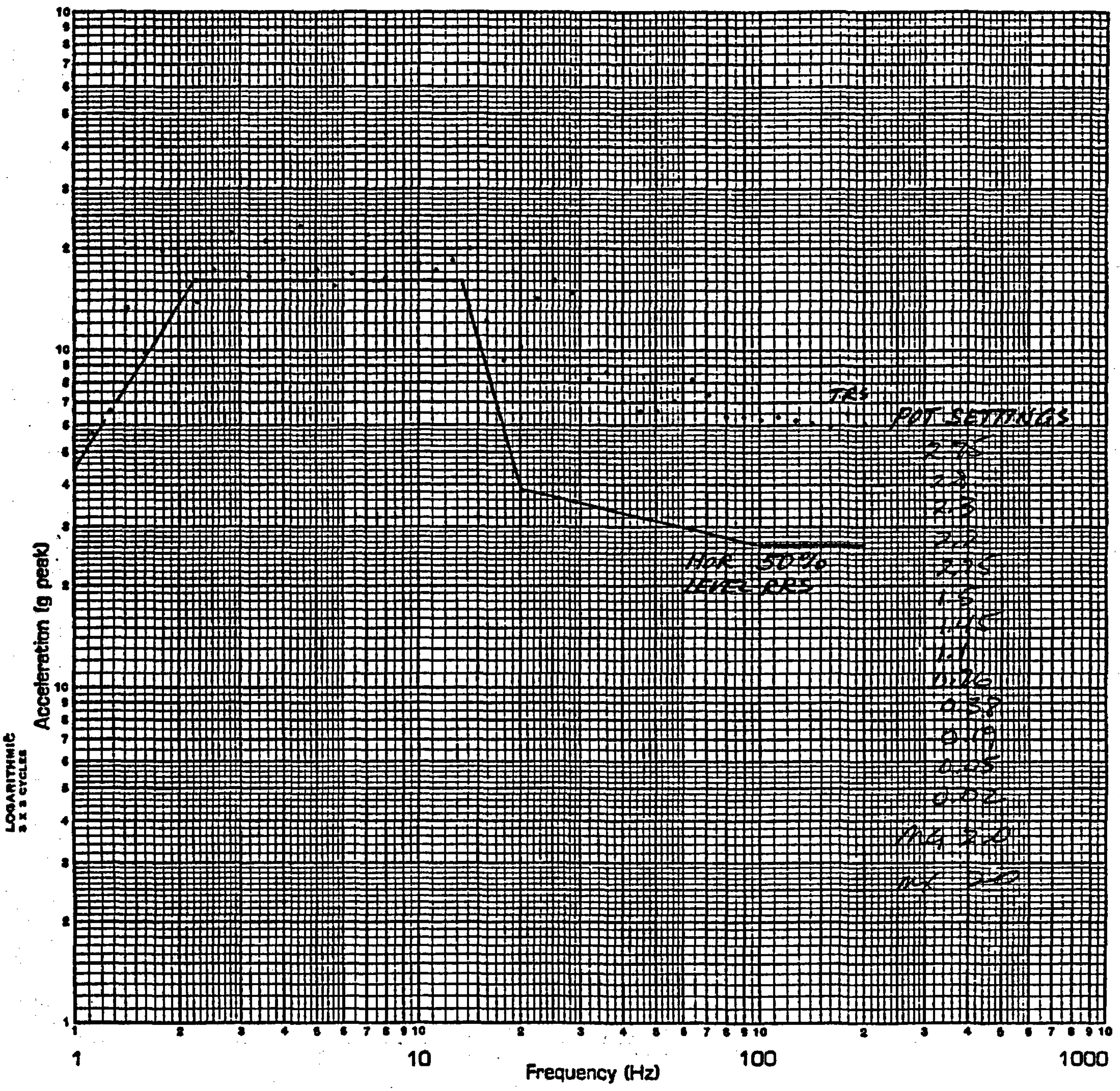
FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2 %



SPECIMEN ——

AXIS TRI

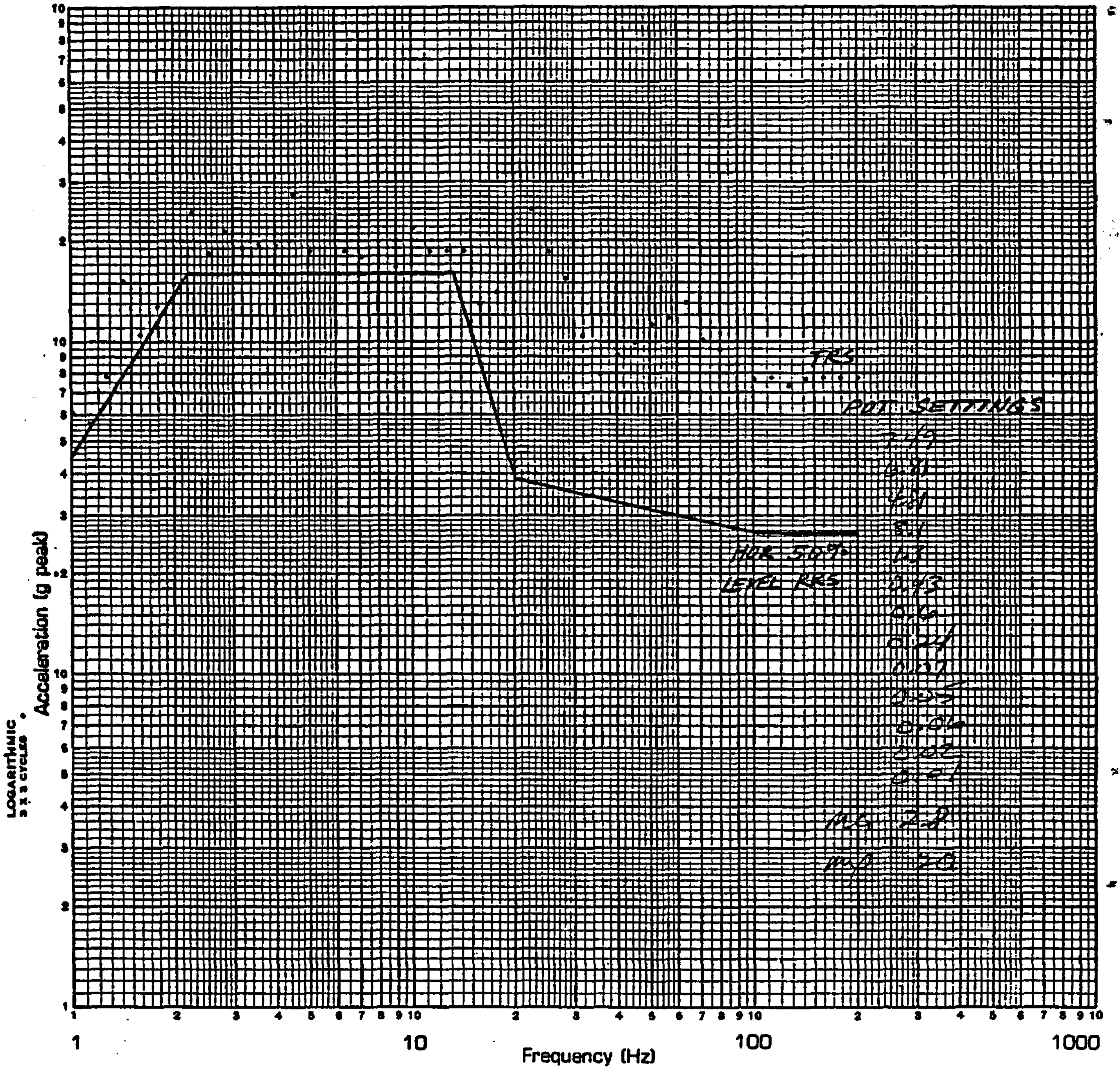
LOCATION NO. FB HCA

TEST RUN NO. BT 1 (50% LEVEL)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN —

AXIS TRI

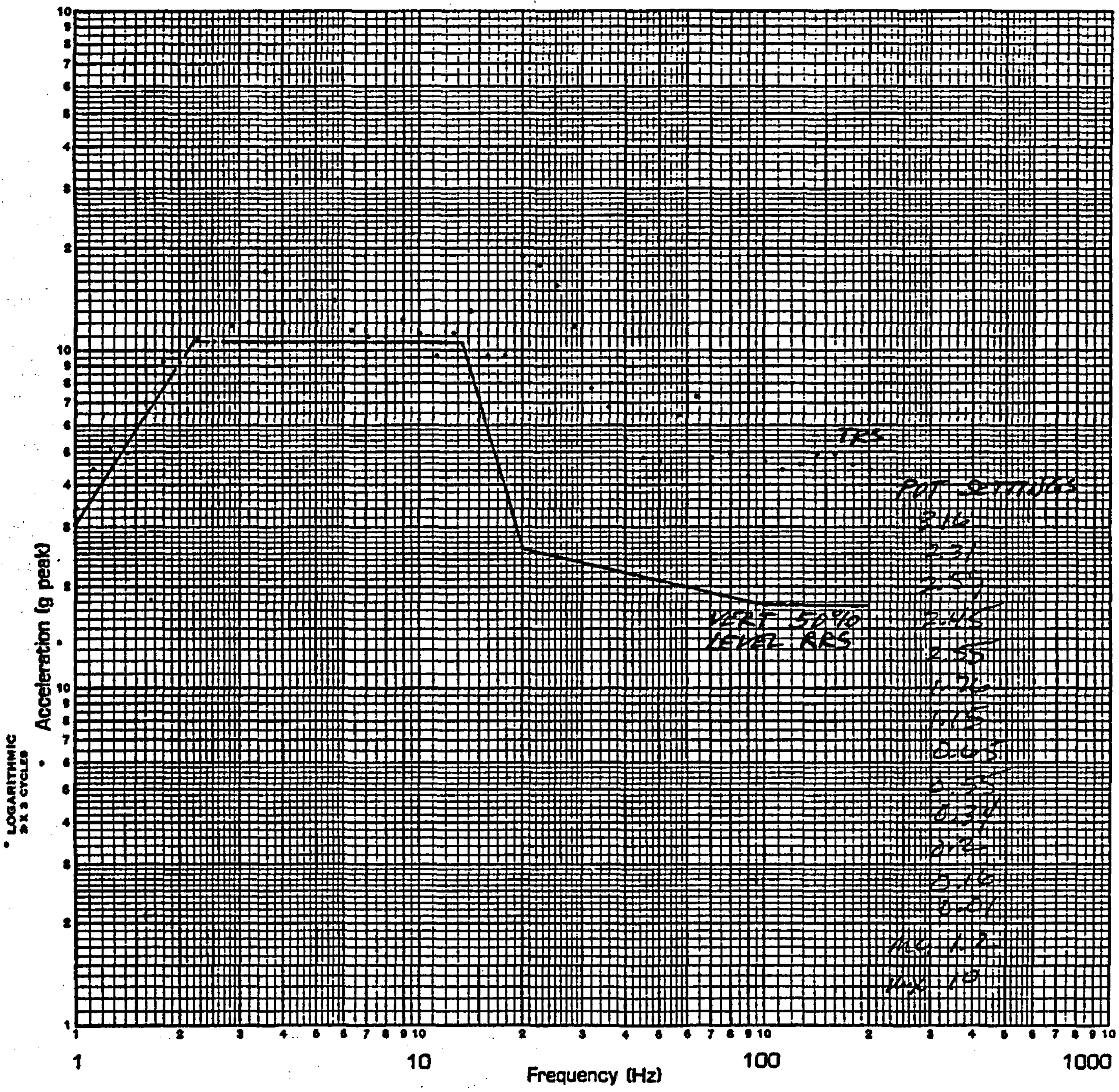
LOCATION NO. SS HCA

TEST RUN NO. BT1 (50% LEVEL)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN —

AXIS TRI

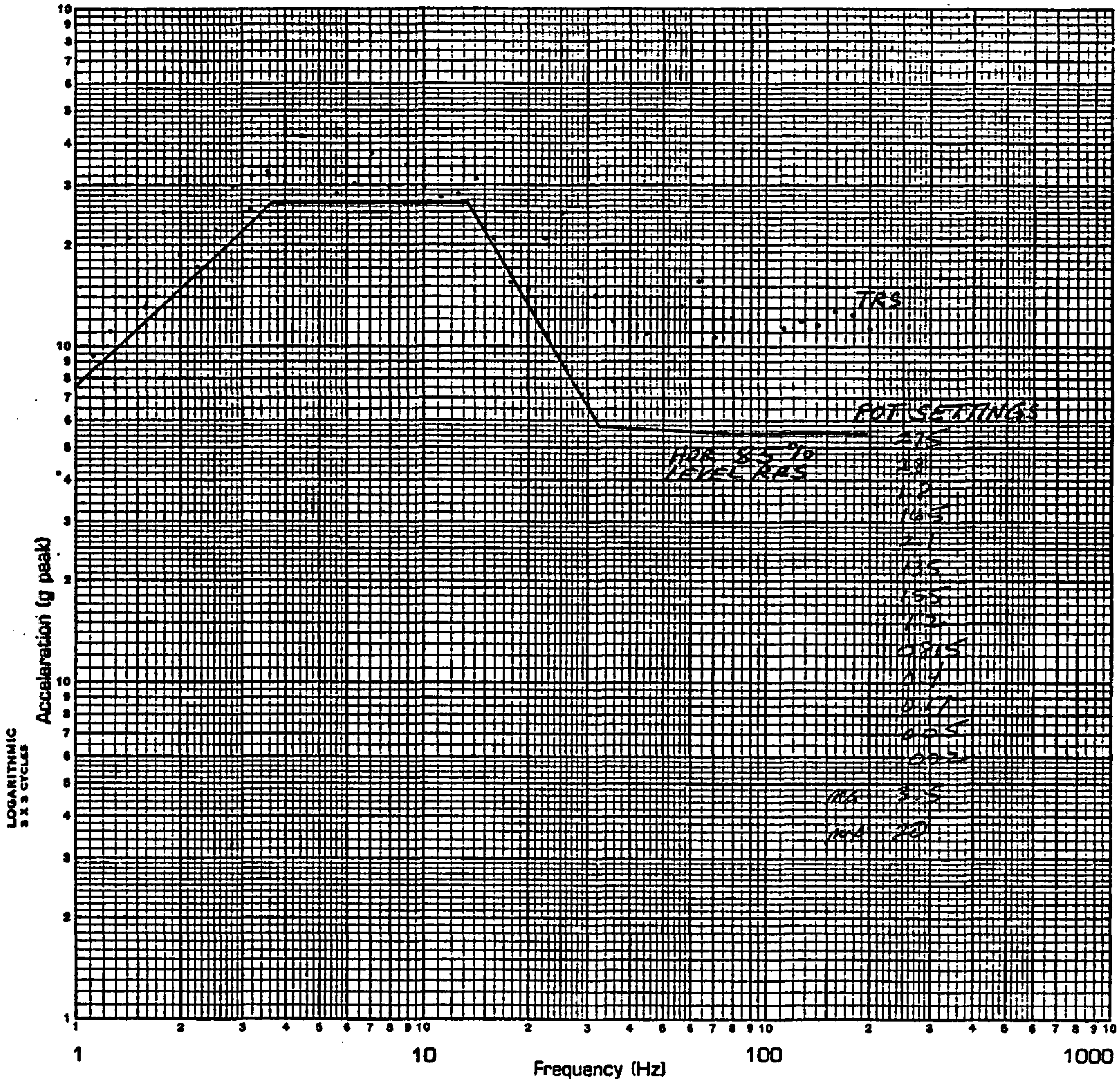
LOCATION NO. VCA

TEST RUN NO. BT 1 (50% LEVEL)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ——

AXIS TRI

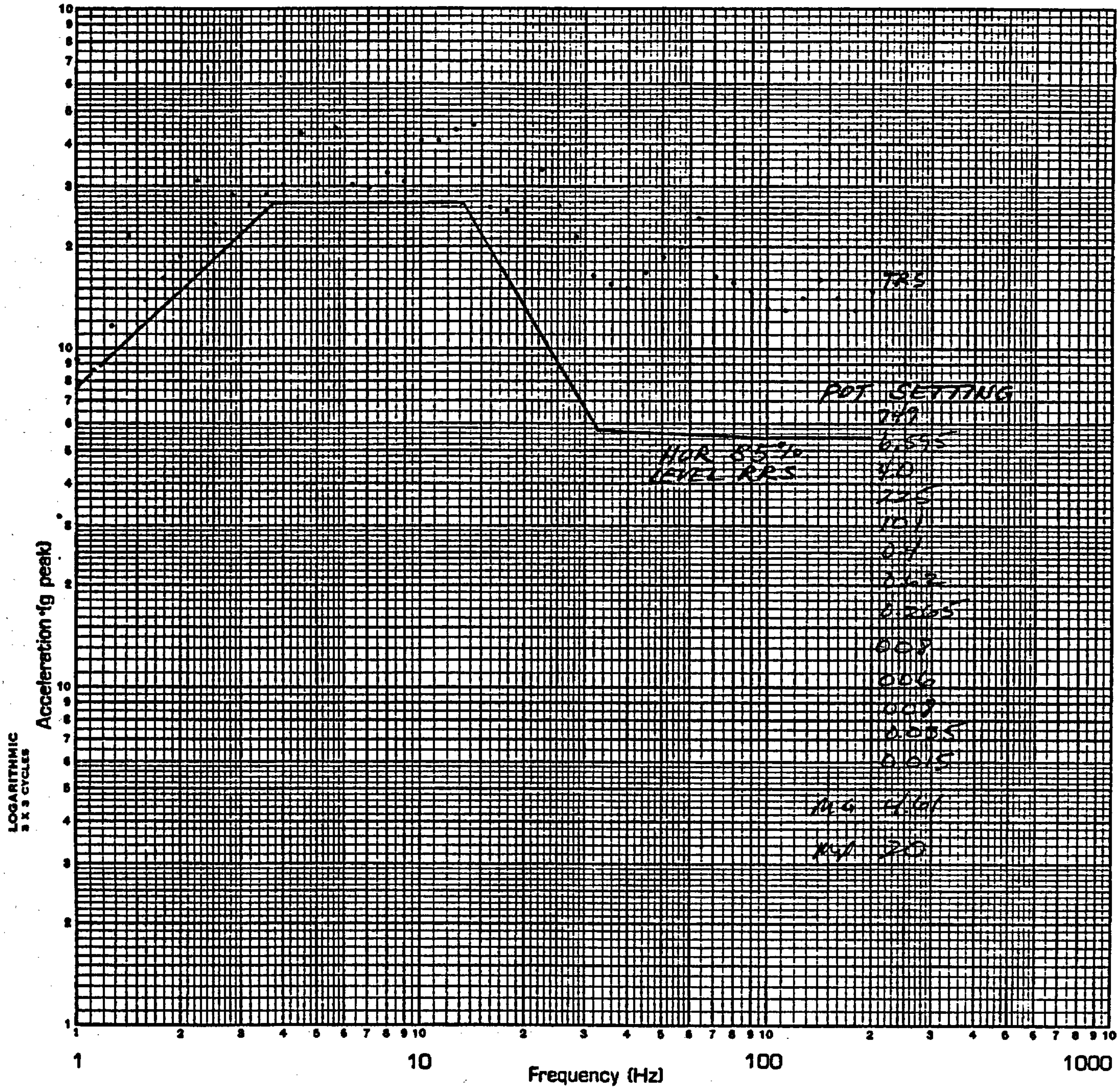
LOCATION NO. FB HCA

TEST RUN NO. BT2 (85% LEVEL)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ———

AXIS TRI

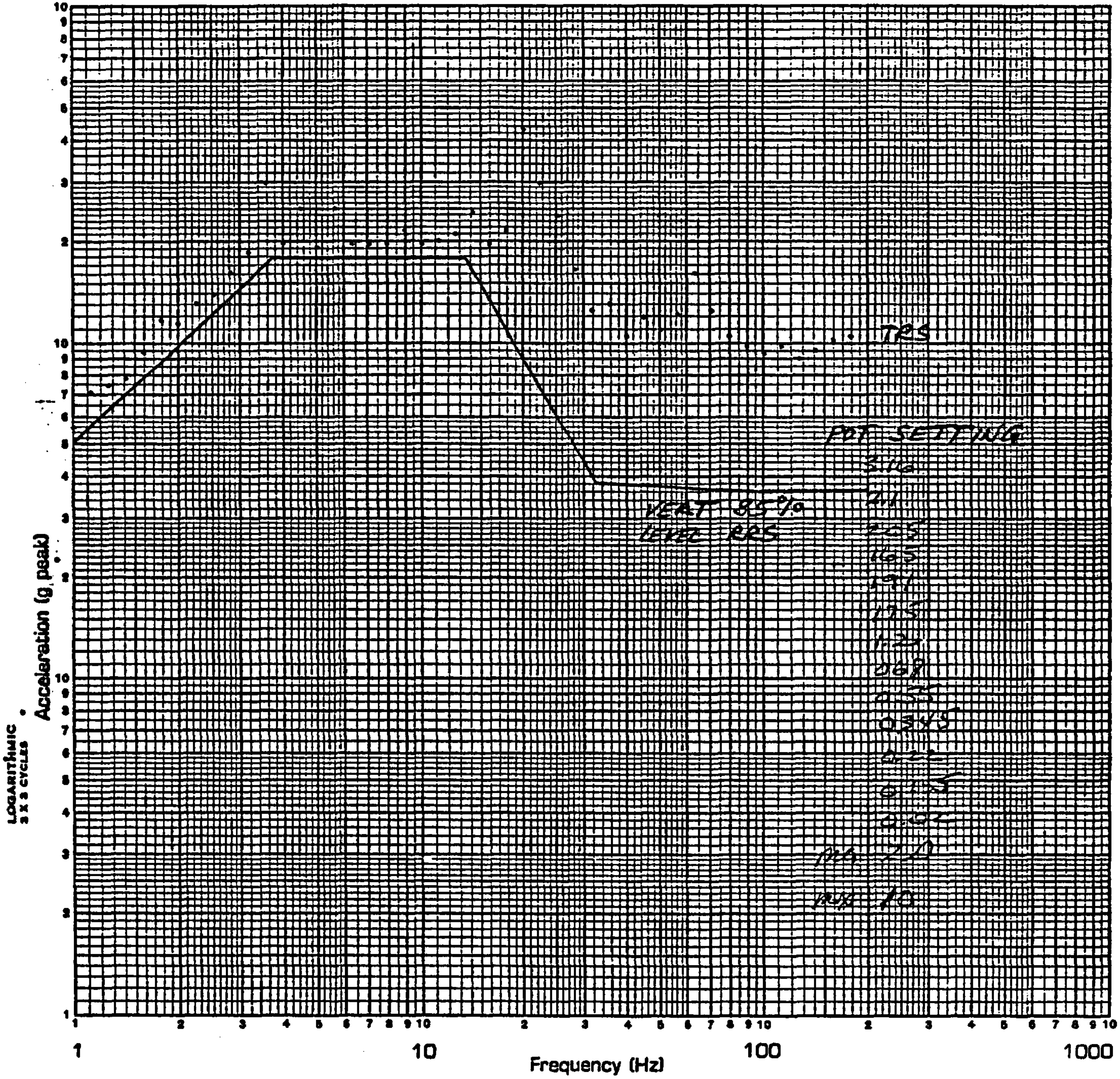
LOCATION NO. SS HCA

TEST RUN NO. BT I (85% LEVEL)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN —

AXIS TRI

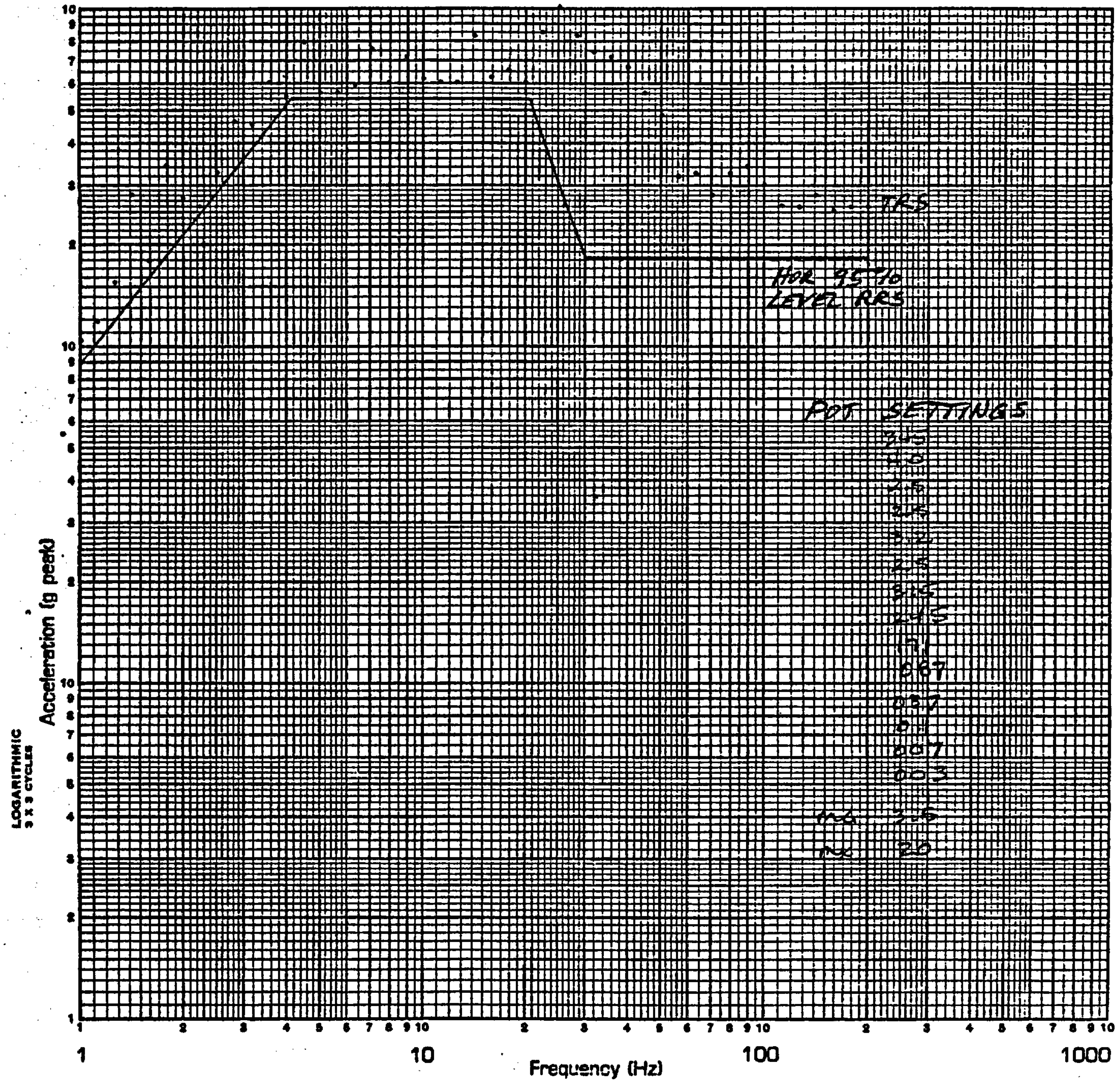
LOCATION NO. VCA

TEST RUN NO. BT-2 (85% LEVEL)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN —

AXIS TRI

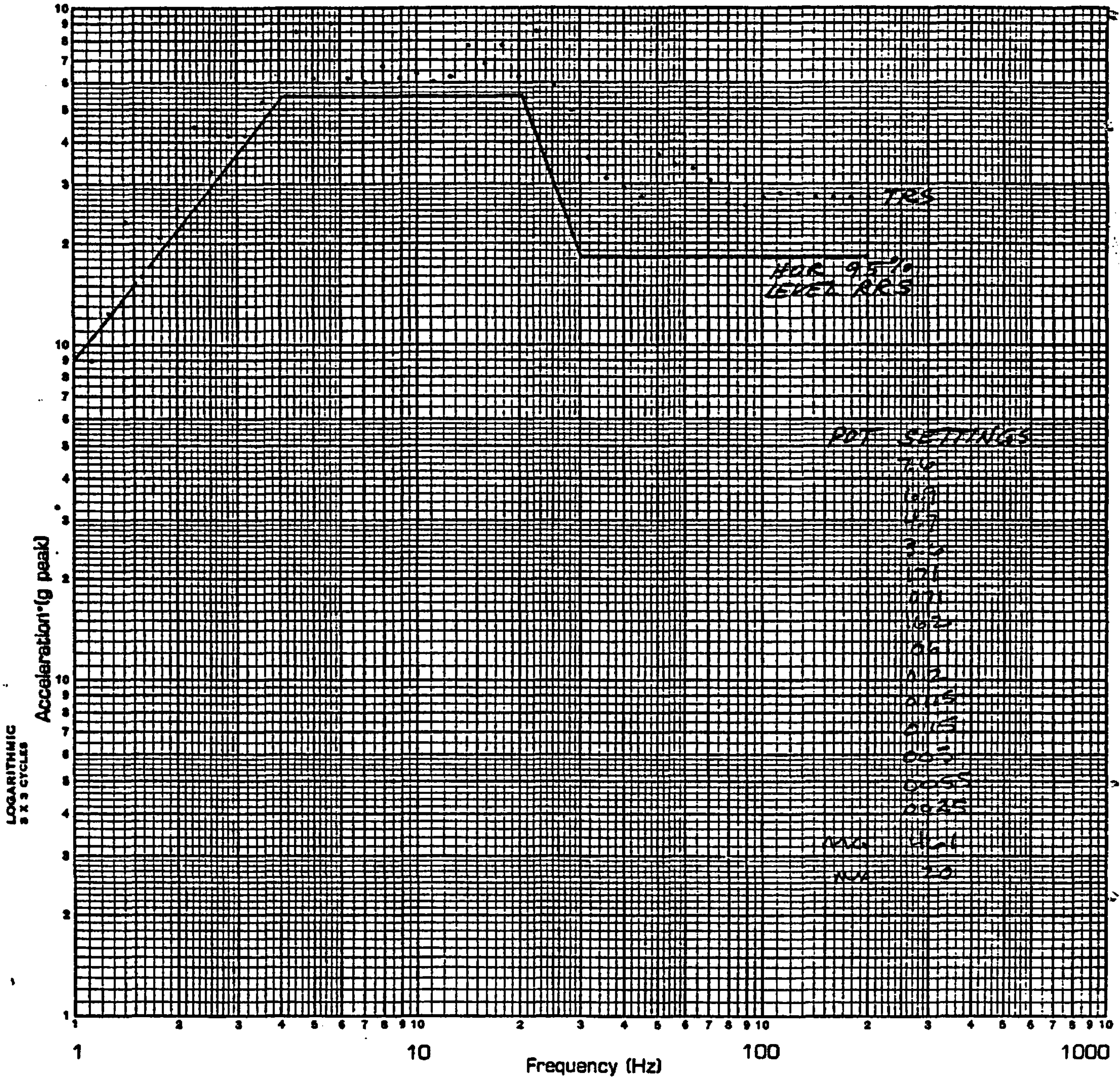
LOCATION NO. FB HCA

TEST RUN NO. BT-3 (95% LEVEL)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN —

AXIS TRI

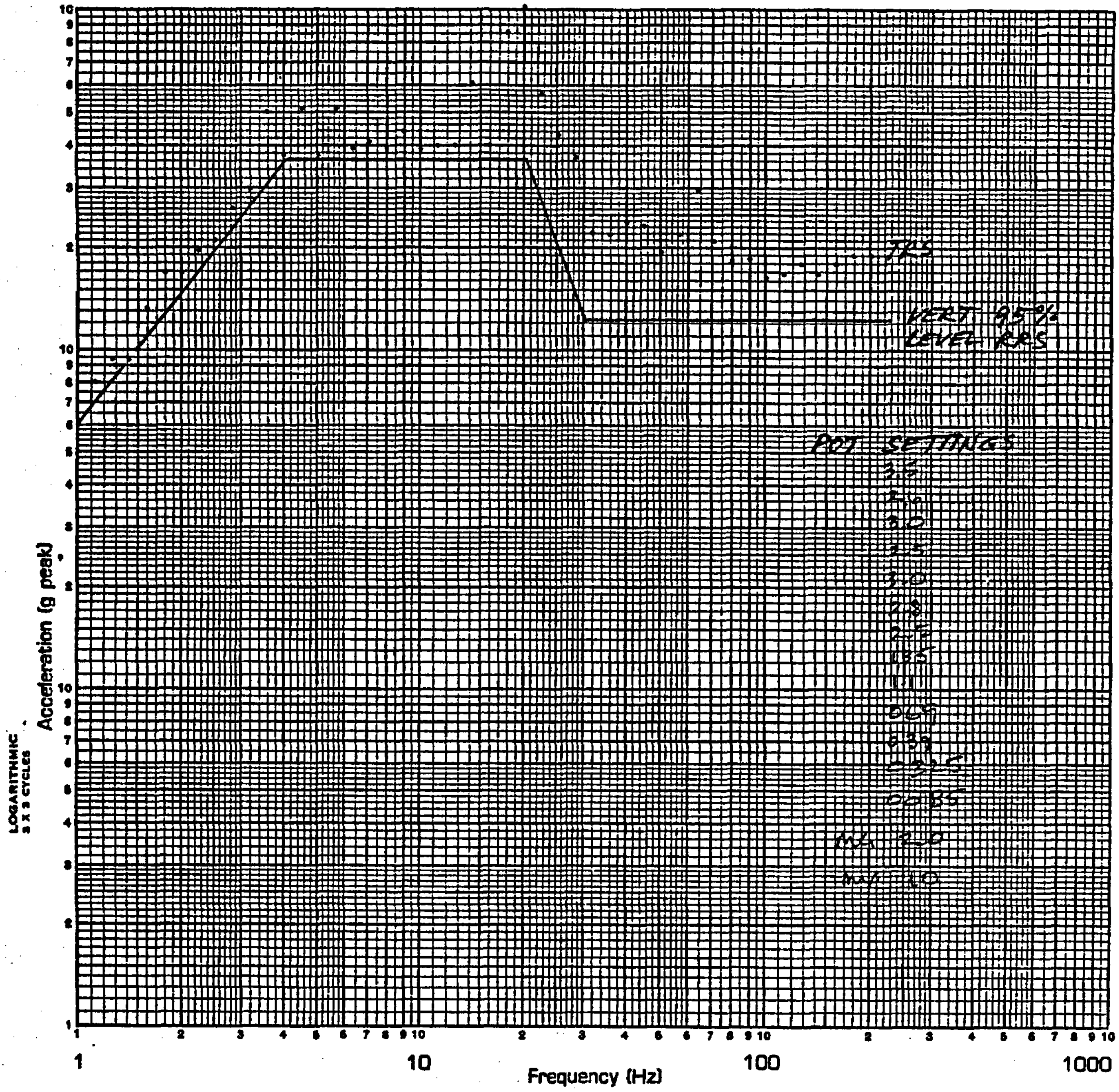
LOCATION NO. SS HCA

TEST RUN NO. BT-3 (95% LEVEL)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%



SPECIMEN ———

LOCATION NO. VCA

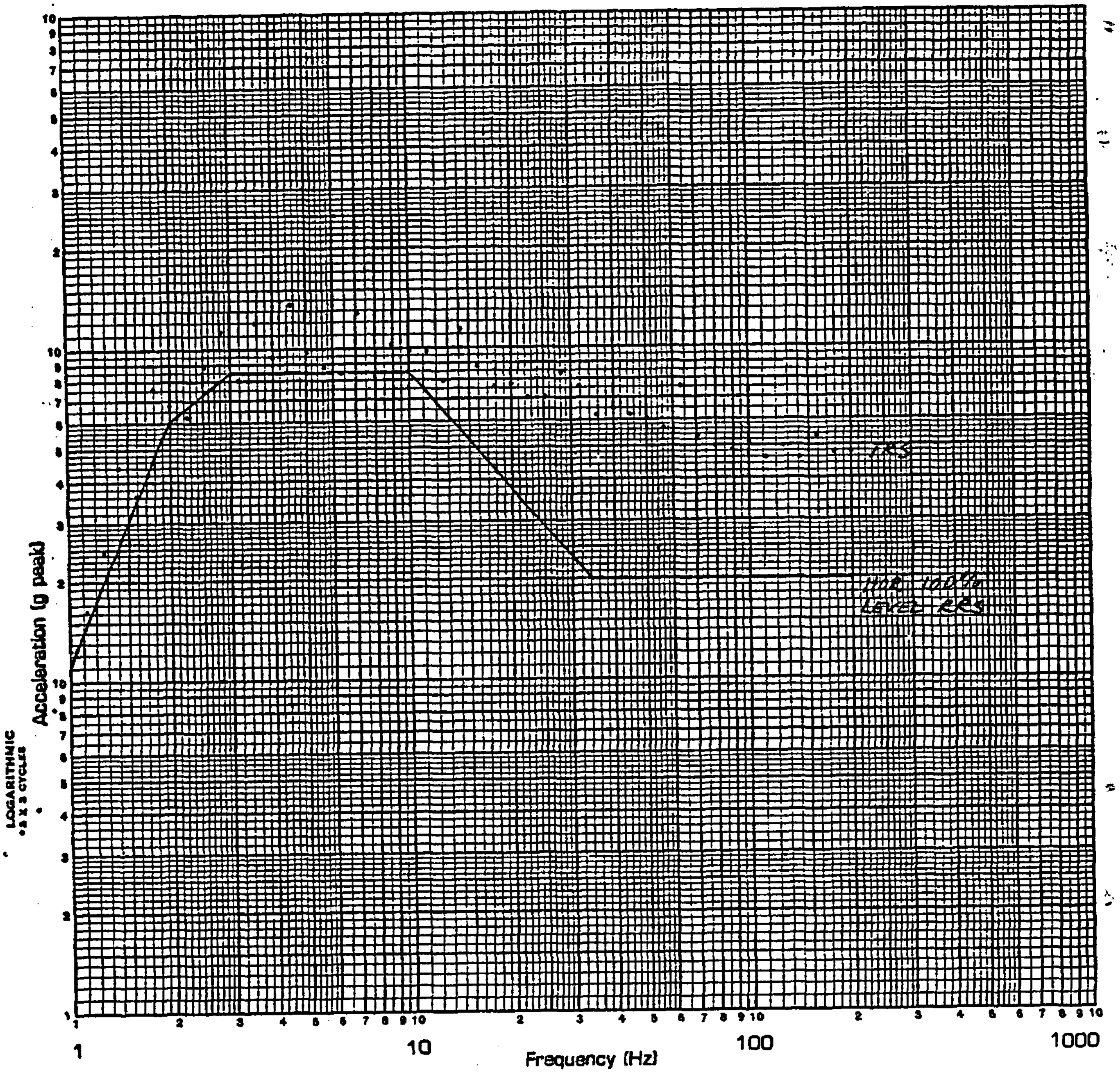
AXIS TRI

TEST RUN NO. BT 3 (95% LEVEL)

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING 2%



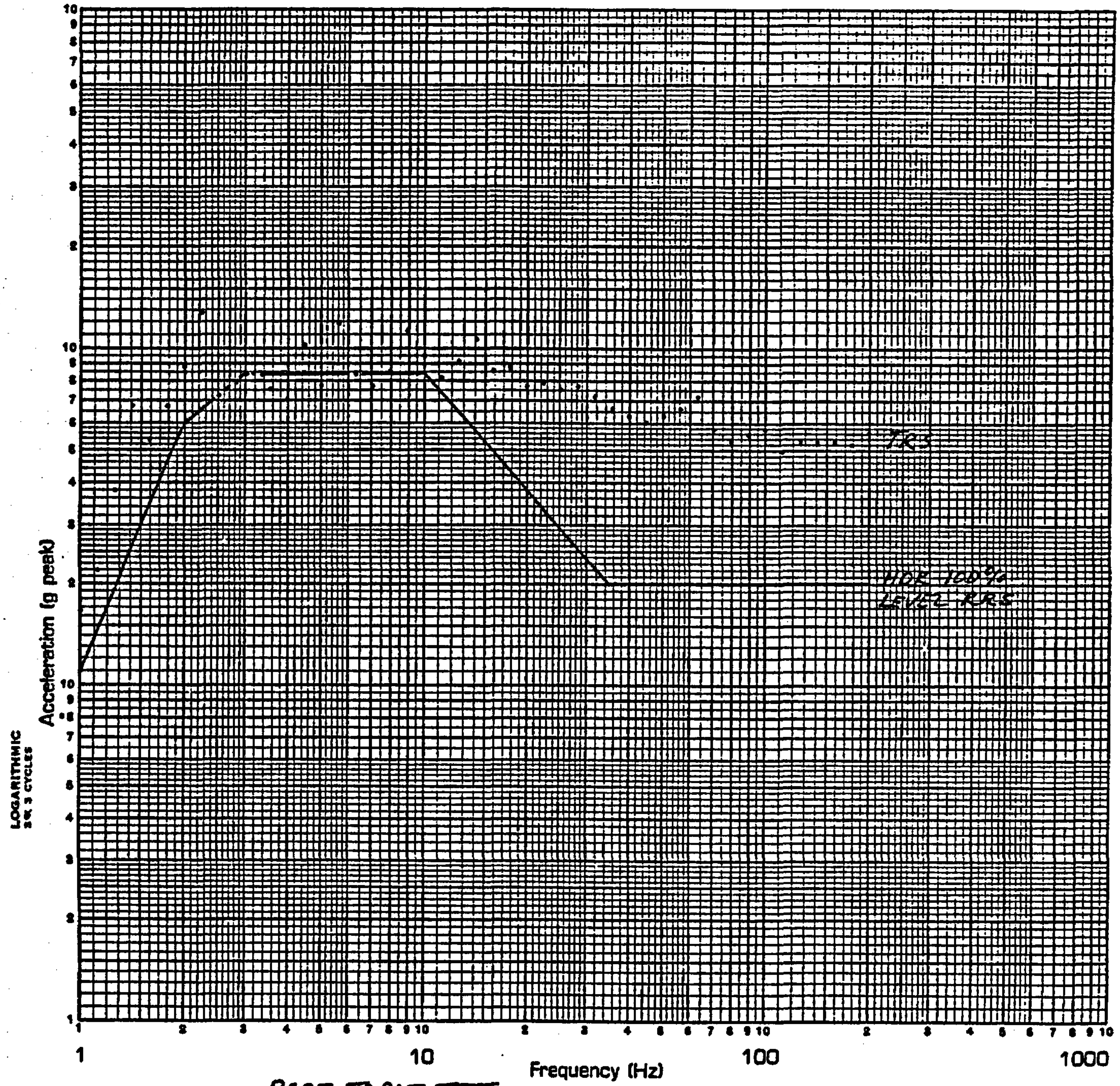
SPECIMEN BARE TABLE TEST BATTERY RACK + DUMMY WEIGHTS LOCATION NO. FB HCA

AXIS TR1 TEST RUN NO. 7

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000☐

DAMPING 2%



BARE TABLE TEST
BATTERY RACK +
SPECIMEN DUMMY WEIGHTS

LOCATION NO. 3S HCA

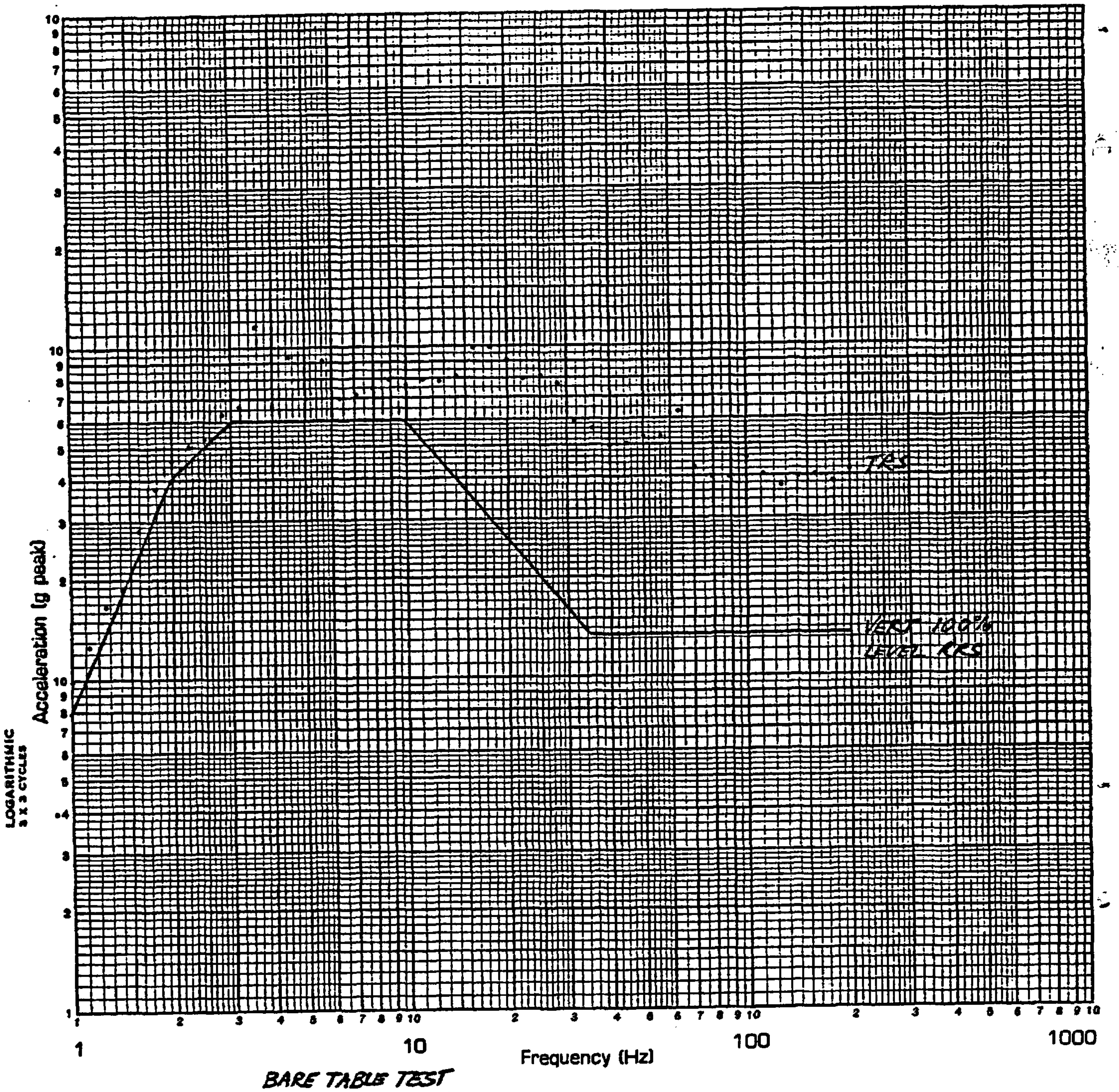
AXIS TR1

TEST RUN NO. 7

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000 ☐

DAMPING 2%



SPECIMEN: BARE TABLE TEST
BATTERY RACK +
DUMMY WEIGHTS

LOCATION NO. VCA

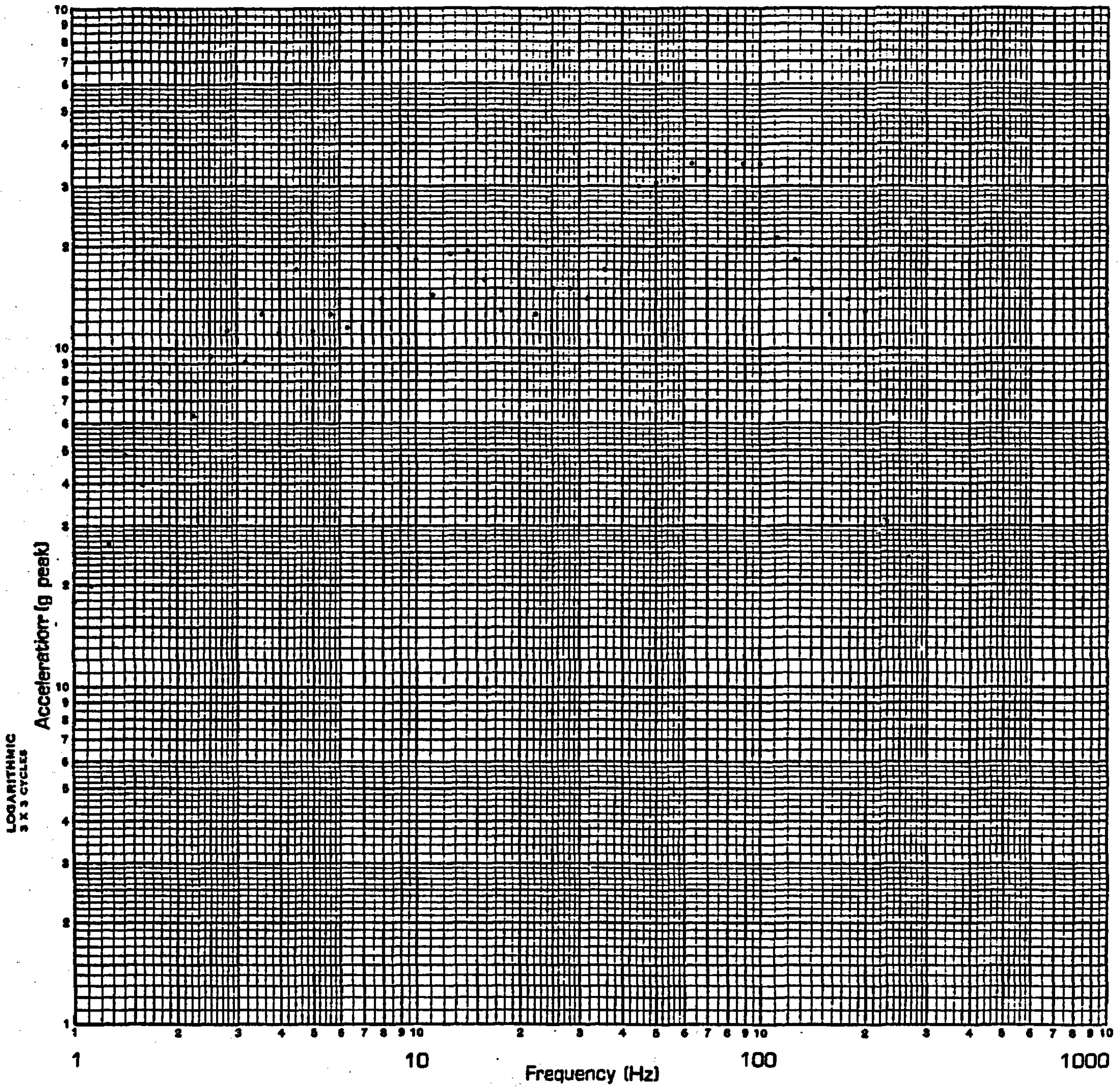
AXIS TR1

TEST RUN NO. 7

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000☐

DAMPING 2%



SPECIMEN RACK

LOCATION NO. 1 FB

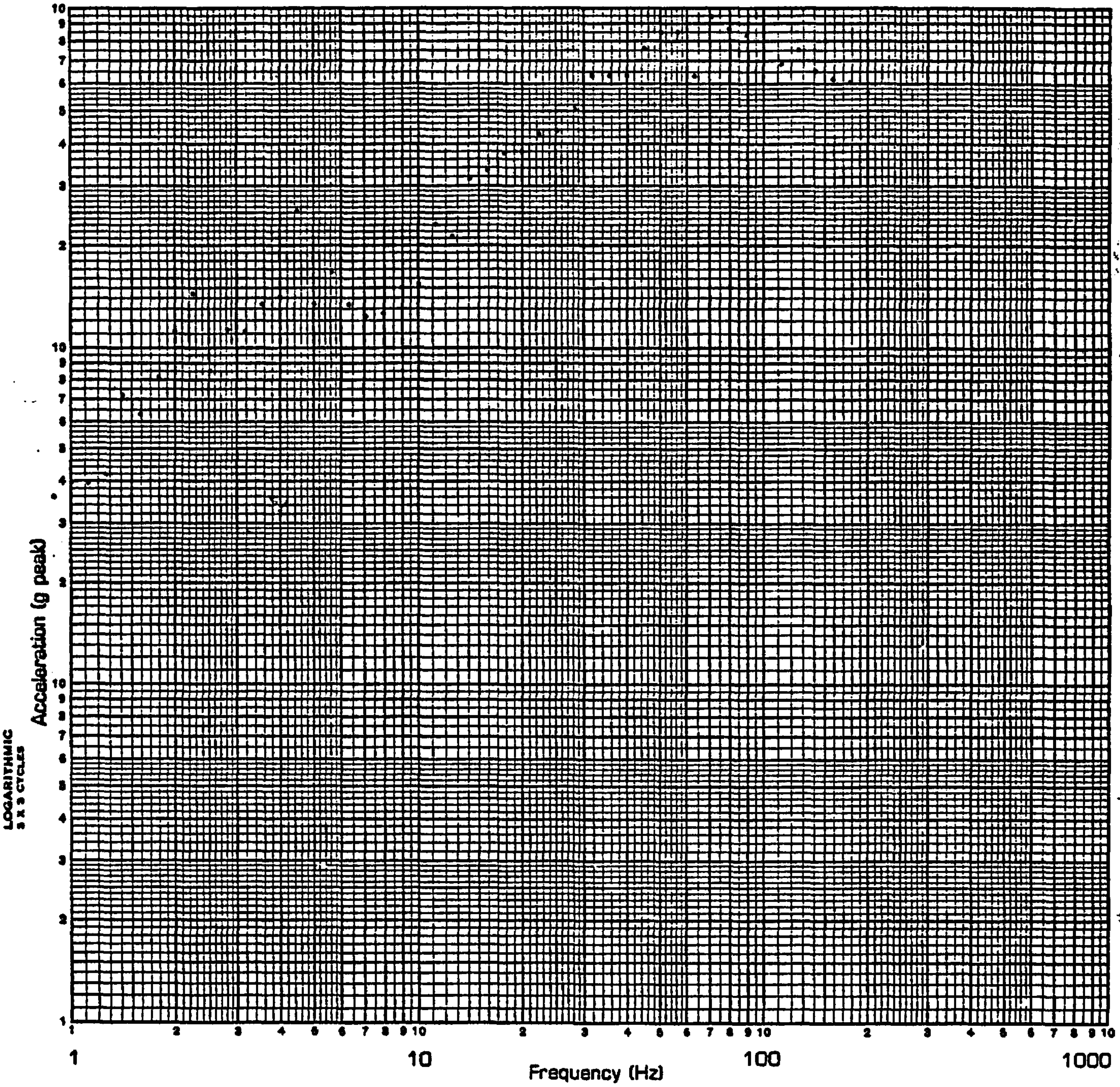
AXIS TR1

TEST RUN NO. 7

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☑ 1000 ☐

DAMPING 2 %



SPECIMEN RACK

AXIS TR1

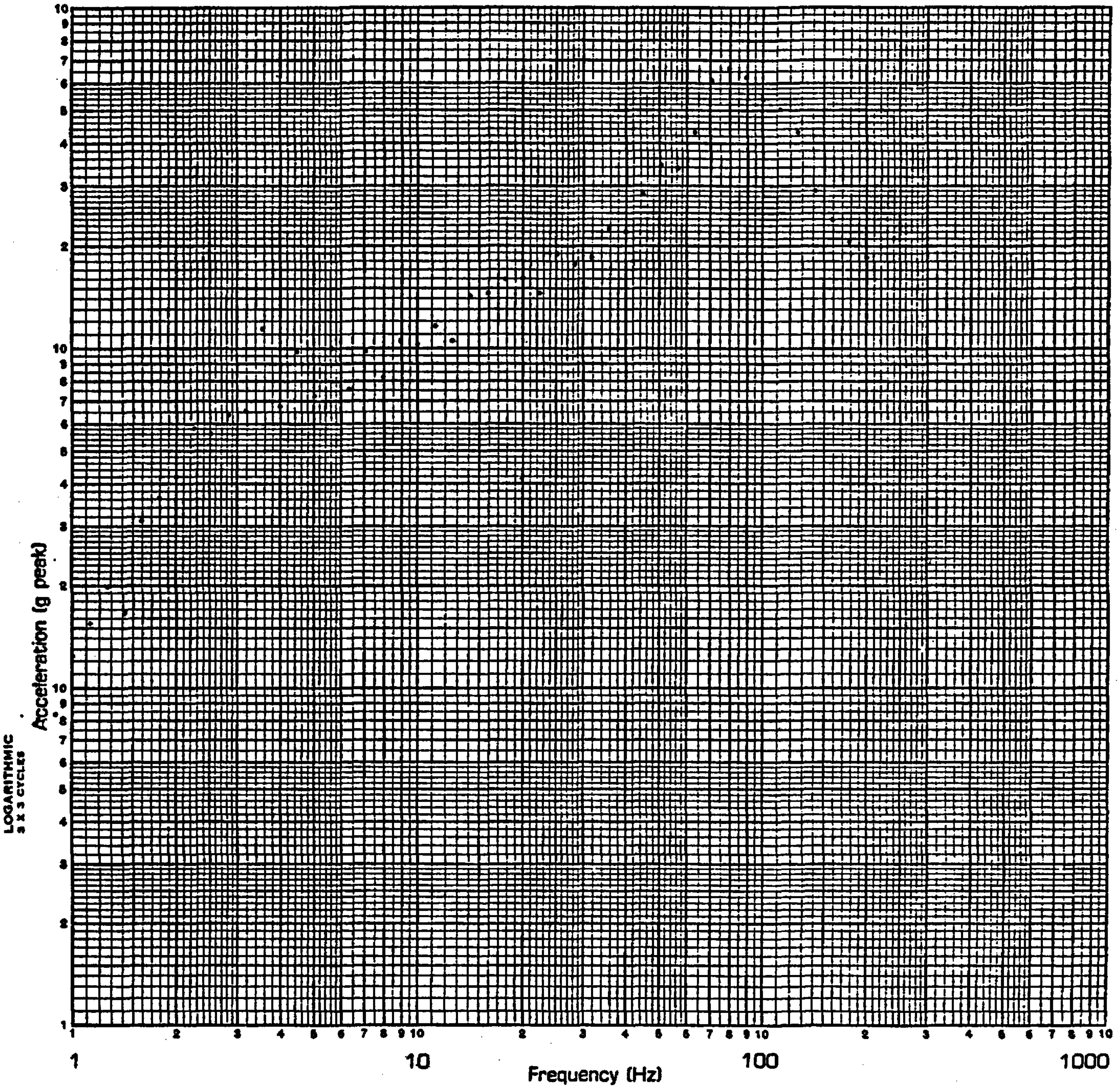
LOCATION NO. 2 SS

TEST RUN NO. 7

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☐ 100 ☒ 1000☐

DAMPING 2 %



SPECIMEN RACK

LOCATION NO. 3 ✓

AXIS TR1

TEST RUN NO. 7

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APPENDIX III

SUMMARY OF OPERABILITY TEST RESULTS

(PROVIDED BY EG&G)

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SEISMIC TESTING OF BATTERIES CONDUCTED AT WYLE LABORATORIES

Seismic testing of naturally aged batteries obtained from ANO-2 was performed at Wyle Laboratories, Huntsville, AL, April 19 through 21, 1989. The following is a summary of the capacity of the batteries measured at the INEL before shipping to Wyle, at Wyle before the seismic tests, and at Wyle after the seismic tests. The performance of the batteries during the seismic tests is also presented. Capacities were determined by discharging the batteries at the 3 hour rate (351 amperes) and measuring the time required for each battery to discharge to 1.75 volts, in accordance with IEEE Std. 450. During the seismic tests the batteries were loaded at 2% of the 3 hour rate (7 amperes) as recommended by IEEE Std. 535. The batteries were divided into three groups of 4 batteries each. Group 1 was tested at the 50% and 100% seismic levels, group 2 was tested at the 85% seismic level and group 3 was tested at the 95% seismic level. Tables 1, 2, & 3 show the electrical capacities of groups 1, 2, & 3, respectively. Figures 1, 2, 3, & 4 show the battery performance during the 50%, 85%, 95%, and 100% seismic levels, respectively.

Table 1 Electrical capacity of the group 1 batteries
(Capacity is percent of rated)

Battery Number	Preseismic at INEL	Preseismic at Wyle	After 50% Seismic Level	After 100% Seismic Level
18	92	93	95	95
24	94	97	94	98
26	97	94	96	99
46	96	98	98	100
Ave	95	96	96	98

Table 2 Electrical capacity of the group 2 batteries
(Capacity is percent of rated)

Battery Number	Preseismic at INEL	Preseismic at Wyle	After 85% Seismic Level
17	97	96	100
25	94	96	93
45	98	99	97
48	92	94	97
Ave	95	96	97

Table 3 Electrical capacity of the group 3 batteries
(Capacity is percent of rated)

Battery Number	Preseismic at INEL	Preseismic at Wyle	After 95% Seismic Level
23	94	96	93
29	93	99	93
30	94	96	96
47	98	98	96
Ave	95	97	95

Figure 1 Battery performance during the 50% seismic level with a 7 ampere discharge

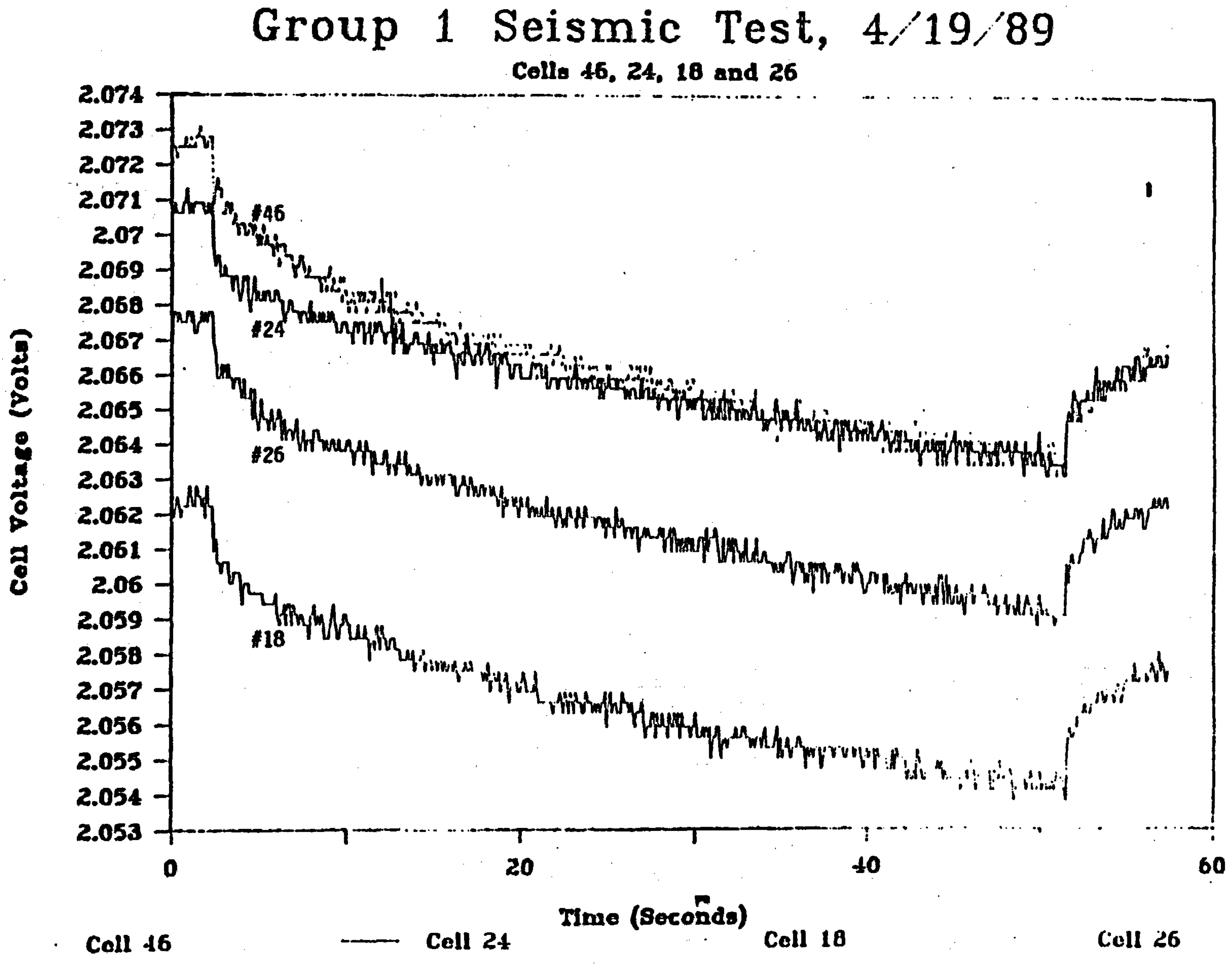


Figure 2 Battery performance during the 85% seismic level with a 7 ampere discharge

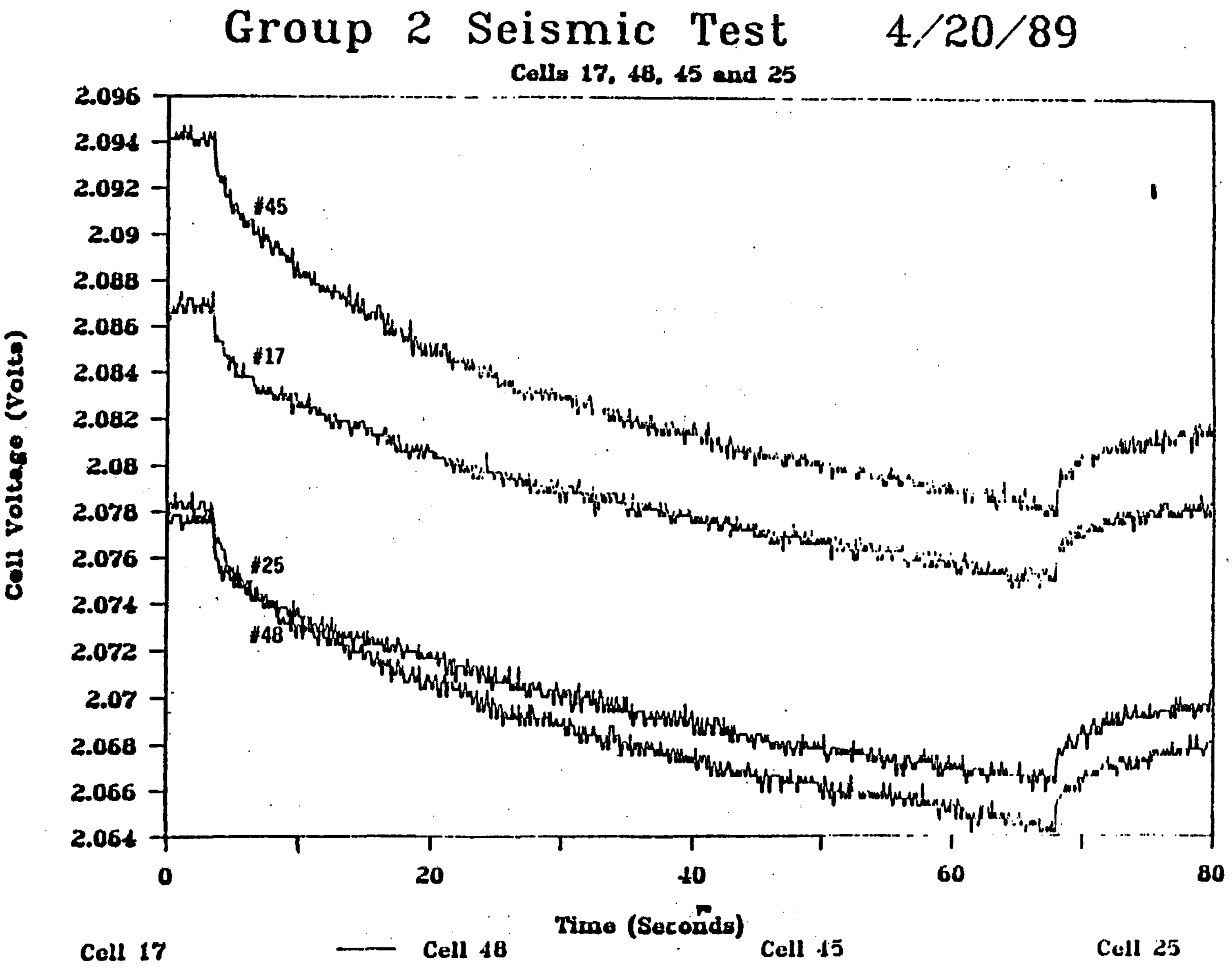


Figure 3 Battery performance during the 95% seismic level with a 7 ampere discharge

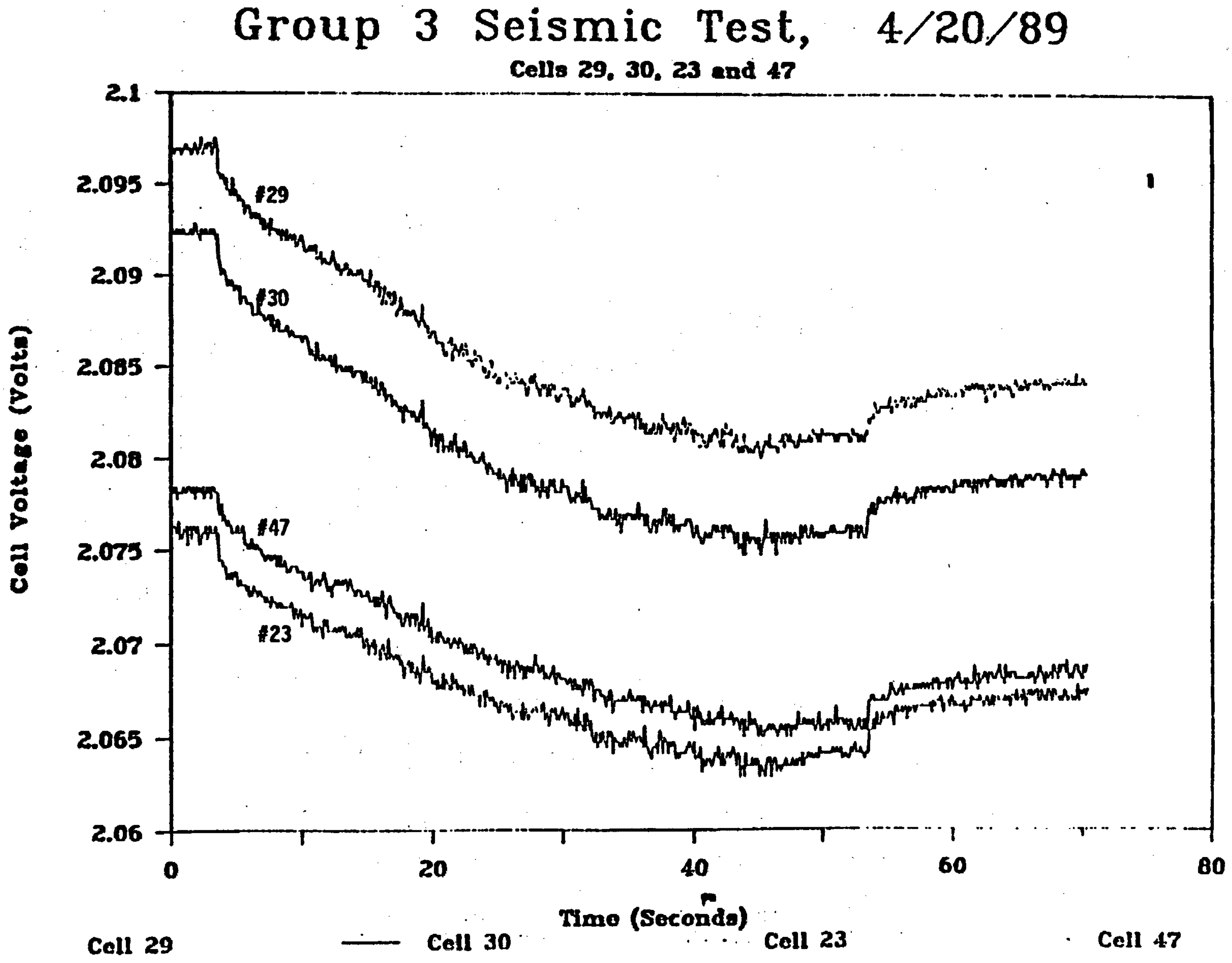
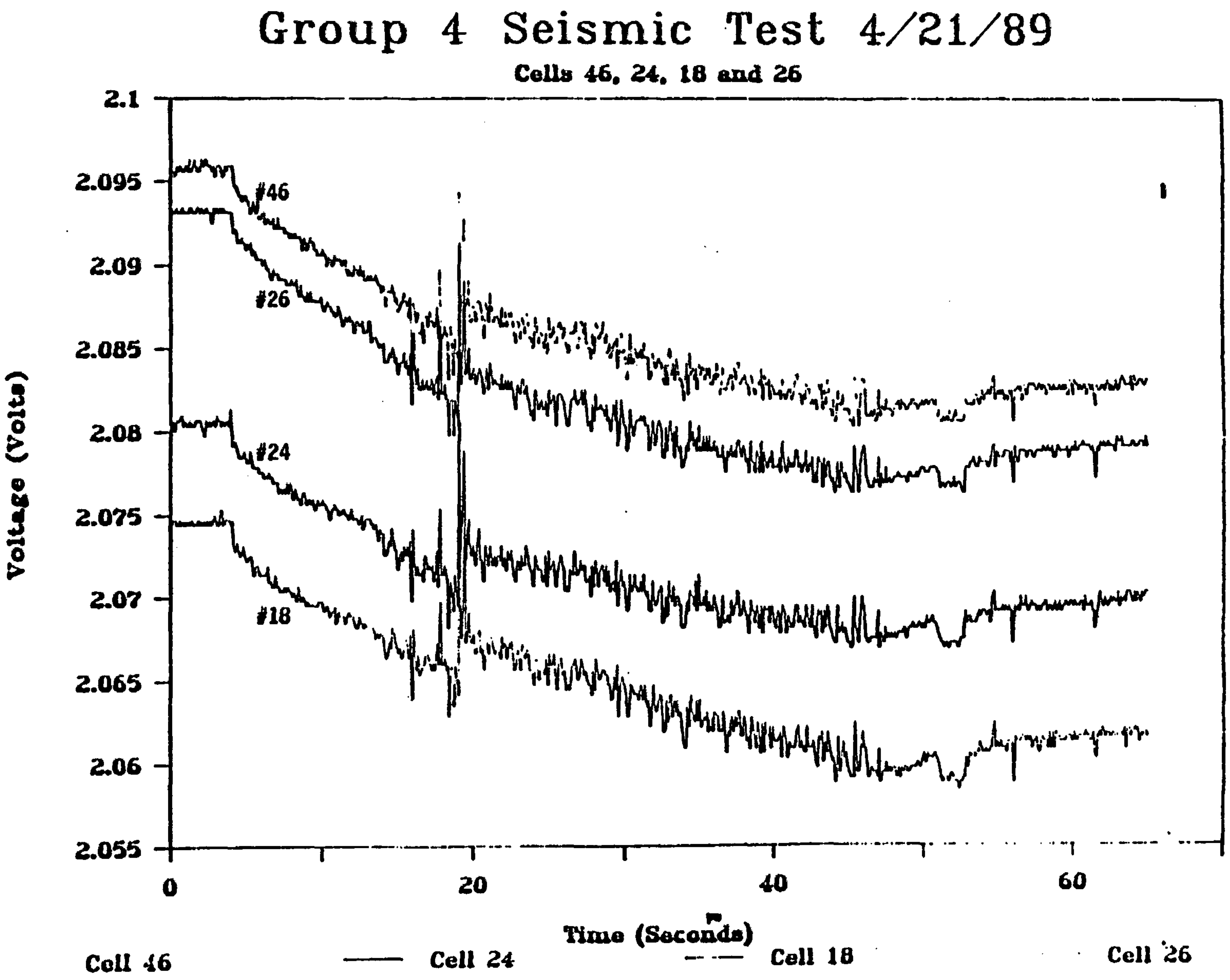


Figure 4 Battery performance during the 100% seismic level with a 7 ampere discharge



APPENDIX IV

INSTRUMENTATION LOG SHEETS, INSTRUMENTATION EQUIPMENT SHEETS, AND INSTRUMENTATION DATA SHEETS

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W 322

WYLE LABORATORIES
INSTRUMENTATION LOG SHEET

JOB NO. 40525

LOG PAGE NO. 1 OF 2

CUSTOMER EG & G

TEST ENGINEER H. MELINZ

DATE	TIME	REMARKS (Include Run Number, Part Changes, Shift Changes and all other pertinent data)
19APR89		SET UP TO RECORD 3 CONTROL & 6 RESPONSE ACCELS ON TAPE
		GROUP #1 SPECIMEN MOUNTED PER INSTRUCTIONS
	1326	RUN #1 SINE SWEEP 1-35Hz 0.2G 1OCT/MIN F-B
		START 0050 STOP 0170
	1333	RUN # 2 SINE SWEEP 1-35Hz 0.2G 1OCT/MIN S-S
		START 0170 STOP 0295
	1339	RUN # 3 SINE SWEEP 1-35Hz 0.2G 1 OCT/MIN V
		START 0295 STOP 0422
	1348	RUN #4 RMF 50% TR1
		START 0422 STOP 0452
		SET UP FOR GROUP #2

W 322

WYLE LABORATORIES
INSTRUMENTATION LOG SHEET

JOB NO. 40525

LOG PAGE NO. 2 OF 2

CUSTOMER E.G.&G.

TEST ENGINEER H. MELINZ

DATE	TIME	REMARKS (Include Run Number, Part Changes, Shift Changes and all other pertinent data)	
20 APR 89	0830	RUN#5 RMF 85%	TR1
		START 0502 STOP 0535	
		SET UP FOR GROUP #3	
	1039	RUN#6 RMF 90-95%	TR1
		START 0535 STOP 0566	
		SET UP FOR SERIES#4 "BARE TABLE" (NO BATTERIES)	
	1356	RUN#7 RMF	TR1
		START 0566 STOP 0595	
		SET UP GROUP#1 SERIES 4	
21APR89	0810	RUN#8 RMF 100%	TR1
		START 0595 STOP 0625	

INSTRUMENTATION EQUIPMENT SHEET

PAGE 1 OF 1

DATE: 04/19/89
TECHNICIAN: C. FROST
JOB NUMBER: 40525-00
CUSTOMER: E. G. & G.
TEST AREA: D MACHINE
TYPE TEST: SEISMIC

NO.	INSTRUMENT	MANUFACTURER	MODEL#	SERIAL #	WYLE #	RANGE 1	ACCURACY 1	CALDATE	CALDUE
1	ANALYZER	SPECTRAL DYN	13231	45	096765	.1HZ TO 10KHZ	.5DB	02/14/89	08/11/89
2	XIENT MEMORY	SPECTRAL DYN	13192	43	096766	.1HZ TO 10KHZ	.5DB	02/14/89	08/11/89
3	X-Y DISPLAY	SPECTRAL DYN	311	435	096767	12INCH SCREEN	1%LIN	02/14/89	08/11/89
4	X-Y RECORDER	H/P	7045B	2164	102373	.5-10V/IN	.2%FS	02/13/89	05/12/89
5	DUAL HI/LO FIL.	WAVETEK	852	1290722	100710	100KHZ	.5DB	02/14/89	08/11/89
6	SYNTHESIZER	WRAD	197S	19717	095477	.5HZ TO 100HZ	4%	02/20/89	08/18/89
7	SYNTHESIZER	WRAD	197S	197-15	095363	.5HZ TO 100HZ	4%	02/13/89	08/11/89
8	SYNTHESIZER	WRAD	197S	N/A	100187	.5HZ TO 100HZ	4%	02/18/89	08/17/89
9	RECORD TAPE	TEAC	R-71	160555	102052	DC-50KC	1%	12/05/88	06/02/89
10	RECORD TAPE	TEAC	XR-5000	32073	R32073	DC-20 KHZ	2% DIST	02/23/89	08/22/89
11	OSCILLOSCOPE	H/P	1715A	245	092337	DC TO 200 MHZ	2%	03/10/89	09/06/89
12	X-Y PLOTTER	H/P	7044A	893	095377	0-5V/IN	.2%	03/23/89	06/21/89
13	FILTER TRACK	SPECTRAL DYN	SD-131	431	092683	2KHZ-10KHZ	.5 Db	03/02/89	08/29/89
14	FILTER TRACK	SPECTRAL DYN	SD-131	427	092684	2HZ-10KHZ	.5DB	03/02/89	08/29/89
15	AMPL CHARGE	ENDEVCO	2721	BE30	092378	GAIN	1.5%	02/08/89	08/07/89
16	AMPL CHARGE	ENDEVCO	2721	BE31	092379	GAIN	1.5%	02/08/89	08/07/89
17	AMPL CHARGE	ENDEVCO	2721	BE41	092389	GAIN	1.5%	02/08/89	08/07/89
18	AMPL CHARGE	ENDEVCO	2721	BE40	092388	GAIN	1.5%	02/08/89	08/07/89
19	AMPL CHARGE	ENDEVCO	2721	BE37	092385	GAIN	1.5%	02/08/89	08/07/89
20	AMPL CHARGE	ENDEVCO	2721	BD99	092384	GAIN	1.5%	02/08/89	08/07/89
21	AMPL CHARGE	ENDEVCO	2721	BE35	092383	GAIN	1.5%	02/08/89	08/07/89
22	AMPL CHARGE	ENDEVCO	2721	BE34	092382	GAIN	1.5%	02/08/89	08/07/89
23	AMPL CHARGE	ENDEVCO	2721	BE32	092380	GAIN	1.5%	02/08/89	08/07/89
24	CHARGE PWR	ENDEVCO	4221A	AB35	092901	15VDC	5%	02/08/89	08/07/89
25	ACCEL	BRUEL & KJAER	4366	1104892	101783	2KGSV/5KGSK	5%	02/08/89	05/09/89
26	ACCEL	BRUEL & KJAER	4366	1104943	101810	2KGSV/5KGSK	5%	02/08/89	05/09/89
27	ACCEL	BRUEL & KJAER	4366	1104821	108058	2KGSV/5KGSK	5%	02/04/89	05/05/89
28	ACCEL	BRUEL & KJAER	4366	1104827	101802	2KGSV/5KGSK	5%	02/08/89	05/09/89
29	ACCEL	BRUEL & KJAER	4366	1104920	101760	2KGSV/5KGSK	5%	02/03/89	05/04/89
30	ACCEL	BRUEL & KJAER	4366	1104944	101809	2KGSV/5KGSK	5%	02/08/89	05/09/89
31	ACCEL	ENDEVCO	7704-100	BJ75	100852	1KGSV/10KGSK	5%	02/08/89	05/09/89
32	ACCEL	ENDEVCO	7704-100	BJ30	100845	1KGSV/10KGSK	5%	02/08/89	05/09/89
33	ACCEL	ENDEVCO	7701-100	BN71	100265	1KGSV/10GKSK	5%	03/01/89	05/30/89
34	TORQUE WRENCH	PROTO	6006A	00136	106127	10-80 FT LBS	6%	02/07/89	08/04/89

This is to certify that the above instruments were calibrated using state-of-the-art techniques with standards whose calibration is traceable to the National Institute of Standards and Technology.

INSTRUMENTATION D E Perry 4/19/89

CHECKED & RECEIVED BY 4-19-89

Q.A. Kevin M Turner 4-19-89

5 Wyle A

INSTRUMENTATION EQUIPMENT SHEET

PAGE 1 OF 1

DATE: 04/19/89
TECHNICIAN: D. VIRGIN
JOB NUMBER: 40525-00
CUSTOMER: E. G. & G.
TEST AREA: D MACHINE
TYPE TEST: SEISMIC

NO.	INSTRUMENT	MANUFACTURER	MODEL#	SERIAL #	WYLE #	RANGE 1	ACCURACY 1	CALDATE	CALDUE
1	TORQUE WRENCH	KD TOOLS	2950	4-84	102647	30-250 IN LB	5%	11/08/88	05/05/89

This is to certify that the above instruments were calibrated using state-of-the-art techniques with standards whose calibration is traceable to the National Institute of Standards and Technology.

INSTRUMENTATION CR Frost 4/19/89

CHECKED & RECEIVED BY 4-19-89

Q.A. 4-19-89 S Wyle A

INSTRUMENTATION EQUIPMENT SHEET

PAGE 1 OF 1

DATE: 04/20/89
TECHNICIAN: D. VIRGIN

JOB NUMBER: 40525-00
CUSTOMER: E. G. & G.

TEST AREA: D MACHINE
TYPE TEST: SEISMIC

NO.	INSTRUMENT	MANUFACTURER	MODEL#	SERIAL #	WYLE #	RANGE ±	ACCURACY ±	CALDATE	CALDUE
1	DATA RECORDER	TEAC	IR-510WB	184030	102524	DC-50KHZ	+.5/-1DB	03/20/89	09/15/89
2	DIG MTR	FLUKE	8060A	4470424	106880	20V DC	.05%	04/11/89	04/11/90

This is to certify that the above instruments were calibrated using state-of-the-art techniques with standards whose calibration is traceable to the National Institute of Standards and Technology.

INSTRUMENTATION C R Scott 4/20/89

CHECKED & RECEIVED BY 4-20-89

Q.A. 4-20-89

5 Wyle A

WYLE LABORATORIES

INSTRUMENTATION DATA SHEET

Recorder No. TEAC XR-5000 Date 19 APR. '89 Axis TL Setup E G & G J/N 40525

Accel. S/N	Amp. Ch.	Galvo Tape	Insert g Pk	Volt g Rms	Location	Comp. Ch.	Run # 1FB 2SS 3V Sweeps mv/g	g/in.	Run #4 RMF mv/g	g/in.	Remarks Group # 1
1104892	1	1	52.5		1 F-B		300		300		on rack
1104943	2	2	51.6		2 S-S						
1104821	3	3	50.2		3 V						
1104827	4	4	51.4		4 F-B						on cell
1104920	5	5	51.5		5 S-S						
1104944	6	6	51.0		6 V		300		300		
BJ75	7	7	117.0	ew	F-B HCA		1000		1000		
BJ30	8	8	117.0	ns	S-S HCA		1000		1000		
BM71	9	9	116.0		VCA		1000		1000		
		10			Cola / Trigger		*******	*******	*******	*******	

WH 1026A

WYLE LABORATORIES

INSTRUMENTATION DATA SHEET

Recorder No. TEAC XR-5000 Date 20 APR. '89 Axis TR1 Setup E G & G J/N 40525

Accel. S/N	Amp. Ch.	Galvo Tape	Insert g Pk	Volt g Rms	Location	Comp. Ch.	Run # 5 mv/g	Run # 5 g/in.	Run # mv/g	Run # g/in.	Remarks Group # 2
1104892	1	1	52.5		1 F-B		300				
1104943	2	2	51.6		2 S-S		a ↓				on rack
1104821	3	3	50.2		3 V						
1104827	4	4	51.4		4 F-B						
1104920	5	5	51.5		5 S-S						on cell
1104944	6	6	51.0		6 V		300				
BJ75	7	7	117.0	ew	F-B HCA		1000				
BJ30	8	8	117.0	ns	S-S HCA		1000				
BM71	9	9	116.0		VCA	–	1000				
		10			Cola / Trigger		*******	********	*******	*******	

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Page No. 131
Test Report No. 40525-1

WYLE LABORATORIES

INSTRUMENTATION DATA SHEET

Recorder No. TEAC XR-5000 Date 20 APR. '89 Axis T21 Setup E G & G J/N 40525

Accel. S/N	Amp. Ch.	Galvo Tape	Insert Volt q Pk	Insert Volt q Rms	Location	Comp. Ch.	Run # 6 mv/g	Run # 6 g/in.	Run # mv/g	Run # g/in.	Remarks
											Group # 3
1104892	1	1	52.5		1 F-B		100				on rack
1104943	2	2	51.6		2 S-S		100				
1104821	3	3	50.2		3 V		300				
1104827	4	4	51.4		4 F-B		100				on cell
1104920	5	5	51.5		5 S-S		100				
1104944	6	6	51.0		6 V		300				
BJ75	7	7	117.0	ew	F-B HCA		300				
BJ30	8	8	117.0	ns	S-S HCA		300				
BM71	9	9	116.0		VCA		300				
		10			Cola / Trigger		**********	**********	**********	**********	

INSTRUMENTATION DATA SHEET

Recorder No. TEAC XR-5000 Date 20 APR. '89 Axis TR1 Setup E G & G J/N 40525

Accel. S/N	Amp. Ch.	Galvo Tape	Insert q Pk	Volt q Rms	Location	Comp. Ch.	Run #7 mv/g	Run #7 g/in.	Run # mv/g	Run # g/in.	Remarks Group #4
1104892	1	1	52.5		1 F-B		30				on rack
1104943	2	2	51.6		2 S-S		30				
1104821	3	3	50.2		3 V		30				
1104827	4	4	51.4		4 F-B		/				on cell
1104920	5	5	51.5		5 S-S		/				
1104944	6	6	51.0		6 V		/				
BJ75	7	7	117.0	ew	F-B HCA		100				
BJ30	8	8	117.0	ns	S-S HCA		100				
BM71	9	9	116.0		VCA		100				
		10			Cola / Trigger		*****	*****	*****	*****	

WH 1026A

WYLE LABORATORIES

INSTRUMENTATION DATA SHEET

Recorder No. TEAC XR-5000 Date 21 APR. '89 Axis TR1 Setup E G & G J/N 40525

Accel. S/N	Amp. Ch.	Galvo Tape	Insert q Pk	Volt q Rms	Location	Comp. Ch.	Run # 8 mv/g	Run # 8 g/in.	Run # mv/g	Run # g/in.	Remarks SERIES 4 Group # 1
1104892	1	1	52.5		1 F-B		30				on rack
1104943	2	2	51.6		2 S-S						
1104821	3	3	50.2		3 V						
1104827	4	4	51.4		4 F-B						on cell
1104920	5	5	51.5		5 S-S						
1104944	6	6	51.0		6 V		30				
BJ75	7	7	117.0	ew	F-B HCA		100				
BJ30	8	8	117.0	ns	S-S HCA		100				
BM71	9	9	116.0		VCA		100				
		10			Cola / Trigger		**********	**********	**********	**********	

WH 1026A

APPENDIX V

TEST PROCEDURE

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TEST PROCEDURE

WYLE SCIENTIFIC SERVICES & SYSTEMS
LABORATORIES GROUP
P. O. Box 1008, Huntsville, AL 35807
TWX (910) 997-0888, Phone (205) 837-4411

TEST PROCEDURE NO. 543/40525-01/JK
DATE: April 1, 1989
Revision A

J/N 40525

SEISMIC TEST PROCEDURE

FOR

TWELVE NATURALLY-AGED
C&D LCU-19 STATIONARY BATTERIES

FOR

EG&G IDAHO, INC.
IDAHO FALLS, IDAHO 83415

APPROVED BY: ____________________
FOR: ____________________
APPROVED BY: ____________________
FOR: ____________________
APPROVED BY: ____________________
FOR: ____________________

APPROVED BY PROJECT MANAGER: Warren R Johnson 4/4/89
APPROVED BY QUALITY ENGINEER: TRHamilton for G.W. Hight 4/4/89
PREPARED BY PROJECT ENGINEER: Herman Melton 4-3-89

(095)

REVISIONS

FORM 1054-1 Rev. 4/74

REV. NO.	DATE	PAGES AFFECTED	BY	APP'L.	DESCRIPTION OF CHANGES
A	4-18-89	7, and 13-18	HM	HM 5-22-89 [illegible]	Deleted 10% margin per EG&G's
				TRH for GWH 5-23-89	request.
A	4-18-89	8	HM	HM 5-22-89 [illegible] 5-22K	Changed "fixture" to "table".
				TRH for GWH 5-23-89	
A	4-18-89	11	HM	HM 5-22-89 [illegible]	Updated figure to reflect
				TRH for GWH 5-23-89	change in setup and added
					accelerometer locations.

1.0 PURPOSE AND SCOPE

The purpose of this test program is to provide functional and seismic test data (for 12 naturally-aged Batteries) that can be utilized to evaluate the seismic ruggedness of aged batteries with respect to their structural and electrical capacity integrity. The evaluation of the test results will be performed by EG&G Idaho, Inc. (EG&G) and is to be presented to the U. S. Nuclear Regulatory Commission under DOE Contract No. DE-AC07-76IDO1570, FIN No. A6389.

1.1 Specimen and Program Description

The actual test specimens consist of 12 naturally-aged (to 13-1/2 years) C&D LCU-19 Batteries, each having an electrical capacity of 1350 ampere-hours. Each Battery is 7-5/8" long, 14-1/8" wide, and 22-1/16" high and weighs 240 pounds. The specimens shall be tested in three groups of four batteries each.

NOTE: Specimen and group identification information for each battery shall be provided by EG&G prior to testing.

Each group of four batteries shall be mounted in the upper shelf of a C&D No. RD-903-5 Seismic Battery Rack Assembly (which is capable of holding 12 batteries as shown in Figure 1) according to the instructions outlined in Appendix C of EG&G Specification ES-51235.

NOTE: Since only four batteries will be tested together, the remaining eight locations on the rack will be filled with simulated batteries. The simulated batteries are constructed of wood and steel, and have the weight and dimensions of an actual battery.

The specimens shall be charged to the specified capacity prior to testing and shall be electrically-loaded (discharged at 2% of the specified 3-hour rate) during the seismic tests. The charge equipment and monitoring environment to perform these tasks shall be the responsibility of others (EG&G and/or INEL).

NOTE: All testing shall be performed at ambient laboratory temperatures which are normally within the specified 77°F ± 5°F.

1.0 PURPOSE AND SCOPE (Continued)

1.2 Government-Furnished Equipment

The following Government-furnished equipment shall be provided to Wyle for the performance of the tests:

(1) 12 ea. C&D LCU-19 Batteries

(2) 10 ea. Simulated Batteries (includes 2 spares)

(3) 1 ea. C&D No. RD-903-5 Battery Rack

(4) Charging and discharging equipment

(5) Straps, bolts, cables, etc. for interconnecting the batteries and for connecting the charging and discharging equipment

(6) Data acquisition equipment for monitoring battery current, voltages, and temperatures

(7) Equipment needed to perform alternate surveillance methods

(8) Sling and spreader bar for handling batteries.

EG&G shall be responsible for the coordination with INEL for the timely arrival of the required equipment and (if required) personnel.

1.3 Test Sequence

The following describes the sequence of events for testing:

	Activity	Paragraph	Performer
1.	Perform Bare Table Test to shape the TRS (for each test level and test axis) to envelope the respective RRS as closely as possible.	2.4.3	Wyle
2.	Perform Specimen Receipt Inspection and identify specimens.	2.1	Wyle/EG&E
3.	Install Battery Rack Assembly and Dummy Batteries on the test table.	2.3	Wyle
4.	Verify capacity of first group of four Batteries and recharge (if required).	2.2	EG&E/INEL
5.	Verify alternate surveillance measurements on first group of Batteries.	2.2	EG&E/INEL
6.	Install first group of Batteries in Rack Assembly and electrically connect them together.	1.5 & 2.3	Wyle

1.0 PURPOSE AND SCOPE (Continued)

1.3 Test Sequence (Continued)

	Activity	Paragraph	Performer
7.	Connect discharger and battery performance data acquisition system to the Batteries.	2.5.4	EG&G/INEL
8.	Connect seismic-related data acquisition system.	2.5.1&2.5.2	Wyle
9.	Perform resonance search test	2.4.2	Wyle/INEL
10.	Perform first level of seismic test (test level as shown in Figures 3 and 4).		Wyle/INEL
11.	Remove the first group of Batteries.	1.5 & 2.3	Wyle
12.	Determine electrical capacity, recharge and perform alternate surveillance measurements.	2.6	EG&G/Wyle
13.	Repeat Steps 4 through 12 (except Step 9 which is only required for the first group of Batteries) for the second group of Batteries (test levels as shown in Figures 5 and 6).	as listed above	Wyle EG&G/INEL
14.	Repeat Steps 4 through 12 (except Step 9) for the third group of Batteries (test levels as shown in Figures 7 and 8).	as listed above	Wyle EG&G/INEL
15.	Remove Battery Rack and Dummy Batteries from the test table.	1.5 & 2.3	Wyle
16.	Test teardown and packing of Batteries and test equipment.	1.5	Wyle

1.4 Acceptance Criteria

For a minimum, the acceptance criteria shall be as follows:

- The specimens shall retain their structural and electrical integrity during and after the seismic tests.
- The specimens shall be capable of performing their designed function during and after the seismic test. (INEL shall monitor the specimens as required and EG&G and INEL shall verify that the specimens operated per their design requirements.)
- Leakage due to cracked cells shall not be acceptable.

1.0 PERFORMANCE AND SCOPE (Continued)

1.5 Handling and Safety Precautions

- Batteries shall be handled according to manufacturer recommendations and shall be lifted utilizing Government-furnished sling and spreader bar.

- Because the Batteries contain sulfuric acid, safety precautions shall be taken to avoid endangering personnel, equipment, and facilities. Provisions shall be included to catch and contain acid that may be ejected from the Batteries during shaking as a result of spillage or cracking of the battery cases.

- Adequate ventilation shall be provided during the performance of the functional tests.

1.6 Applicable Documents

1.6.1 EG&G Engineering Specification ES-51235 entitled "Seismic Testing of Naturally-Aged Stationary Batteries" dated January 20, 1989.

1.6.2 American National Standards Institute (ANSI)/American Society of Mechanical Engineers (ASME) specification NQA-1 entitled "Quality Assurance Program Requirements for Nuclear Facilities."

1.6.3 American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code Section III.

1.6.4 Institute of Electrical and Electronics Engineers (IEEE) Specification IEEE-344 entitled "IEEE Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations."

1.6.5 IEEE-450 Specification entitled "IEEE Recommended Practice for. Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations."

1.6.6 IEEE-484 Specification entitled "IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations."

1.6.7 IEEE Standard for Qualification of Class 1E Storage Batteries for Nuclear Power Generating Stations."

2.0 TESTING

2.1 Receipt Inspection

Upon receipt of the Batteries and test equipment at the test facility, the specimens shall be inspected for obvious physical defects. Additionally, the applicable model, part, and/or serial numbers shall be checked and recorded. Photographs shall be taken of any noted defects.

2.2 Pre-Seismic Functional Check

Prior to performing the seismic test, all specimens shall be subjected to

- Electrical capacity checks by discharging at the three-hour rate.
- Recharging to the required charge level.
- Alternate surveillance measurements.

These tests will be performed by INEL/EG&G.

2.3 Specimen Mounting

The Seismic Battery Rack Assembly (pre-mounted on two 4" x 46" x 3/4"-thick carbon steel bars using 1/2-13 Grade 5 bolts) shall be placed on the seismic test table such that its principal orthogonal axes are colinear with the test table's axes of excitation. The test fixture shall be welded to the test table. Subsequently, the eight Dummy Batteries shall be installed. Each group of four aged Batteries (specimens) shall be loaded in the rack located at one end of the top step of the rack assembly (as shown in Figure 1). Installation and tie-down of the Batteries in the rack shall be according to the instructions outlined in Appendix C of EG&G Specification ES-51235.

2.4 Seismic Testing

Each group of four specimens shall be subjected to seismic tests according to the procedures outlined below.

2.4.1 Excitation

- **For Single-Axis Testing (Group 1 only)**

  For the performance of the resonance search tests (Paragraph 2.4.2), each orthogonal specimen axis shall be excited separately and independently.

- **For Triaxial Testing**

  For the triaxial random multifrequency tests (Paragraph 2.4.3), both horizontal axes and the vertical axis shall be excited separately, but simultaneously. The input acceleration levels for each of the three axes shall be phase incoherent during the multifrequency tests.

2.0 TESTING (Continued)

2.4 Seismic Testing (Continued)

2.4.2 Resonance Search (Group 1 only)

A low-level (0.2g horizontally and vertically) single-axis sine sweep shall be performed in each of the three orthogonal axes to determine resonant frequencies. The sine sweep shall be performed from 1 to 35 Hz at a sweep rate of one octave per minute. Transmissibility plots of the in-line specimen-mounted accelerometers shall be included in the test report.

2.4.3 Random Multifrequency Tests (All Groups)

The specimens shall be subjected to 30-second duration triaxial multifrequency random motion which shall be amplitude-controlled in one-third octave bandwidths spaced one-third octave apart over the frequency range of 1 to 100 Hz. Three simultaneous, but independent, random signals shall be used as the excitation to produce phase-incoherent motions in the vertical and two horizontal axes. The amplitude of each one-third octave bandwidth shall be independently adjusted in each of the three axes until the Test Response Spectra (TRS) envelop the Required Response Spectra (RRS) within the limitations of the test machine, as shown in Figure 2. The Zero Period Acceleration (ZPA), as well as other areas of the RRS, may be exceeded in order to meet the peaks of the curves. The resulting table motion shall be analyzed by a response spectrum analyzer at 2% damping and plotted at one-sixth octave intervals over the frequency range of 1 to 200 Hz.

One full-level test shall be performed for each group of Batteries:

Group	Applicable RRS Curves
1	Figures 3 and 4
2	Figures 5 and 6
3	Figures 7 and 8

The RRS shown in Figures 3 through 8 were derived from the information shown in Figures 9 and 10. A

Additional test runs at any desired level (within the limitations of the test machine) can be performed if the test results merit an increase in the test level.

2.0 TESTING (Continued)

2.4 Seismic Testing (Continued)

2.4.3 Random Multifrequency Tests (All Groups) (Continued)

NOTE 1: Bare table tests to shape the TRS (for each test level and test axis) to envelope the respective RRS as closely as possible will be performed prior to performing any testing on the specimens.

NOTE 2: INEL will discharge the Batteries at 2% of the 3-hour rate, with current and battery voltages being monitored during the seismic tests to detect the existence of catastrophic failure. This rate is consistent with the rate recommended by IEEE STD 535-1986 Paragraph 8.3.1.1(2). Any battery that fails to continuously provide at least 1.75 volts will be considered to have failed and will not be subjected to further testing. After each level of seismic testing, the capacity of the Batteries will be determined by discharging at the 3-hour rate. After the 3-hour discharge, the Batteries will be recharged.

2.5 Instrumentation

All instrumentation, measuring, and test equipment to be used in the performance of this test program shall be calibrated in accordance with Wyle Laboratories' Quality Assurance Program which complies with the requirements of Military Specification MIL-STD-45662A. Standards used in performing all calibrations are traceable to the National Institute of Standards and Technology (NIST) by report number and date. When no national standards exist, the standards are traceable to international standards or the basis for calibration is otherwise documented.

NOTE: INEL shall be responsible for the calibration documentation of the Government-provided equipment.

2.5.1 Excitation Control

Control accelerometers shall be mounted on the test table at a location near the bases of the specimens. TRS plots (filtered at 100 Hz) of the accelerometers for each test at 2% damping, shall be included in the test report. A

2.0 TESTING (Continued)

2.5 Instrumentation (Continued)

2.5.2 Specimen Response

A total of six specimen-mounted uniaxial piezoelectric accelerometers shall be located on the specimens under test. The placement of the accelerometers shall be per the EG&G Technical Representative or the Wyle Project Engineer. Magnetic tape recorders shall provide a record of each accelerometer's response. TRS plots (filtered at 100 Hz) of the specimen's response accelerometers at 2% damping for each full-level test shall be provided in the test report.

2.5.3 Electrical Powering

Electrical power of 480 VAC, 60 Hz, 3-phase at 15 amperes per phase, for the charging and discharging equipment shall be provided.

Additionally, standard electrical power of 120 VAC or 120 VDC at 20 amperes or less, single-phase, for the operation of the data acquisition equipment shall also be provided.

2.5.4 Electrical Monitoring

The Battery performance data (including voltages, currents, temperatures, and specific gravities) will be acquired and stored by INEL for all performed functional and seismic tests.

2.6 Post-Seismic Inspection and Operational Verification

The specimen shall be inspected for any obvious structural damage, loose parts, etc.

Additionally, the operational check described in Paragraph 2.2 shall be repeated.

3.0 IN-PROCESS INSPECTION

The records shall be checked for quality of performance after each test.

The specimens shall be examined for possible damage following all violent tests.

All important vibration effects shall be logged.

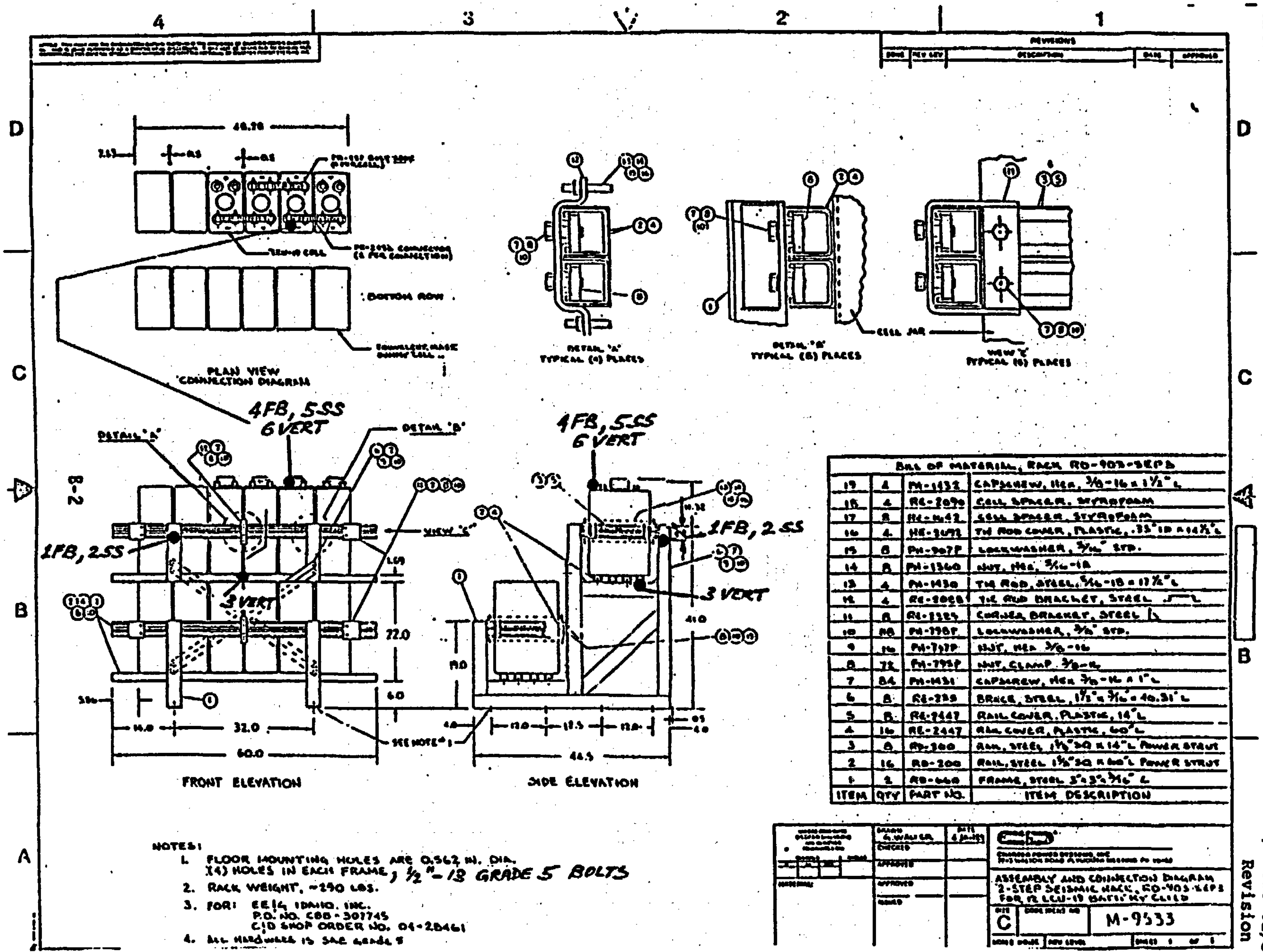
Photographs shall be taken of any noticeable physical damage that may occur.

4.0 REPORTS

Two spiral-bound (and one unbound) copies of a certification-type test report shall be issued subsequent to completion of testing. This report shall be signed by a Registered Professional Engineer and shall summarize the maximum g levels, details and recommendations concerning deficiencies and repairs, and contain photographs of test setups, accelerometers, failures, etc. The report shall also contain a list of test equipment used, calibrations, and Instrumentation Log Sheets.

5.0 QUALITY ASSURANCE

All work performed on this test program shall be completed in accordance with Wyle Laboratories' Quality Assurance Program which complies with the applicable requirements of Military Specification MIL-STD-45662A, 10 CFR 50 Appendix B, ANSI N 45.2, and Regulatory Guides.



BILL OF MATERIAL, RACK RD-903-SEPS			
19	4	PH-1432	CAPSCREW, HEX, 3/8-16 x 1½" L
18	4	RE-2090	CELL SPACER, STYROFOAM
17	8	RE-1142	CELL SPACER, STYROFOAM
16	4	RE-3092	TIE ROD COVER, PLASTIC, .33" ID x 14¾" L
15	8	PH-9077	LOCKWASHER, 5/16" STD.
14	8	PH-1360	NUT, HEX, 5/16-18
13	4	PH-1430	TIE ROD, STEEL, 5/16-18 x 17½" L
12	4	RE-2088	TIE ROD BRACKET, STEEL
11	8	RE-1325	CORNER BRACKET, STEEL
10	88	PH-7787	LOCKWASHER, 3/8" STD.
9	16	PH-7477	NUT, HEX 3/8-16
8	72	PH-7957	NUT, CLAMP 3/8-16
7	84	PH-1431	CAPSCREW, HEX 3/8-16 x 1" L
6	8	RE-239	BRACE, STEEL, 1½" x 3/16" x 40.31" L
5	8	RE-2447	RAIL COVER, PLASTIC, 14" L
4	16	RE-2447	RAIL COVER, PLASTIC, 60" L
3	8	RD-300	RAIL, STEEL 1⅝" SQ x 14" L POWER STRUT
2	16	RD-200	RAIL, STEEL 1⅝" SQ x 60" L POWER STRUT
1	2	RD-660	FRAME, STEEL 3" x 3" x 3/16" L
ITEM	QTY	PART NO.	ITEM DESCRIPTION

NOTES:

1. FLOOR MOUNTING HOLES ARE 0.562 IN. DIA. (4) HOLES IN EACH FRAME, ½"-13 GRADE 5 BOLTS
2. RACK WEIGHT, ~290 LBS.
3. FOR: EG&G IDAHO, INC.
   P.O. NO. C88-307745
   C&D SHOP ORDER NO. 04-28461
4. ALL HARDWARE IS SAE GRADE 5

DRAWN G. WALKER 4 JAN-83

C&D

CHARGED POWER SYSTEMS, INC

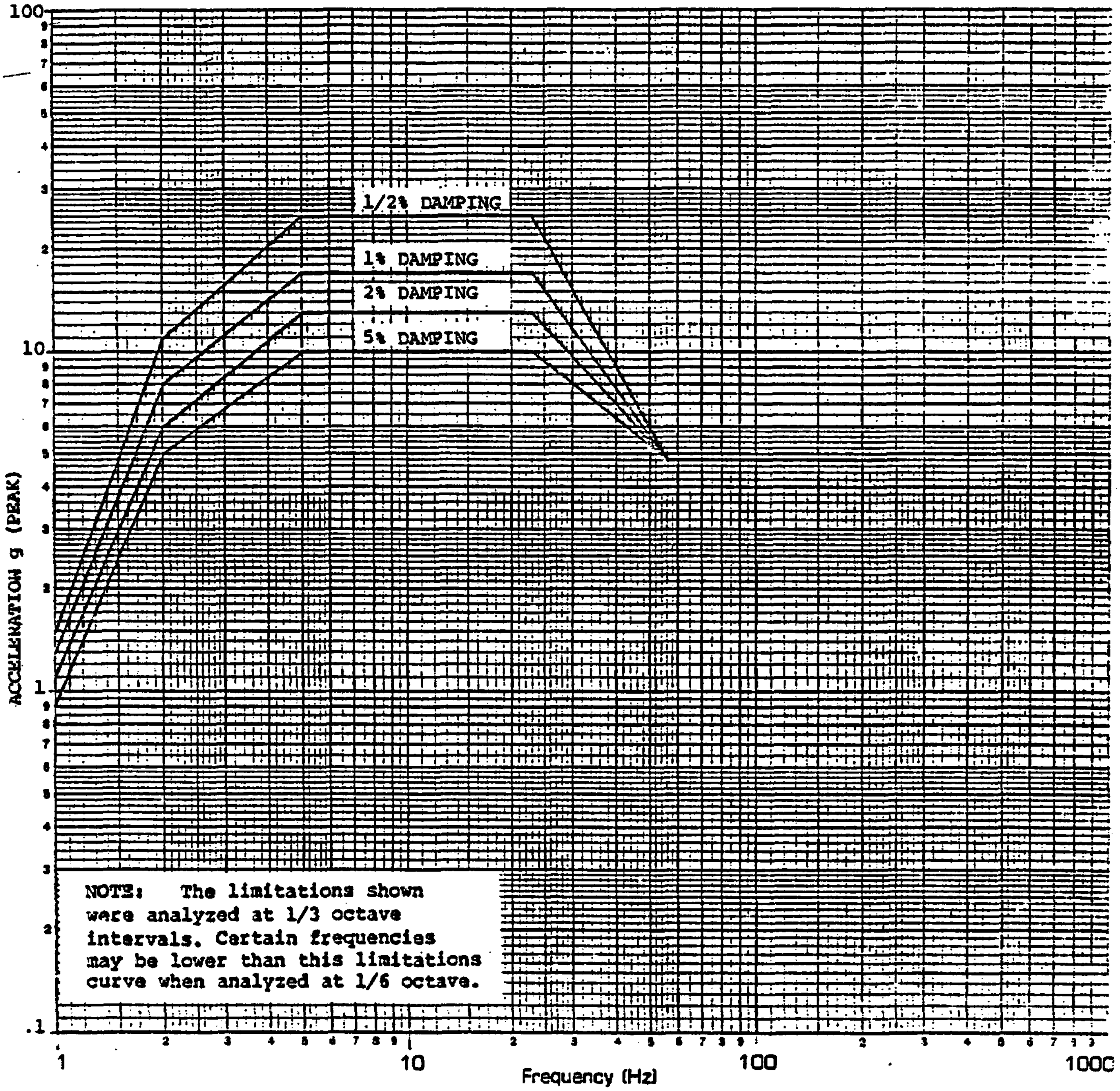
ASSEMBLY AND CONNECTION DIAGRAM
2-STEP SEISMIC RACK, RD-903-SEPS
FOR 12 LCU-13 BATTERY CELLS

SIZE C M-9533

SHEET 1 OF 1

FIGURE 1. BATTERY AND RESPONSE ACCELEROMETER MOUNTING LOCATIONS (APPLICABLE TO ALL TEST SERIES)

FULL SCALE SHOCK SPECTRUM (g Peak)



NOTE: The limitations shown were analyzed at 1/3 octave intervals. Certain frequencies may be lower than this limitations curve when analyzed at 1/6 octave.

FIGURE 2. APPROXIMATE HORIZONTAL AND VERTICAL BROADBAND LIMITATIONS OF THE WYLE TRIAXIAL SEISMIC SIMULATOR (MACHINE D). RESPONSE ANALYZED AT DAMPINGS SHOWN.

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000☐

DAMPING 2%

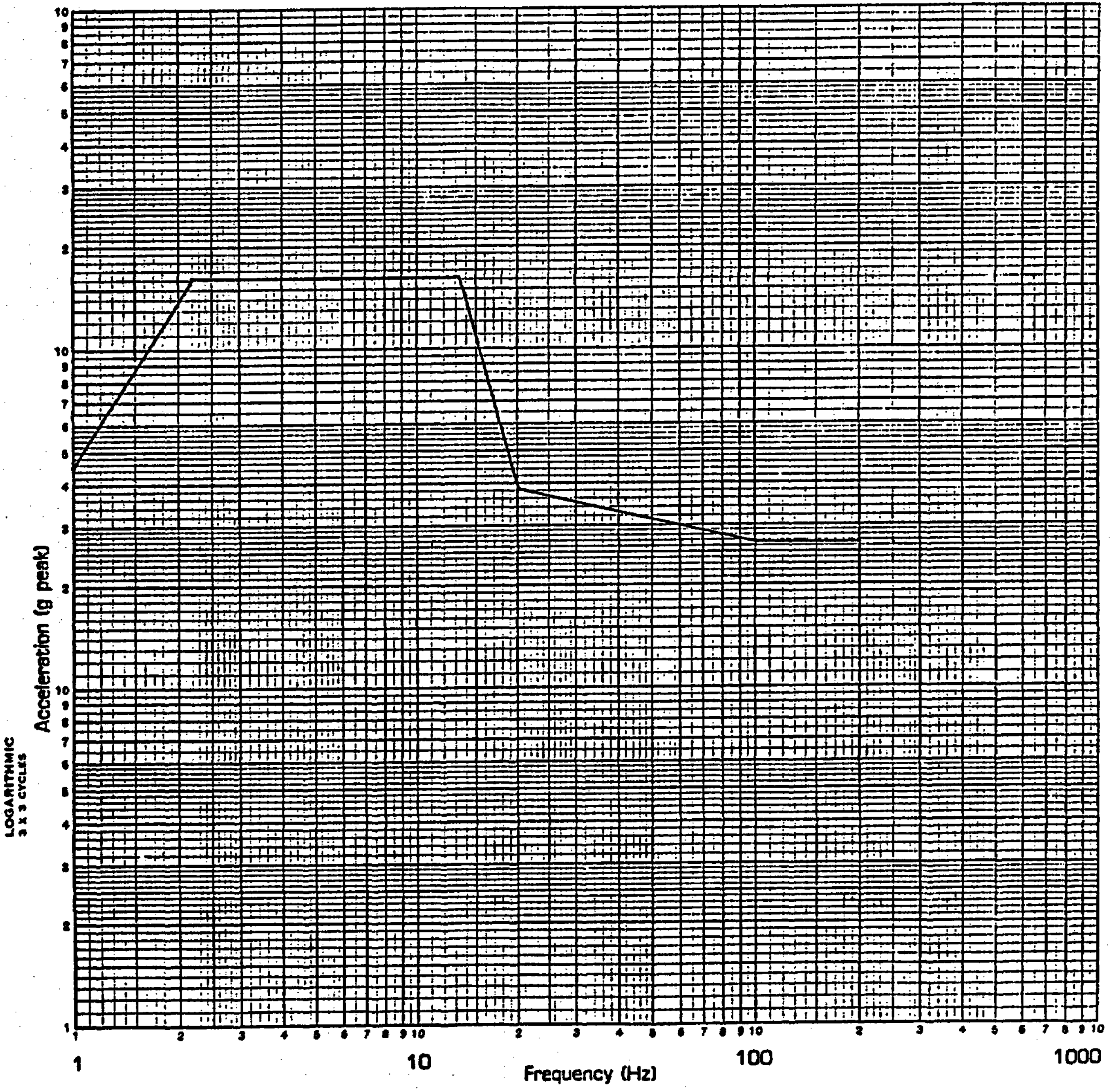


FIGURE 3. HORIZONTAL 50% LEVEL
REQUIRED RESPONSE SPECTRUM

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%

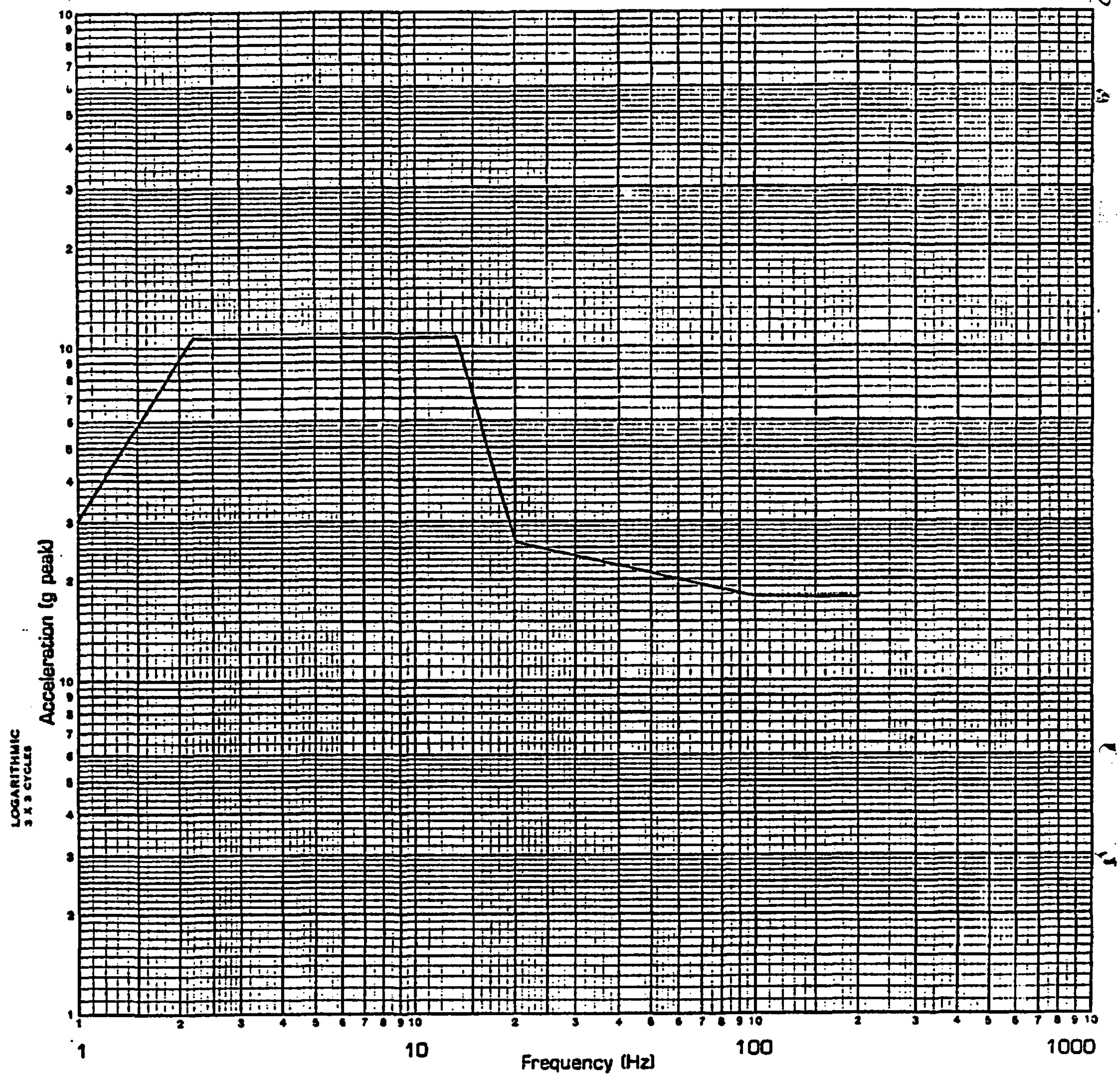


FIGURE 4. VERTICAL 50% LEVEL
REQUIRED RESPONSE SPECTRUM

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☒ 100 ☐ 1000 ☐

DAMPING 2%

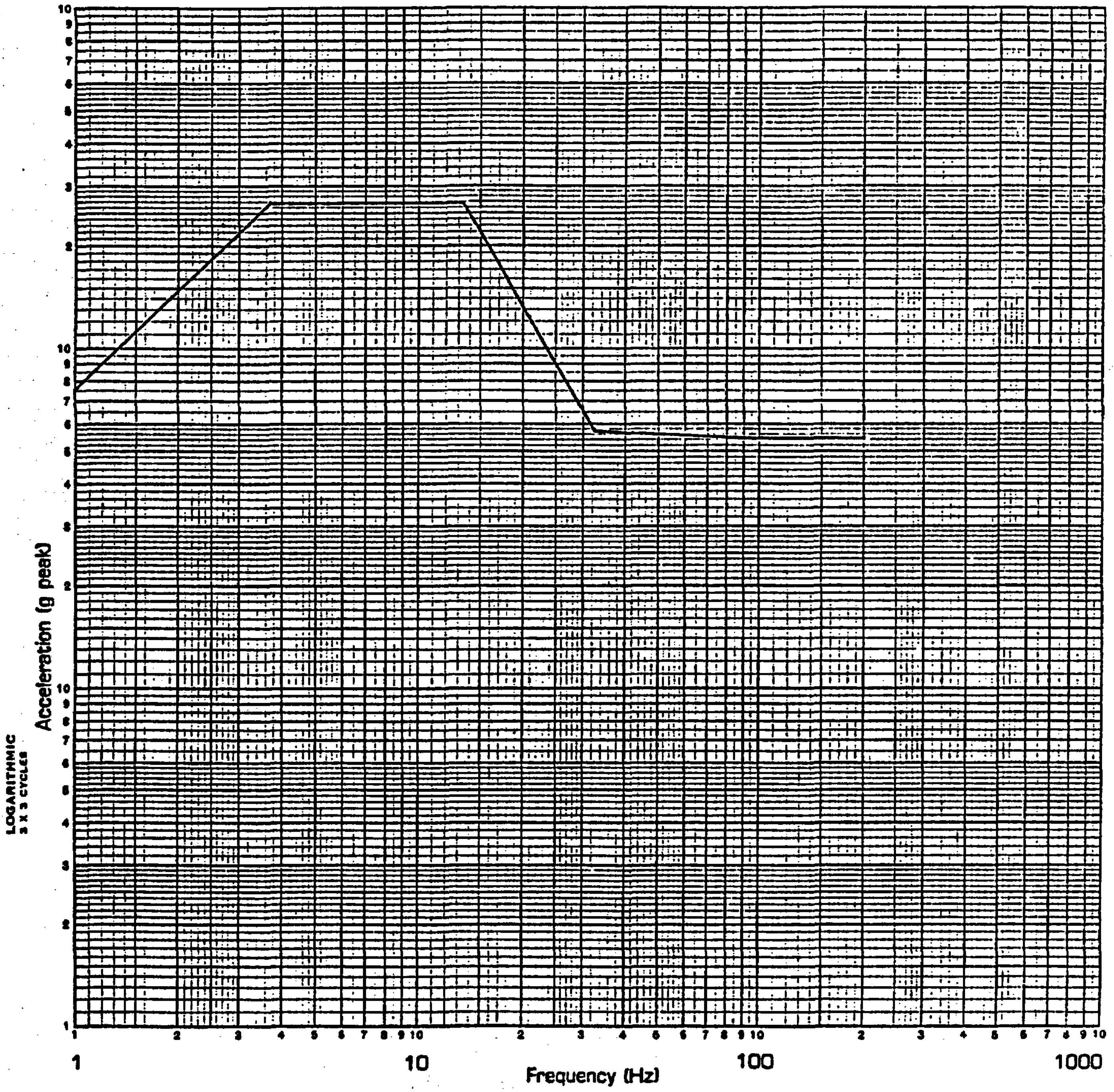


FIGURE 5. HORIZONTAL 85% LEVEL
REQUIRED RESPONSE SPECTRUM

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%

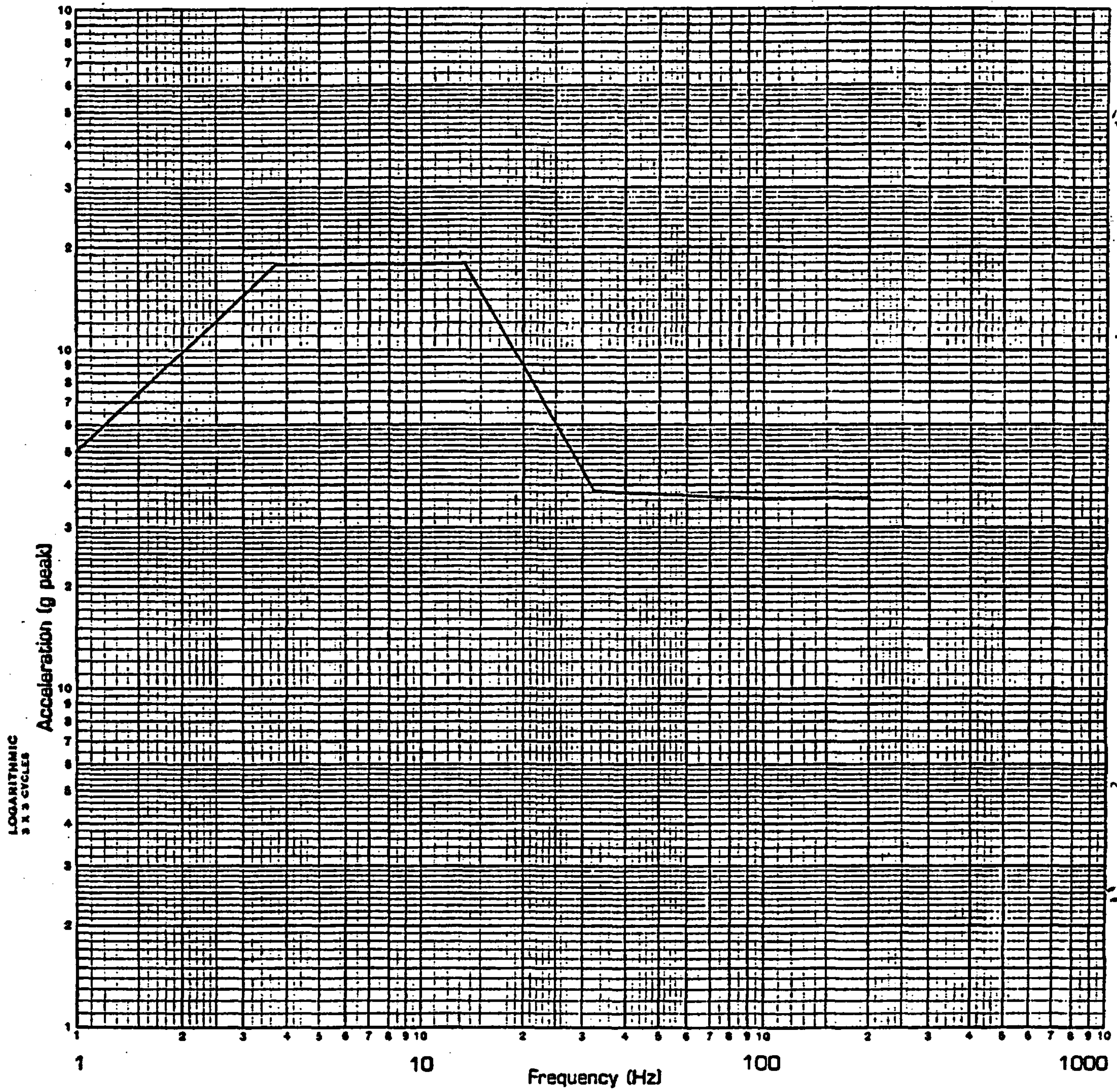


FIGURE 6. VERTICAL 85% LEVEL
REQUIRED RESPONSE SPECTRUM

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%

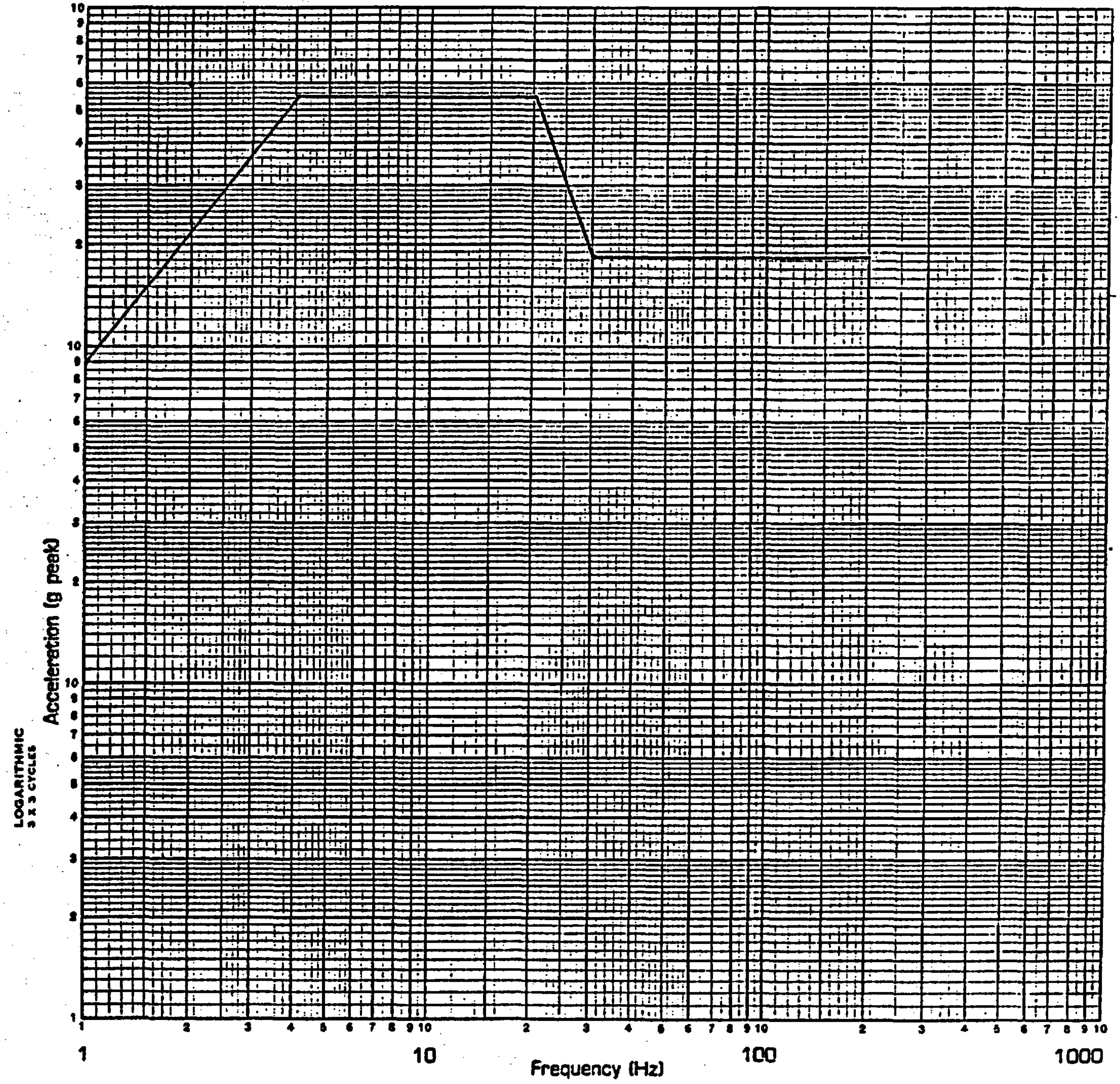


FIGURE 7. HORIZONTAL 95% LEVEL
REQUIRED RESPONSE SPECTRUM

FULL SCALE SHOCK SPECTRUM (g Peak)

1.0 ☐ 10 ☑ 100 ☐ 1000☐

DAMPING 2%

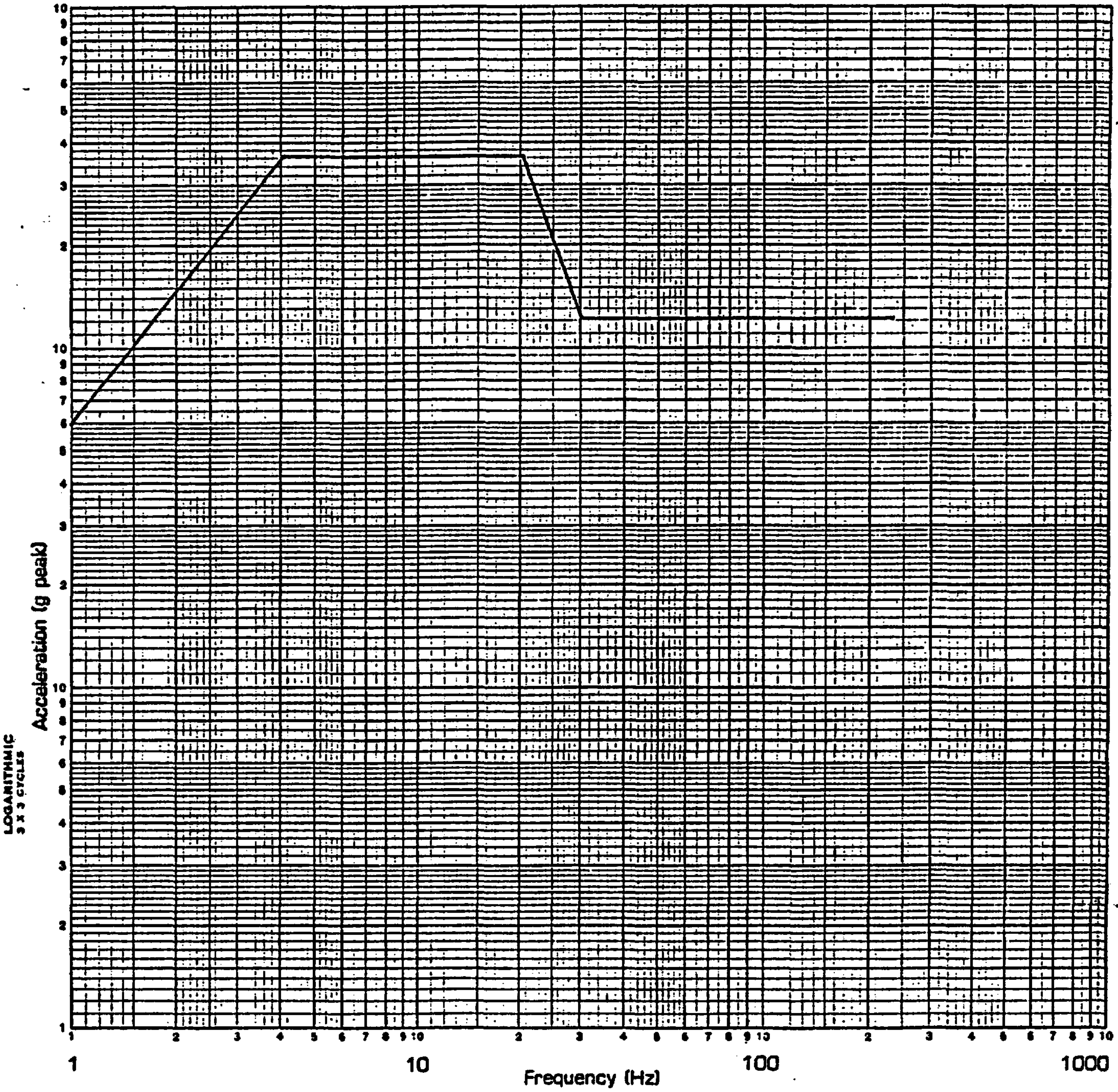


FIGURE 8. VERTICAL 95% LEVEL
REQUIRED RESPONSE SPECTRUM

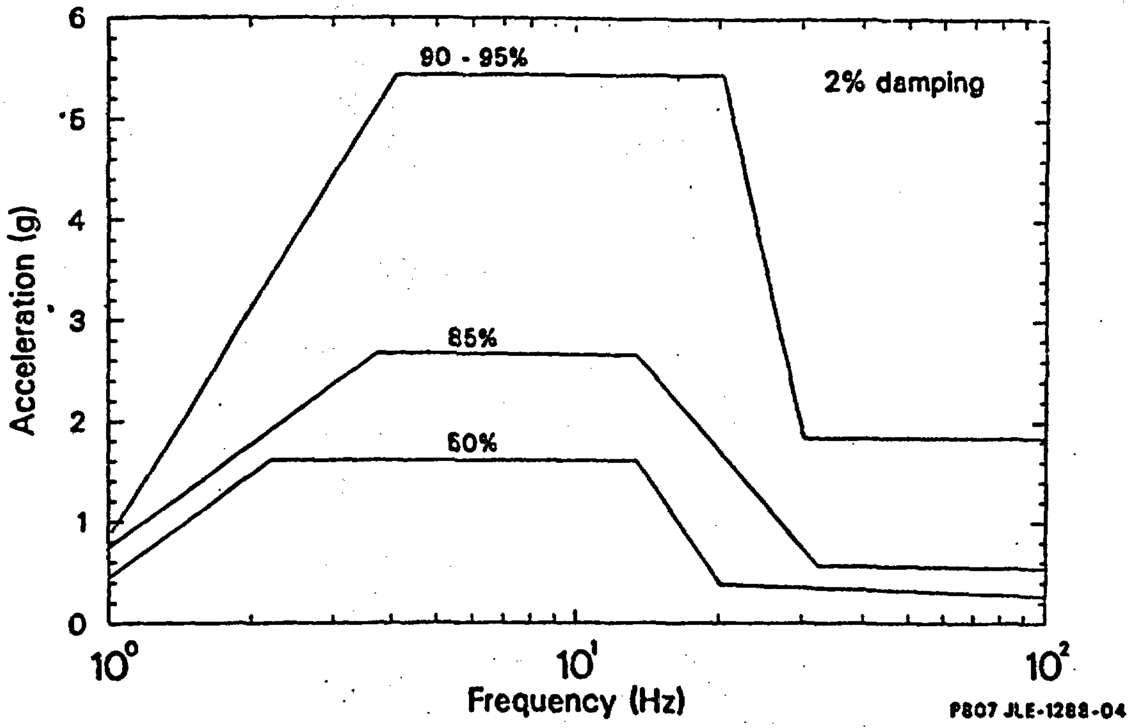


FIGURE 9. OVERLAY OF 50%, 85%, AND 90% to 95% REQUIRED RESPONSE SPECTRA CURVES

ES-51235

50% of Nuclear Plants

Frequency (Hz)	Acceleration (g)
1.00	0.453
2.20	1.608
13.39	1.608
20.11	0.385
100.00	0.266

85% of Nuclear Plants

Frequency (Hz)	Acceleration (g)
1.00	0.750
3.70	2.671
13.39	2.671
32.43	0.571
100.00	0.545

90 to 95% of Nuclear Plants

Frequency (Hz)	Acceleration (g)
1.00	0.896
4.07	5.440
20.37	5.440
30.26	1.843
100.00	1.843

FIGURE 10. **TABULATION OF RRS CURVE ACCELERATIONS**

NRC FORM 335
(2-89)
NRCM 1102,
3201, 3202

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

This report presents the results of a seismic testing program on naturally aged class 1E batteries obtained from a nuclear plant. The testing program is a Phase II activity resulting from a Phase I aging evaluation of class 1E batteries in safety systems of nuclear power plants, performed previously as a part of the U.S. Nuclear Regulatory Commission's Nuclear Plant Aging Research Program and reported in NUREG/CR-4457. The primary purpose of the program was to evaluate the seismic ruggedness of naturally aged batteries to determine if aged batteries could have adequate electrical capacity, as determined by tests recommended by IEEE Standards, and yet have inadequate seismic ruggedness to provide needed electrical power during and after a safe shutdown earthquake (SSE) event. A secondary purpose of the program was to evaluate selected advanced surveillance methods to determine if they were likely to be more sensitive to the aging degradation that reduces seismic ruggedness. The program used twelve batteries naturally aged to about 14 years of age in a nuclear facility and tested them at four different seismic levels representative of the levels of possible earthquakes specified for nuclear plants in the United States. Seismic testing of the batteries did not cause any loss of electrical capacity.

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