NUREG/CR-3923
SAND84-1737
RV
Printed September 1984

Test Series 1: Seismic-Fragility Tests of Naturally-Aged Class 1E Gould NCX-2250 Battery Cells

Lloyd L. Bonzon, Donald B. Hente

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

Prepared for
U. S. NUCLEAR REGULATORY COMMISSION

Available from
GPO Sales Program
Division of Technical Information and Document Control
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

and

National Technical Information Service
Springfield, Virginia 22161

NUREG/CR-3923
SAND84-1737
RV

TEST SERIES 1: SEISMIC-FRAGILITY TESTS OF NATURALLY-AGED CLASS 1E GOULD NCX-2250 BATTERY CELLS

September 1984

Lloyd L. Bonzon
Donald B. Hente

Sandia National Laboratories
Albuquerque, New Mexico 87185
Operated by
Sandia Corporation
for the
U.S. Department of Energy

Appendices Prepared by

Bharat M. Kukreti
Jerry S. Schendel
James D. Tulk
W. John Janis
David A. Black
Gordon D. Paulsen
Brian D. Aucoin

Ontario Hydro
Toronto, Ontario, Canada
Performed under Sandia Contract No. 47-4077

Prepared for
Electrical Engineering Instrumentation and Control Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
Under Memorandum of Understanding 40-550-75
NRC FIN No. A-1051

ABSTRACT

The seismic-fragility response of naturally-aged nuclear station safety-related batteries is of interest for two reasons: (1) to determine actual failure modes and thresholds and (2) to determine the validity of using the electrical capacity of individual cells as an indicator of the "end-of-life" of a battery given a seismic event. This report covers the first test series of an extensive program using 12-year old lead-calcium Gould NCX-2250 cells from the James A. Fitzpatrick Nuclear Power Station operated by the New York Power Authority.

Seismic tests with three cell configurations were performed using a triaxial shake table: single-cell tests, rigidly mounted; multi-cell (three) tests, mounted in a typical battery rack; and single-cell tests specifically aimed towards examining propagation of pre-existing case cracks. In general the test philosophy was to monitor the electrical properties including discharge capacity of cells through a graduated series of g-level step increases until either the shake-table limits were reached or until electrical "failure" of the cells occurred.

Of nine electrically active cells, six failed during seismic testing over a range of imposed g-level loads in excess of a 1-g ZPA. Post-test examination revealed a common failure mode, the cracking at the abnormally brittle, positive lead bus-bar/post interface; further examination showed that the failure zone was extremely coarse grained and extensively corroded. Presently accepted accelerated-aging methods for qualifying batteries, per IEEE Std. 535-1979, are based on plate growth, but these naturally-aged 12-year old cells showed no significant plate growth.

While cracks were propagated and leaks were observed in the propagation tests at high g-levels, it appears that this failure mechanism was less significant than the bus-bar/post interface failures.

CONTENTS

FORWARD AND ACKNOWLEDGEMENTS

This work was performed at the Ontario Hydro Research Centre, Toronto, Ontario, Canada, under Sandia National Laboratories (SNL) contract 47-4077. It covers the period from October 1, 1983, through June 30, 1984. The SNL technical project monitors are Lloyd L. Bonzon and Donald B. Hente.

The overall development and execution of this program were carried out by Mr. B. M. Kukreti assisted by Mr. J. S. Schendel of the Electrical Design Department. Dr. James W. Tulk of the Applied Structural and Solid Mechanics Section, Mechanical Research Department, provided the expertise in seismic technology and coordinated the research activities. Messrs. D. A. Black and G. D. Paulsen of the Mechanical Testing and Development Section, Mechanical Research Department, provided expertise in seismic testing. Messrs. W. John Janis and B. D. Aucoin, Chemical Research Department performed the battery testing and the chemical analyses of the components of the battery cells.

EXECUTIVE SUMMARY

The seismic-fragility response of naturally-aged nuclear station safety-related batteries is of interest for two reasons: (1) to determine actual failure modes and thresholds and (2) to determine the validity of using the electrical capacity of individual cells as an indicator of the "end of-life" of a battery given a seismic event. This report covers the first test series of an extensive program using 12-year old lead-calcium Gould NCX-2250 cells from the James A. Fitzpatrick Nuclear Power Station operated by the New York Power Authority.

Seismic tests with three cell configurations were performed using a triaxial shake table: single-cell tests, rigidly mounted; multi-cell (three) tests, mounted in a typical battery rack; and single-cell tests specifically aimed towards examining propagation of pre-existing case cracks. In general the test philosophy was to monitor the electrical properties including discharge capacity of cells through a graduated series of g-level step increases until either the shake-table limits were reached or until electrical "failure" of the cells occurred.

Of nine electrically active cells, six failed during seismic testing over a range of imposed g-level loads in excess of a 1-g ZPA. Post-test examination revealed a common failure mode, the cracking at the abnormally brittle, positive lead bus-bar/post interface; further examination showed that the failure zone was extremely coarse grained and extensively corroded. Presently accepted accelerated-aging methods for qualifying batteries, per IEEE Std. 535-1979, are based on plate growth but these naturally-aged 12-year old cells showed no significant plate growth thus raising questions about the prescribed aging methods.

While cracks in the battery cases were propagated and electrolyte leaks were observed in the propagation seismic tests, it appears that this failure mechanism was less significant than the bus-bar/post interface failures in determining battery fragility.

It has been postulated in the Ontario Hydro reports (Appendices A and B) that the lead bus bar "failure" may be due to inadequate or deficient manufacturing processes. The data are not conclusive and this issue will certainly be included in our scheduled follow-on activities.

Follow-on activities are in progress, and they include: (1) procurement and testing of naturally-aged battery cells from other nuclear power stations representing product lines from the other two major battery manufacturers; (2) procurement of new, same type, cells from the three manufacturers for "baseline" examination and testing; (3) comparison of typical nuclear plant required response spectra for comparison with the fragility levels experienced in these and follow-on tests; and (4) if required, additional lead-chemistry evaluations.

This effort is a subpart of a broader program to evaluate the accelerated aging methods used in qualifying Class 1E batteries (e.g., in IEEE Std 535-1979). By seismic-fragility testing naturally-aged battery cells, the actual failure modes and thresholds can be determined. This determination serves to focus the evaluation and development of other aging methods on those specific failure modes, thresholds, and locations that have been observed.

1.0 BACKGROUND

1.1 General

The seismic-fragility response of naturally-aged nuclear station safety-related batteries is of interest for two reasons: (1) to determine actual failure modes and thresholds and (2) to determine the validity of using the electrical capacity of individual cells as an indicator of the "end-of-life" of a battery given a seismic event.

1.2 Historical Perspective

The concern over seismic susceptibility of naturally-aged lead-acid batteries used for safety-related emergency power in nuclear power stations was brought about by battery problems that periodically had been reported in Licensee Event Reports (LERs). The Turkey Point Station had reported cracked and buckled plates in several cells in October 1974 (LER 74-5).[1] The Fitzpatrick Station had reported cracked battery cell cases in October 1977 (LER 77-55)[2] and again in September 1979 (LER 79-59).[3] The Browns Ferry Station had reported a cracked cell, leaking a small quantity of electrolyte, in July 1981 (LER 81-42).[4] The Indian Point Station reported cracked and leaking cells in both February (LER 82-7)[5] and April 1982 (LER 82-16);[6] both of these LERs indicated that the cracked cells were due to expansion (i.e., growth) of the positive plates.

Similar problems at the Connecticut Yankee Station in June and September 1982 (LER 82-6)[7] prompted the NRC staff to conduct a general investigation which included a visit to Connecticut Yankee and discussions with manufacturers of Class 1E* batteries. The visit to Connecticut Yankee revealed a number of cells with case cracks which were attributed to swelling of the positive plates. The report[8] of the investigation concluded that aged batteries may be vulnerable to common-mode failure because of a seismic event. Such a seismic event, even a relatively mild one, could cause otherwise electrically acceptable batteries to suffer plate or cell cracking or shorting due to the sloughing of plate material.

The report[8] also concluded that the existing technical specifications for surveillance are designed to ensure the availability of sufficient battery capacity without regard to the effect of a seismic event on an aged battery. To make nuclear power plant personnel aware of the finding, the NRC

---

* Class 1E is the safety-class designation as defined in IEEE 323-1974.

Office of Inspection and Enforcement issued Information Notice 83-11, Possible Seismic Vulnerability of Old Lead Storage Batteries on March 14, 1983.[9]

There is no information available on how the battery cells identified in the LERs would have responded to a seismic event (or performed their electrical function) just prior to their replacement. There is, however, a general belief that the electrical life of these types of battery cells is longer than their seismic life. That is because past experience with aged batteries has shown the cells will pass all their surveillance requirements, meet all technical specifications, and provide adequate capacity even after it appears the plates are too embrittled to survive a mild seismic test.[10]

1.3 Programmatic Perspective

In response to the increasing NRC staff concern over aged-battery behavior in seismic events, the NRC-sponsored Qualification Testing Evaluation (QTE) research program[11] initiated an effort to evaluate the adequacy of batteries to survive a seismic event. The choice of nuclear station batteries as the equipment for evaluation was supported by two other specific developments.

First, SNL staff were made aware of a 1977 Ontario Hydro test report[12] in which the results of seismic-fragility tests on naturally-aged batteries showed that a 9-year old battery cell and a 16-year old battery cell showed differences in failure threshold. While the data was sparse, age-related effects were indicated.

Second, naturally-aged batteries became available to SNL from the decommissioned Shippingport station. This, in turn, prompted a search for naturally-aged batteries more typical of those currently used in the U.S. nuclear power stations.

2.0 PROGRAM OBJECTIVES

2.1 Evaluation of Battery Aging Methodologies (Overall Program)[13]

The present method of qualifying lead storage batteries for Class 1E service is to expose either naturally-aged or accelerated-aged battery cells to a simulated seismic environment. Cells are considered qualified that show no abrupt change of more than 5 percent of either the current or voltage during the cell discharge while being exposed to a simulated seismic event, and when the post-seismic discharge capacity is 80 percent or more of the cells rated discharge capacity. The presently accepted procedure to accelerate aging is to heat complete battery cells at a specified temperature for a length of time determined by published Accelerated Thermal Aging Factors. The Institute of Electrical and Electronics Engineers, Inc. (IEEE) Standard 535-1979[14] lists the two specific temperatures at which cells should be aged and provides a table of Aging Factors for each of the two temperatures. The Standard states that "This procedure will age the entire cell to the predominant aging failure mode which is based on the failure of the positive plates. Other cell components with age-related failure mechanisms will be stressed to a life beyond the qualified life of the positive plates."[14] While this latter statement may be true, the fact that battery jars sometimes need to be replaced because of cracking and subsequent leaking of electrolyte during aging suggests there may be exceptions to the statement.[15] If, as shown, one battery cell component is stressed to a life shorter than the qualified life of the positive plates, then components other than the case could also be stressed to a shorter life.*

The currently accepted method(s) to accelerate the age of battery cells is to be evaluated in the Sandia QTE research program. While the thermal aging procedure is recognized by consensus (i.e., in IEEE Std. 535-1979) as the means to accelerate aging, it appears not to be widely accepted.[16] The present evaluation will attempt to validate the aging procedure or provide other data-based aging methodologies. The aging of all components of battery cells and investigation of the dominant aging mechanisms will be studied in this program.

The objectives of the overall research program are:

1. To determine seismic failure modes and thresholds, primarily using naturally-aged cells.

2. To select the dominant aging mechanism(s) through this testing experience, other test experience, and expert evaluations.

3. To compare/correlate the response of naturally-aged cells and cells aged by the accelerated methods described in IEEE Std. 535-1979 and compare dominant failure modes in both cases.

4. To determine appropriate aging methodologies for the dominant mechanism(s).

---

* Sandia Staff are also aware of proprietary test data in which naturally-aged and artificially-aged batteries showed completely different responses in seismic tests.

5. To demonstrate the methodologies by a specific demonstration test program.

6. To make final recommendations of the appropriate accelerated-aging methodology(ies) for nuclear station batteries.

7. To develop in situ testing methods which can predict the remaining age and seismic tolerance of batteries.

2.2 Seismic Fragility Testing of Batteries (Failure Modes/Thresholds)[17]

The objectives listed above, for the overall program, can, in fact, be regrouped into four subprograms or goals. Objectives 1-3 relate to an effort to determine by test the actual failure modes and thresholds experienced in natural aging. Objectives 3-5 relate to an effort to compare/correlate current accelerated-aging methods and to recommend, develop, and prove modified aging methods based on the dominant failure modes observed. Objectives 5-6 lead to recommended aging method changes and incorporation into appropriate standards and guides. Objective 7 will lead to a predictive technique to determine "end-of-qualified" life of batteries.

This report summarizes the first seismic-fragility test series on naturally-aged battery cells under the program; it corresponds to a subtask of the objectives 1-3 grouping. This test series had these specific objectives:

1. To determine the seismic fragility level of naturally-aged battery cells

2. To evaluate the impact of seismic exposure on the electrical capacity of naturally-aged cells.

3. To investigate the propagation of cracks and crazes (i.e., integrity of the battery cell case) as a result of seismic exposure.

4. To identify aging degradations by post-test evaluations of the battery cell and by performing functional and material tests on the cell components.

2.3 General Approach in Testing (Overall Program)

The general approach to the testing of cells is outlined in the following paragraphs.

There are three battery manufacturers producing a number of different types of qualified stationary battery cells. Information available shows that each of the three manufacturers has about an equal share of the battery market with no one type or size predominating. The cost to age and test all of these Class 1E battery cells is prohibitive. The optimum approach is to select a limited number of battery cells for accelerated aging that are of the same type (same size and same number of plates) that have been naturally-aged and that are available from commercial nuclear power plants. The most favorable approach is to have battery cells for testing from each of the three manufacturers so that any aging degradations may be extrapolated (by analyses) to other types of cells made by the same manufacturer. While the subject of qualification by analysis is addressed in Reference 14, we are aware of no publication relating to the extrapolation of aging degradations of one type cell to another type cell.

In preparing the cells for seismic testing, the electrical capacity of the cell will be determined. That will allow an assessment of the electrical capacity/capability of the cells and a correlation of the performance of naturally-aged cells with accelerated-aged cells. In performing the seismic testing, the seismic fragility levels of aged (and new) batteries will be determined and subsequently the effect of seismic exposure on the electrical capacity of the cells.

The testing and subsequent analysis will be done using battery cells in both a single (rigidly mounted in a jig) and multicell (placed in a battery rack) configuration.

Post-test electrical and mechanical analyses will be done on the battery cells. Any "failure modes" will be documented, so that a more thorough evaluation can be made. The electrical analyses will include functional-electrical measurements as well as selected electrical cell characterizations.

3.0 APPROACH AND REPORT FORMAT

Naturally-aged, Class 1E, battery cells have been obtained from four nuclear power stations in the United States and sent to the Ontario Hydro Research Center for cell conditioning and subsequent seismic testing and analyses. All three manufacturers of Class 1E batteries are represented among the four groups of cells obtained. This report discusses the results of testing Gould, NCX-2250, battery cells obtained from the James A. Fitzpatrick Nuclear Power Station, courtesy of the New York Power Authority. (There is no implication of preference of battery type for testing or suspected failure; merely, these were available first.)

The details of the testing are summarized in the Appendices to this report. The generic approach followed this pattern: cell conditioning and pre-seismic electrical capacity measurements were made; some cells were exposed to simulated seismic (fragility) tests in both single- and multi-cell configurations; separate crack propagation tests were performed on some cells; post-seismic electrical capacity checks were made on cells which "survived"; selected cells were disassembled and evaluated; material tests were performed as necessary; and the results were analyzed and reported.

3.1 Report Format

Ontario Hydro staff performed all testing and analyses; their results, presented in four stand-alone reports, are included as Appendices:

A: Seismic Testing of Naturally Aged Station Battery Cells

B: Seismic Testing of Fitzpatrick Nuclear Generating Station Batteries-Cell Inspection and Capacity Tests

C: Seismic Testing of Fitzpatrick Nuclear Generating Station Batteries (Gould Model NCX-2250)

D: Seismic Testing of Fitzpatrick Nuclear Generating Station Simulated Battery Rack with Cells

Appendix A is the collection and summary of the complete Ontario Hydro effort along with results, conclusions, and recommendations sections.

Appendix B describes the pre-seismic cell conditioning, pre- and post-seismic electrical capacity tests, and results of the post-seismic degradation evaluation and material studies. Attachment 1 to the report provides cell specifications provided by the battery manufacturer; Attachment 2 provides discharge data obtained during the seismic tests;calculations to convert discharge times at the 1.5-hour rate to the 3-hour rate are shown in Attachment 3; postmortem information is shown in Attachment 4; and Attachment 5 reports on the brittle fracture analyses of the terminal posts and plates.

Appendix C reports on the seismic testing of the battery cells in the single-cell configuration. The report describes the test procedures followed, the test equipment used, and interprets the results of the tests. Sixty figures show the response spectrum in each of the X, Y, and Z axes from accelerometers located both on a terminal post of the cell and on the base of the shake-table mounting jig.

Appendix D reports on the seismic testing of the battery cells in a multicell configuration. It follows the same format of Appendix C in describing the test procedures, equipment and results. Twenty-two figures show the response spectrum in the three axes from accelerometers located both on a terminal post of the cell and on the base of the shake-table mounting jig.

In addition, Sections 4-6, which follow, draw from the Appendices the salient results, conclusions and suggested follow-on activities as determined by Sandia staff.

4.0 SEISMIC-FRAGILITY TESTS OF NATURALLY-AGED GOULD, NCX-2250, CELLS

4.1 Cells Selection and Condition

Some 60 12-year old cells were retired from service at the Fitzpatrick Nuclear Generating Station, largely on the basis of overall battery capacity loss and observed cracks in some of the polycarbonate cases.[18] A total of twenty cells, "randomly" selected, were supplied for this testing.

Neither the loss-of-battery capacity nor the case cracks invalidate our test results. First, we selected for these tests, those cells which had sufficient capacity (not withstanding the overall battery capacity). Thus, the cells were not degraded to a beyond "end-of-life" condition. Second, those cells which had case cracks were desirable for the specific study of crack propagation. We are fully aware that the specific cracking of these cases has been attributed to the improper use of a "lubricant" on the case.[19] However, the root cause is not important to us, only that cracks were present (so crack-propagation tests could be performed).

4.2 Results During Seismic-Fragility Tests

Single-Cell Electrical Tests

The appendices describe the test methods, results, and analyses in detail. The results are only highlighted here. The table below summarizes the results.

While, in general, there was a broad range of g-levels at which "failure" occurred, the g-levels are rather extreme. For the data shown in Table 1, the cells were rigidly mounted to the table. This was confirmed by accelerometers mounted on a cell terminal post and on the shake-table mounting jig; their respective data were initially identical.

Table 1

Single-Cell Electrical Tests

Cell No.	Test Sequence Span Setting	"Best-Fit" ZPA Response Levels-g (x/y/z)	Comments
13	2		
	3		
	4		
	5	1.6/1.9/1.9	-Loss of voltage, considerable loss of electrolyte around terminal posts
	6		
3	2		
	3		-Voltage increased
	4		-Voltage dropped, then recovered
	4		
	5		
	6	1.7/2.0/2.2	-Voltage dropped steadily, below 1.7 V
6	4		
	5		
	6		
	6.8	1.8/2.5/2.2	-No failure
7	4	1.4/1.8/1.8	-Rapid loss of voltage
43	5		
	6	1.6/1.9/2.0	-Loss of voltage to failure
12	5		-Loss of voltage but not to failure
	6	2.0/2.1/2.2	-Loss of voltage but not to failure
	5		-Voltage loss to failure
14	5		
	6		
	6.8	1.9/2.0/2.5	-No failure
48	5	1.3/1.6/1.7	-Cell lost voltage almost as soon as shaking started

The span setting nominally indicates equivalent vibration levels, but because of the use of a random signal, the input acceleration varied from test to test. There is, however, an approximate one-to-one relationship between span settings and maximum acceleration response levels; i.e., a span setting of 3 is "equivalent" to a maximum acceleration of 3-g.

The "Best Fit" ZPA Response Levels are the zero period accelerations of a normalized spectrum hand fitted to the experimental data over the 4 to 33 Hz range. The ZPA is used to express the intensity of the seismic motion of a typical seismic environment. The ZPAs shown are for the spectra when the cells failed (voltage dropped to below 1.7 volts) or shake table limits were reached (cells survived).

Multi-Cell (Rack-Mounted) Tests

The goal here was to check for the influence of the rack on the cell responses and for the effect of typical rigid cell-to-cell electrical couplers between cell terminal posts. Table 2 summarizes the results.

Because of the few cells available, both electrically-active and water-filled cells were used (as noted under "comments" in the table). But overall, there seemed to be no particular difference in cell-response from that observed in the single-cell, rigidly-mounted, testing.

Table 2

Multi-Cell, Rack-Mounted, Tests

Cell No.	Test Sequence Span Setting	"Best-Fit" ZPA Response Levels-g (x/y/z)	Comments
49 42,25			-Test on three water-filled cells. Cells interconnected but no electrical monitoring.
	3		-Some leakage from previously cracked sample
	4		-Some spill from vents
	5	1.4/1.5/0.9	-Some spill from vents -End bar on rack loosened and cells shifted longitudinally
	6	1.5/2.0/1.0	-End cell (49) fractures on lower corner - no apparent previous cracking. Posts lift on center cell (42)
	6.8		-Bottom of cell 49 breaks off -Posts and bus bars broken on cell 42 -Overall - loosening of bolts on interconnection and frame
30 23, 8			-Cells 23 and 8 filled with electrolyte and loaded electrically
	3		-No apparent damage
	4	1.1/1.3/0.74	-No apparent damage. Frame bolts require retightening.
	5	1.5/1.7/0.93	-Cell 23 fails electrically -Some jar cracking in cell 30 (water filled)

Crack-Propagation Tests

To examine a separate failure mode, crack-propagation tests were done on a few cells that were already cracked. (See also the discussion under Section 4.1). Table 3 summarizes these results; water replaced electrolyte in these tests, and no electrical connections were made to the cells.

Table 3

Crack-Propagation Tests

Cell No.	Test Sequence Span Setting	"Best-Fit" ZPA Response Levels-g (x/y/z)	Comments
15			
	3		-Jar clamped in jig-no crack propagation
	4		-Jar clamped-no crack propagation
	4		-Jar loose-sidecrack grew 3mm
	5		-Jar loose-no further cracking
	6		-Jar clamped; 103 mm crack grew to 140 mm
	6	1.5/2.5/2.3	-Jar clamped; 140 mm crack grew to 310 mm
25	4		-Jar loose
	5		-Run aborted when clamping bars fell off
	5		-No apparent crack propagation
	6.8	2.0/3.1/2.2	-No apparent crack propagation

Cracks were propagated in these tests, as indicated in the "comments" to the table. And, as noted in Table 2, during a multi-cell test, cell 49 catastrophically lost a section of the case. We would conclude that cell cracking is a potential failure mechanism through leakage of electrolyte but of second-order <u>in these tests</u> to electrical failure.

4.3 Post-Test Disassembly and Evaluation

Plate Growth

As Ontario Hydro staff reported in Appendices A and B, "In general, all plates and separators were in very good condition. The negative plates were easily scratched to reveal lead metal, and the positive grids showed minimal loss of active material. No evidence of significant plate growth was detected and positive active material could be removed easily with a knife--it was not unduly compressed."

We believe this finding is particularly significant in defining an acceptable accelerated-aging methodology. Based upon the results observed and contrary to IEEE-535[14] exceptions, it seems inappropriate to determine an accelerated age based upon plate growth, at least for these cells.

Internal Failure Modes

The following paragraphs are taken from Appendices A and B:

> "All seismically tested cells and one non-tested cell (#15) were disassembled and inspected for internal damage... The cells which failed electrically during the shaking tests all experienced fractures in the connection between the posts and bus bar supporting the positive plates.
>
> "The lead in the region where the fractures occurred was found to be heavily corroded and extremely weak. Bus bar material was found to crumble easily when manipulated by hand. Microscopic examination of the material showed that corrosion had proceeded along the grain boundaries and that the grain size of the samples from cells which had failed in this region was relatively large. When samples from cells which had survived the shaker tests up to the the machine limit were examined, it was found that the metal grain size was much smaller than for the failed cells and that the degree of corrosion was much more limited.
>
> "All of the cells which failed had fractures on the positive side. This is apparently because the more severe chemical environment around the positive plates promotes heavier corrosion. One cell had a minor fracture on the negative side.
>
> "A metallurgical examination of positive and negative post/bus interface from cells 7 (failed) and 14

(passed) was performed to determine the nature of brittle and ductile interface areas, respectively. The analysis identified the following:

1. Brittleness in seismically-failed cell positive or negative bus materials was characterized by an extremely coarse grain size material, prone to intergranular fracture.

2. Fracture paths deliberately induced in ductile material from seismically-passed cell positive or negative buses were primarily transgranular, and through sound, fine-grained material.

3. Brittle materials (cell 7) exhibited extensive intergranular decohesion behind the fracture face and interfacial decohesion between bus and post material.

4. Coarse grain size almost certainly originated with the cell manufacturer's casting process.

5. Creep is a possible failure mechanism for brittle material but the precise failure mechanism remains obscure.

6. Intergranular corrosion may be a significant contributor to failure.

"The results of these investigations suggest that the failure of the bus bars was due to a combination of unsuitable material properties and chemical attack. It was not immediately apparent why the grain size of the lead in the bus bars of the failed cells was larger than that in the surviving cells. To check whether this might be the result of manufacturing conditions, samples from the negative bus bars of failed and surviving cells were compared. It was found that again, grain sizes were much larger in the cells where fracture had occurred. Oxidation was much less apparent on the negative side. This suggests that the large grain size was developed during the process and was not due to in-service conditions. The hypothesis, that the problem arose during manufacturing, is supported by the observation that all of the cells which failed bore serial numbers between 130 and 155, while the serial numbers of the surviving cells were 022 and 024.

"Another failure mode that occurred during the multi-cell tests was lifting and twisting of the connector posts. This was apparently due to the mechanical forces exerted by the rigid connecting bars joining the cells. We believe that these forces could make the cells more vulnerable to failure in the bus bar region, but our test sample was too small to provide any estimate of the change in fragility level."

The manufacturing-process deficiency hypothesis suggested by Ontario Hydro staff may prove correct and is appealing. The data are not conclusive, and this issue will certainly be included in follow-on activities. For example, we plan to obtain new cells of the same type and conduct baseline evaluations of these cells as received and after accelerated aging.

5.0 CONCLUSIONS

The Appendix A conclusions are repeated here:

1. Six of the nine 12-year old cells, selected at random from approximately sixty cells retired from service at the James A. Fitzpatrick Nuclear Power Station, failed under electrical load during shaking. One which did not fail electrically suffered significant internal damage.

2. Electrical failure of the test cells was caused by severe cracking of abnormally brittle positive bus material and/or disconnection of positive posts from the bus material.

3. Decohesion, leading to fracture, occurred mostly along the boundaries of extremely large lead grains and was assisted by chemical corrosion. Coarse grain structure can be attributed to abnormalities in the bus casting process.*

4. Internal components and connections in two cells without bus defects were extremely durable. These cells survived violent and repeated seismic testing and were capable of meeting the acceptance criterion of 80% of rated capacity after the test.

5. Plates and separators were generally in very good condition, with no significant plate growth.

---

* Proof of a manufacturing-process anomaly is not yet available.

6. Failures in the cell jars also occurred after repeated testing at high acceleration levels. These failures lead to electrolyte leakage.

7. The fragility level of cells mounted together in batteries appears to be marginally lower than the fragility level of cells tested individually, due to amplification of seismic motion through the rack and because of relative movement between the cells and the rack.

8. The failure modes observed during these tests may be specific to this type of cell or even to this particular installation. Testing should continue to include samples from other manufacturers.

9. The tests described in this report do not imply that this type of cell is, or is not, seismically qualified for any particular installation. The objective of the tests was to identify failure modes in naturally-aged cells so that the cells were shaken repeatedly at high acceleration levels until damage occurred.

6.0 RECOMMENDATIONS FOR FOLLOW-ON ACTIVITIES

Ontario Hydro staff offered these three recommendations, in **Appendix A**:

1. The principal mode of deterioration of these cells was the corrosion at the grain boundaries of the positive bus bars. Where metal grain size was large, this corrosion seems to have reduced the electrical capacity of the cells and reduced their mechanical strength. We recommend that manufacturing processes and quality assurance procedures be reviewed to eliminate coarse grained structures in the internal components of lead acid storage cells.

2. Because the failure mode may be specific to the cells that were tested, samples from other manufacturers should be tested before general conclusions are drawn about the fragility level of aged cells.

3. The battery rack used in these tests was designed to simulate the racks typically used in seismically qualified systems. On the basis of our observations of the behavior of a set of cells in this rack during a simulated earthquake, we offer the following suggestions:

   - Cells should be restrained vertically if the vertical component of the floor motion is expected to exceed 1 g.

- Cells that are tied together with rigid connectors tend to move together. This means that a cell on the end of a long string could be subjected to large forces if it is crushed between its neighbors and the end of the rack. In severe seismic environments, it would be beneficial to separate the cells into groups of three or so, with rigid partitions on the rack and flexible electrical connections between groups.

We certainly concur in the first two recommendations, and pass along the third to the user-utilities for their consideration and/or incorporation.

These follow-on activities are the subject of our continuing investigation into naturally-aged batteries seismic-fragility.

1. Naturally-aged cells from Calvert Cliffs (manufactured by Exide) and from North Anna (manufactured by C&D) are scheduled for similar seismic-fragility testing. This will result in the testing of battery cells from all three manufacturers.

2. New cells have been ordered from all three manufacturers for "baseline" tests and to attempt to address the question of manufacturing-process deficiencies.

3. The required response spectrum (RRS) for battery locations at a number of nuclear power plants will be obtained for comparison with the fragility levels obtained by this testing. (We anticipate the fragility levels of these Class 1E battery cells will exceed the RRS of most plants.)

4. Depending on failure modes observed in subsequent testing, additional lead-chemistry evaluations may be conducted.

7.0 REFERENCES

1. LER 75-4, Turkey Point-4, "Cracked and Buckled Plates," Event date: October 13, 1974, Report date: October 23, 1984.

2. LER 77-55, Fitzpatrick-1, "Cracked Battery Cell Case," Event date: October 20, 1977, Report date: November 14, 1977.

3. LER 79-59, Fitzpatrick-1, "Cracked Battery Cell Case," Event date: September 4, 1979, Report date: October 2, 1979.

4. LER 81-42, Browns Ferry-1, "Cracked Cell," Event date: July 22, 1981, Report date: August 14, 1981.

5. LER 82-7, Indian Point-2, "Battery Inoperable Due to Cracked Cell," Event date: February 2, 1982, Report date: March 19, 1982.

6. LER 82-16, Indian Point-2, "Battery Cell Cracks," Event date: April 23, 1982, Report date: May 24, 1982.

7. LER 82-6, Connecticut Yankee, "Cracked Emergency DC Battery Cells," Event date: September 19, 1982, Report date: October 5, 1982.

8. Eric W. Weiss, Possible Generic Battery Problem, Memo for R. William Mills, Chief, Events Analysis Branch, Office of Inspection and Enforcement, Nuclear Regulatory Commission, November 26, 1982.

9. IE Information Notice No. 83-11, Possible Seismic Vulnerability of Old Lead Storage Batteries, Office of Inspection and Enforcement, Nuclear Regulatory Commission, Washington, D.C., March 14, 1983.

10. Frank Ashe, Degradation of Safety-Related Batteries Due to Cracking of Battery Cell Cases and/or Other Possible Aging-Related Mechanisms, AEOD Engineering Evaluation Report, AEOD/E307, Nuclear Regulatory Commission, April 18, 1983.

11. L. L. Bonzon, et al., "An Overview of Equipment Survivability Studies at Sandia National Laboratories (SNL)," SAND83-0759C, Proceedings of the ANS/ENS International Meeting on Light Water Reactor Severe Accident Evaluation, Cambridge, Massachusetts, August 28 - September 1, 1983.

12. T. Lowen, Ontario Hydro Report 77-221-H, Seismic Qualification Tests for Nuclear Generating Station Batteries, Toronto, Ontario, Canada, May 17, 1977.

13. Ltr, L. L. Bonzon, SNL, to William Farmer, NRC, Subject: "Test Plan to Evaluate Nuclear Station Class 1E Battery Aging Methodologies," dtd June 20, 1984

14. "IEEE Standard for Qualification of Class 1E Lead Storage Batteries for Nuclear Power Generating Stations," IEEE Std. 535-1979.

15. "Nuclear Environmental Qualification Report of KC-9, KC-21, and LC-25 Battery Racks and Cells," Report Number A-472-82, Corporate Consulting and Development Company, Ltd., Raleigh, North Carolina, June 23, 1982.

16. Personal discussions between L. L. Bonzon and D. B. Hente, Sandia National Laboratories, and members of American National Standards Committee C40, Storage Batteries, Albuquerque, New Mexico, September 1983, and B. E. Bader, Sandia National Laboratories, and GNB personnel, Langhorne, Pennsylvania, March 1984.

17. Ltr, L. L. Bonzon, SNL, to William Farmer, NRC, Subject: "Test Plan for Seismic Testing of Naturally-Aged Nuclear-Station Stationary Battery Cells," dtd June 12, 1984.

18. Ltr, from R. W. Hopewell (GNB Batteries, Inc.) to D. Ruddy (Fitzpatrick Nuclear Power Plant), Subject: "Cracked NCX-2250 cell containers," dtd June 24, 1983.

19. A. J. Vecchio, Cracked Gould NCX-2250 Battery, Lucius Pitkin, Inc., L. P. No. M-7210, New York, New York, June 28, 1983.

APPENDIX A

SEISMIC TESTING OF NATURALLY-AGED STATION BATTERY CELL

J. D. Tulk

Ontario Hydro Research Division

ontario hydro
research division

EXECUTIVE SUMMARY

SEISMIC TESTING OF NATURALLY AGED STATION BATTERY CELLS

J.D. Tulk
Applied Structural and Solid Mechanics Section
Mechanical Research Department

A sample of 12 year old lead acid storage battery cells from a nuclear power station were tested for seismic fragility level on a shaker table. Of the nine cells that were electrically active during the shaker tests, six failed due to severe cracking of the positive bus connecting the posts to the positive plates. It was found that the metal in the failure zone was extremely coarse grained and extensively corroded. The grain structure is apparently due to unsuitable casting technique, while the degree of corrosion will increase with age. Cells from the same sample with fine grained lead in the connector busses were able to survive shaker tests up to the table limits without unacceptable loss of electrical capacity.

Cell jar failures were observed, but only for specimens with significant prior cracking, and only after repeated, violent shaking. Six cells were tested in a battery configuration, ie, mounted on a rack and interconnected with solid connecting bars. During these tests, one electrical failure and one jar failure occurred.

job	file	date	report no.
740621-108-450	825.92	July 25, 1984	84-211-K

TABLE OF CONTENTS

ontario hydro
research division

To Mr. B.A. Oliver
Manager
Electrical Design Department

SEISMIC TESTING OF NATURALLY AGED
STATION BATTERY CELLS

1.0 INTRODUCTION

The large lead-acid storage battery cells that are the subject of this report are used to provide DC power for nuclear power stations during and following an earthquake. It is well known that these cells deteriorate with age and it is normal practice to test their electrical capacity at regular intervals to ensure that they are capable of meeting a specified adequate level of performance. What is not so well understood however, is the effect of age on the mechanical fragility of the cells and whether aged cells would be capable of surviving earthquakes at operating basis earthquake (OBE) and safe shutdown earthquake (SSE) levels and continue to meet the load profile required by the Class 1E System. Because of the importance of storage batteries to the Class 1E System, the US Nuclear Regulatory Commission staff has requested Sandia National Laboratories (SNL) to evaluate the impact of aging and seismic exposure on battery cell capacity. Ontario Hydro has been sub-contracted to carry out capacity and seismic shaker table tests on naturally aged cells supplied by SNL from several US nuclear power stations (SNL contract 47-4077). The program will address possible variations between designs produced by different manufacturers.

This report describes the results of a series of experiments carried out at the Ontario Hydro Research Division laboratories on a set of twelve year old Gould NCX2250 cells selected at random from a larger group from the James A. Fitzpatrick Nuclear Power Station (New York Power Authority). The tests were designed to determine the fragility level of the cells (ie, the level of shaking above which the cells would experience damage that would reduce their capacity) and the associated failure modes. Material analysis was carried out to determine if the failures that occurred in the bus bars of some cells were due to age-dependent deterioration of the material.

The present project is centred on the study of the seismic withstand capabilities of naturally aged cells. For the qualification of cells being installed in plants, it is not normally possible to obtain suitably aged specimens for testing. A long term objective will be to investigate present methods for artificially aging new cells to ascertain that the mechanical properties of cells nearing the end of their useful life can be reproduced in newly manufactured cells.

This report summarizes the tests and results and presents recommendations while the details of the tests and results are presented in separate reports. Report C84-49-P presents battery condition and performance data obtained before, during and after the shaker table tests, while Reports B84-37-P and B84-39-P describe the shaker tests. A test plan prepared for this project by SNL is included in the present report as an appendix. The material problem that was later identified as a main contributor to cell failure was not anticipated when this plan was prepared, so that much of the investigative work described in Report C84-49-P is not included in the test plan.

2.0 BACKGROUND

Some preliminary shaker table tests on station batteries were carried out at Ontario Hydro in 1977/1/. During these tests a group of new or nearly new cells survived sine-sweep tests (input amplitude between 1.2 and 2 g) while the oldest member of the sample, a 16 year old veteran failed. While this experiment suggested that old cells are more fragile than new ones, the sample was too small and the input accelerations were too large to provide a clear conclusion. Ontario Hydro has recently done seismic testing on a sample of eight 13 year old lead-antimony cells (Gould FKR, 912 A-h rating) from a nuclear power station. This set of cells survived simulated earthquake motions without significant loss of capacity/2/. These cells were tested singly in a very stiff mounting rig and on a multi cell rack, patterned on a typical seismically qualified battery rack.

3.0 TEST METHODS AND RESULTS

The test methods and results are summarized in this section. A more detailed record of the test data is contained in the other test reports.

3.1 Initial Inspection and Conditioning

Twenty Gould NCX2250 cells were received from the Fitzpatrick plant. Most of the cells had cracks in the clear plastic jar material. The degree of cracking varied from minor to severe with six of the cells so badly cracked that they leaked electrolyte. These cells had been drained before they were shipped to Ontario Hydro. Jar cracking has been attributed to chemical attack on the plastic by an inappropriate lubricant material that was used when the cells were slid into place on the racks/3/. (The nature of the damage on some cells suggested that handling mishaps may have also contributed to jar cracking).

Once inspected for superficial damage, the cells were conditioned (charged and discharged for several cycles to stabilize their condition) and tested for capacity. The electrical state of the cells prior to the seismic tests is summarized in Table 1.

3.2 Seismic Testing - Single Cells

The shaker table and instrumentation used in these experiments is described in Report B84-39-P The table provides independent motion on each of the three axes. The motion is based on a quasi-random signal, filtered to match the frequency content of a typical earthquake. The duration of each test was 30 s. The seismic test method conformed to the recommendations of IEEE Std 344-1975 and IEEE Std 501-1978.

For the first phase of seismic testing, the cells where mounted on the shaker table in a frame which was designed to minimize relative motion between the table and the jar (see Figure 1). This series of tests was intended to investigate failure modes of the internal components of the cell and the rig was designed to minimize the possibility of a general jar failure and acid spill. Accelerometers were mounted on the base of the frame and on one of the top posts of the cell.

Each of the cells was subjected to a series of tests at successively higher acceleration levels. The test sequence for each cell is shown in the test log given in Table 2. In this record, the acceleration level for each test is quoted in terms of the span setting of the amplifier in the shaker control system. Because the input motion is random, it is impossible to make an exact correlation between the span setting and the input acceleration. An approximate relationship between span setting and acceleration response level is given below.

Span Setting	ZPA of Fitted IEEE 501 Spectrum (g)	Maximum Acceleration (g)
2	0.8	2
3	1.2	3
4	1.6	4
5	2.0	5
6	2.3	6
6.8 (machine limits)	2.5	6.5

The acceleration data is presented in Report B84-39-P in terms of acceleration response spectra. (For an explanation of response spectra see reference/4/). To provide a convenient means of comparing the acceleration levels encountered during various tests, each test spectrum is compared to a normalized spectral shape defined by the IEEE Standard 501/5/. This spectral shape is intended to represent the frequency content of a "typical" seismic environment for electrical equipment. According to this representation, the intensity of the simulated seismic motion is expressed in terms of the ZPA (Zero Period Acceleration); the peak acceleration of a hypothetical oscillator with a natural frequency above 33 Hz. Because a high frequency oscillator is stiff, it will tend to follow the base motion quite closely so that the ZPA effectively represents the peak acceleration of the base.

According to the IEEE 501 standard, the normalized spectrum curve is to be scaled to lie below the experimental spectrum at all frequencies between 1 Hz and 33 Hz. Figures 4 through 45 show samples of the experimental results reproduced from reports B84-39-P (single cells) and B84-37-P (multi-cell racks). The dashed lines on these plots show normalized IEEE 501 spectra that were scaled to meet this standard. Examination of these figures reveals that in many instances, the scaling level of the IEEE 501 curve is set by a relatively low level of response at the low end of the frequency scale. As a result, the normalized spectrum may lie substantially below the test spectrum over much of the frequency range. Because the battery cells and racks are relatively stiff structures, with no natural frequencies below 10 Hz, the low frequency component of the shaker motion has little influence on the response of the cells. This means that the normalized curves, for which the scaling level is dominated by low frequency response, will not reflect the true acceleration levels. To provide more meaningful ZPA data, we have fitted an alternative set of normalized spectra to the experimental data over the 4 Hz to 33 Hz range. These alternative spectra are shown on Figures 4 through 45 as double lines. Tables 2 and 3 show test logs for the single cell and multi-cell rack tests. The response levels quoted in these tables are ZPA levels determined for IEEE 501 normalized spectra fitted over the 4 to 33 Hz range.

Cells were tested at progressively higher acceleration levels until they failed or until the machine reached its upper limit. Failure was taken to occur when the cell was no longer able to maintain a voltage of a least 1.75 V when discharging against a resistive load at a 1.5 h discharge rate (approximately 1000 A).

A total of eight cells were tested for electrical capacity loss during shaking. Two cells survived up to the shaker table limit. Four more failed after two or more shaker tests while the other two failed during the first shake. Of these last two, one cell (No 48) was tested later and found to be functioning normally, indicating that the apparent failure was due to a loss of electrical contact in the instrumentation circuitry during the test. (See Table 2).

The failure mode in each of the cells that failed electrically was a fracture of the connection between one or both of the positive posts and the bus bars connecting the posts to the positive plates. The details of this failure mode are discussed later.

3.3 Crack and Craze Propagation

The integrity of the jar material was investigated for specimens with significant prior cracking. The samples for these tests were selected from the six that had been shipped dry. The cells were filled with water and neutralized with sodium bicarbonate to reduce the safety hazard. The cells were then shaken to see if any of the cracks in the jars could be made to propagate. For several of the test runs, the clamping mechanism on the support frame was loosened so that the cell was free to move around inside the frame and the shock loading was higher. These tests were informal in the sense that they did not simulate any particular operating condition. The results of these tests indicated that cell jars could be made to crack only after repeated violent shaking (see Table 2).

3.4 Multi-Cell Rack Tests

The mounting arrangement for the single cell tests was designed to minimize the possibility of jar failure. This meant that the tests focussed on failure modes of internal components. To examine the failure modes, due to cell-to-cell interactions, that would be encountered with normal in-plant mounted arrangements, shaker tests were carried out using a three cell battery rack based on the designs for seismically qualified station battery racks (Figure 2).

The test log for the multi-cell rack tests is shown in Table 3.

The first set of cells tested was selected from the group with significant cracking of the jar material. The electrolyte was replaced with water to reduce the safety hazard in the event of a jar failure. The shaker test was repeated five times at successively higher acceleration amplitudes. Two failure modes were observed: cracking on the bottom of one of the end cells (during the final test, the bottom of this cell effectively broke off, see Figure 3); and lifting of the connecting posts of the middle cell. Because the cells were not functioning electrically, the level of shaking at which internal damage occurred is not known.

For the second set of tests, two electrically live cells were used, combined with one water-filled "dummy". Again, the cells were mounted in the rack and electrically interconnected with copper tie bars. The cells were subjected to a series of shaking tests at increasing amplitudes. In this instance, an end cell failed electrically on the third test due to a fracture of the connection between the posts and the internal positive bus bar. The pre-cracked end cell showed some leakage after this test. The center cell showed some cracking, but had not failed at the point when the testing stopped.

3.5 Impact Tests on Rack

As described in Report B84-37-P, the battery rack was tested in the loaded condition to determine the natural frequencies of the predominant vibration modes. Two modes were found, a side-to side mode at about 10.8 Hz and a longitudinal mode around 12.8 Hz. This implies a relatively stiff structure, with limited amplification of table motion. During the shaker tests, it appeared that flexing of the rack was small when compared to the movement of the cells relative to the rack.

4.0 DISCUSSION OF RESULTS

4.1 Internal Failure Modes

The cells which failed electrically during the shaking tests all experienced fractures in the connection between the posts and the bus bar supporting the positive plates (see Report C84-49-P, Figure 3). Following the shaker tests, several of the failed cells were opened for a more detailed examination of this region. The results of this examination are discussed in Report C84-49-P. The following is a brief summary of these findings.

The lead in the region where the fractures occurred was found to be heavily corroded and extremely weak. Bus bar material was found to crumble easily when manipulated by hand. Microscopic examination of the material showed that corrosion had proceeded along the grain boundaries and that the grain size of the samples from cells which had failed in this region was relatively large. When samples from cells which had survived the shaker tests up to the machine limit were examined, it was found that the metal grain size was much smaller than for the failed cells and that the degree of corrosion was much more limited.

All of the cells which failed had fractures on the positive side. This is apparently because the more severe chemical environment around the positive plates promotes heavier corrosion. One cell had a minor fracture on the negative side.

The results of these investigations suggest that the failure of the bus bars was due to a combination of unsuitable material properties and chemical attack. It was not immediately apparent why the grain size of the lead in the bus bars of the failed cells was larger than that in the surviving cells. To check whether this might be the result of manufacturing conditions, samples from the negative bus bars of failed and surviving cells were compared. It was found that again, grain sizes were much larger in the cells where fracture had occurred. Oxidation was much less apparent on the negative side. This suggests that the large grain size was developed during the process and was not due to in-service conditions. The hypothesis, that the problem arose during manufacturing, is supported by the observation that all of the cells which failed bore serial numbers between 130 and 155, while the serial numbers of the surviving cells were 022 and 024.

4.2 Crack and Craze Propagation

As mentioned above, many of the cells had small cracks in the jar material while a few had major cracks large enough to cause leaks. Except for some large holes that appear to have been caused by handling accidents, the cracks were located on the bottoms of the jars and on the sides, in bands where the side rails of the battery racks contacted the cells. The cracks on the cells sides were generally less than 50 mm long and 5 mm deep. (Wall thickness was about 8 mm.) This cracking had been a cause of concern to the original owners of the cells and had been the subject of a study commissioned by them/3/. The cause of cracking implicated by that investigation was the use of an unsuitable lubricant material while the cells were being installed.

The first stage of crack and craze propagation tests were an attempt to determine if simulated earthquake shaking would cause the cracks to grow significantly. These tests, carried out on single cells, showed that the cracks could be made to grow. However, this required repeated nigh amplitude shaking. Short and shallow cracks showed little tendency to grow compared to longer, through-wall cracks. Most crack growth occurred when the cell restraints were loosened, indicating that much of the damage was done when the cases impacted the restraining frame. The loss of compressive stresses on the jars in the region of the cracks may also have contributed to crack growth.

Case cracking occurred during the multi-cell tests as well. Again, repeated, high-amplitude shaking was required to develop significant damage. This appeared to be due to the repeated, violent impact between the cells and the mounting frame that occurred when the vertical component of the table motion exceeded 1 g. During testing, the cells were observed to lift above the supporting structure and to strike the support heavily as they fell back.

4.3 Post Failures

Another failure mode that occurred during the multi-cell tests was lifting and twisting of the connector posts. This was apparently due to the mechanical forces exerted by the rigid connecting bars joining the cells. We believe that these forces could make the cells more vulnerable to failure in the bus bar region, but our test sample was too small to provide any estimate of the change in fragility level.

5.0 CONCLUSIONS

1. Six of the nine 12-year old cells, selected at random from approximately 60 cells retired from service at the James A. Fitzpatrick Nuclear Power Station, failed under electrical load during shaking. One which did not fail electrically suffered significant internal damage.

2. Electrical failure of the test cells was caused by severe cracking of abnormally brittle positive bus material and/or disconnection of positive posts from the bus material.

3. Decohesion, leading to fracture, occurred mostly along the boundaries of extremely large lead grains and was assisted by chemical corrosion. Coarse grain structure can be attributed to abnormalities in the bus casting process.

4. Internal components and connections in two cells without bus defects were extremely durable. These cells survived violent and repeated seismic testing and were capable of meeting the acceptance criterion of 80% of rated capacity after the test.

5. Plates and separators were generally in very good condition, with no significant plate growth.

6. Failures in the cell jars also occurred after repeated testing at high acceleration levels. These failures lead to electrolyte leakage.

7. The fragility level of cells mounted together in batteries appears to be marginally lower than the fragility level of cells tested individually, due to amplification of seismic motion through the rack and because of relative movement between the cells and the rack.

8. The failure modes observed during these tests may be specific to this type of cell or even to this particular installation. Testing should continue to include samples from other manufacturers.

9. The tests described in this report do not imply that this type of cell is, or is not, seismically qualified for any particular installation. The objective of the tests was to identify failure modes in naturally aged cells so that the cells were shaken repeatedly at high acceleration levels until damage occurred.

6.0 RECOMMENDATIONS

1. The principal mode of deterioration of these cells was the corrosion at the grain boundaries of the positive bus bars. Where metal grain size was large, this corrosion seems to have reduced the electrical capacity of the cells and reduced their mechanical strength. We recommend that manufacturing processes and quality assurance procedures be reviewed to eliminate coarse grained structures in the internal components of lead acid storage cells.

2. Because the failure mode may be specific to the cells that were tested, samples from other manufacturers should be tested before general conclusions are drawn about the fragility level of aged cells.

3. The battery rack used in these tests was designed to simulate the racks typically used in seismically qualified systems. On the basis of our observations of the behaviour of a set of cells in this rack during a simulated earthquake, we offer the following suggestions:

   - Cells should be restrained vertically if the vertical component of the floor motion is expected to exceed 1 g.

   - Cells that are tied together with rigid connectors tend to move together. This means that the cell on the end of a long string could be subjected to large forces if it is crushed between its neighbours and the end of the rack. In severe seismic environments, it would be beneficial to separate the cells into groups of three or so, with rigid partitions on the rack and flexible electrical connections between groups.

7.0 ACKNOWLEDGEMENTS

Test cells and much of the funding for this project were provided by Sandia National Laboratories. This support is gratefully acknowledged. Lloyd Bonzon and Don Hente of SNL are thanked for their large contribution to the progress of the project. Supplementary funding was provided by the Ontario Hydro Research Division. Within Ontario Hydro, contract co-ordination was handled by the Electrical Design Department. We are grateful to Colin Royce and Jerry Schendel for their efforts. Much of the testing and analysis was carried out by Brian Aucoin of the Chemical Research Department and Gordon Paulson of the Mechanical Research Department. Their very able efforts were essential to the successful outcome of the project.

Approved:

G.J. Clarke
Manager
Mechancial Research Dept

R.W. Glass
Acting Manager
Chemical Research Dept

B.A. Oliver
Manager
Electrical Design Dept
Design & Development Div

Submitted:

J.D. Tulk
Unit Head - Special Projects & Computing
Applied Structural and Solid Mechanics Section

D.A. Black
Engineer
Lines, Materials & Seismology

W.J. Janis
Chemist
Organic Section

B.M. Kukreti
Engineer
Electrical Design Dept

JDT/DAB/WJJ/BMK:km/djb

REFERENCES

1. T. Loewen, "Seismic Qualification Tests for Nuclear Generating Station Batteries". Ontario Hydro Research Division Report 77-221-H, May 17, 1977.

2. D.A. Black, W.J. Janis and J.D. Tulk, "Seismic Testing of Naturally aged Gould FKR Station Battery Cells". Ontario Hydro Research Division Report (to be issued).

3. A.J. Vecchio, "Cracked Gould NCX-2250 Battery", Lucius Pitkin Inc, Metallurgical and Chemical Consultants, June 1983.

4. R.W. Clough and J. Penzien, "Dynamics of Structures", McGraw Hill, 1975.

5. IEEE Std501-1978, "IEEE Standard, Seismic Testing of Relays", The Institute of Electrical and Electronics Engineers Inc, 1978.

TABLE 1

CELL INSPECTION RECORD

Fitzpatrick Cell ID Number	Gould Serial Number	Specific Gravity		Observations
		In Plant (1983)	As Received at OHRD	
3	00155	1.220	1.194	no visible damage
6	K1148	1.232	1.205	no visible damage
7	00154	1.228	1.195	no visible damage
8	K74	1.238	1.209	no visible damage
9	00024	--	--	empty-no visible damage
12	00130	1.236	N/A***	slightly low electrolyte
13	00144	1.232	N/A***	slightly low electrolyte
14	00022	1.230	1.195	no visible damage
15	00158	-	-	empty-no visible damage
16	00177	-	-	empty-cracked seam**
17	00167	-	-	empty-large hole in base**
22	K1149	1.230	1.210	no visible damage
23	00152	1.238	1.200	no visible damage
24	00156	-	-	empty-crack at bottom corner**
25	00143	-	-	leaking-crack on bottom
30	00014	-	-	empty-no visible damage
42	00135	-	-	almost empty-crack on bottom
43	00141*	1.230	1.194	no visible damage
48	00032*	1.236	1.200	no visible damage
49	00181	-	-	empty-no visible damage

* Serial number order may be reversed
** Documentation photograph taken
*** Electrolyte level too low for accurate determination

TABLE 2

TEST LOG - SINGLE CELL TESTS

Cell No	Date	Time	Span Setting	Response Levels-g (x/y/z)	Comments
13	16/01/84	2:22 2:23 2:23 2:24 2:25	2 3 4 5 6	1.6/1.9/1.9	Loss of voltage considerable loss of electrolyte around terminal posts
3	16/01/84	3:17 3:18 3:20 3:21 3:21 3:22	2 3 4 4 5 6	1.7/2.0/2.2	voltage increased voltage dropped, then recovered voltage dropped steadily, below 1.7 V
6	17/01/84	11:32 11:32 11:33 11:34	4 5 6 6.8	1.8/2.5/2.6	no failure
7	17/01/84	2:01	4	1.4/1.8/1.8	rapid loss of voltage
15	18/01/84				Jar crack propagation test -water replaced electrolyte -no electrical connections
		10:48	3		Jar clamped in jig-no crack propagation
		11:02	4		Jar clamped-no crack propagation
		11:08	4		Jar loose-sidecrack grew 3 mm
		11:15	5		Jar loose-no further cracking
		11:26	5		Jar clamped;no further cracking
		11:36	6		Jar clamped; 103 mm crack spread to 140 mm
		11:42	6	1.5/2.5/2.3	Jar clamped; 140 mm crack spread to 310 mm
25	18/01/84	2:17	4		Crack propagation test - jar loose
		2:19	5		Run aborted when clamping bars fell off
		2:38	5		No apparent crack propagation
		2:52	6.8	2.0/3.1/2.2	No apparent crack propagation
43	20/01/84	9:10 9:12	5 6	1.6/1.9/2.0	Loss of voltage-to failure
12	23/01/84	11:08	5		Loss of voltage but not to failure
		11:10	6	2.0/2.1/2.2	Loss of voltage but not to failure
		11:14	5		Voltage loss to failure
14	23/01/84	1:52 1:54 1:56	5 6 6.8	1.9/2.0/2.5	No failure
48	23/01/84	2:58	5	1.3/1.6/1.7	Cell lost voltage almost as soon as shaking started

TABLE 3

TEST LOG - THREE CELL BATTERY TESTS

Cell No	Date	Time	Span Setting	Response Levels (g) x/y/z	Comments
49, 42,25	12/03/84				Test on three water-filled cells. Cells interconnected but no electrical monitoring.
		10:46	3		Some leakage from previously cracked sample
		10:52	4		Some spill from vents
		10:54	5	1.4/1.5/0.9	-Some spill from vents -End bar on rack loosened and cells shifted longitudinally
		11:00	6	1.5/2.0/1.0	-End cell (#49) fractures on lower corner - no apparent previous cracking posts lift on centre cell (#42)
		11:06	6.8		-Bottom of cell 49 breaks off -Posts and bus bars broken on cell #42 Overall - loosening of bolts on interconnection and frame
30, 23, 8	12/03/84				Cells 23 and 8 filled with electrolyte and loaded electrically
		3:39	3		No apparent damage
		3:42	4	1.1/1.3/0.74	No apparent damage. Frame bolts require retightening.
		4:00	5	1.5/1.7/0.93	-Cell 23 fails electrically -Some jar cracking in cell 30 (water filled)

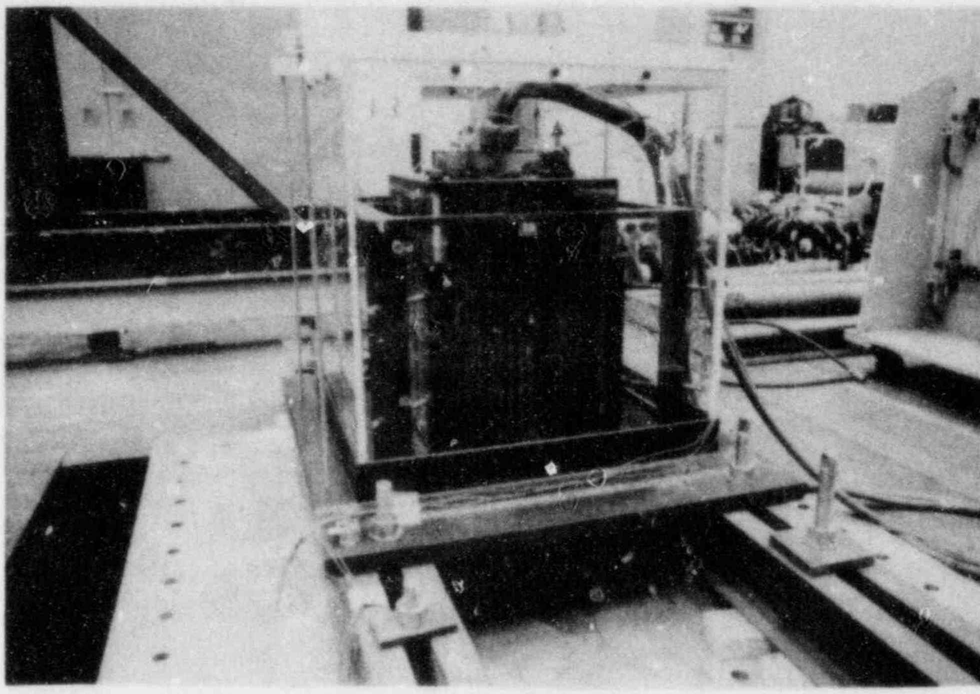


FIGURE 1
Single Cell Test Rig

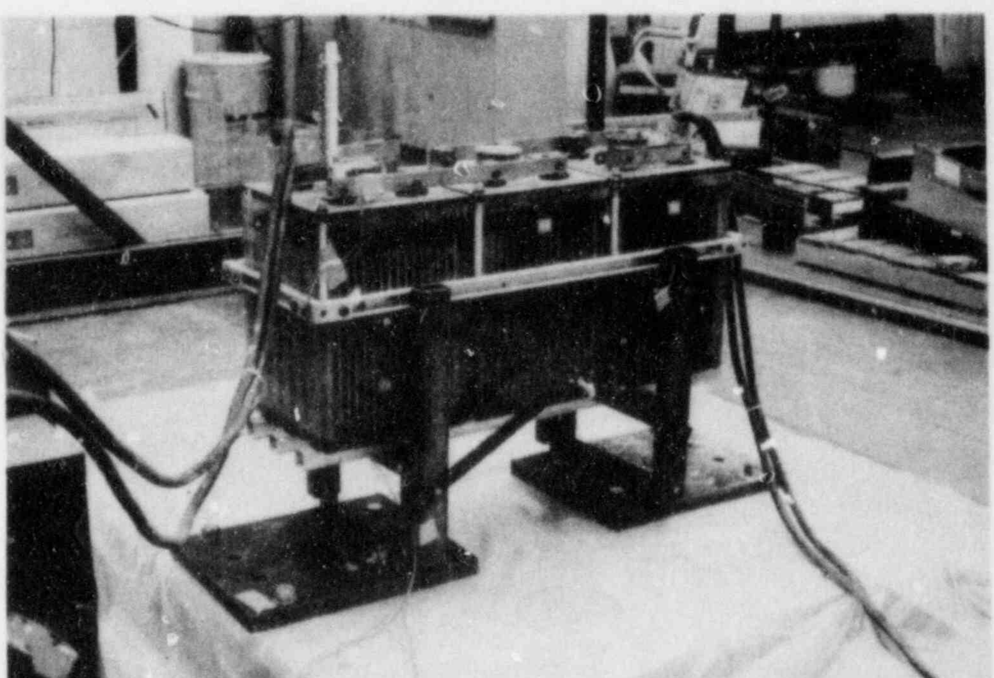


FIGURE 2
Multi-Cell Rack

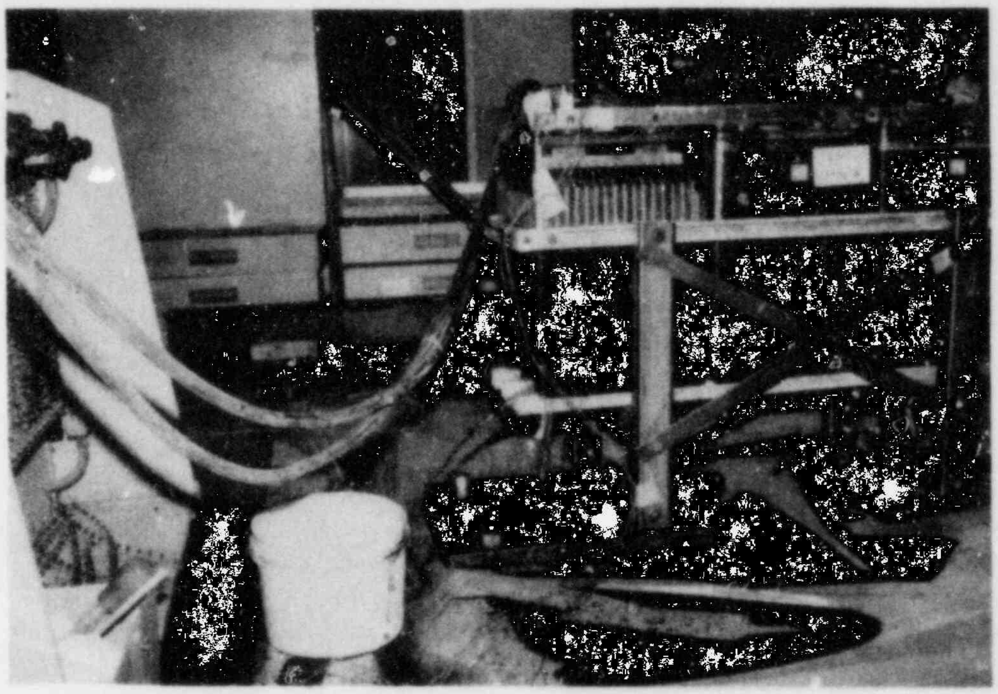
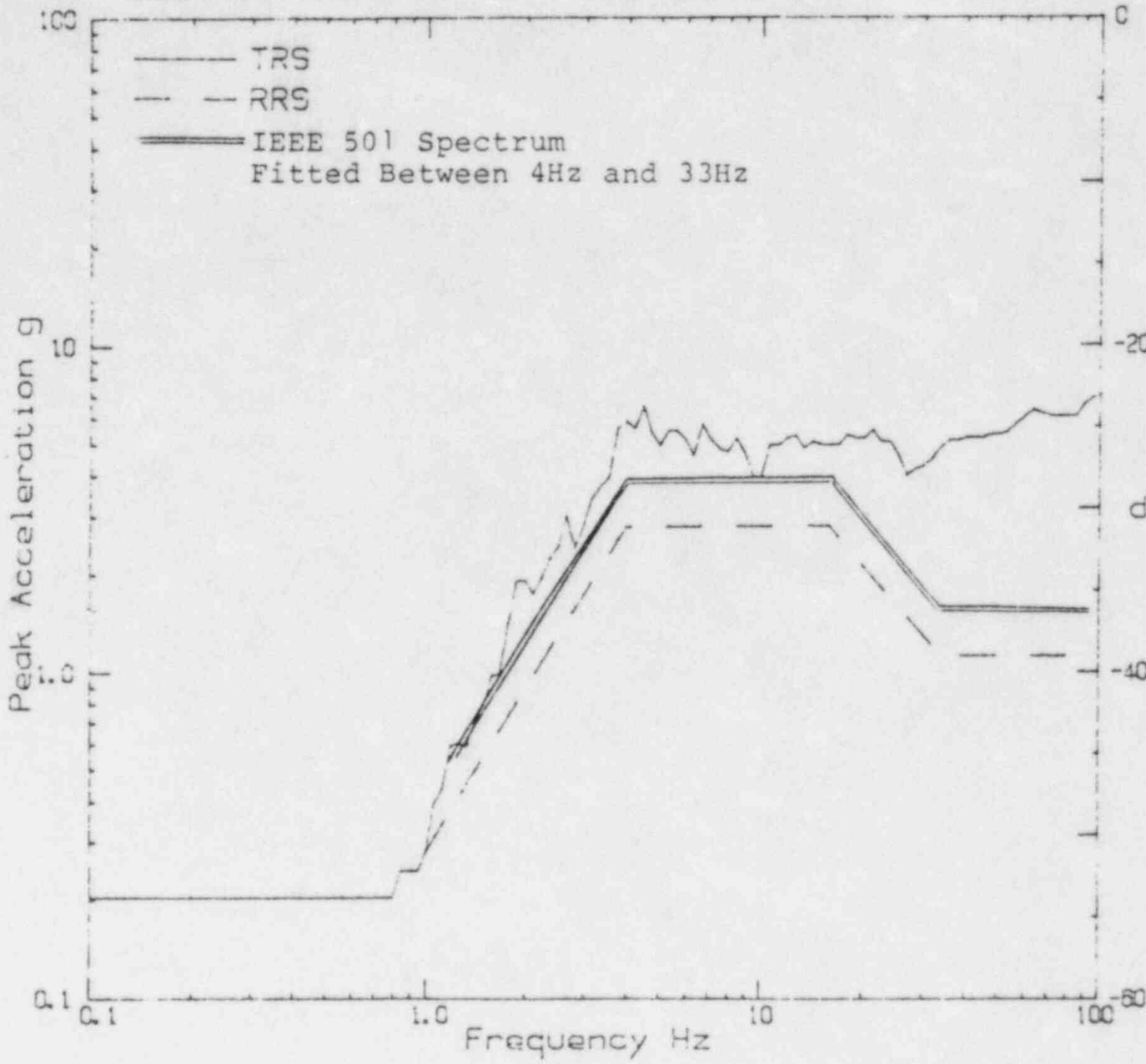


FIGURE 3
Case Failure After
High-Level Shaking

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 4

TEST ITEM
station cells. Gould. Model NCX 2250. #13

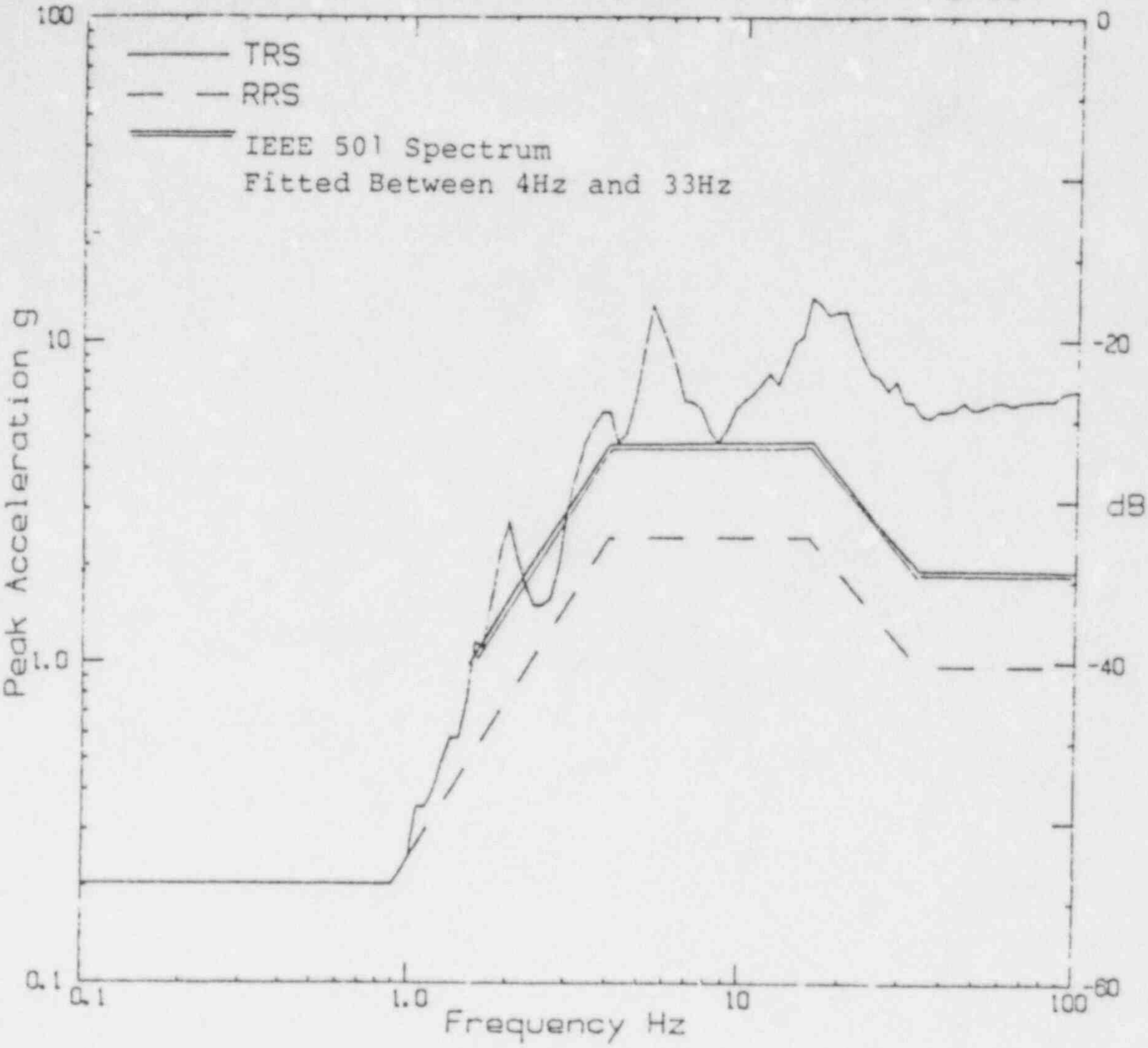
PARTICULARS
Jan 18/84. Time 1:35. Temp('C) 23. Humidity(%) 22. Press (kPa)100.3.
Graph 4963

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 3-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA= 1.6 g

ACCELEROMETER
Wilcoxon. Serial S757. Range d858. Location base-mounting jig.
TT 558. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 5

TEST ITEM
station cells. Gould. Model NCX 2250. #13

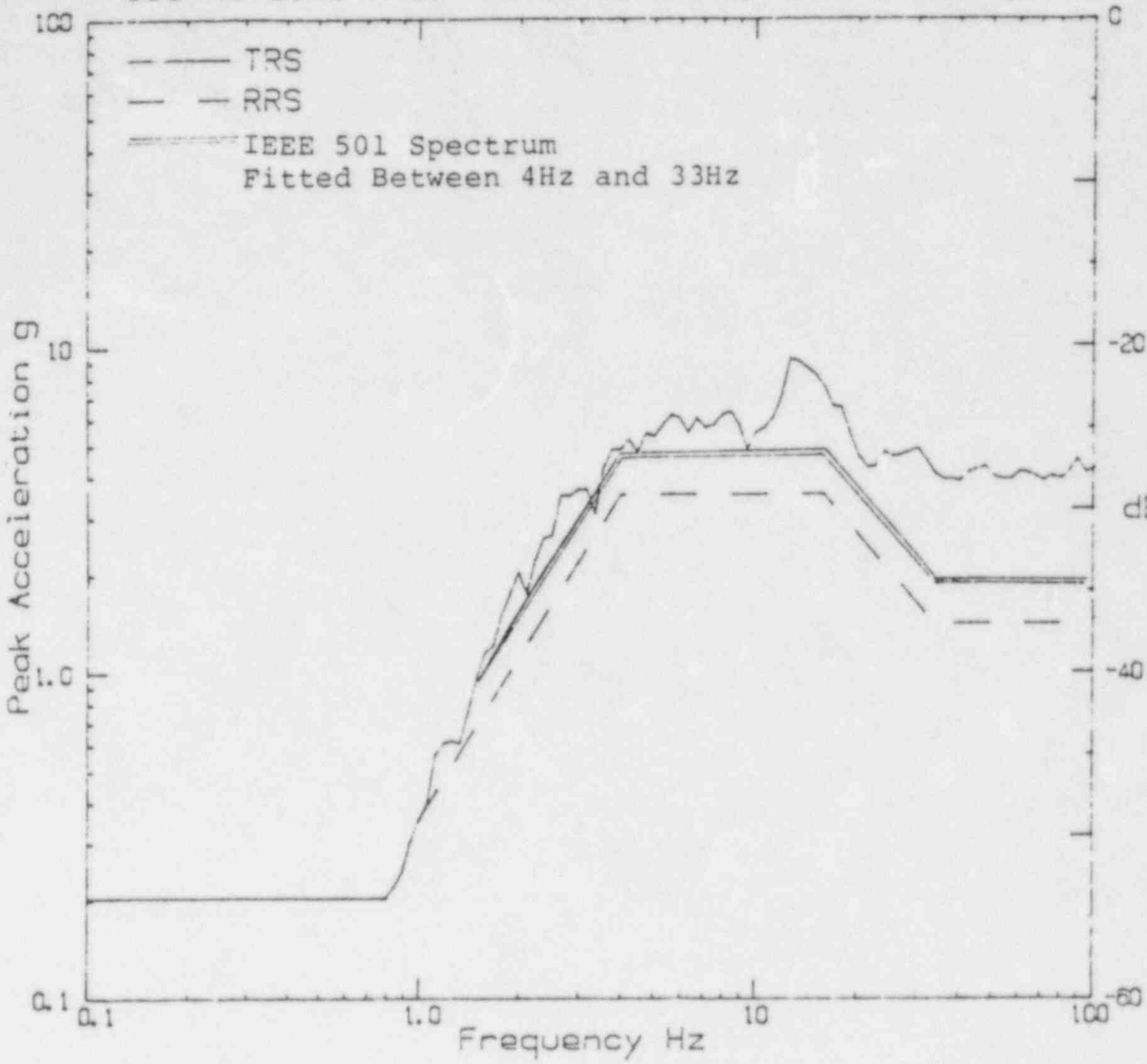
PARTICULARS
Jan 16/84. Time 1:35. Temp('C) 23. Humidity(%) 22. Press (kPa)100.3.
Graph 4964

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 3-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 1.9 g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 558. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 6

TEST ITEM
station cells, Gould, Model NCX 2250, #13

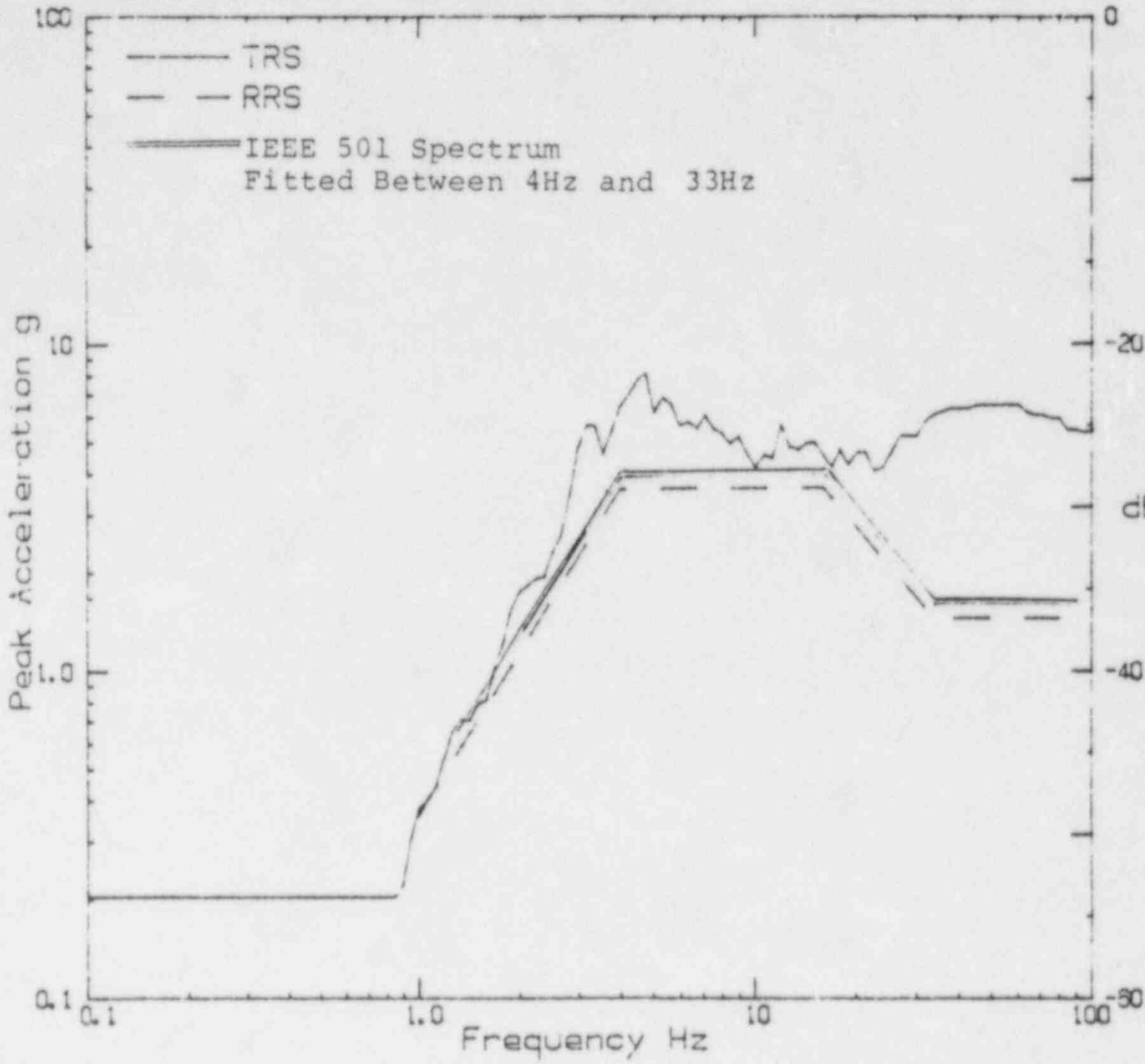
PARTICULARS
Jan 16/84, Time 1:35, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.3,
Graph 4965

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 3-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA= 1.9g

ACCELEROMETER
Wilcoxon, Serial 5901, Range d858, Location base-mounting jig,
TT 558, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE C7

TEST ITEM
station cells. Gould. Model NCX 225C. #3

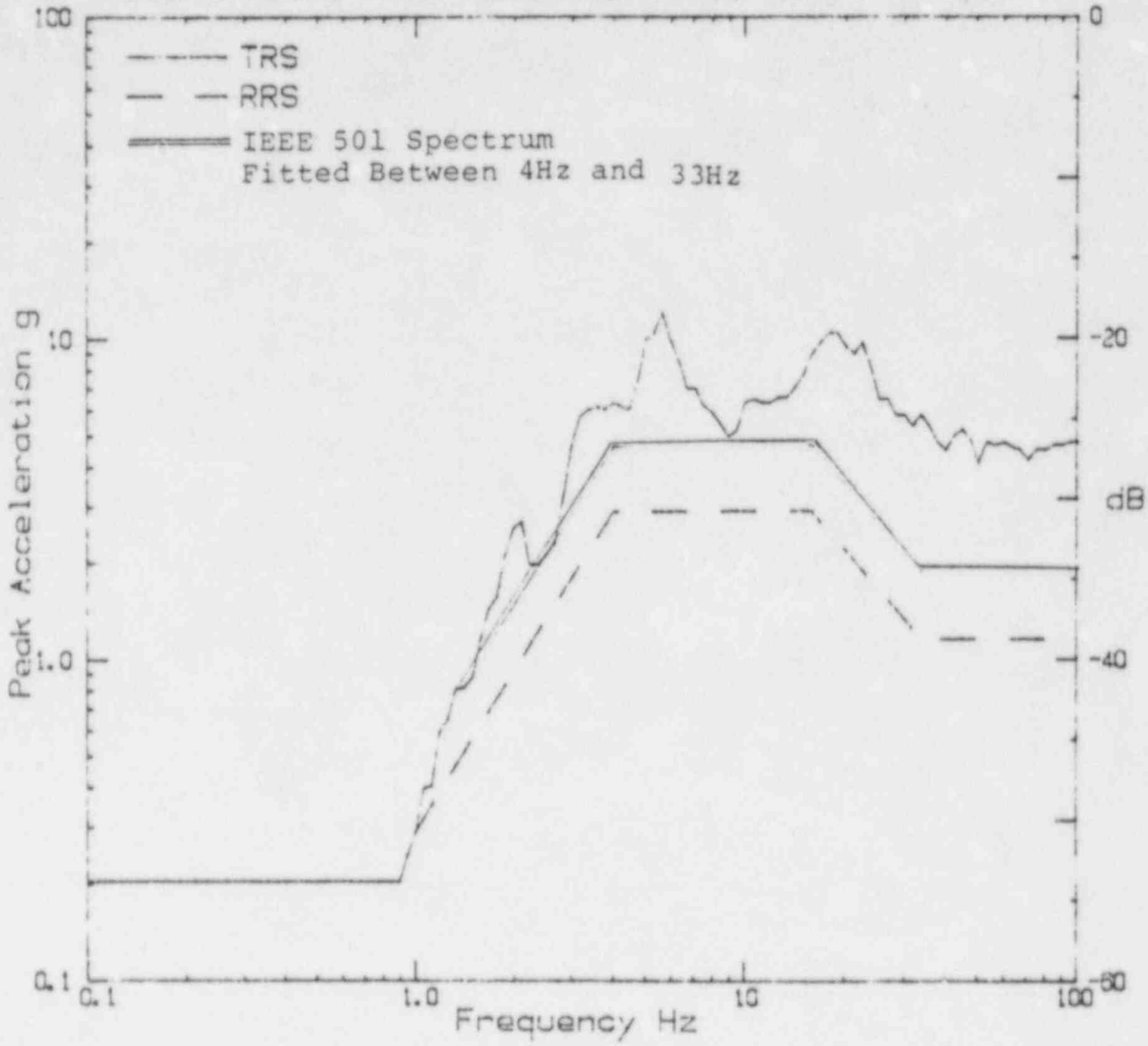
PARTICULARS
Jan 16/84. Time 3:20. Temp('C) 23. Humidity(%) 22. Press (kPa)100.3.
Graph 4969

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA= 1.7g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 575. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE C8

TEST ITEM
station cells. Gould. Model NCX 2250. #3

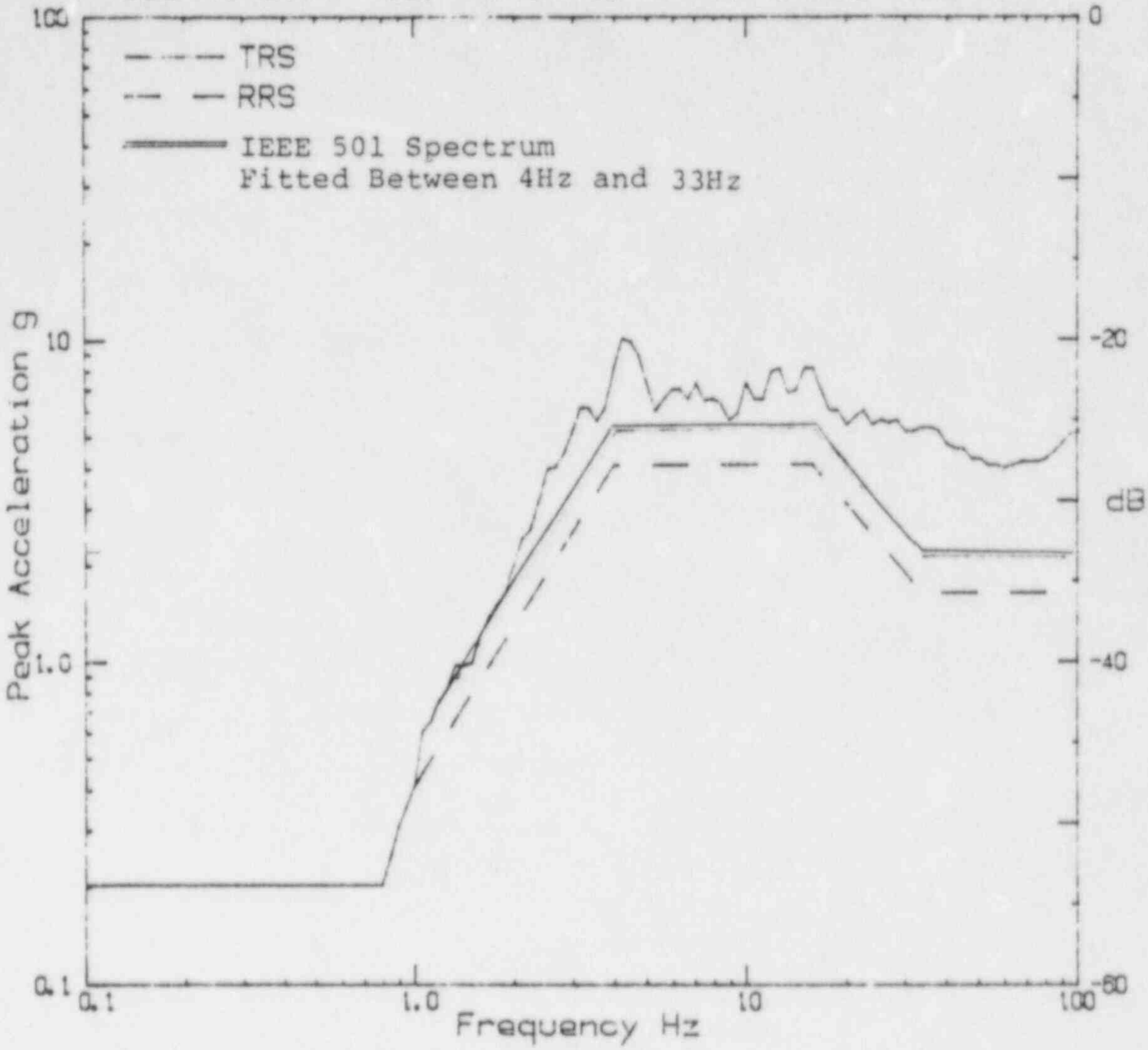
PARTICULARS
Jan 16/84. Time 3:20. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.3.
Graph 4970

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 2.0g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 575. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 09

TEST ITEM
station cells. Gould. Model NCX 2250. #3

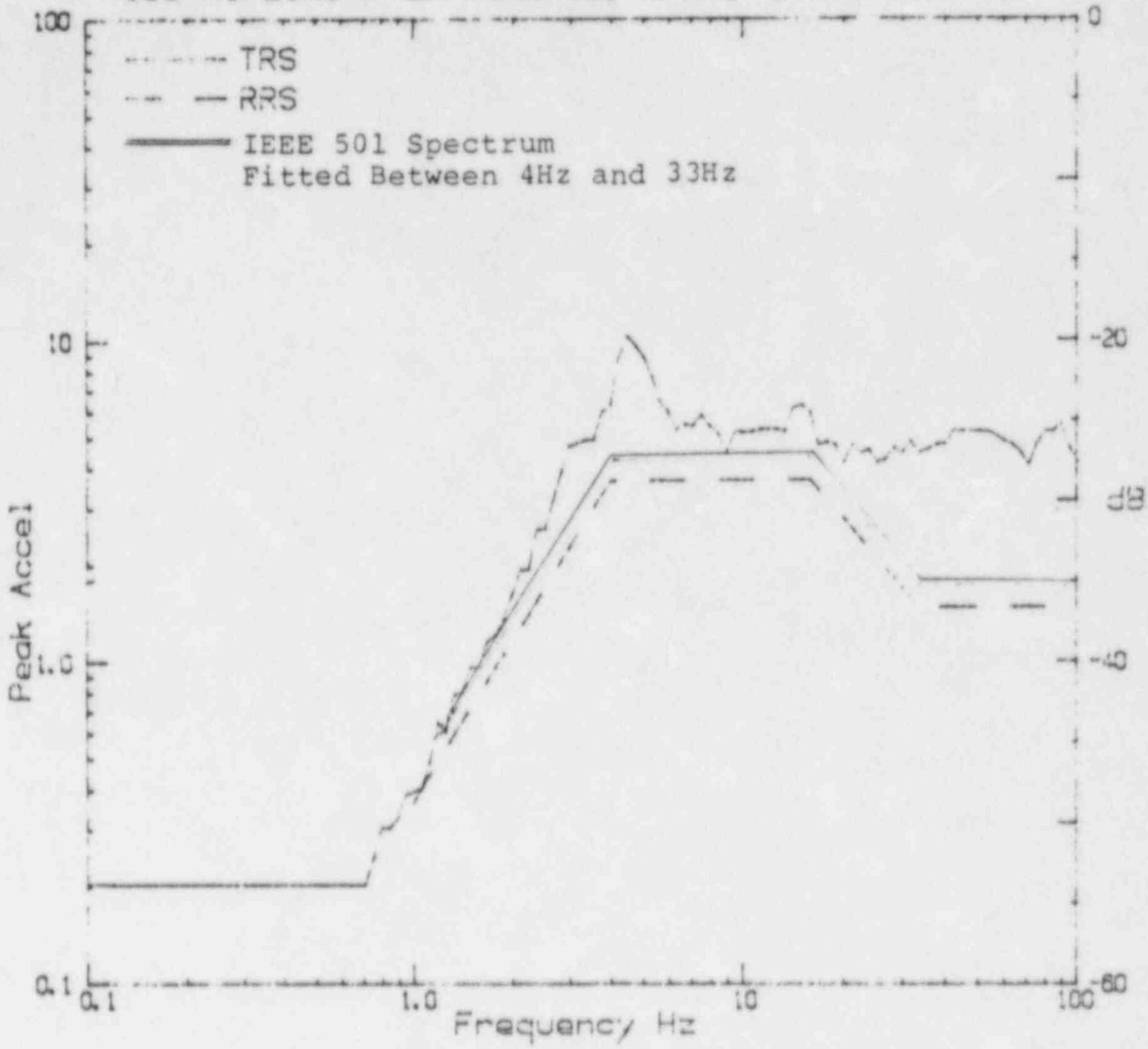
PARTICULARS
Jan 16/84. Time 3:20. Temp('C) 23. Humidity(%) 22. Press (kPa)100.3.
Graph 4971

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA= 2.2g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 575. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
900 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 10

ST ITEM
station cells. Gould. Model NCX 2250. #6

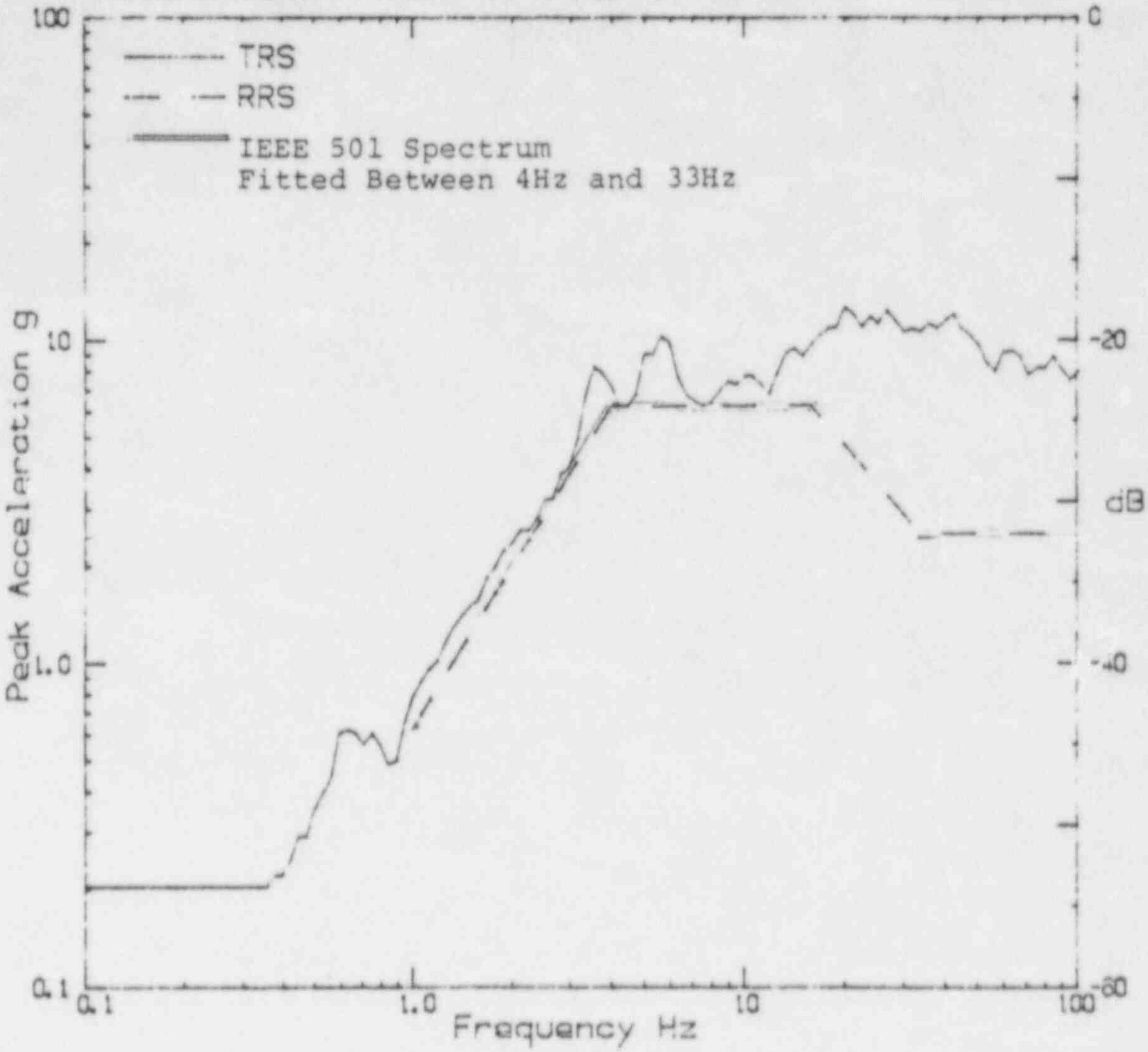
PARTICULARS
Jan 16/84. Time 1:20. Temp('C) 23. Humidity(%) 22. Press (kPa)100.3.
Graph 4975

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. shaker limit

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA 1.8g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 584. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 11

TEST ITEM
station cells. Gould. Model NCX 2250. #6

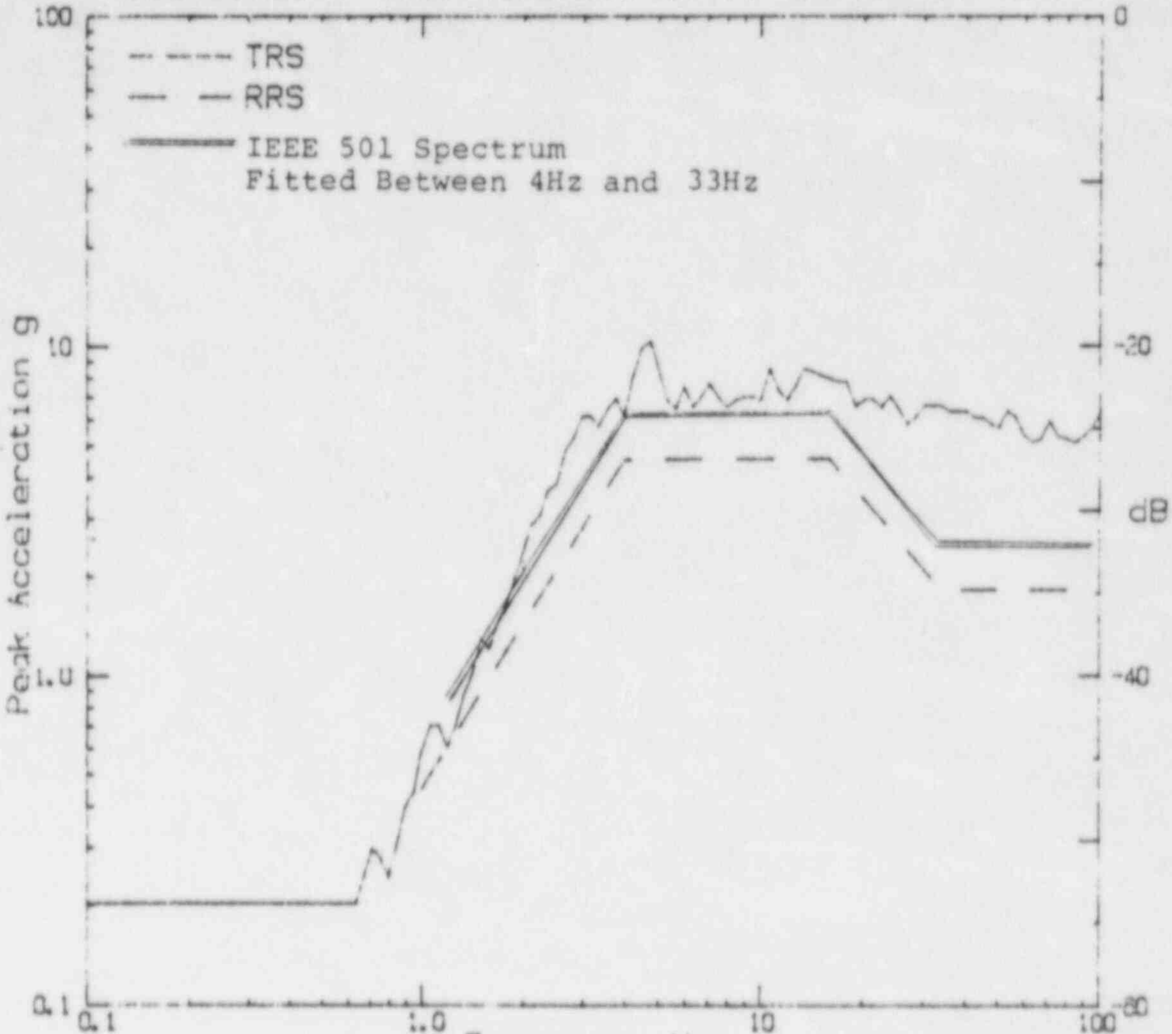
PARTICULARS
Jan 18/84. Time 1:20. Temp('C) 23. Humidity(%) 22. Press (kPa)100.3.
Graph 4976

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. shaker limit

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 2.5g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 584. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 12

TEST ITEM
station cells. Gould. Model NCX 2250. #6

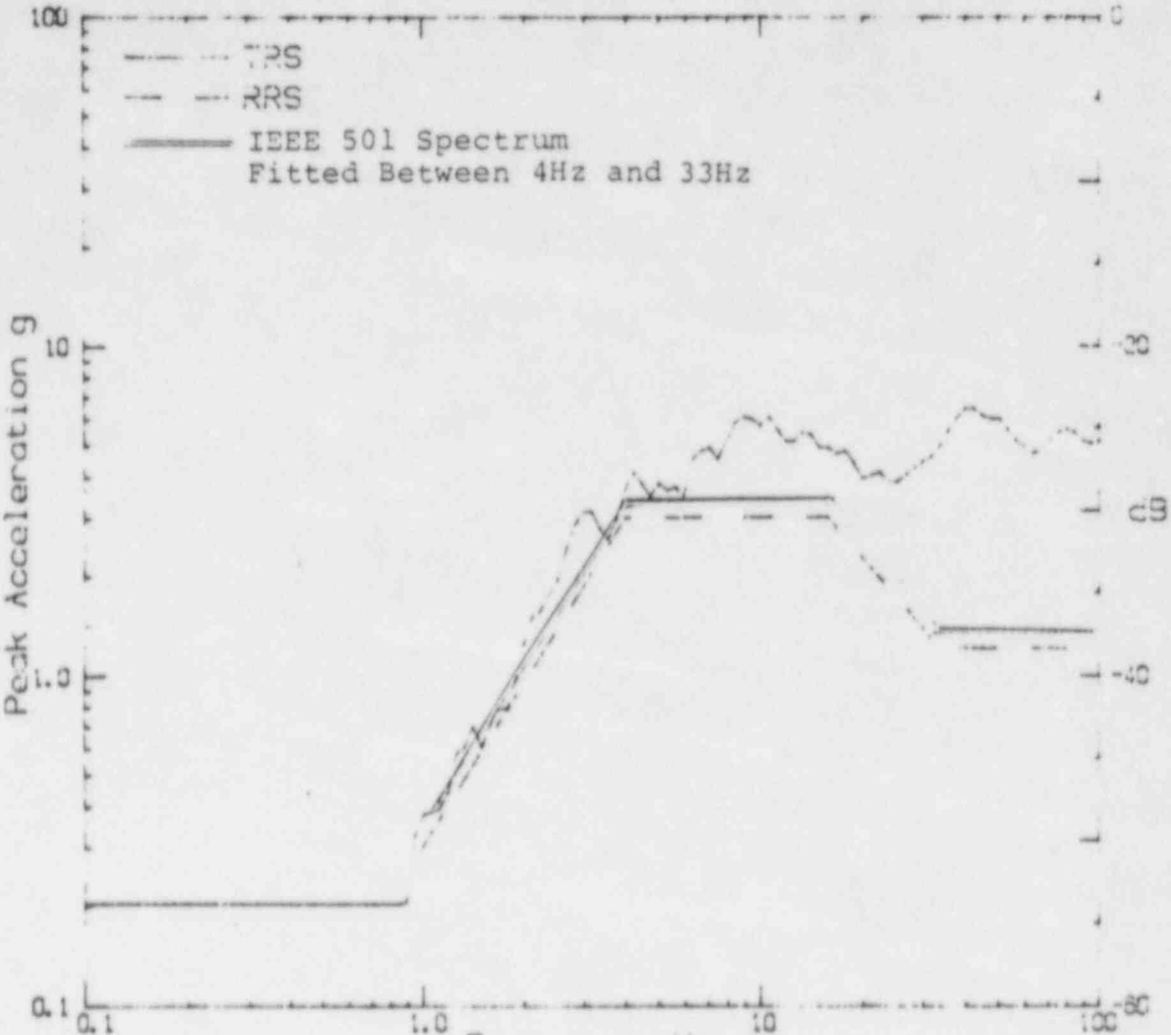
PARTICULARS
Jan 18.'84. Time 1:20. Temp('C) 23. Humidity(%) 22. Press (kPa)100.3.
Graph 4977

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. shaker limit

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA= 2.6g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 584. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 13

TEST ITEM
station cell, Gould, Model NCX 2250, sample 7

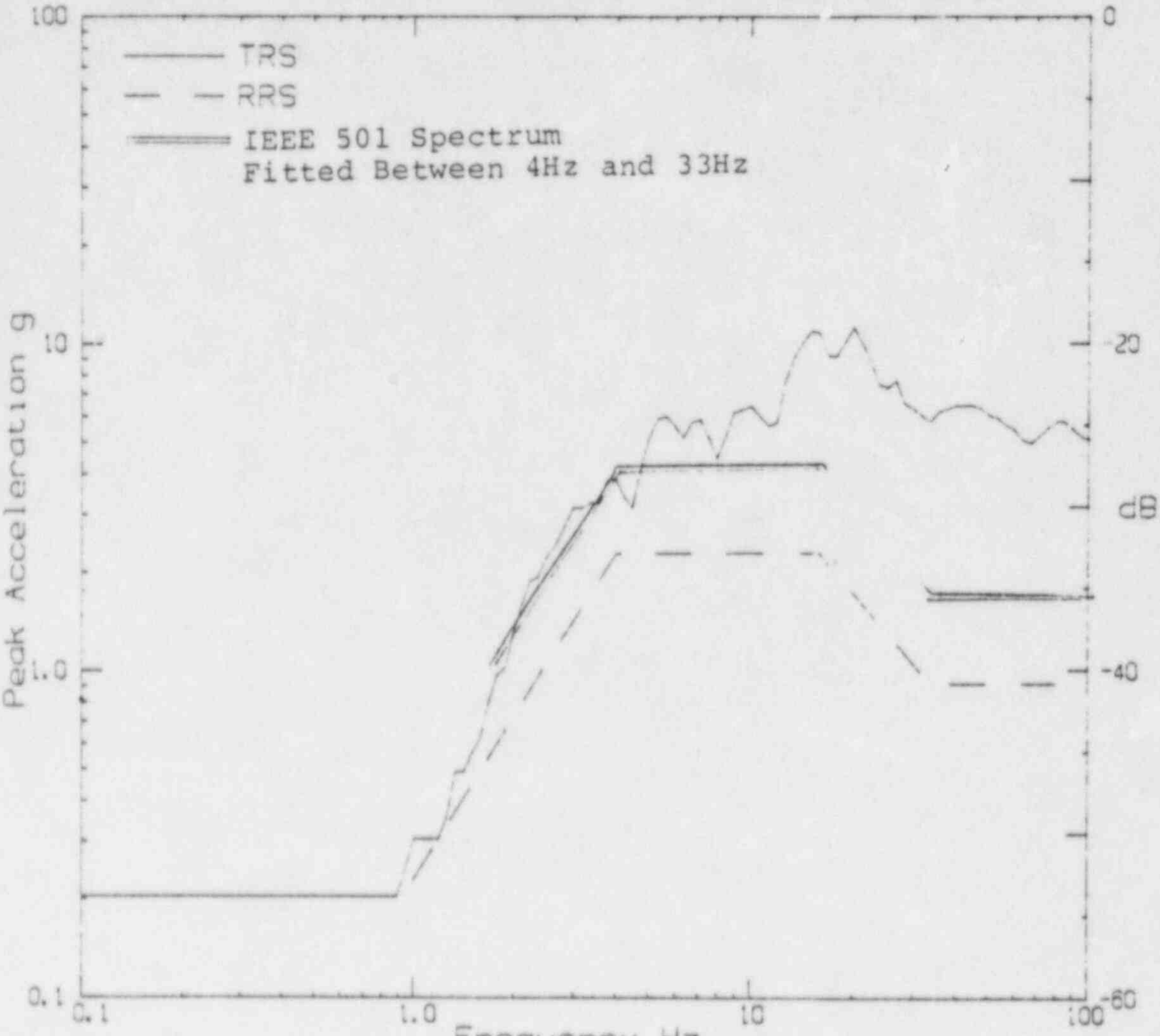
PARTICULARS
Jan 17/84, Time 2:02, Temp('C) 23, Humidity(%) 24, Press (kPa)100.5, Graph 4981

SPECIFICATIONS
Specs IEEE 501, Conditions operating 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X, Shaker tri-axial, ZPA= 1.4g

ACCELEROMETER
Wilcoxon, Serial S757, Range d858, Location base-mounting jig, TT 586, Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 14

TEST ITEM
station cell, Gould, Model NCX 2250, sample 7

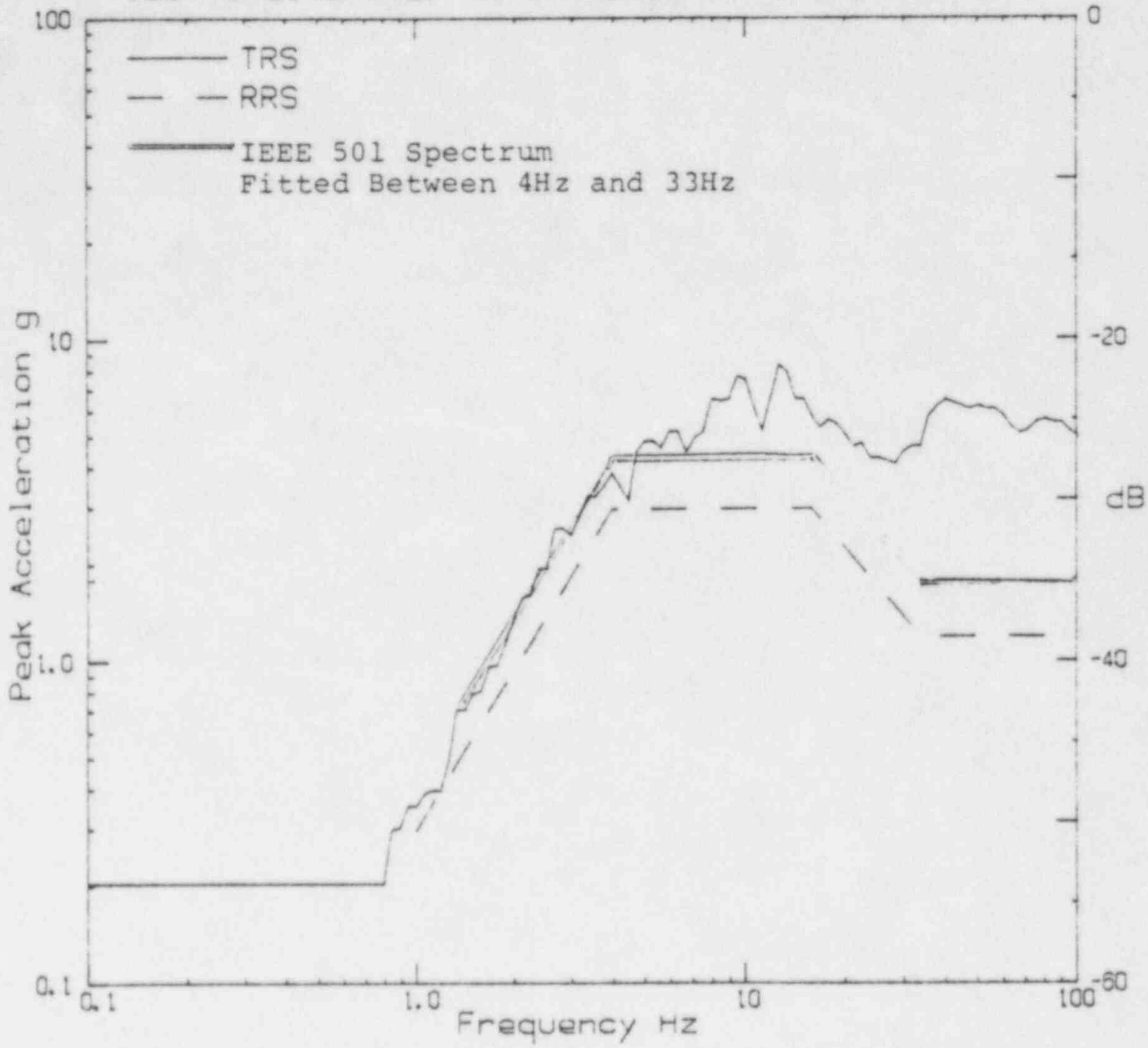
PARTICULARS
Jan 17/84, Time 2:02, Temp('C) 23, Humidity(%) 24, Press (kPa)100.5,
Graph 4982

SPECIFICATIONS
Specs IEEE 501, Conditions operating 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA= 1.8g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB58, Location base-mounting jig,
TT 586, Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 15

TEST ITEM
station cell, Gould, Model NCX 2250, sample 7

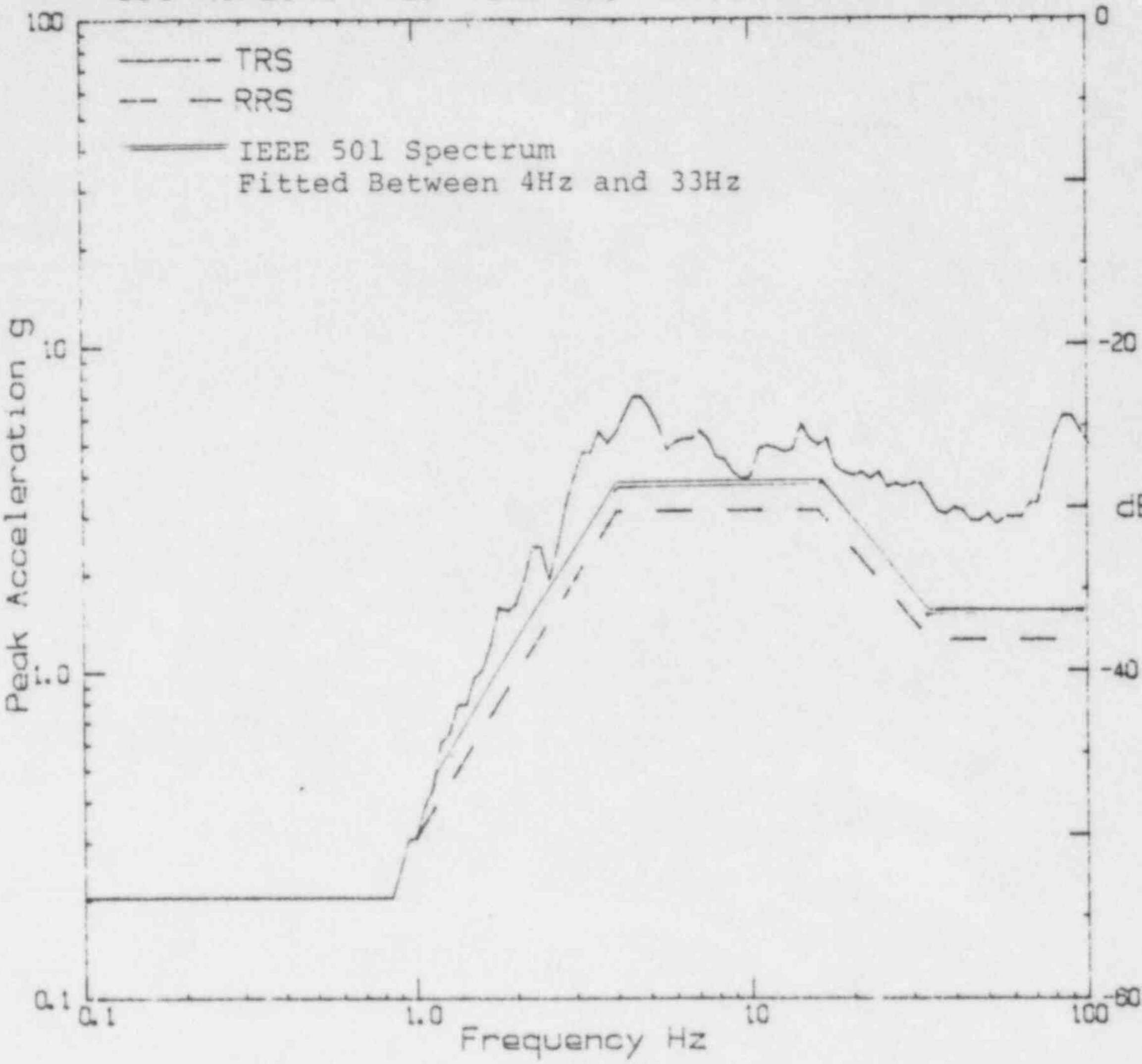
PARTICULARS
Jan 17/84, Time 2:02, Temp('C) 23, Humidity(%) 24, Press (kPa)100.5, Graph 4983

SPECIFICATIONS
Specs IEEE 501, Conditions operating 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z, Shaker tri-axial, ZPA =1.8g

ACCELEROMETER
Wilcoxon, Serial 5901, Range dB58, Location base-mounting jig, TT 586, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 16

TEST ITEM
station cell. Gould. Model NCX 2250. sample 15

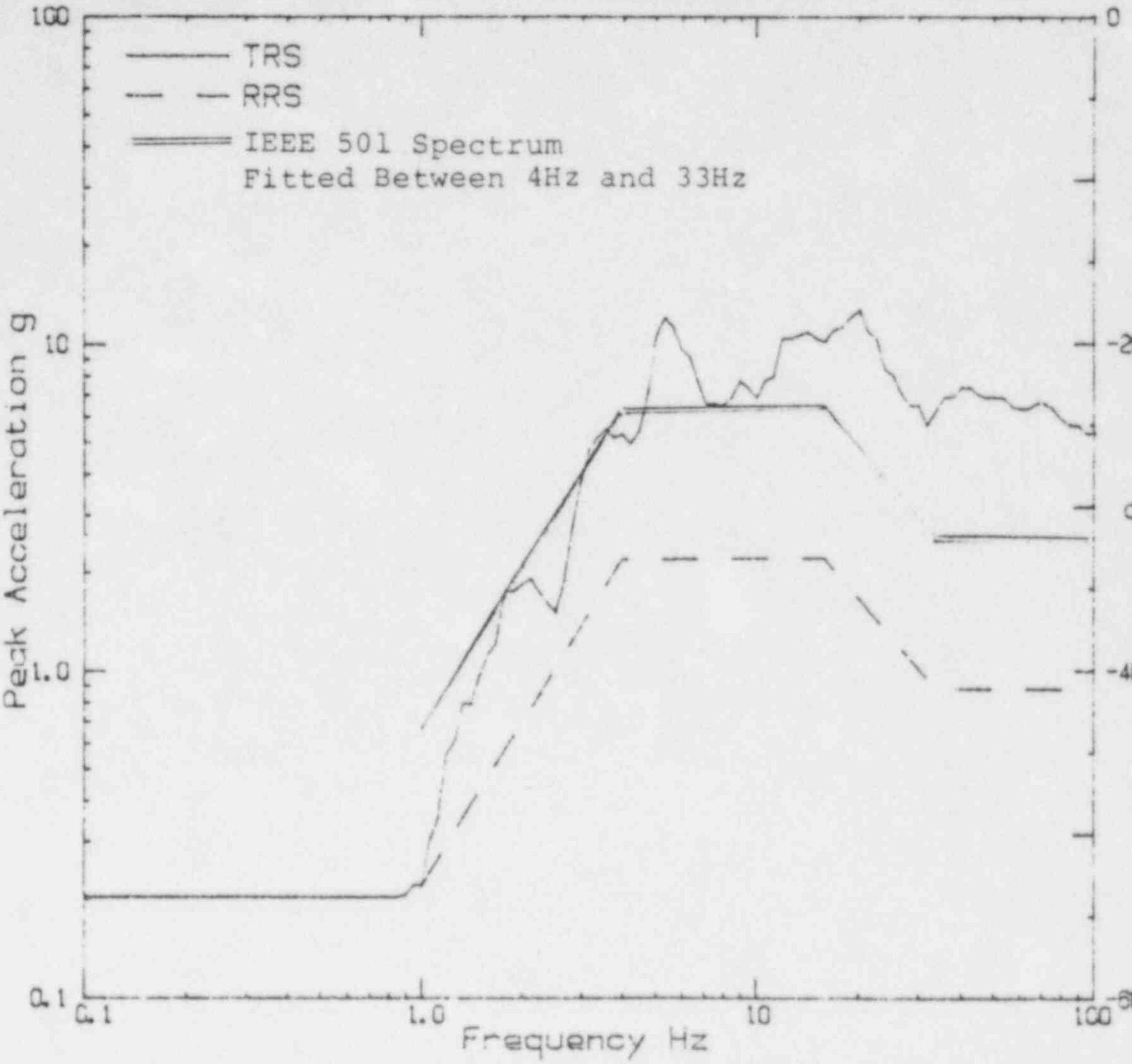
PARTICULARS
Jan 19/84. Time 10:00. Temp('C) 23. Humidity(%) 24. Press (kPa)100.3.
Graph 4987

SPECIFICATIONS
Specs IEEE 501. Conditions not operating: crack propagation.
clamps tight

ANALYSIS
Type Maximax. Damping (%)5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA = 1.5g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 604. Channel 1

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 17

TEST ITEM
station cell. Gould. Model NCX 2250. sample 15

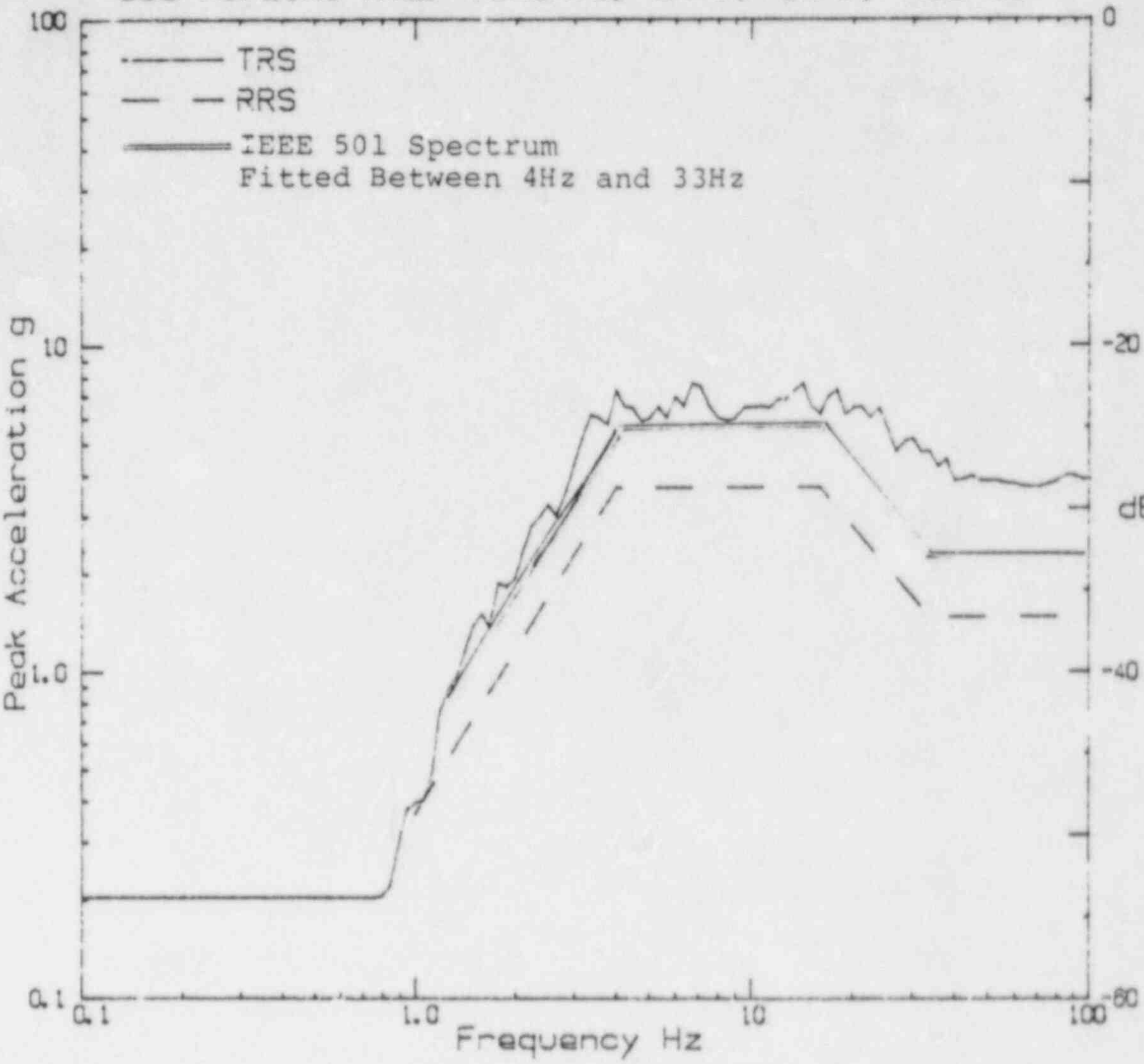
PARTICULARS
Jan 19/84. Time 10:00. Temp('C) 23. Humidity(%) 24. Press (kPa) 100.3.
Graph 4988

SPECIFICATIONS
Specs IEEE 501. Conditions not operating: crack propagation.
clamps tight

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 2.5g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 604. Channel 2

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 18

TEST ITEM
station cell, Gould, Model NCX 2250, sample 15

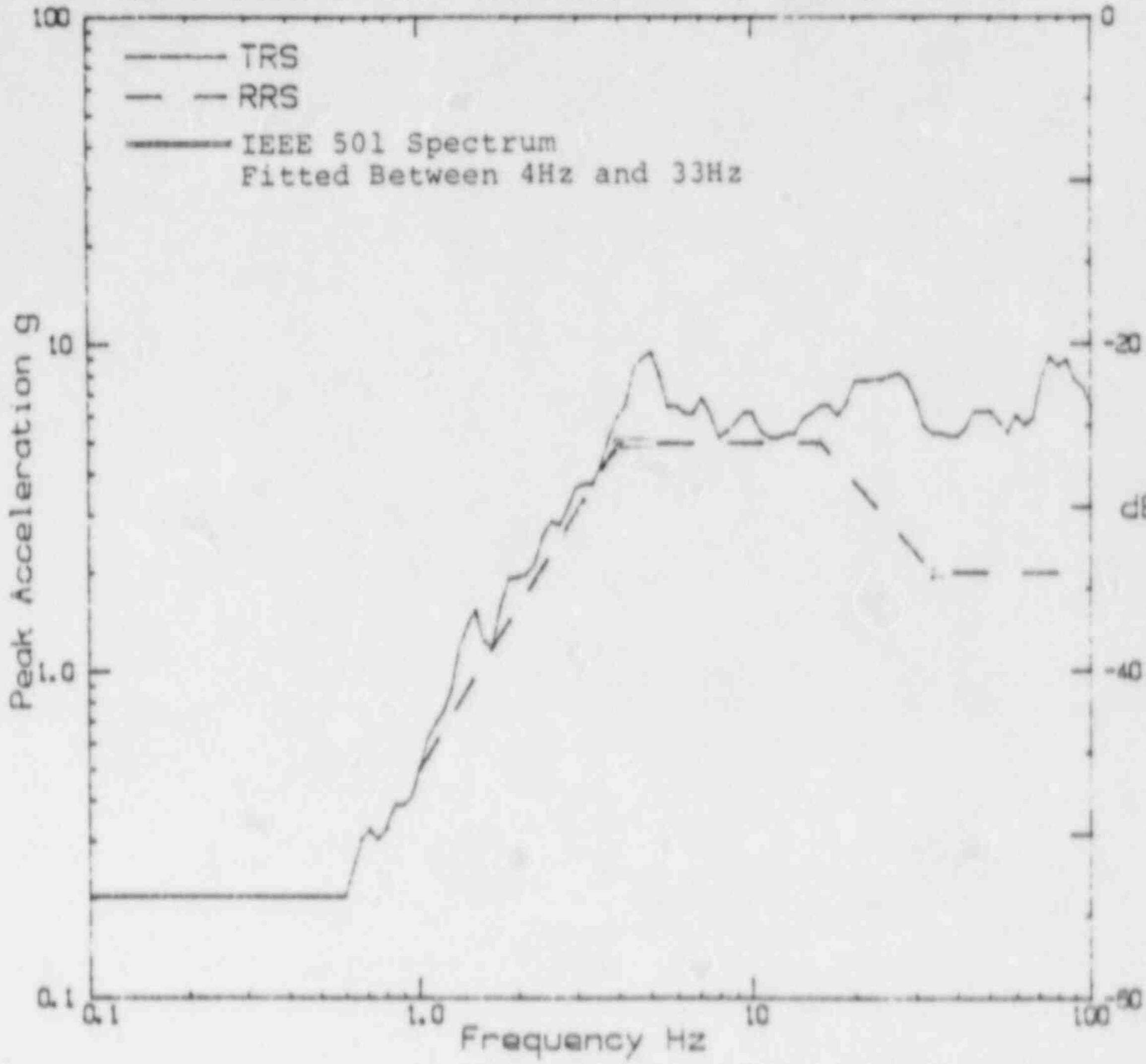
PARTICULARS
Jan 19/84, Time 10:00, Temp('C) 23, Humidity(%) 24, Press (kPa)100.3, Graph 4989

SPECIFICATIONS
Specs IEEE 501. Conditions not operating: crack propagation, clamps tight

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z, Shaker tri-axial, ZPA= 2.3g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting jig, TT 604, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 19

TEST ITEM
station cell. Gould. Model NCX 2250. sample 25

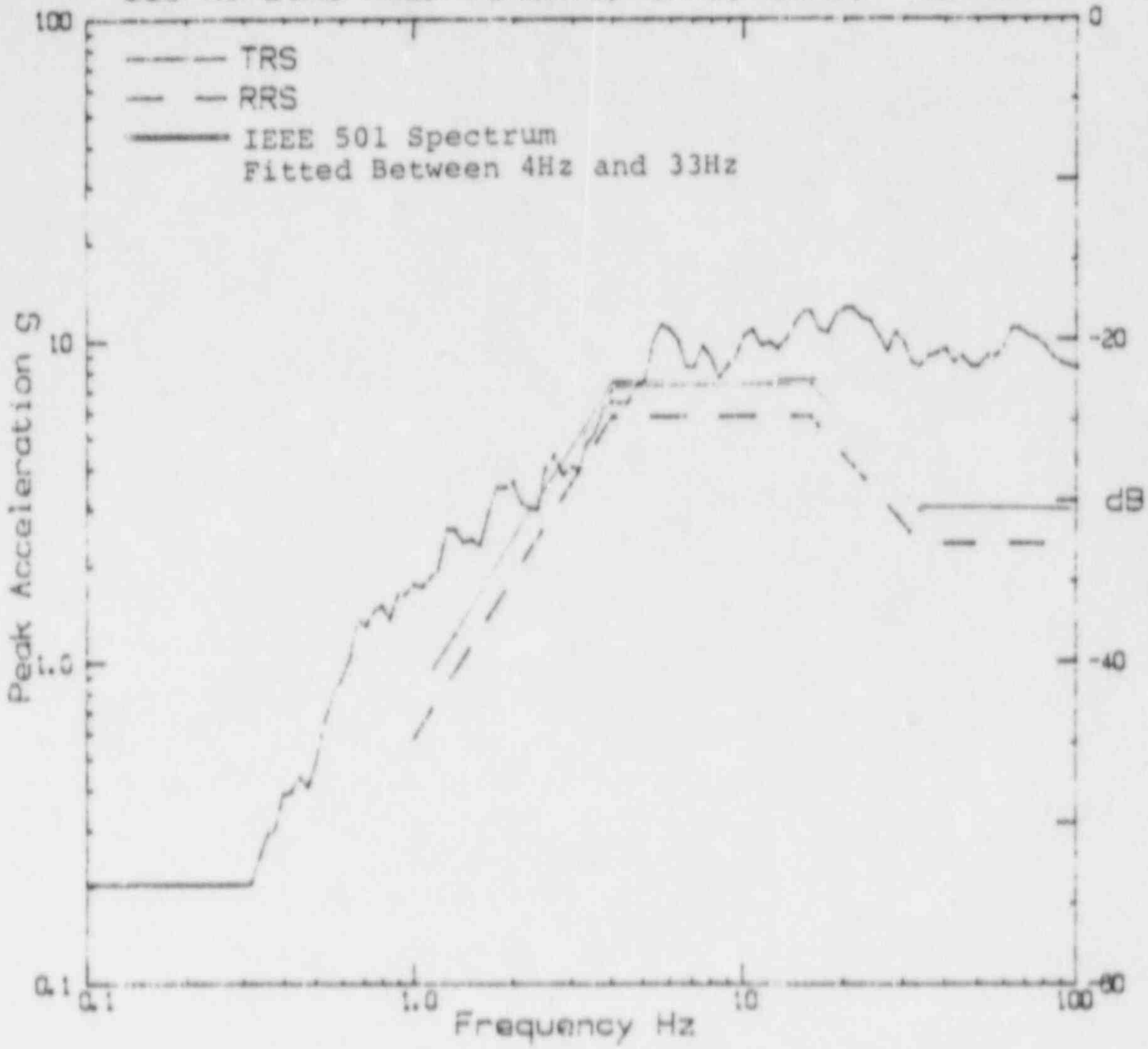
PARTICULARS
Jan 19/84. Time 2:30. Temp('C) 23. Humidity(%) 24. Press (kPa)100.3.
Graph 4993

SPECIFICATIONS
Specs IEEE 501. Conditions not operating: crack propagation.
clamps loosened

ANALYSIS
Type Maximax. Damping (%)5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA =2.0g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 816. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 20

TEST ITEM
station cell. Gould. Model NCX 2250. sample 25

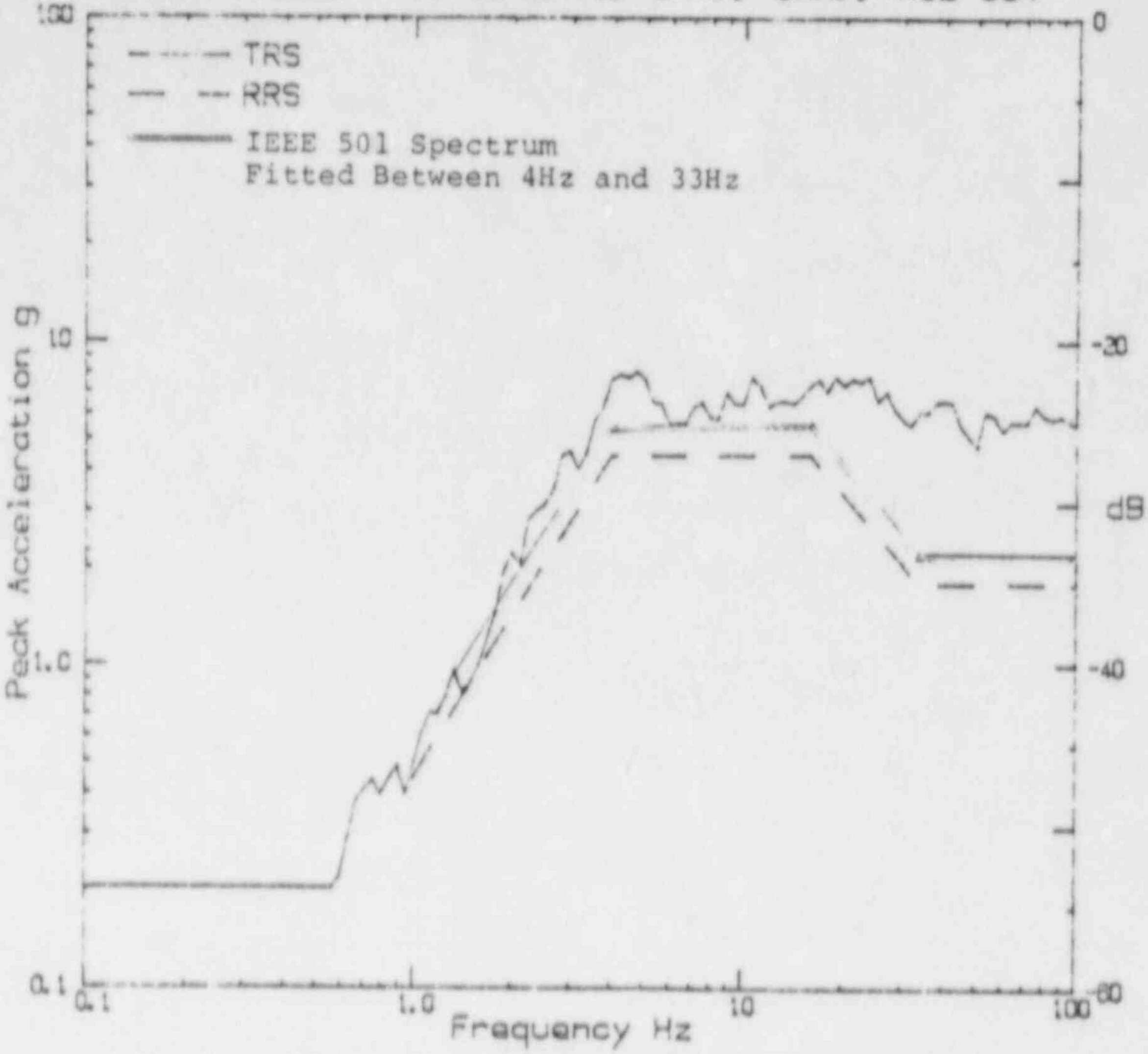
PARTICULARS
Jan 19/84. Time 2:30. Temp('C) 23. Humidity(%) 24. Press (kPa)100.3.
Graph 4994

SPECIFICATIONS
Specs IEEE 501. Conditions not operating: crack propagation.
clamps loosened

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 3.1g

ACCELEROMETER
Wilcoxon. Serial 5771. Range dB58. Location base-mounting jig.
TT 616. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 21

TEST ITEM
station cell. Gould. Model NCX 2250. sample 25

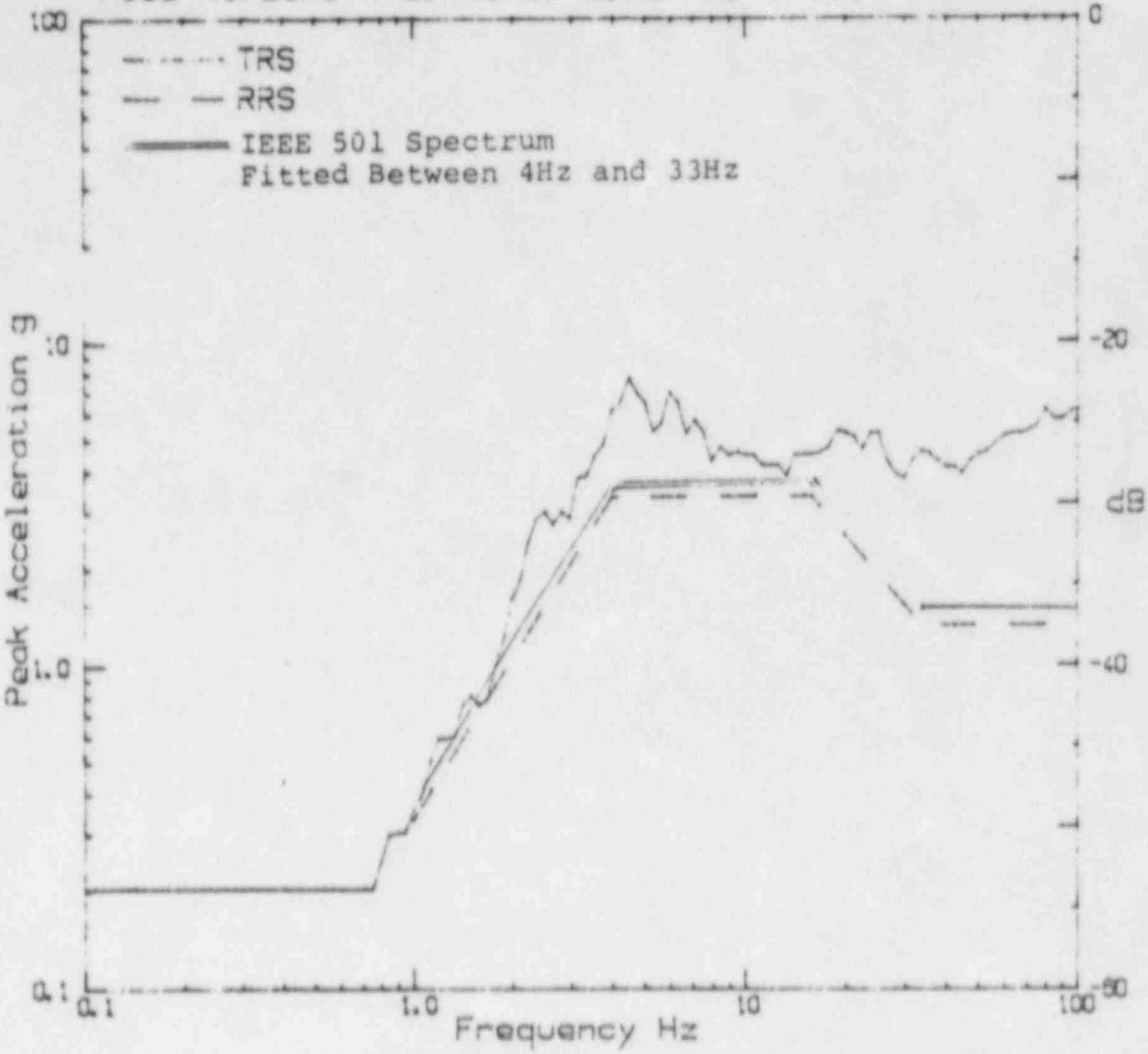
PARTICULARS
Jan 19/84. Time 2:30. Temp('C) 23. Humidity(%) 24. Press (kPa)100.3.
Graph 4995

SPECIFICATIONS
Specs IEEE 501. Conditions not operating: crack propagation.
clamps loosened

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA= 2.2g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 616. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 22

TEST ITEM
station cells. Gould. Model NCX 2250. sample #43

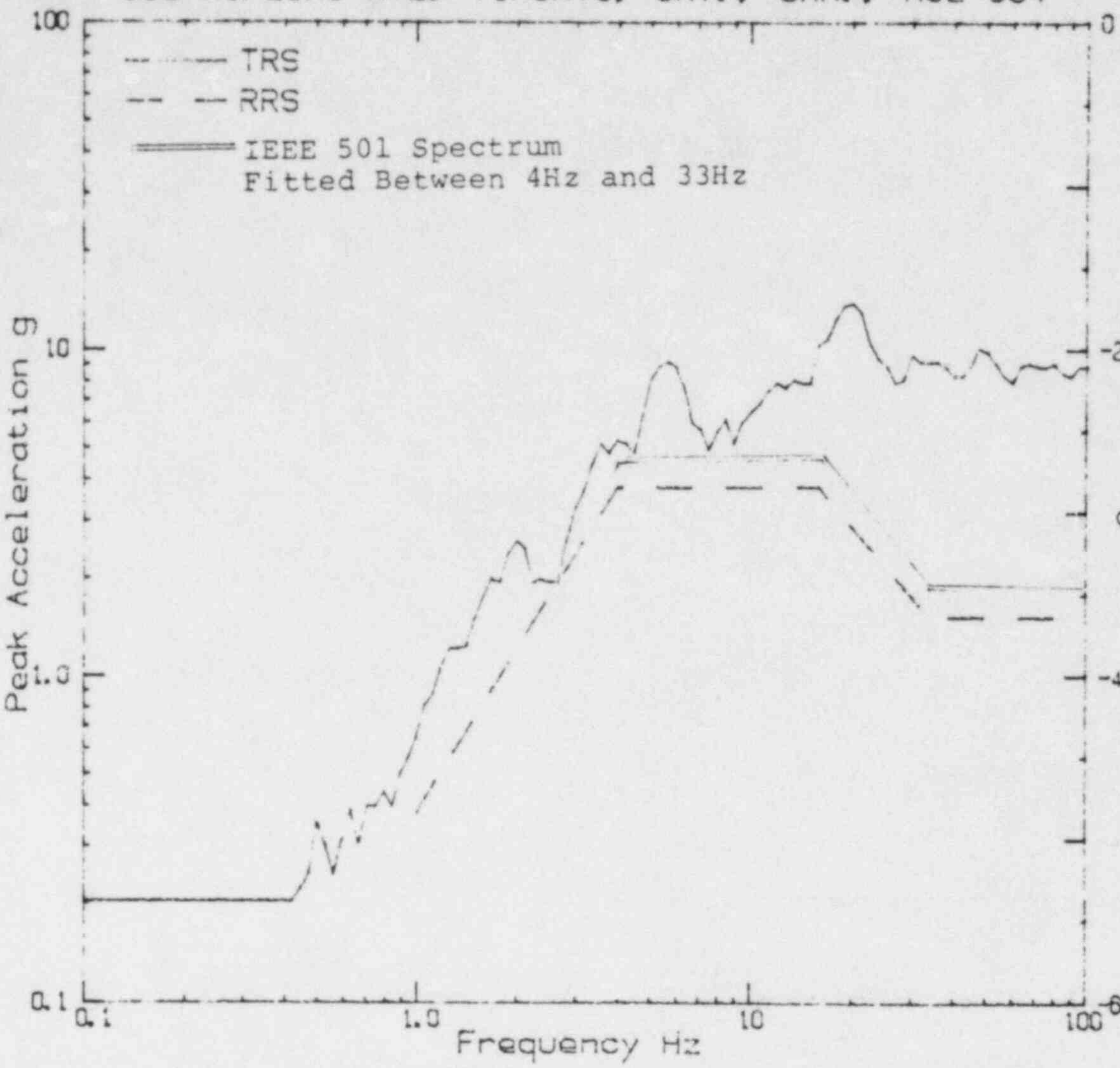
PARTICULARS
Jan 20/84. Time 9:15. Temp('C) 23. Humidity(%) 25. Press (kPa) 101.2.
Graph 4999

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA= 1.6g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 628. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 23

TEST ITEM
station cells. Gould. Model NCX 2250. sample #43

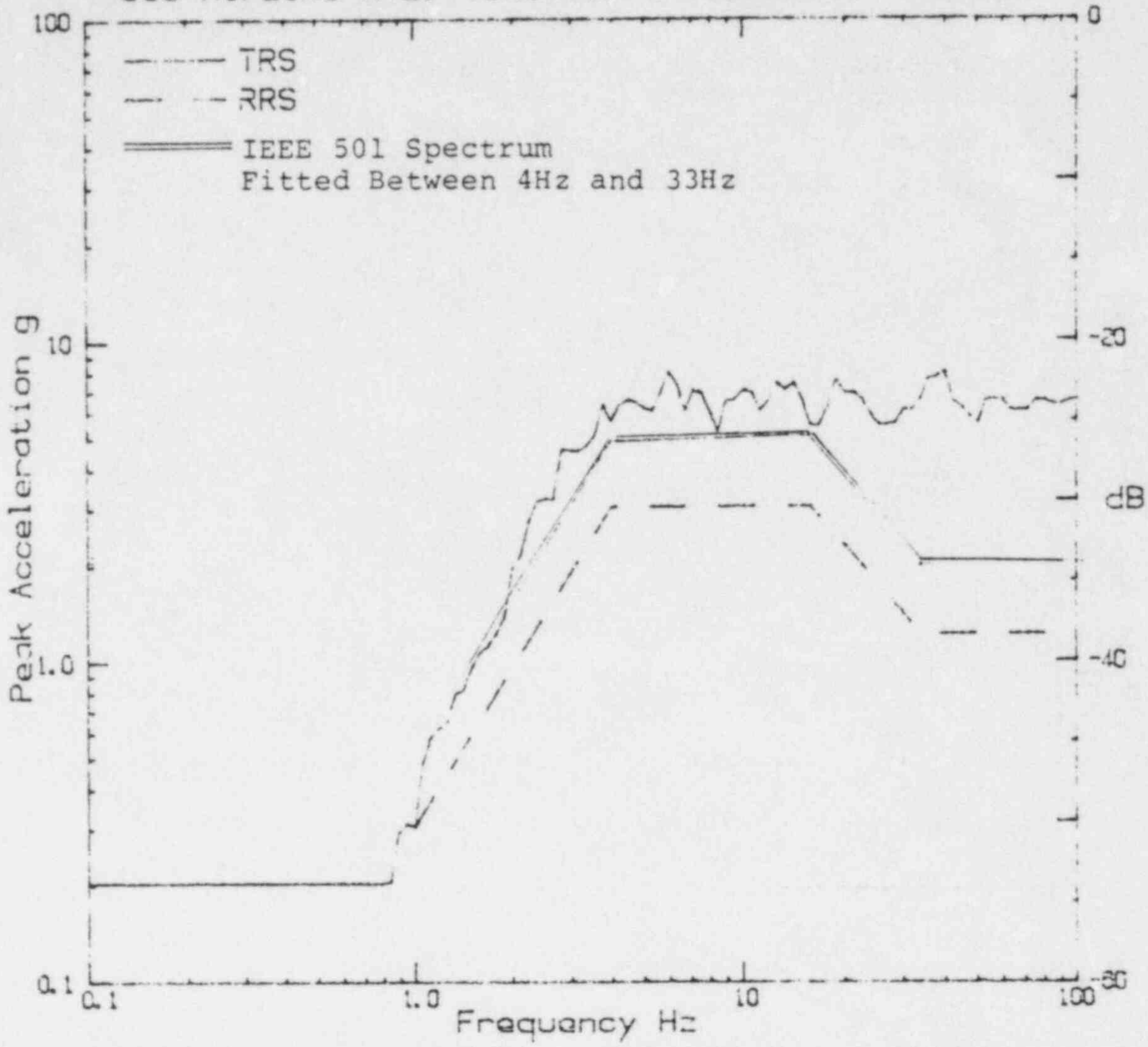
PARTICULARS
Jan 20/'84. Time 9:15. Temp('C) 23. Humidity(%) 25. Press (kPa) 101.2.
Graph 5000

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 1.9g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 628. Channel 2

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 24

TEST ITEM
station cells. Gould. Model NCX 2250. sample #43

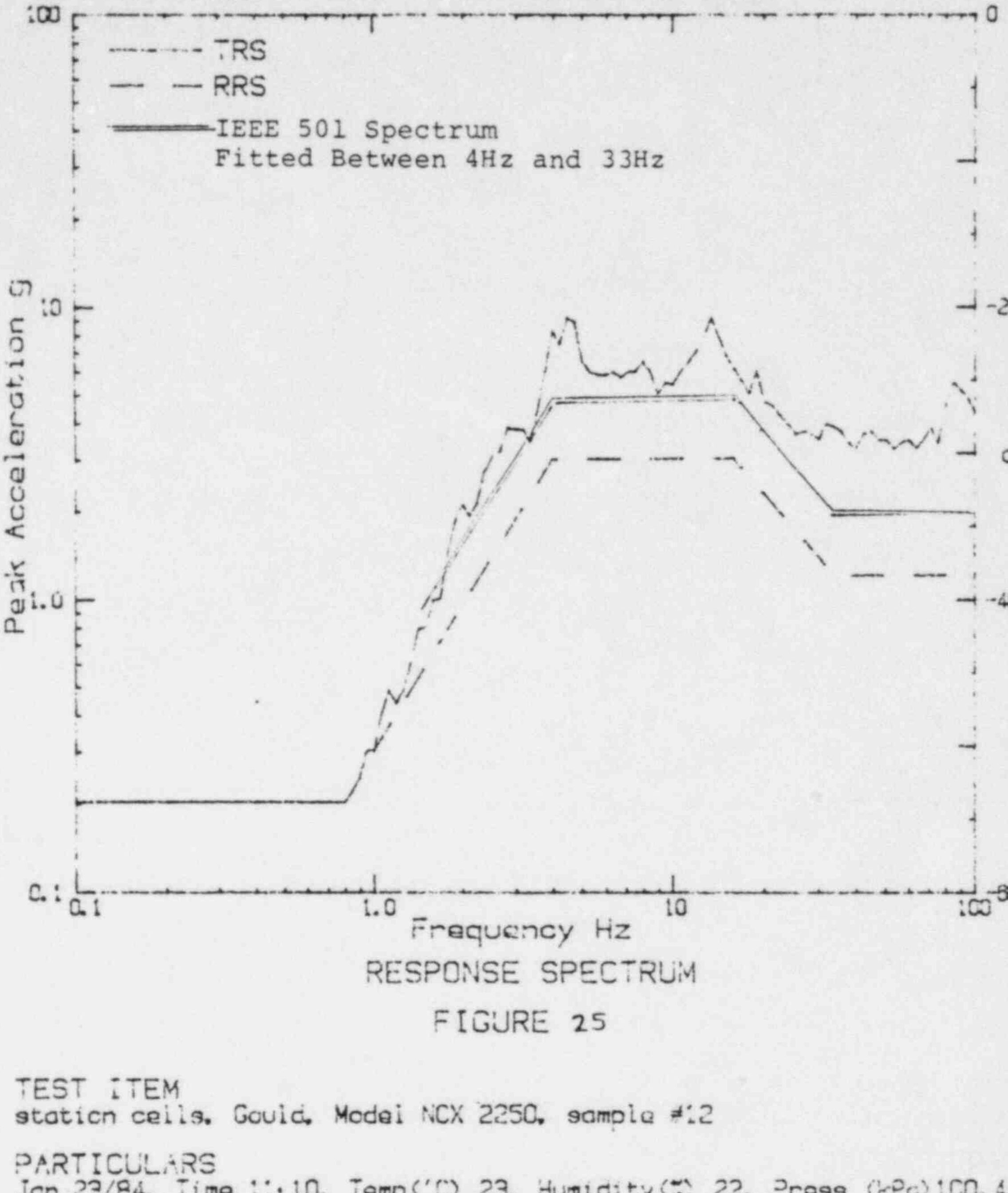
PARTICULARS
Jan 20/84. Time 9:15. Temp('C) 23. Humidity(%) 25. Press (kPa) 101.2.
Graph 5001

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA = 2.0g

ACCELEROMETER
Wilcoxon. Serial 5901. Range dB58. Location base-mounting jig.
TT 628. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 25

TEST ITEM
station cells. Gould. Model NCX 2250. sample #12

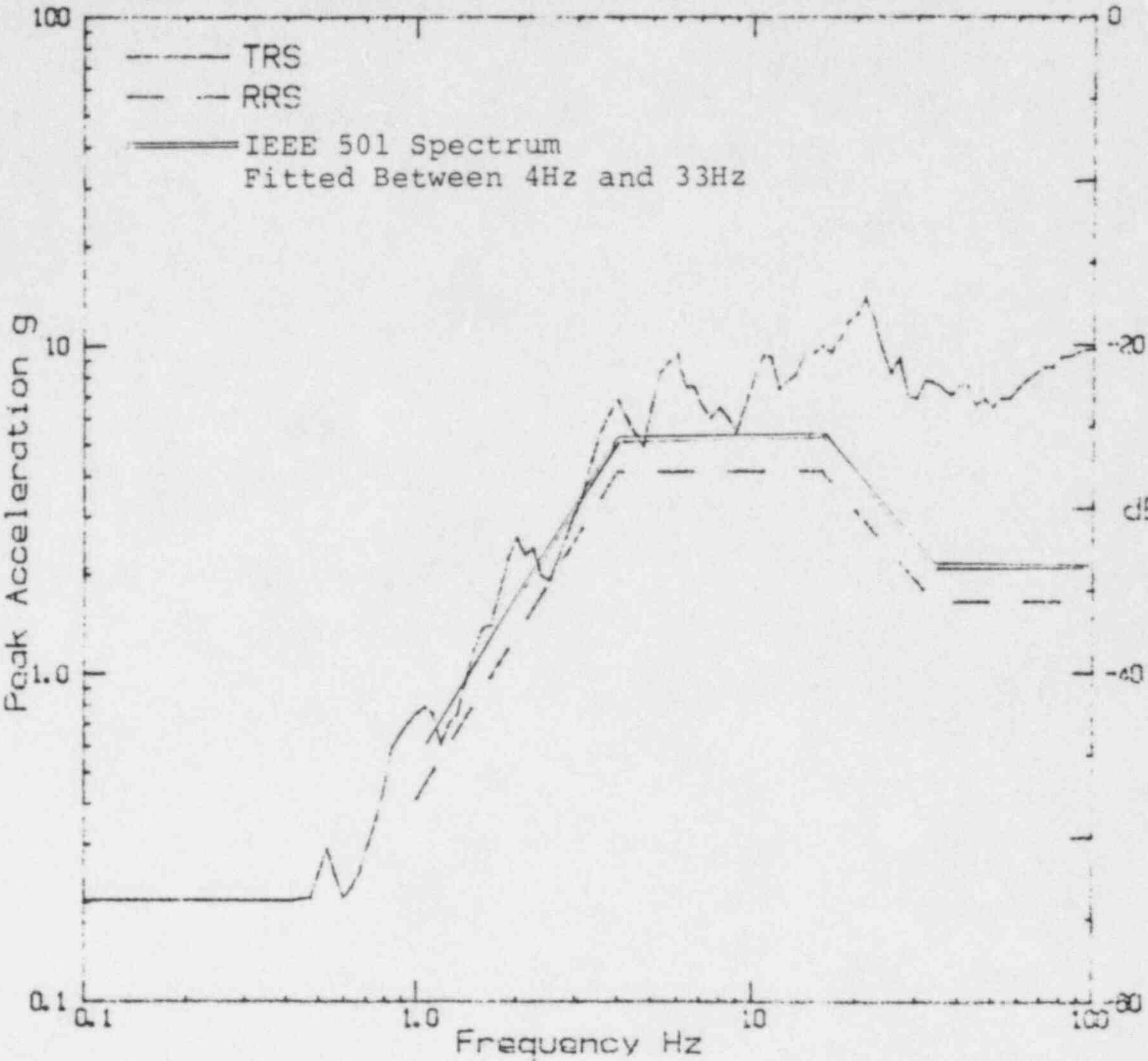
PARTICULARS
Jan 23/84. Time 11:10. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.4.
Graph 5005

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA= 2.0g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 634. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 26

TEST ITEM
station cells. Gould. Model NCX 2250. sample #12

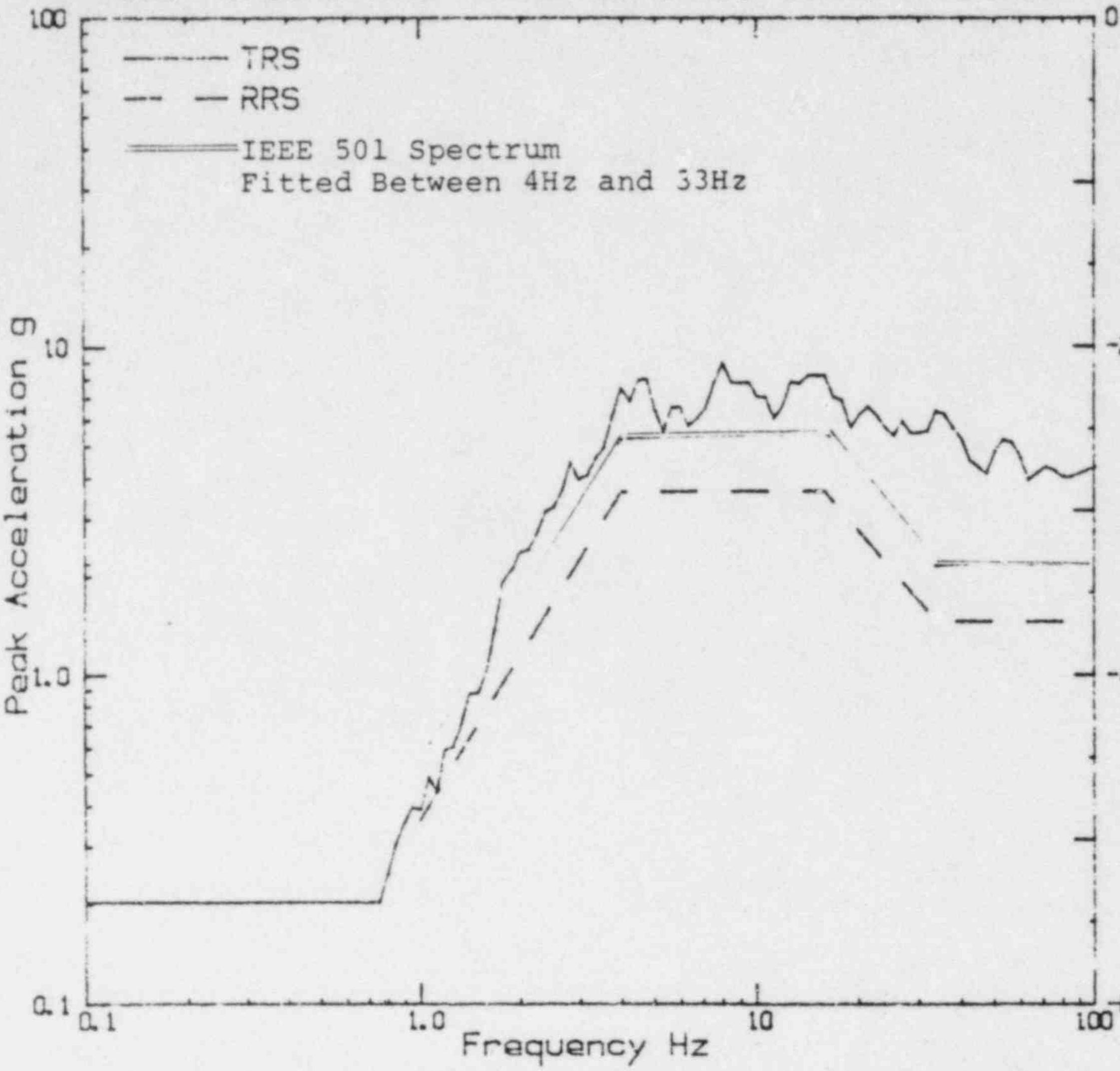
PARTICULARS
Jan 23/84. Time 11:10. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.4.
Graph 5006

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 2.1g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 634. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 27

TEST ITEM
station cells. Gould. Model NCX 2250. sample #12

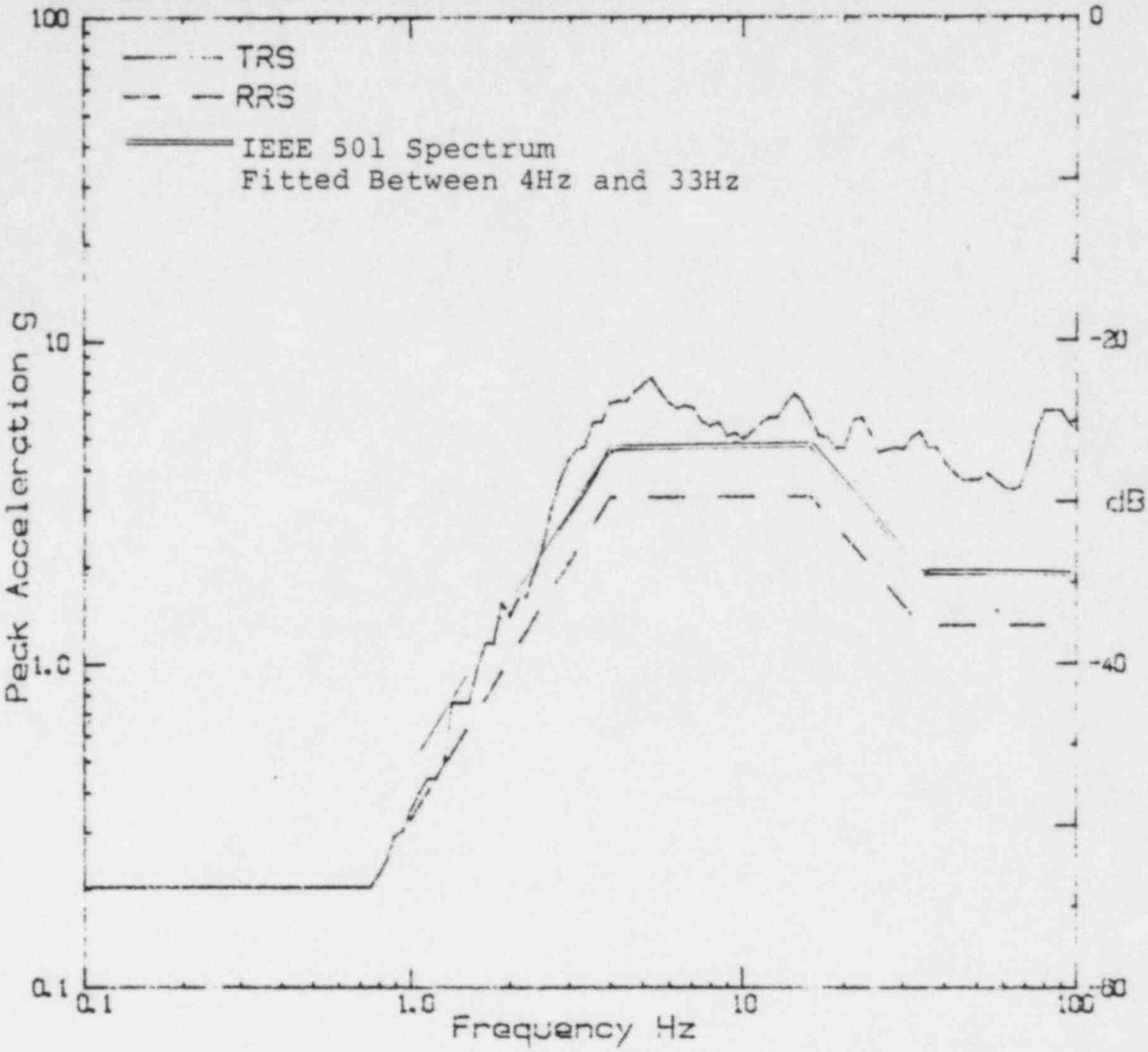
PARTICULARS
Jan 23/84. Time 11:10. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.4.
Graph 5007

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA= 2.2g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 634. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 28

TEST ITEM
station cells. Gould. Model NCX 2250. sample-#14

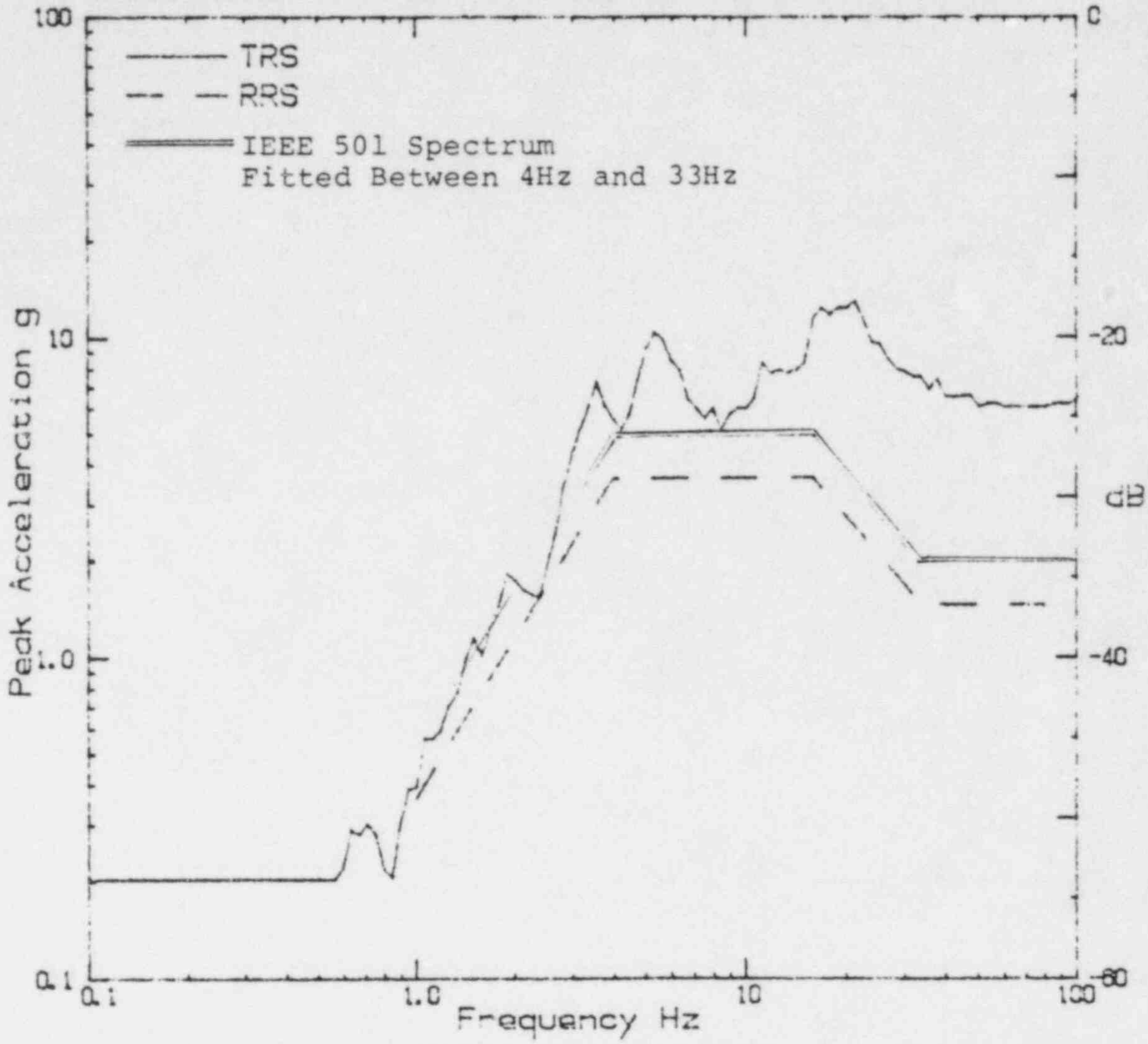
PARTICULARS
Jan 23/84. Time 2:15. Temp('C) 23. Humidity(%) 22. Press (kPa)100.4.
Graph 5011

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6.8: shaker limit

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA= 1.9g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 844. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 29

TEST ITEM
station cells. Gould. Model NCX 2250. sample-#14

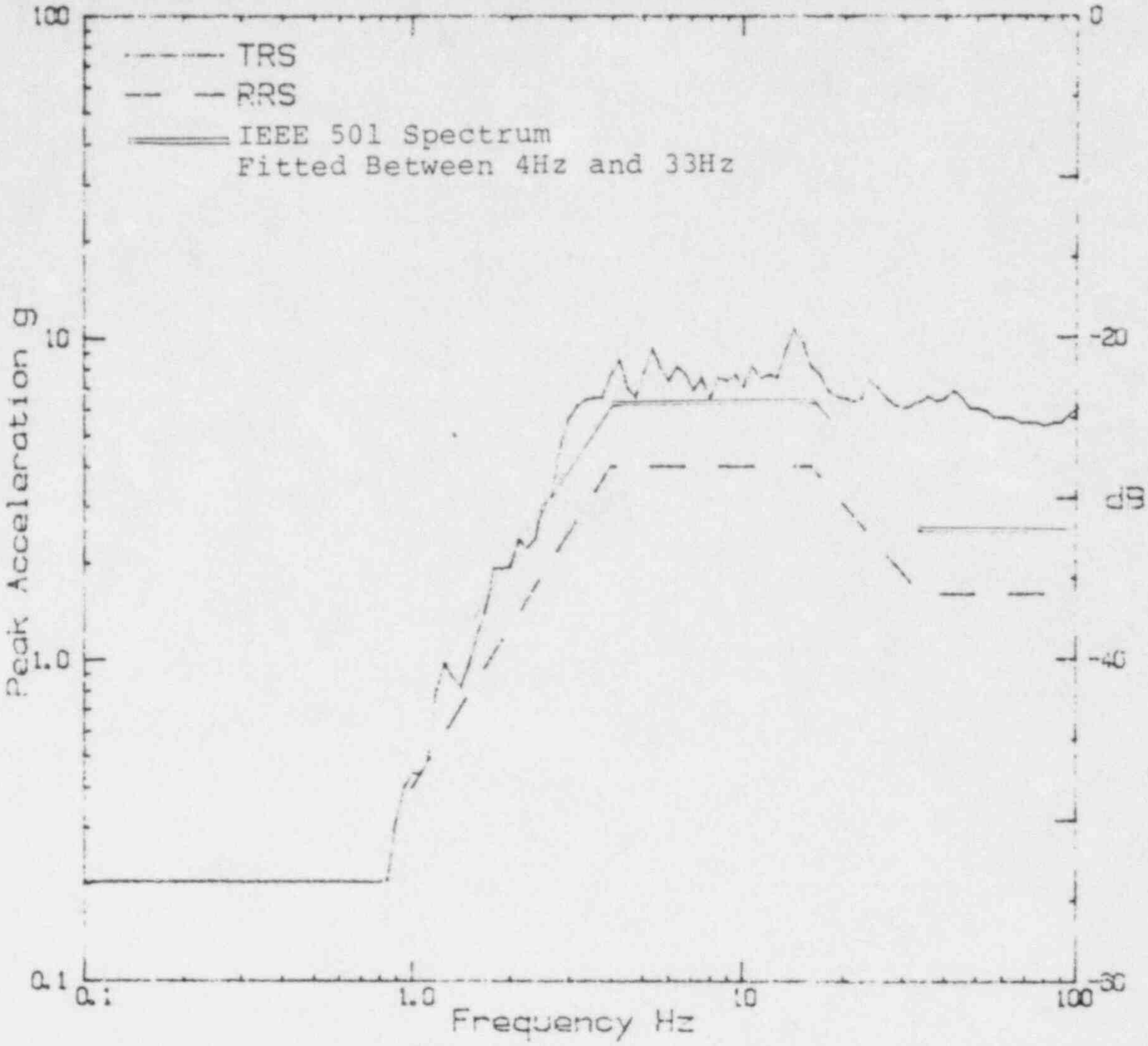
PARTICULARS
Jan 23/84. Time 2:15. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.4.
Graph 5012

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6.8: shaker limit

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 2.0g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 644. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 30

TEST ITEM
station cells, Gould, Model NCX 2250, sample#14

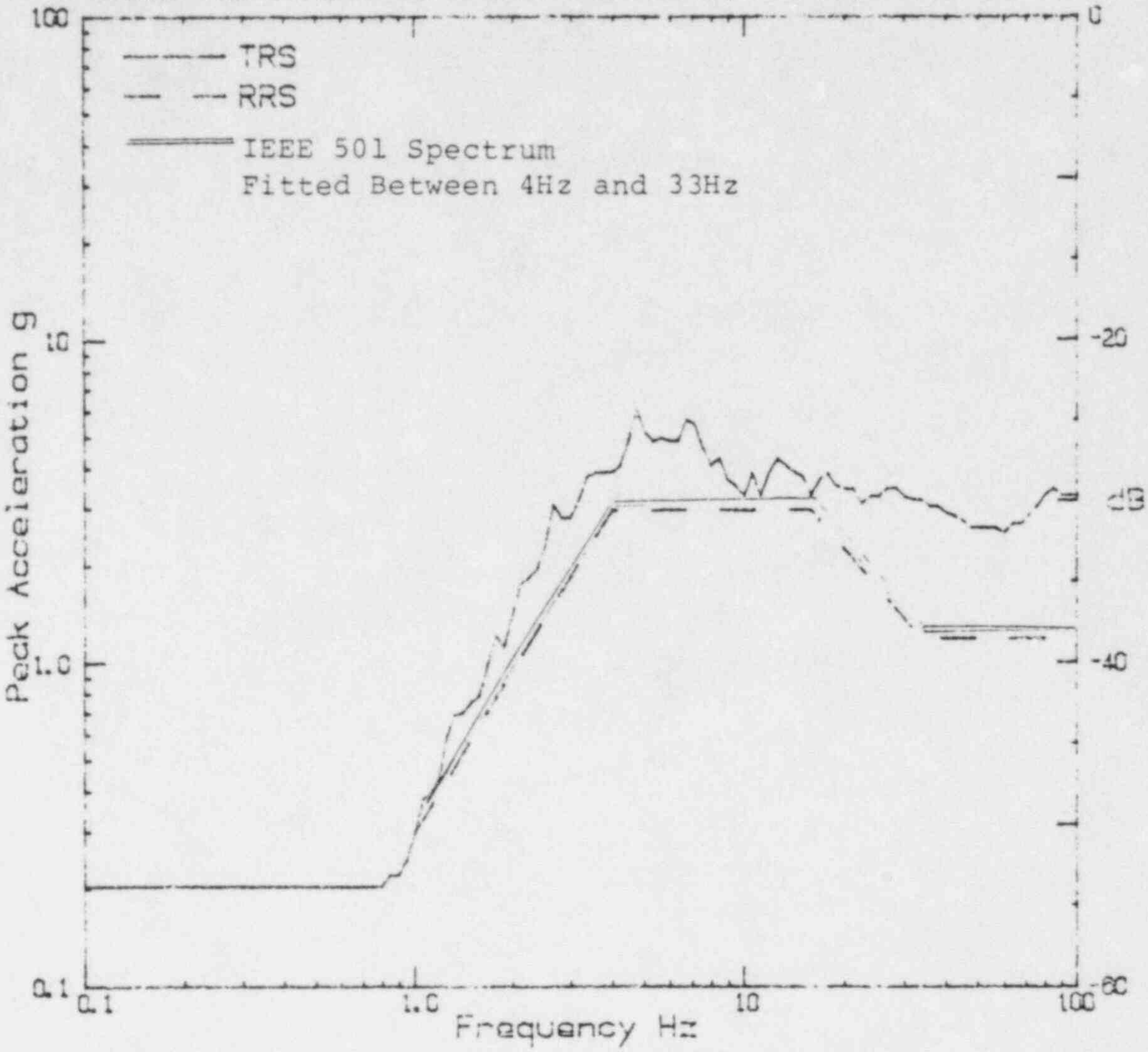
PARTICULARS
Jan 23/84, Time 2:15, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.4,
Graph 5013

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate,
span 6.8: shaker limit

ANALYSIS
Type Maximax, Damping (%) 5, B.W.= 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA= 2.5g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 644, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 31

TEST ITEM
station cells, Gould, Model NCX 2250, sample#48

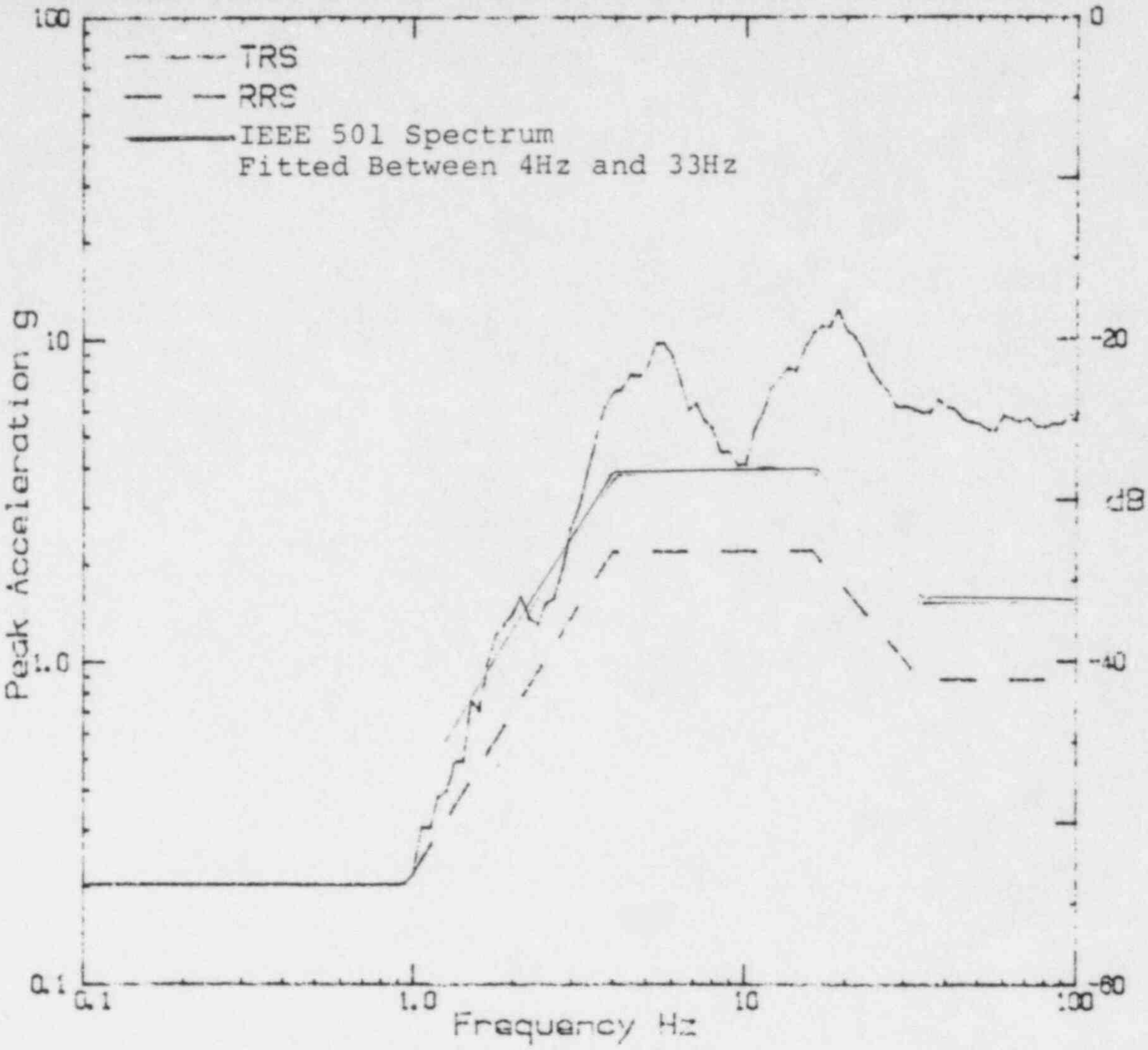
PARTICULARS
Jan 23/84, Time 3:00, Temp('C) 23, Humidity(%) 22, Press (kPa)100.4,
Graph 5017

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate, span 5

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA= 1.3g

ACCELEROMETER
Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 647, Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 32

TEST ITEM
station cells. Gould. Model NCX 2250. sample #48

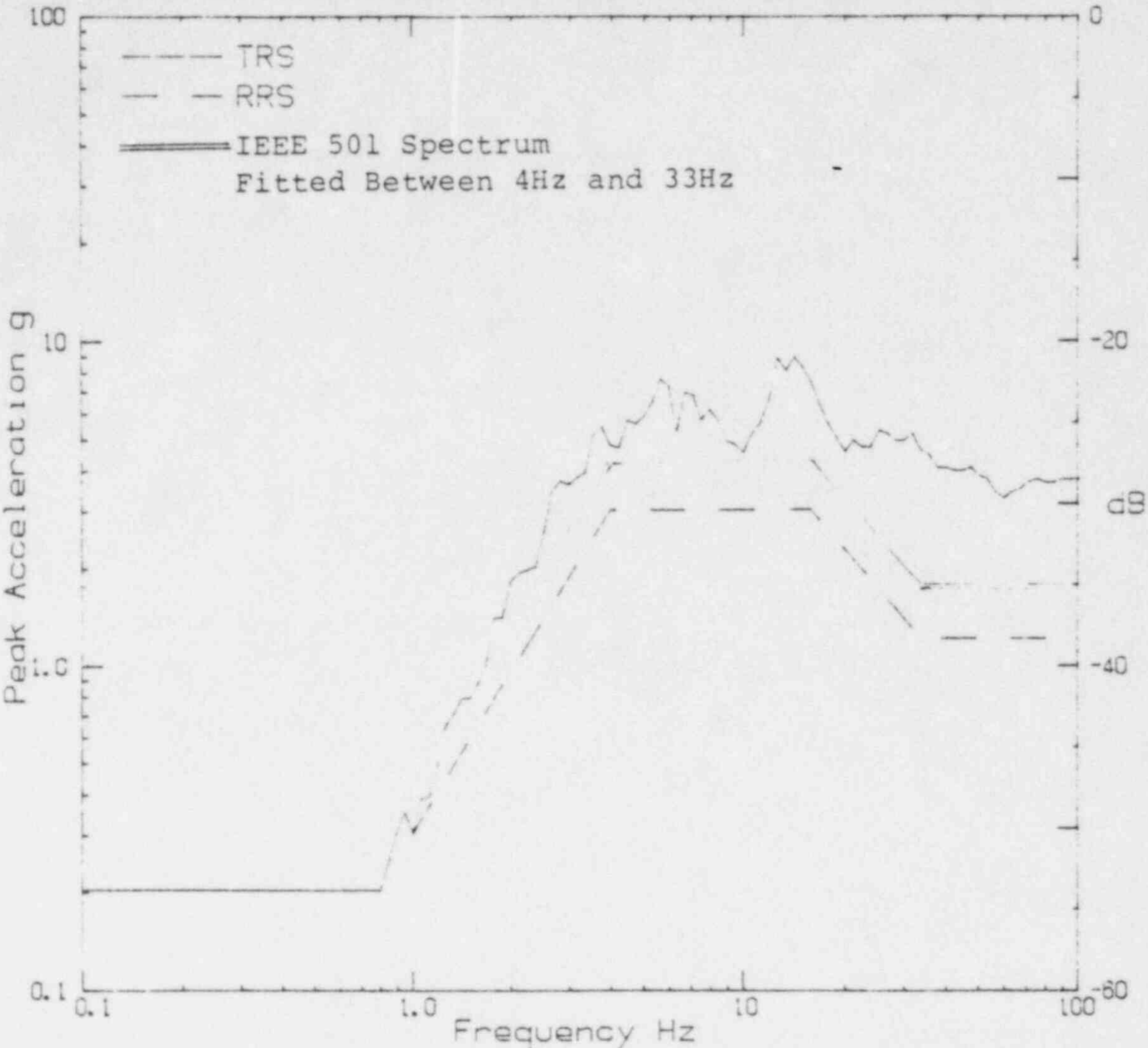
PARTICULARS
Jan 23/84. Time 3:00. Temp('C) 23. Humidity(%) 22. Press (kPa)100.4.
Graph 501d

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate. span 5

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 1.6g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 647. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 33

TEST ITEM
station cells. Gould. Model NCX 2250. sampler#48

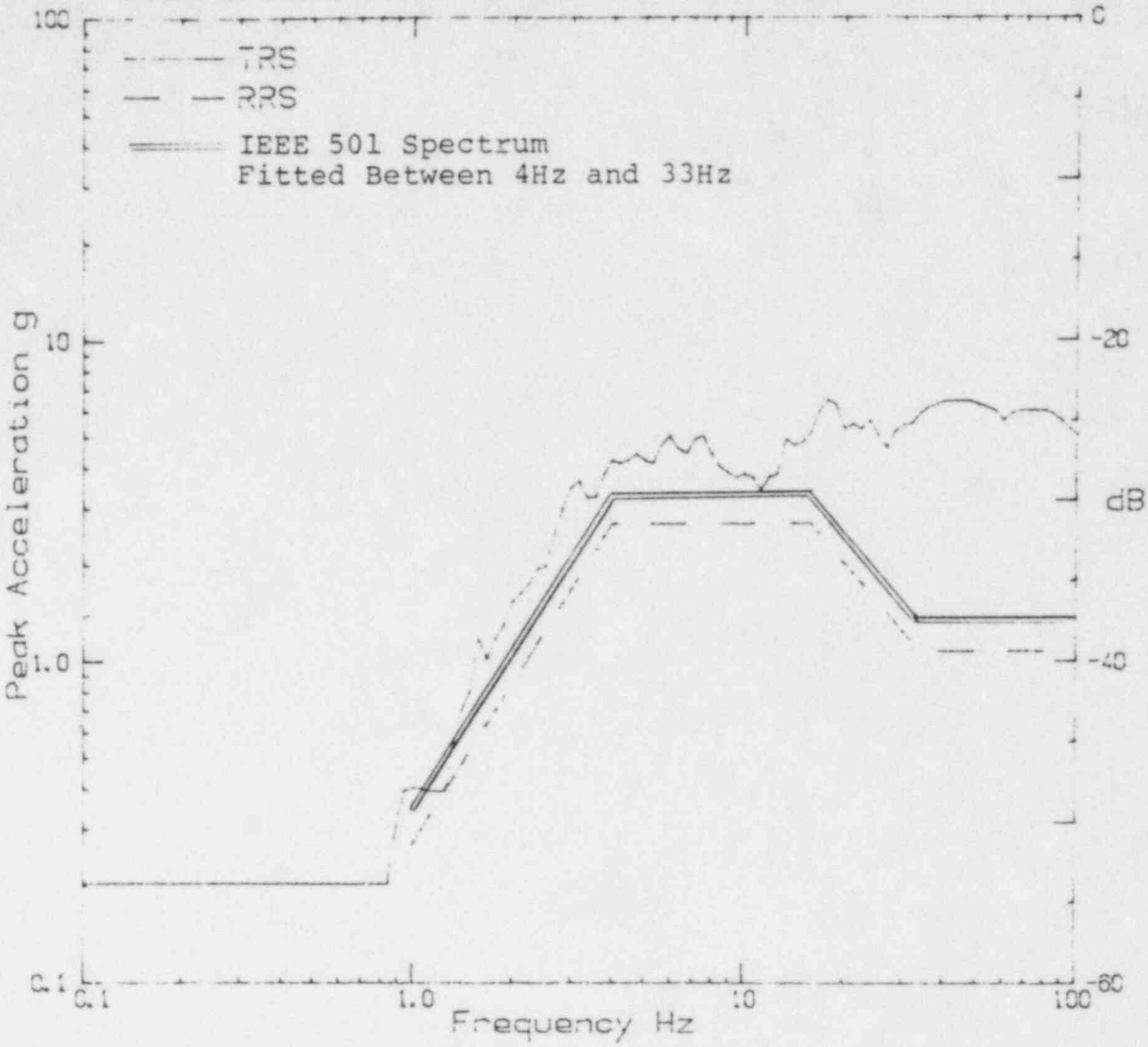
PARTICULARS
Jan 23/84. Time 3:00. Temp('C) 23. Humidity(%) 22. Press (kPa)100.4.
Graph 5019

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate. span 5

ANALYSIS
Type Maximax. Damping (%)5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA= 1.7g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 647. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 34

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
-. Part 49: 42: 25

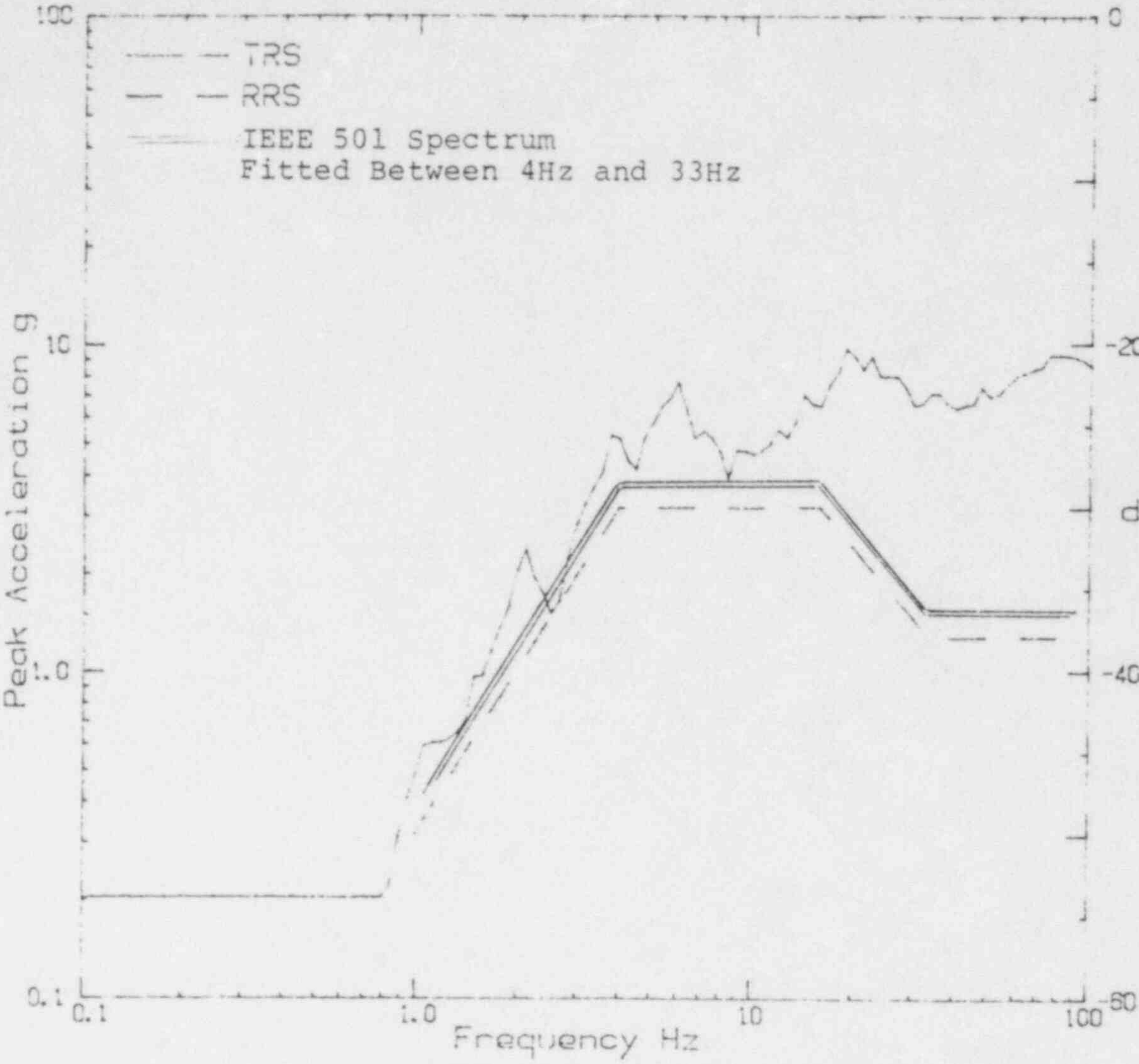
PARTICULARS
March 12/84. Time 10: 46. Temp('C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5080

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 5. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA =1.4g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting plate.
TT 668. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 35

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
. Part 49:42:25

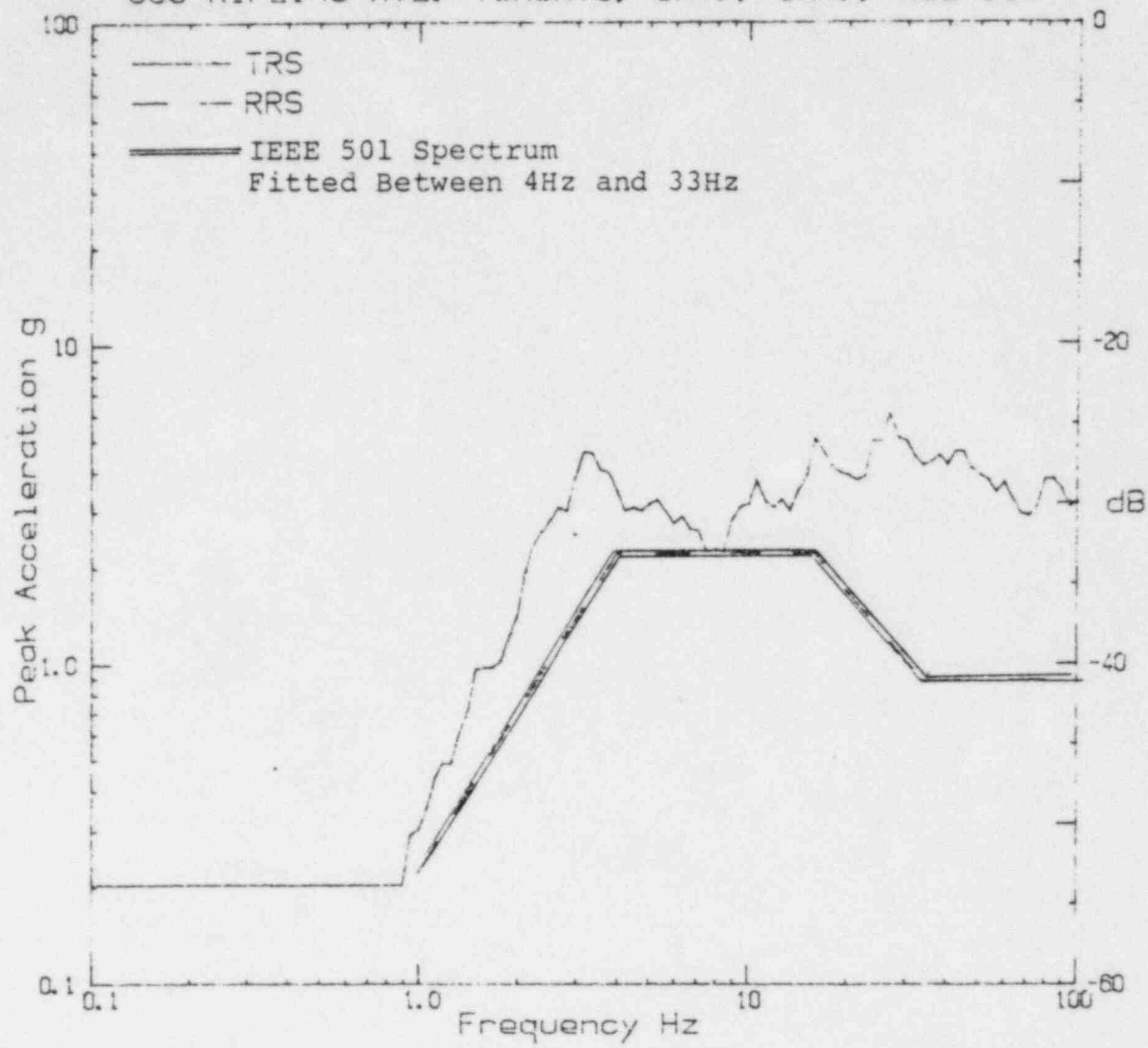
PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5081

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 5. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 1.5g

ACCELEROMETER
Wilcoxon. Serial S761 Range dB58. Location base-mounting plate.
TT 658. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 36

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part 49; 42; 25

PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5082

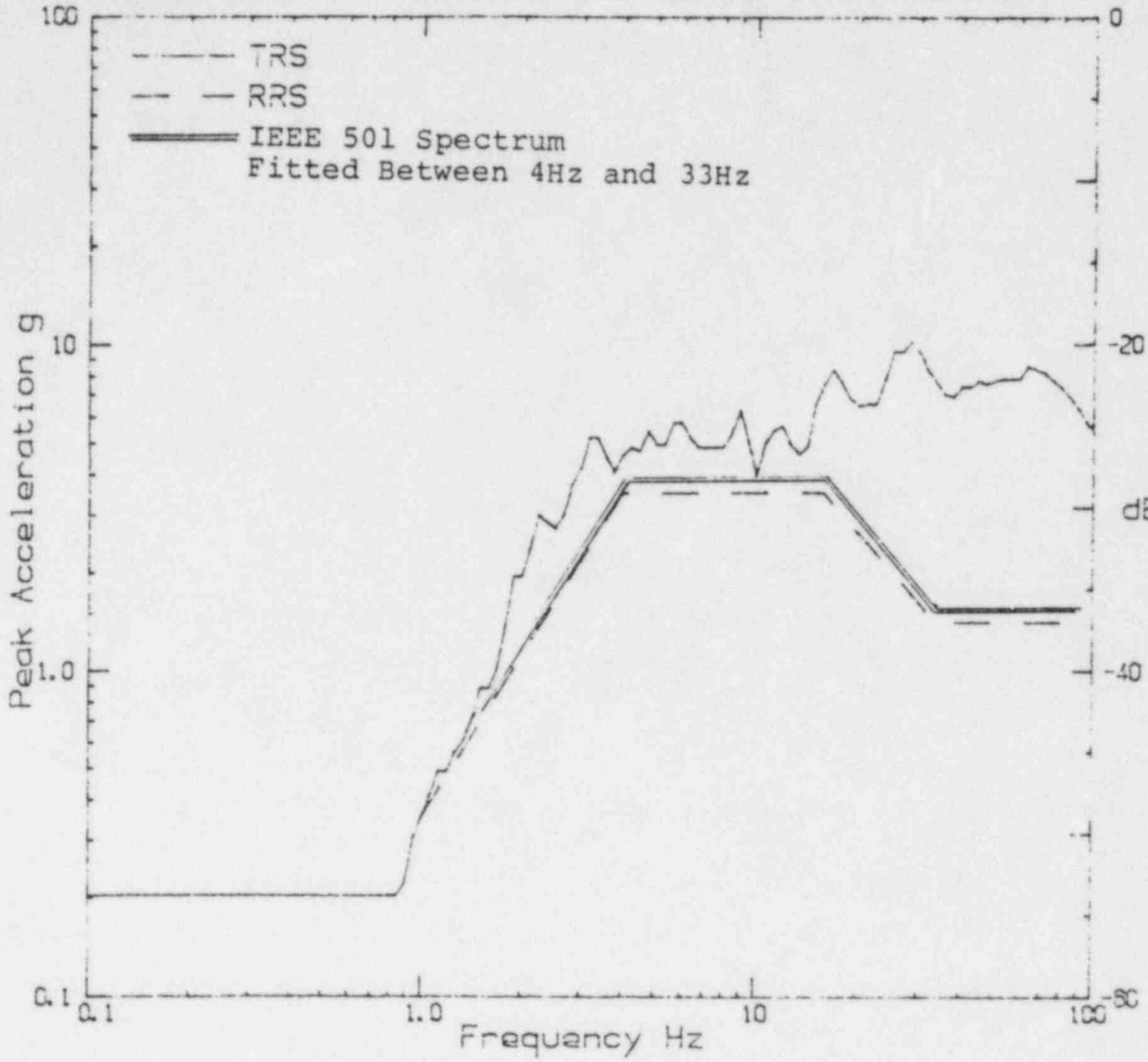
SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells ; span 5. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=.9g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting plate.
TT 668. Channel 3

B84-37

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 37

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
[illegible]. Part 49:42:25

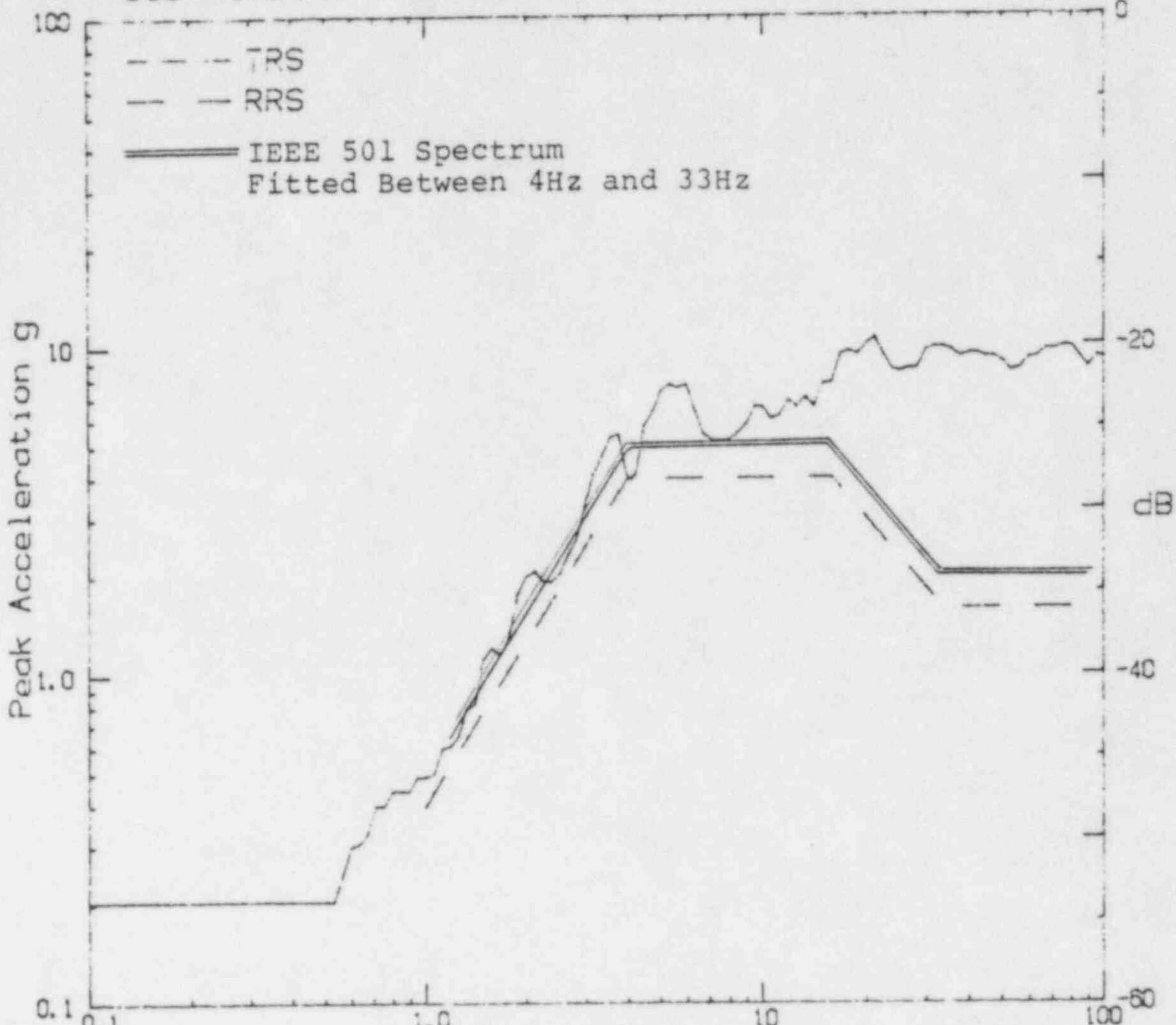
PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5086

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 6. one cell broken

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA = 1.5g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting plate.
TT 670. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 38

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part 49: 42: 25

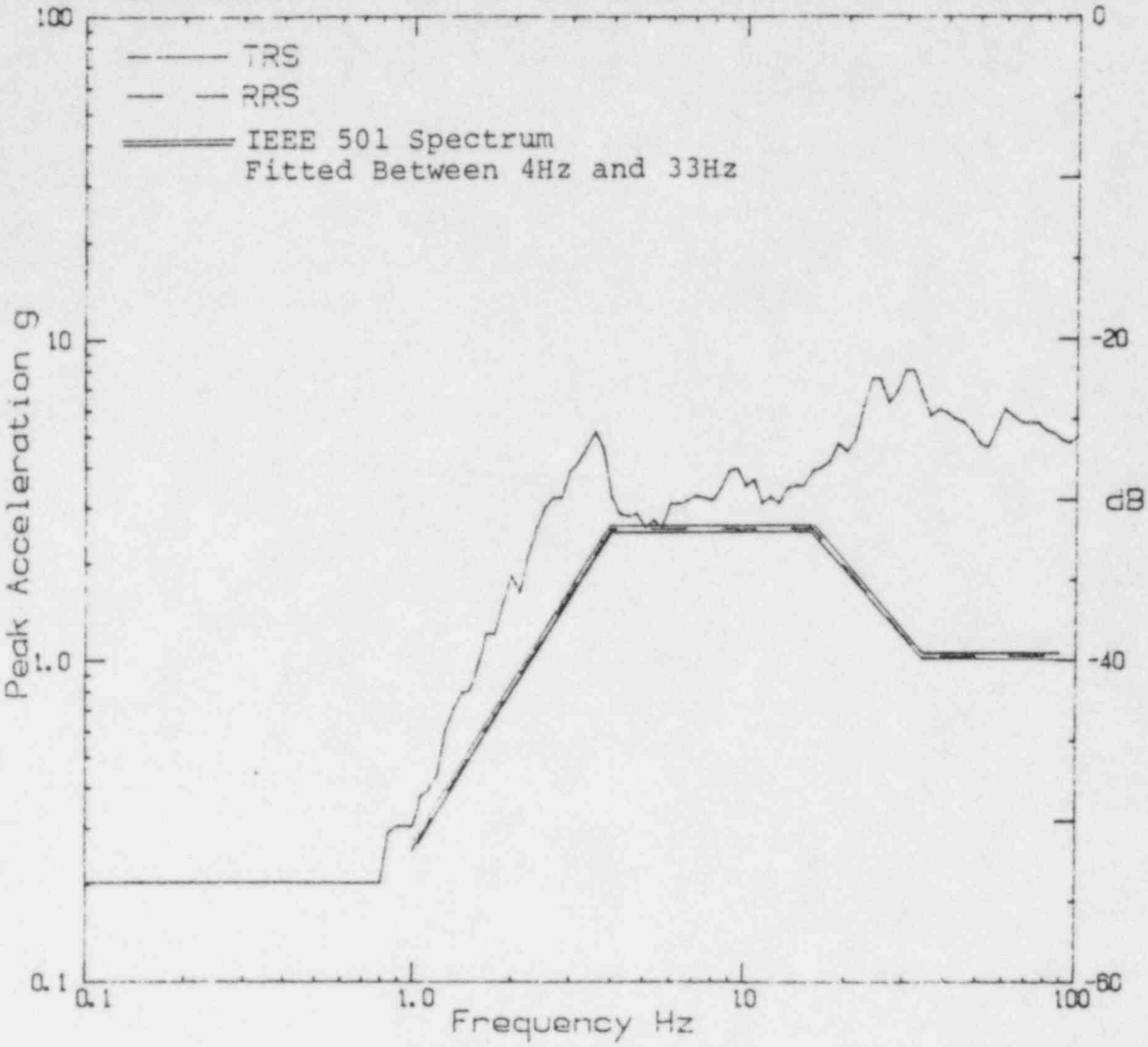
PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5087

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 6. one cell broken

ANALYSIS
Type Maximax. Damping (%)5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA= 2.0g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting plate.
TT 570. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 39

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part 49:42:25

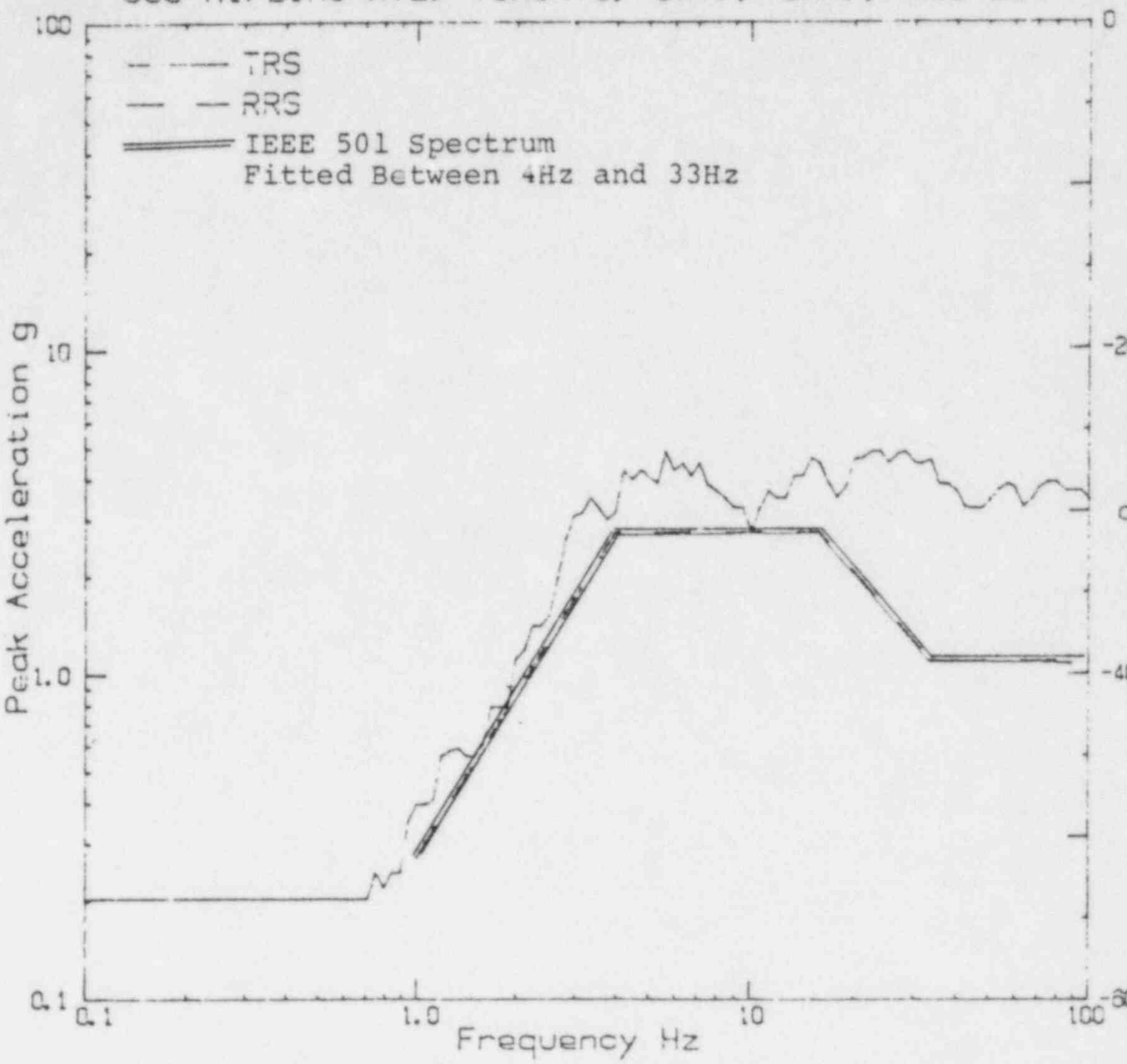
PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5088

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 6. one cell broken

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.04g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting plate.
TT 670. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 40

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells #30: 23: 8

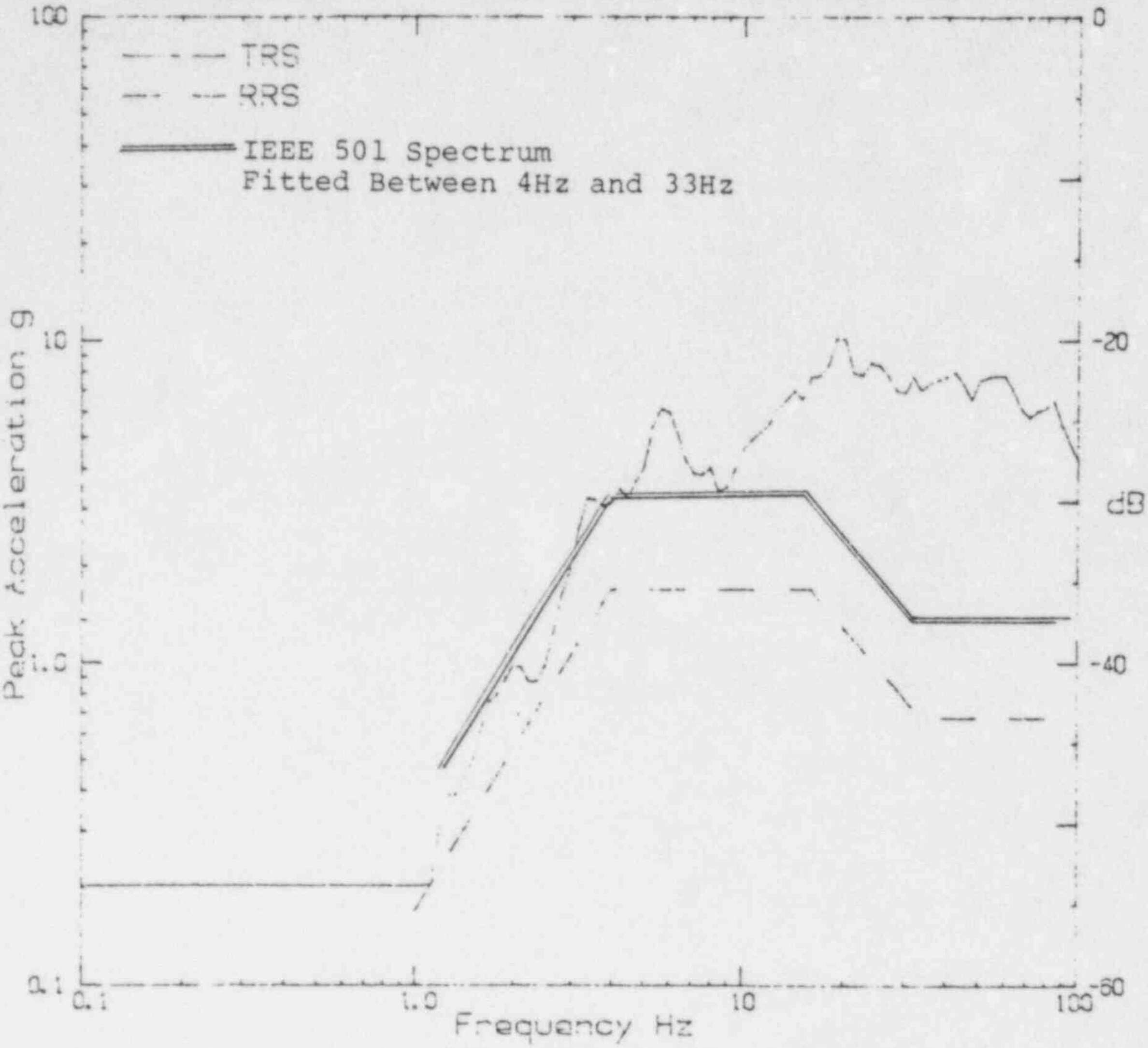
PARTICULARS
March 12/84. Time 3:42. Temp('C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5092. Record 0

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.1g

ACCELEROMETER
Wilcoxon. Serial S757. Range d858. Location base-mounting plate.
TT 678. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 41

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells #30:23:8

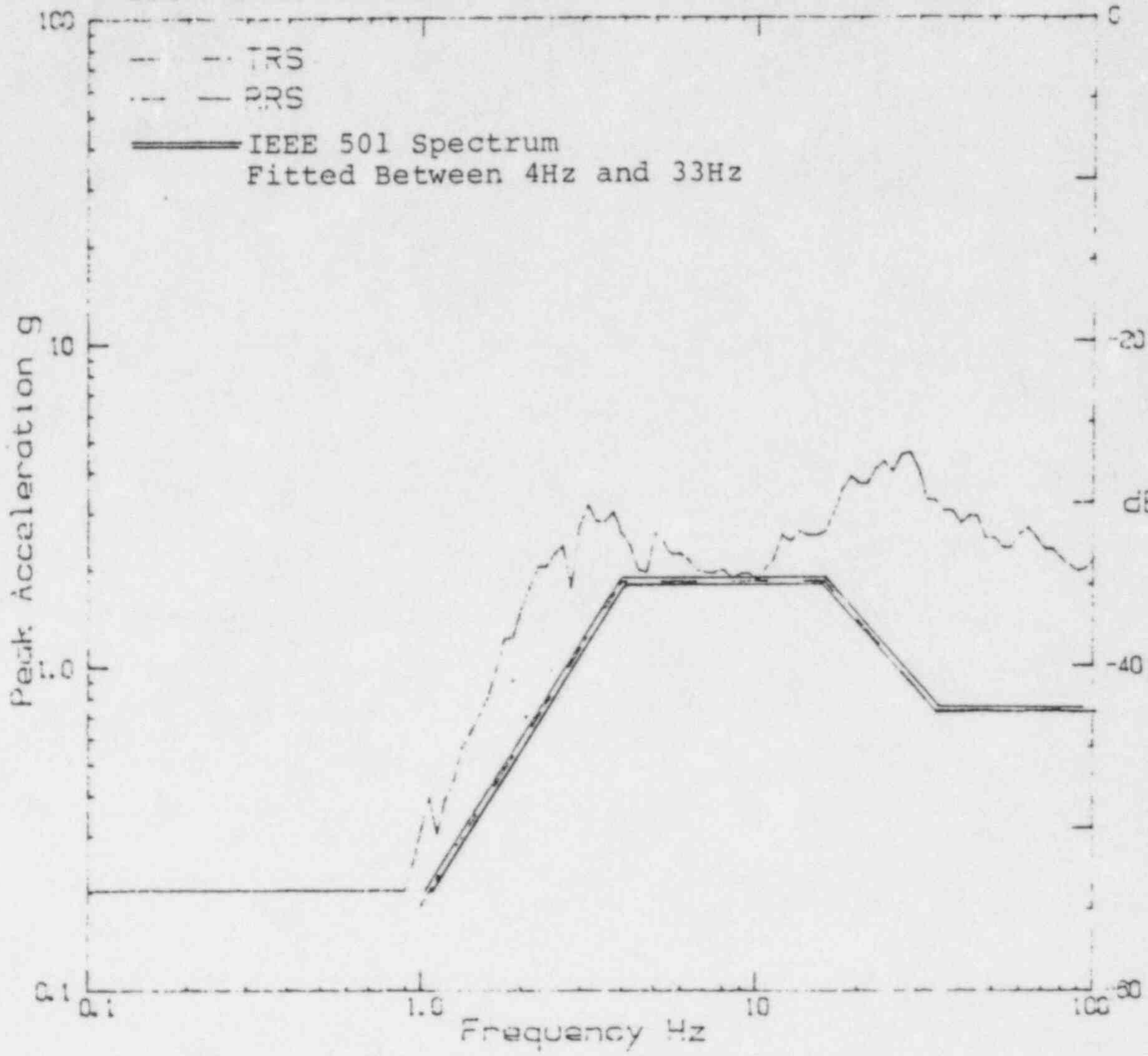
PARTICULARS
March 12/84. Time 3:42. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5093. Record 0

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells +1 dummy. Fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA =1.3g

ACCELEROMETER
Wilcoxon. Serial 5761. Range d358. Location base-mounting plate.
TT 678. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE **42**

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells #30; 23; 8

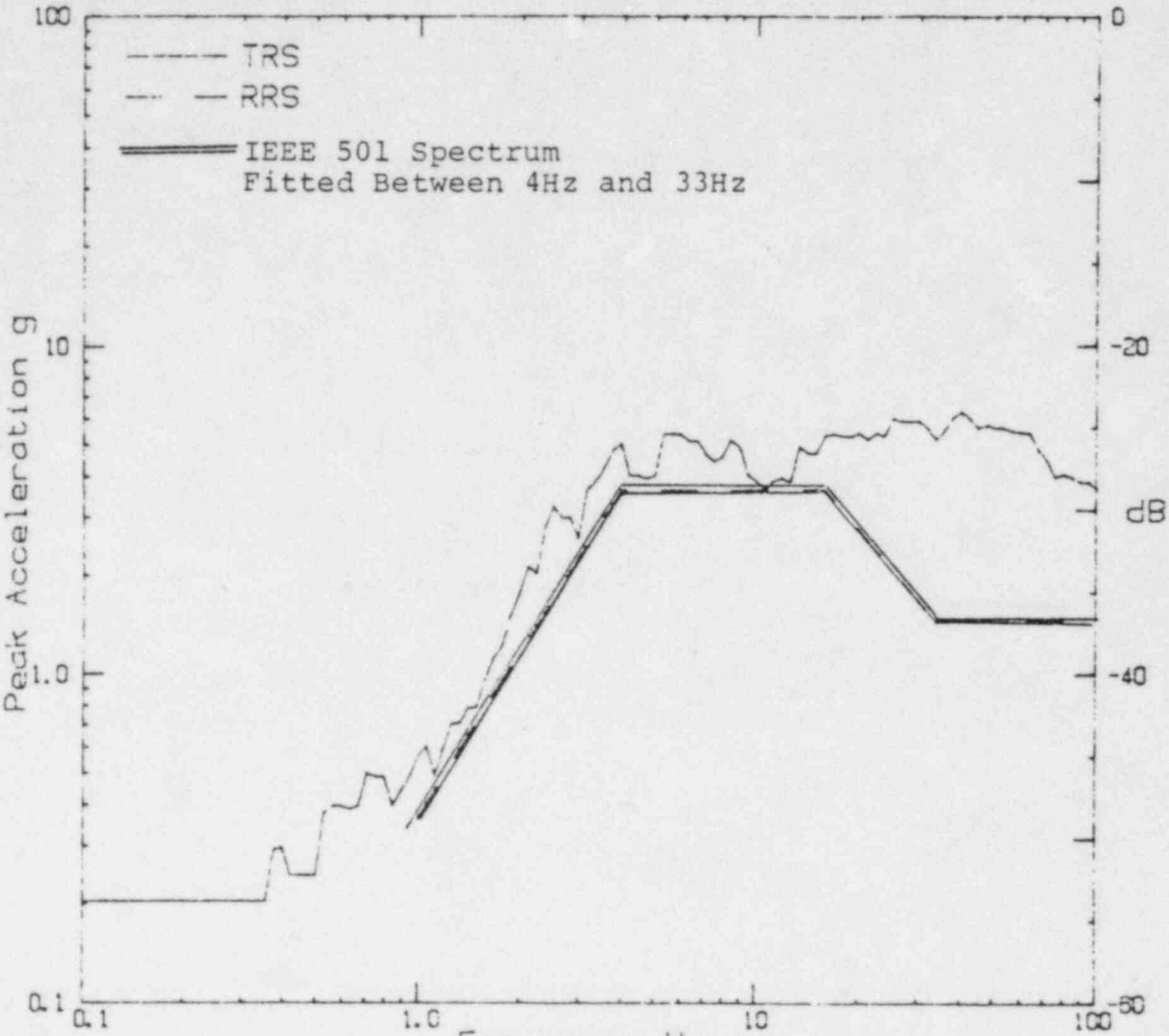
PARTICULARS
March 12/84. Time 9:42. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5094. Record 0

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells :1 dummy. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis I.
Shaker tri-axial. ZPA=.74g

ACCELEROMETER
Wilcoxon. Serial 5901. Range d958. Location base-mounting plate.
TT 578. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 43

TEST ITEM
Station cells & rack. Gould. Model NCX225G & Gould type rack.
Part cells 30 . 23 . 8.

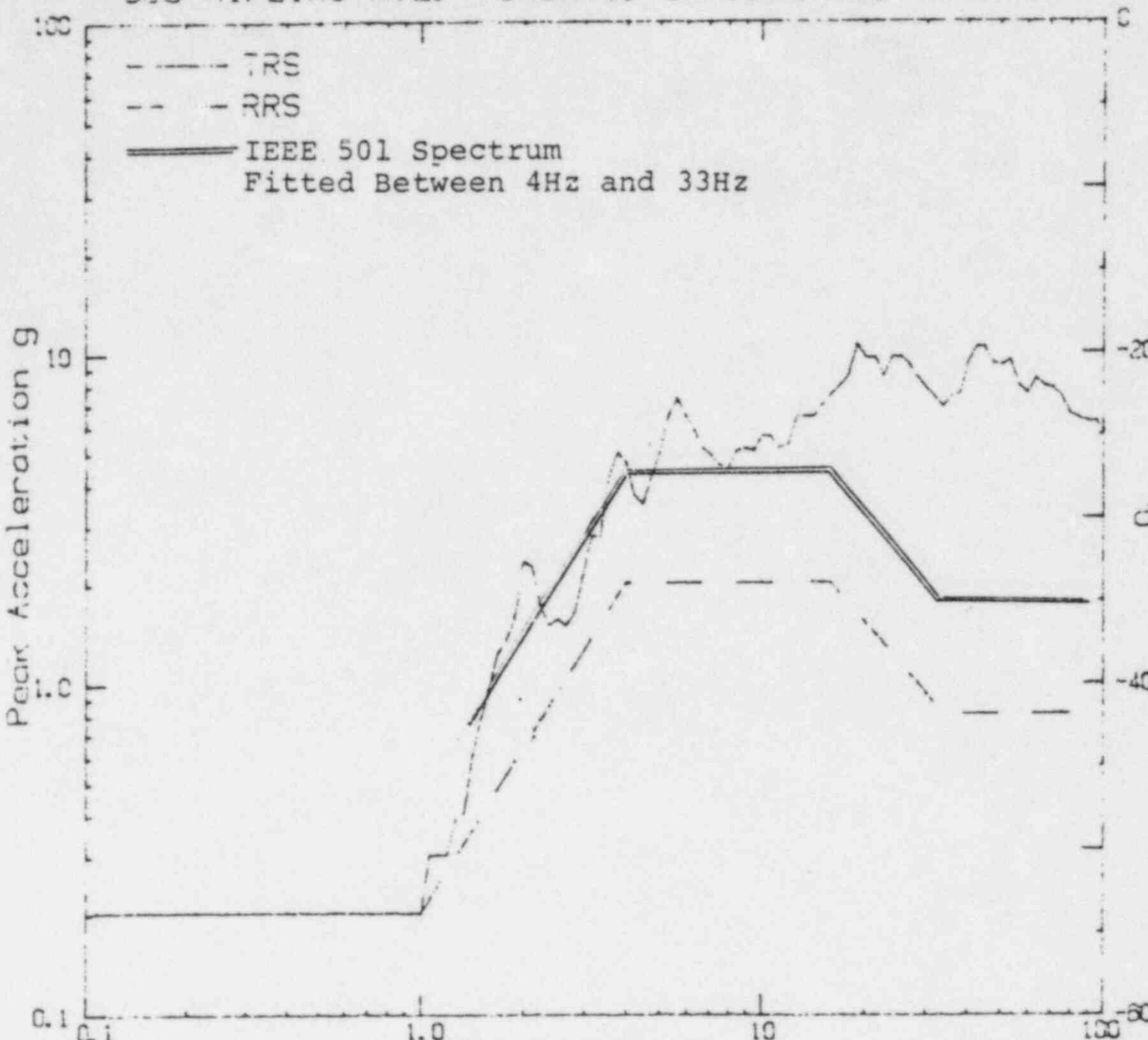
PARTICULARS
March 12/84. Time 9:45. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5098

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. failure level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.47g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting plate.
TT 680. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 44

TEST ITEM
Station cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells 30 , 23 . 8.

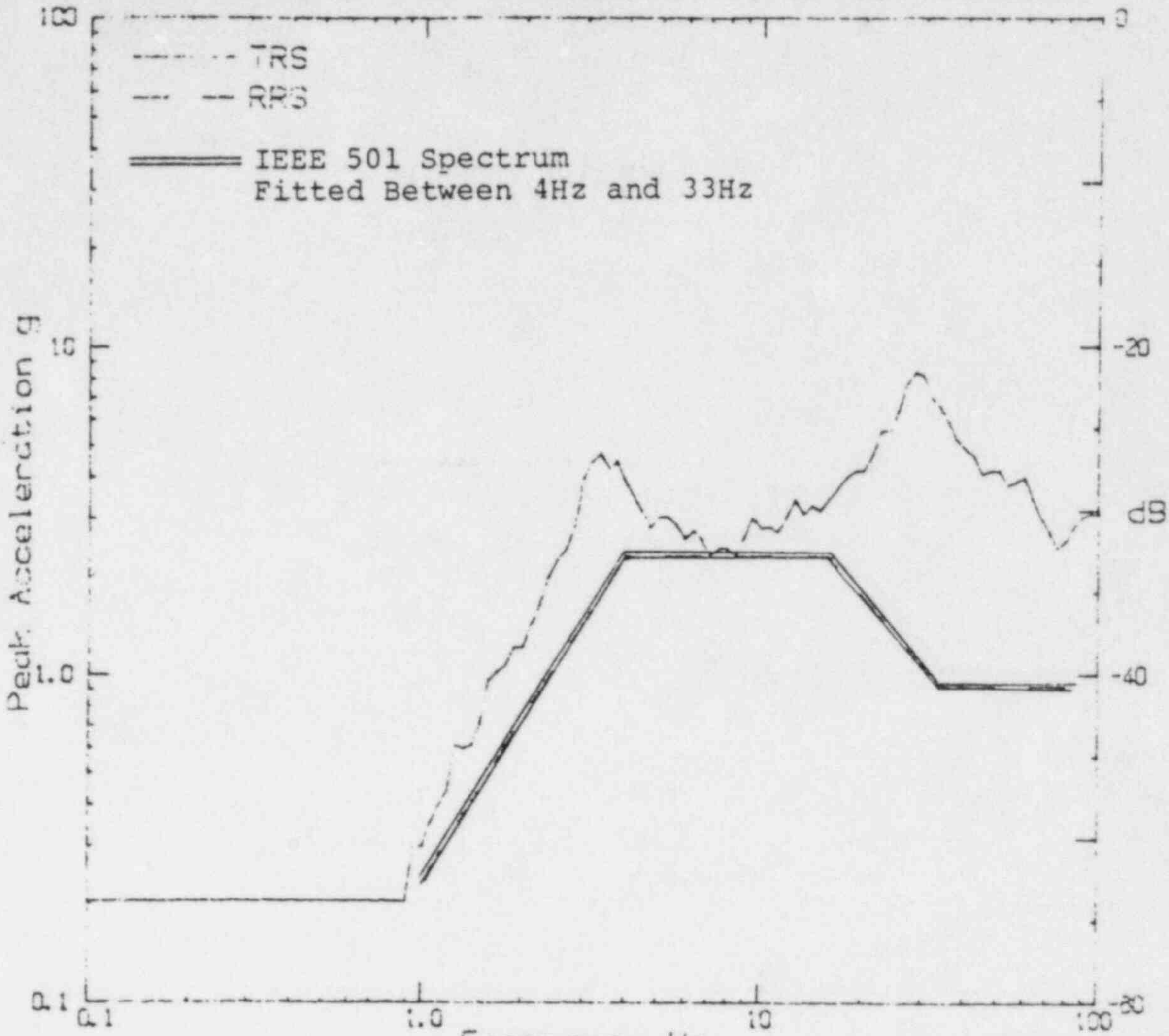
PARTICULARS
March 12/84. Time 3:45. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5099

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. failure level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=. 1.7g

ACCELEROMETER
Wilcoxon. Serial 5761. Range dB58. Location base-mounting plate.
TT 680. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 45

TEST ITEM
Station cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells 30 . 23 . 8.

PARTICULARS
March 12/84. Time 3:45. Temp('C) 24. humidity(%) 39.
Press (kPa)100.9. Graph 5100

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. failure level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=.93g

ACCELEROMETER
Wilcoxon. Serial 9901. Range d958. Location base-mounting plate.
TT 680. Channel 3

"APPENDIX 1"

Test Plan
for
Seismic Testing of Naturally-Aged Nuclear-Station Stationary Battery Cells

June 24, 1983
Revision A - October, 1983

Donald B. Hente

Light Water Reactor Safety Department
Safety Component Assessment Division
6446

Sandia National Laboratories
Albuquerque, New Mexico

SEISMIC TESTING OF NATURALLY-AGED
NUCLEAR-STATION STATIONARY BATTERY CELLS

1. INTRODUCTION

This seismic testing research program will be used to determine the seismic-withstand capability of naturally-aged lead-acid battery cells. This research effort is needed to evaluate seismic testing with regard to overall equipment qualification. The results will be used to determine an age band beyond which batteries are susceptible to degradation or failure due to a seismic event. The results will be used to help determine if the cells are capable of surviving a seismic event for their entire qualified service life or if the effects of natural aging make them susceptible to seismic damage in effect shortening their qualified service life.

The following program describes the test sequence to be followed to assess the seismic effects on various naturally-aged battery cells used as stationary batteries in U.S. nuclear power plants. This program, in conjunction with the present testing efforts being accomplished by Ontario Hydro, Canada, should expand the current but very limited baseline data presently available on the capability of naturally-aged battery cells to meet their discharge capacity requirements and to provide adequate power during and following a seismic event.

2. BACKGROUND

Because of the importance of stationary storage batteries to the emergency power systems in nuclear power plants, the U.S. Nuclear Regulatory Commission staff has requested an evaluation of the impact of aging and seismic exposure on battery cell capacity. The concern is that as battery cells age, they may become so fragile the they are susceptible to damage and subsequent loss of capacity as a result of an exposure to seismic event.

A portion of the qualification proccess for lead-acid storage batteries involves accelerated aging and then exposing the artifically-aged batteries to a vibratory motion which simulates that motion resulting from a seismic event. While this initial testing of battery cells will add to the limited data base of seismic effects on aged cells, the long-range goal is to obtain data that will contribute to the evaluation of the adequacy of seismic testing with regard to overall battery qualification.

Negotiations are continuing with a number of utilities to obtain naturally-aged lead-calcium battery cells (e.g. Virginia Power and Electric Company, six 10-year old C&D LCU-13 cells; Philadelphia Electric, 50 plus 13-year old Exide FTC-21 cells; and Wisconsin Public Service Corporation, six 10-year old C&D LCU-25 cells) to be used for this seismic testing program. Already available are 20 11-year old lead-calcium cells from the Fitzpatrick Nuclear Power Plant and 20 28-year old and 24 8-year old lead-antimony cells from the Shippingport Nuclear Power Station. Testing of all of these cells will supplement the testing of 13-year old lead-antimony battery cells by Ontario Hydro (Ref. 1). The lead-antimony battery cells are not necessarily typical of the battery cells (lead-calcium) currently being installed in nuclear power plants. They do, however, provide an opportunity to conduct a general test to identify fragility levels of typical aged lead-antimony battery cells. Fragility testing (testing to determine the capability of a battery cell) has been selected versus proof testing (testing to a specific seismic motion) because the intent of this program is not to qualify battery cells but to determine at which seismic level aged battery cells will fail.

During 1977, Ontario Hydro seismically tested five sets of three cell batteries. Three of the batteries were new, one was nine years old, and the fifth was 16 years old. All of the batteries except the 16-year old survived, but as Ontario Hydro has reported "the sample was too small ...to draw firm conclusions about the seismic capability of aged batteries" (Ref. 2). The tests did indicate that a 16-year old battery is more fragile than a new battery.

This program, in conjunction with the Ontario Hydro effort, will contribute data which eventually will allow firm conclusions to be drawn on the seismic capabilities of aged batteries.

3. TEST PROCEDURES

The following described test procedures are to be used for the seismic testing of naturally-aged lead-antimony and lead-calcium cells obtained by Sandia National Laboratories. As battery cells of various ages are obtained, arrangements will also be made for their storage, conditioning, and testing.

3.1 Pre-Seismic Inspection

As naturally-aged cells are received, they will be inspected for leaks, excess sediment, broken posts, cracks, crazing, and damage that was obviously caused while the battery cells were in transit. Those battery cells obviously damaged during shipment will not be exposed to a seismic test, but they may be used for any other appropriate requirements such as dissecting for informational purposes, material property tests, and chemical analysis. If required, leaking cells may be used for seismic tests; in addition they also may be used for the same requirements as damaged cells. All abnormalities will be documented and photographed. The condition of all cells will be documented for subsequent analysis.

3.2 Cell Conditioning

Those cells that are acceptable for seismic testing will be charged so that each individual cell has a specific gravity between 1.200 and 1.220 corrected to 25°C (77°F) using the factors provided in Table 1, IEEE Std 450-1980. The fully charged cells will be placed on a float charge of 2.15 volts per cell (VPC) for 24 hours. Following the 24-hour float charge, capacity tests will be performed on all cells following the procedures of paragraph 6 of IEEE Std 450-1980.

To provide a uniform bases for all capacity tests, the cells will be discharged at the three-hour rate. The capacity test will be terminated when the individual cell voltage falls to 1.7 VPC or when the average battery terminal voltage falls to 1.75VPC. These results , as well as any capacity test results received from the facility providing the cells, will be recorded. Following the capacity tests, the cells will be given a finishing charge and placed on float preparatory to the impact hammer resonance response test (if accomplished) and the fragility test program.

The condition of each cell at each stage of cell conditioning will be documented and photographed for subsequent analysis.

3.3 Fragility Tests of Individual Cells

In evaluating the type of seismic test to which the cells should be exposed, both single and multiple frequency proof and fragility testing were considered. Single and multiple proof testing were eliminated because they require cell exposures to a particular response spectrum or time history defined for a specific location. On the other hand, fragility testing was chosen because it determines the ultimate capability of a piece of equipment. Single frequency fragility testing was eliminated because multiple frequency testing, even on a generic basis, should provide a response spectrum that is determined from single frequency data. Thus the multiple frequency encompasses the single frequency. In addition multiple frequency testing provides a closer simulation to a typical seismic ground motion thus allowing fragility data relating to the battery cells to be obtained by testing the cells to a realistic simulation of the environment.

The excitation for the fragility testing will be random in nature with five percent damping. The response spectra in each of the two horizontal and one vertical directions will be equal and close to the generic spectrum of Figure 1, IEEE Std 501-1978. Initially, each seismic test will consist of a single cell rigidly mounted to a triaxial shake table. Each cell will be subjected to a series of seismic tests of repeatable multifrequency input motions with an increase in amplitude with each test. The duration of each test should be about 30 seconds.

As fragility testing determines the ultimate capability of battery cells, the test sequence should get to the fragility level as soon as possible to minimize fatigue damage. To determine a general fragility level, several test cells will be sacrificed by estimating (assuming) a maximum (or failure) g level and then approaching and exceeding that level by increasing the g level in rapid, discrete steps. The starting level for the cells to be sacrificed should be about 0.6 of the estimated g level for failure. After determining the general fragility level, the fragility test sequence will start with a g level that is 0.8 of the lowest fragility level of the cells that were sacrificed. Increases will be in steps of 10 percent until failure (internal damage resulting in voltage loss) or the individual cell voltage falls to 1.7 volts.

The individual cells will be placed on a fixed load discharge to maintain a current equal to approximately the one-hour ampere discharge rate. If the seismic testing is terminated prior to when the individual cell voltage falls to 1.7 volts, the cell will be continued to be discharged until the 1.7 volts are reached.

As the number of available aged battery cells will vary with each type obtained, no minimum number of cells to be tested can be established. Regardless of the number available only about eight of the same type and age will be tested.

Visual inspection, photographs, and a written description of the cells at each phase of the seismic testing will be accomplished, i.e., at each new level in the fragility test sequence.

Accelerometers will be placed on the rigidly mounted cells during the fragility test sequence for comparison with the input to the shaker table.

3.4 Fragility Tests of Multicell Batteries

Although the condition of the individual cells following the seismic tests cannot be determined in advance of the tests, very preliminary results indicate that at least some battery cells will survive electrically and the cell jar will survive mechanically. If the battery cells have survived the fragility tests of the individual cells, the cells will be mounted on a typical plant battery rack in either a three- or four-cell battery configuration (whatever the applicable unit configuration) and exposed to the same fragility test. The purpose of the multicell battery seismic test will be to determine if interactions between cells causes individual internal damage and to check for case/jar failures when cells are mounted in their typical battery rack. Procedures to reach the fragility level will be the same as those described in paragraph 3.3.

The intent will be to test the batteries with their original electrolyte in place. If leaks develop during the individual cell testing or during the initial phases of the multicell testing, the electrolyte may be replaced with water to eliminate a possible safety hazard. With water in the battery cells, only the case/jar failures can be determined.

As in the individual cell testing, the three- or four-cell batteries with electrolyte will be placed on a fixed load discharge to maintain a current equal to approximately the one-hour ampere discharge rate. The multicell battery will be discharged until the individual cell voltage falls below 1.7 VPC or when the average battery terminal voltage falls below 1.75 VPC.

Initially each rack mounted battery configuration will be subjected to an impulsive excitation using an impact hammer to identify distinct natural frequencies and mode shapes. As the results of these impulsive excitations become known, it may be necessary to redefine the need and spectrum for the excitations of additional configurations.

3.5 Capacity Tests

Following completion of the fragility tests of both the individual cells and the multicell batteries (when the batteries have been tested with electrolyte in them), capacity tests as described in paragraph 3.2 will be performed. These results will be compared with the results of the capacity tests made before exposing the cells to a seismic event. The comparison should indicate the impact of exposing a battery cell to a fragility level seismic event.

3.6 Crack and Craze Propagation

To examine the possible mechanisms for crack and craze propagation and to investigate the probability of any leaks developing as a result of such propagation, available cracked and crazed cells with the electrolyte replaced with water will be tested in three configurations. Seismic tests will be conducted (1) on individual cells with the cells rigidly mounted in the jig used for the fragility tests, (2) on individual cells loosely mounted (1/4" clearance from the support frames) in the jig, and (3) on the multicell battery mounted in the battery rack.

These propagation tests will follow the fragility tests, will use fragility levels as determined by the procedures described in paragraph 3.3, and will use cells that were either cracked and crazed when obtained or became cracked and crazed during the fragility testing.

As with the impulsive excitation effort, the first results of the propagation effort may require a redefinition of the need for additional tests.

REFERENCES

1. Tulk, J. D., Ontario Hydro Report B83-21K, Seismic Testing of Aged Nuclear Generating Station Batteries, Toronto, Canada, July 19, 1983.

2. Lowen, T., Ontario Hydro Report 77-221-H, Seismic Qualification Tests for Nuclear Generating Station Batteries, Toronto, Canada, May 17, 1977.

DISTRIBUTION

Mr. B.A. Oliver	Electrical Design, H12G03
Mr. C.J. Royce (4)	Electrical Design, H12D5
Mr. D. Harrison	Chemical Research
Dr. R.W. Glass	Chemical Research
Mr. W.J. Janis	Chemical Research
Mr. G.J. Clarke	Mechanical Research
Mr. D.B. Craig	Mechanical Research
Mr. D.A. Black	Mechanical Research

Official Record
Public Reference Centre
Editorial Section
Office Copies (2)
Extra Copies (3)

- last page - 84-211

APPENDIX B

SEISMIC TESTING OF FITZPATRICK NUCLEAR GENERATING STATION BATTERIES: CELL INSPECTION AND CAPACITY TESTS

W. J. Janis

Ontario Hydro Research Division

ontario hydro
research division

To Mr. B.A. Oliver
Manager
Electrical Design Dept

SEISMIC TESTING OF FITZPATRICK NUCLEAR GENERATING STATION BATTERIES - CELL INSPECTION AND CAPACITY TESTS

W.J. Janis

The performance and condition of 12-year-old, calcium alloy, lead-acid cells were monitored before, during and after seismic testing to determine cell resistance to damage by seismic stresses. Six of nine cells failed electrically during seismic testing and one cell which did not fail suffered significant internal damage. Failures were caused by cracking of abnormally brittle, positive bus material and/or by post disconnection. Two cells which survived seismic testing did not possess bus defects and could deliver 80% of rated capacity after testing. Bus brittleness probably originated with the casting process and was promoted by chemical corrosion during service.

1.0 INTRODUCTION

Sandia National Laboratories (SNL) is currently under contract to the United States Nuclear Regulatory Commission (NRC) to conduct studies on the degradation and failure modes of safety related components used in nuclear power plants. Of particular interest to SNL and NRC, and also to Ontario Hydro, is the significance of aging on the seismic-accident survivability of stationary, Class 1E, emergency power batteries.

Because of mutual interest, past experience in seismic testing of batteries and the availability of special test facilities, Ontario Hydro was sub-contracted by SNL to carry out seismic fragility tests of naturally aged, lead-acid cells from the J.A. Fitzpatrick Nuclear Generating Station, Lycoming, New York. Following guidelines set out by SNL, a research program was developed by the Electrical Design Department (Design and Development Division), and the Mechanical and Chemical Research

job	file	date	report no.
740632-168-950	823.31 X836.74	July 10, 1984	C84-49-P

Departments (Research Division). In this program the performance and condition of aged cells were monitored before, during and after shaker table testing under simulated earthquake conditions.

This report presents cell condition and performance data obtained during the test program.

2.0 TEST CELLS

Twenty Gould NCX-2250 cells were selected at random by Fitzpatrick NGS personnel from a large number of cells recently released after 12 years of service. Six of the cells were shipped without electrolyte, as case leaks and cracks had developed during service. These empty cells were used in tests of case crack propagation under the influence of seismic stresses.

The test cells were all of the lead-calcium type, that is the grid material of these cells contained a small amount of calcium, less than 0.1%, alloyed with lead. Cell specifications supplied by the manufacturer are given in Appendix 1.

3.0 EXPERIMENTAL

3.1 Cell Inspection and Initial Conditioning

On delivery to Ontario Hydro Research Division (OHRD) the cells were inspected for leaks, excess sediment, broken posts, cracks, crazing and any damage which might have been induced by handling during transportation. Leaking cells were excluded from the test program and the remainder put on equalizing, then floating charge at 2.25 and 2.15 V per cell (VPC), respectively. Cells were placed on floating charge prior to, and between, capacity tests to minimize capacity loss through self-discharge.

During storage the specific gravity of the cells was maintained between 1.200 and 1.220, corrected to 25°C per standard 450-1980 of the Institute of Electrical and Electronic Engineers (IEEE)/1/. Specific gravity, cell voltage, electrolyte level and temperature were monitored and adjusted as necessary to maintain the cells in serviceable condition.

3.2 Initial Capacity Tests

Following inspection, charge equalization, and a minimum of 24 h float charging, all serviceable cells were discharged at the manufacturer's specified 3 h rate to a final cell potential of

1.75 VPC. The discharge tests provided benchmark capacity data for cells selected for seismic test and were carried out per reference 1 as follows:

1. Three or four cells and a resistance load were connected in series and the cells were discharged at a constant current following the procedure outlined in OHRD report No E76-85-H/2/.

2. Cell potentials, discharge current and temperature were monitored during the discharge test. The data were recorded at 3 min intervals.

3. Discharged cells were recharged in series at a potential of 2.25 V for 35-70 h, followed by sustained float charging at 2.15 V.

3.3 Cell Discharge During Seismic Testing

To assess the immediate effect of a seismic event on cell performance, cells were kept on discharge during seismic tests and cell voltages and currents were monitored continuously during the tests. A 1.5 h discharge rate was used for the Fitzpatrick cells to simulate a high load emergency service condition.

Discharge was initiated a few seconds prior to the first 30 s seismic event and was continued until the cell either failed during a seismic event or passed the scheduled sequence of seismic events. Failure was defined as the inability of a cell to maintain a potential greater than 1.75 V while under a constant current discharge at the 1.5 h rate.

The seismic test procedure is discussed in OHRD reports B84-39-P and B84-37-P from the Mechanical Research Department.

3.4 Post Seismic Capacity Tests

After seismic testing, two cells which did not fail were discharged at the 3 h rate. The procedure was the same as for the initial capacity tests except that cells were discharged individually.

3.5 Cell Disassembly and Material Studies

Eight test cells were disassembled following seismic and capacity testing to identify changes in internal components resulting directly from seismic testing. A photographic record of abnormalities was maintained and samples of fractured and un-fractured grid connector bus material were subjected to detailed metallurgical analysis.

4.0 RESULTS AND DISCUSSION

4.1 Cell Inspection

Twenty cells from Fitzpatrick NGS arrived at OHRD on September 6, 1983. Nine cells showed no outward evidence of damage, 8 had little or no electrolyte and three showed slightly low electrolyte levels. On standing indoors at 20°C for 3 days, electrolyte levels rose to acceptable values in 2 of the latter 3 cells. The third cell lost approximately 50% of its electrolyte on standing as a result of leakage from a crack on the bottom of the cell jar.

Eleven cells passed visual inspection and, after extensive clean-up of spilled sulphuric acid electrolyte, were put on charge on September 13, 1983. A record of observations made during the cell inspection is presented in Table I.

As expected for lead-calcium alloy cells, the plate growth, warping and sediment, observed during cell inspection was minimal.

<u>TABLE I</u>

<u>CELL INSPECTION RECORD</u>

Fitzpartrick Cell ID Number	Gould Serial Number	Specific Gravity		Observations
		In Plant (1977)	As Received at OHRD	
3	00155	1.230	1.194	no visible damage
6	K1148	1.232	1.205	no visible damage
7	00154	1.228	1.195	no visible damage
8	K74	1.238	1.209	no visible damage
9	00024	-	-	no electrolyte but no visible damage
12	00130	1.236	N/A***	slightly low electrolyte level
13	00144	1.232	N/A***	slightly low electrolyte level
14	00022	1.230	1.195	no visible damage
15	00158	-	-	no electrolyte but no visible damge
16	00177	-	-	no electrolyte-cracked seam**
17	00167	-	-	no electrolyte-large hole in base**
22	K1149	1.230	1.210	no visible damage
23	00152	1.238	1.200	no visible damage
24	00156	-	-	no electrolyte-crack at bottom corner**
25	00143	-	-	leaking-crack on bottom
30	00014	-	-	no electrolyte but no visible damage
42	00135	-	-	little electrolyte -crack on bottom
43	00141*	1.230	1.194	no visible damage
48	00032*	1.236	1.200	no visible damage
49	00181	-	-	no electrolyte but no visible damage

* Serial number order may be reversed.
** Documentation photograph taken.
*** Electrolyte level too low for accurate determination.

4.2 Initial Capacity Tests

Capacity data and pre-test specific gravities and open circuit cell potentials are presented in Table II. Only cell 7 failed to meet the IEEE recommended acceptance criterion of 80% rated capacity.

TABLE II

CAPACITY TEST DATA*

Cell Number	25°C Gravity Prior to Discharge	Open Circuit Potential (Volts)	Time to 1.75 VPC at 3 h rate of 585 A (min)	Percent Rated Capacity at 3 h Rate
3	1.208	2.19	194	108
6	1.213	2.19	173	96
7	1.208	2.20	124	69
8	1.209	2.10	175	97
12	1.190	2.20	176	98
13	1.195	2.20	208	116
14	1.200	2.23	186	103
22	1.213	2.13	175	97
23	1.200	2.10	191	106
43	1.200	2.21	183	102
48	1.200	2.12	183	102

* Cells equalized at 2.25 VPC for 15 days, then float charged at 2.15 VPC for 25 days prior to discharge.

After initial capacity tests, the cells were recharged. However, after 17 days of equalizing at 2.25 VPC, cell specific gravities averaged only 1.190, although both open circuit voltages and charging current had stabilized. As indicated in Appendix A of IEEE Standard 450/1/, the low apparent specific gravity is due to the persistance of a sulphuric acid concentration gradient within the cell. Following Appendix B of IEEE Standard 450, stabilization of the voltage-regulated charging current at the charging voltage was taken as an indication that the cells in question were charged. The cells were therefore allowed to proceed to seismic testing.

4.3 Cell Discharge During Seismic Testing

Sudden loss of cell potential was observed for all but two cells during seismic testing. The pass/fail results are summarized in

Table III and presented in more detail in Appendix 2. Details of the seismic testing procedure and fragility level assessment are presented in OHRD reports B84-37-P and B84-39-P.

TABLE III

DISCHARGE DATA SUMMARY - SEISMIC EVENT TESTS

Cell Number	Pass/Fail at 1.5 h Discharge Rate*	Shaker Table Setting at Failure	Cell Potential (V)		Time on Discharge (s)
			Before Failure	After Failure	
3	Fail	6	1.81	1.71	320
6	Pass	survived 6.8	1.89	-	260
7	Fail	4	1.76	1.57	30
8	Pass**	survived 5	1.87	-	505
12	Fail	6	1.80	1.71	195
13	Fail	5	1.78	1.71	296
14	Pass	survived 6.8	1.85	-	145
22	not tested	0	-	-	-
23	Fail	5	1.73	1.50	505
43	Fail	6	1.78	1.29	90
48	rejected	5***	2.06	1.60	20

* 1000 Amperes
** To setting = 5. Multi-cell test discontinued when cell 23 failed.
*** Cell lost voltage almost as soon as shaking commenced.

The data in Table III indicate that a significant fraction of the Fitzpatrick test cells experienced internal failure at a seismic fragility level below the capacity of the shaker table test equipment. Physical damage is discussed in Section 4.5.

4.4 Post Seismic Capacity Tests

Post test discharge capacities were determined for cells 6 and 14 which survived seismic testing. The data are compared to pre-seismic values in Table IV. Also in Table IV is the cumulative capacity for the cells, as measured from the start of the seismic test, expressed as a percentage of the 3 h rated capacity. The required calculations to convert discharge times at the 1.5 h rate to discharge times at the 3 h rate is provided in Appendix 3.

TABLE IV

CELL CAPACITIES BEFORE AND AFTER SEISMIC TESTING

Cell	Time to 1.75 VPC at 3 h Rate (min)		Percent of Rated Capacity at 3 h Rate		
	Pre-Seismic	Post-Seismic*	Pre-Seismic	Post-Seismic*	Post-Seismic Plus Seismic**
6	173	143	96	79	84
14	186	153	103	85	87

* Cells not recharged following seismic testing.
** Capacity during seismic test at 1.5 h rate converted to 3 h capacity and added to post-seismic capacity, as discussed in Appendix 3.

The Table IV data indicate a loss of discharge capacity for cells 6 and 14 as a result of seismic testing. However, the cell capacities as measured from the start of the seismic event series meet the acceptance criteria of $\geq$80% of rated capacity for both cells.

4.5 Cell Disassembly and Material Study

All seismically tested cells and one non-tested cell (cell 15) were disassembled and inspected for internal damage. Common features identified during the inspection are documented in Photographs 1-24 and summarized below. Detailed post-mortem information on each cell is presented in Appendix 4.

Photograph 1 shows the placement of cell posts, positive and negative bus materials and plate connectors as they appear when the cell jar top is removed from a typical NCX-2250 cell drained of electrolyte. Closer inspection, Photographs 2 and 3, reveals serious horizontal cracking of positive bus material in the vicinity of one of the positive posts of cell 3. Such cracking was typical of the damage found in all cells which failed during seismic testing. All cracked areas were below the normal operating level of the electrolyte.

Photograph 4 shows the result of gentle pressure applied to the positive posts of cell 3. The posts were broken away easily by hand to reveal a coarsely-grained, porous, bus structure. The absence of silver-coloured lead surfaces at the fractures indicates that significant chemical attack has occurred within the bus material. These observations were common to all cells which failed the seismic tests.

Photographs 5-7 show a positive-bus/positive-post point of attachment in cell 6 - a cell which survived seismic testing. In this cell the positive posts and bus materials had no cracks, and several blows with a hammer were required to crack the post/bus interface (Photograph 6) and break the post from the bus (Photograph 7). However, as shown in Photograph 7, considerable chemical attack at the fracture interface had taken place and only bus areas between the vertical plate connections appear to be composed of non-corroded lead.

Photographs 8-11 again show the positive bus cracking and bus/post separation typical of seismically failed cells. In cell 7, one positive post was broken prior to the removal of the cell jar top and the other yielded easily to hand pressure.

In cell 12 (Photographs 12-13) one positive post was broken prior to cell disassembly, and showed evidence of chemical attack, along large grain boundaries. A serious crack was also discovered in the negative bus material of this cell (Photograph 14), the only significant crack found in any of the negative bus material inspected.

A close-up of positive and negative bus material from cell 13 is shown in Photograph 15. Both cross-sections reveal coarse-grained structure but only the positive bus is discoloured, presumably by anodic oxidation of the lead in the presence of sulphuric acid to form lead oxides.

Upon opening, both positive posts of cell 13 were found to be disconnected from the bus material (Photograph 16). Removal of all loosely held material from one of the positive posts left only the post and a flange of lead, as shown in Photograph 17, as solid material. This indicates the problem of material corrosion is confined to the bus area. Again, this observation was common to all cells which failed seismic testing.

Photograph 18 shows the result of vigorous hammering of a positive post of cell 14, a cell which survived the seismic tests. The post could not be hammered from the bus, and the bus was uncharacteristically ductile relative to the others.

Cell 43 exhibited severe horizontal cracking of both positive post/bus interfaces as shown in Photographs 19 and 20, and yielded easily to hand pressure.

Photographs 21-24 show the components of cell 15, which were typical of all the cells. They are, in sequence, (1) negative plate; (2) separator; (3) positive plate and; (4) the reverse side of a separator with fiberglass coating peeled back.

In general, all plates and separators were in very good condition. The negative plates were easily scratched to reveal lead metal, and the positive grids showed minimal loss of active material. No evidence of significant plate growth was detected and positive active material could be removed easily with a knife - it was not unduly compressed.

The visual evidence indicates that seismic failure occurred when positive posts became detached from chemically weakened bus material or when cracking of the positive post/bus interface area caused a significant loss in conductive cross-section. In at least one cell, internal cracking of the negative bus may have been a contributing factor to cell capacity loss.

A metallurgical examination of positive and negative post/bus interface from cells 7 (failed) and 14 (passed) was performed to determine the nature of brittle and ductile interface areas, respectively. The analysis, detailed in OHRD Report M84-54-K (Appendix 5), identified the following:

1. Brittleness in seismically-failed cell positive or negative bus materials was characterized by an extremely coarse grain size material, prone to intergranular fracture.

2. Fracture paths deliberately induced in ductile material from seismically-passed cell positive or negative buses were primarily transgranular, and through sound, fine-grained material.

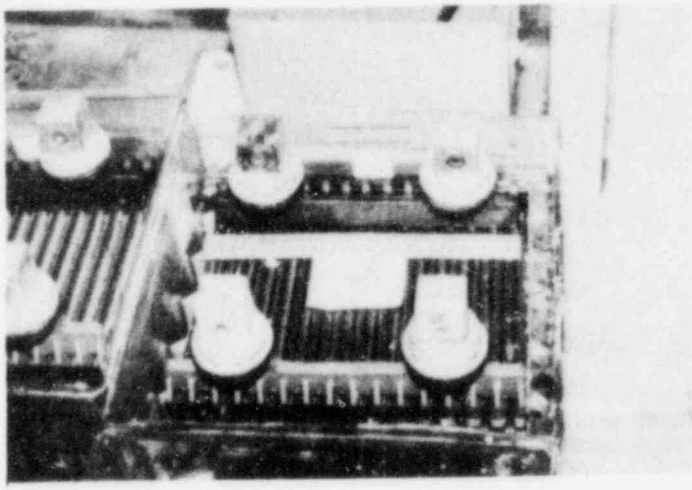
3. Brittle materials (cell 7) exhibited extensive intergranular decohesion behind the fracture face and interfacial decohesion between bus and post material.

4. Coarse grain size almost certainly originated with the cell manufacturer's casting process.

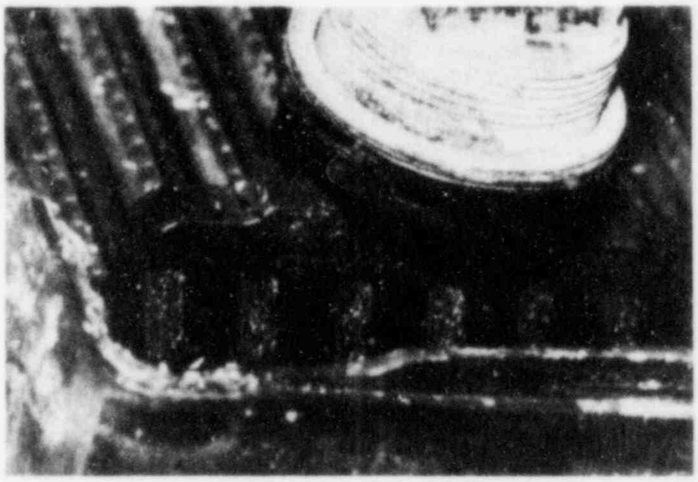
5. Creep is a possible failure mechanism for brittle material but the precise failure mechanism remains obscure.

6. Intergranular corrosion may be a significant contributor to failure.

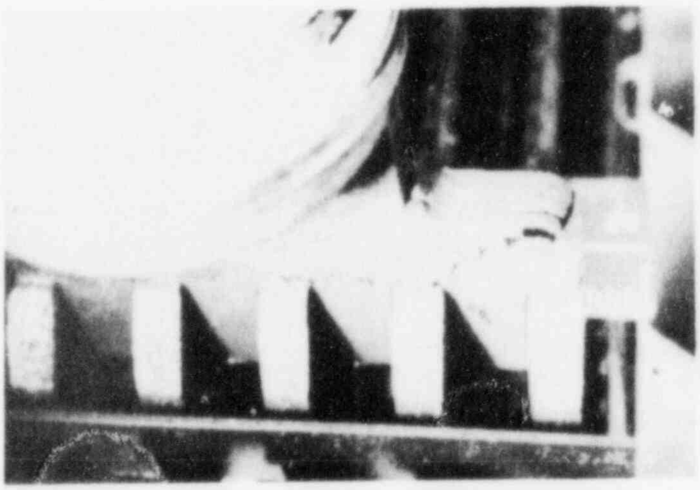
DOCUMENTATION PHOTOGRAPHS
FITZPATRICK LEAD-CALCIUM CELLS



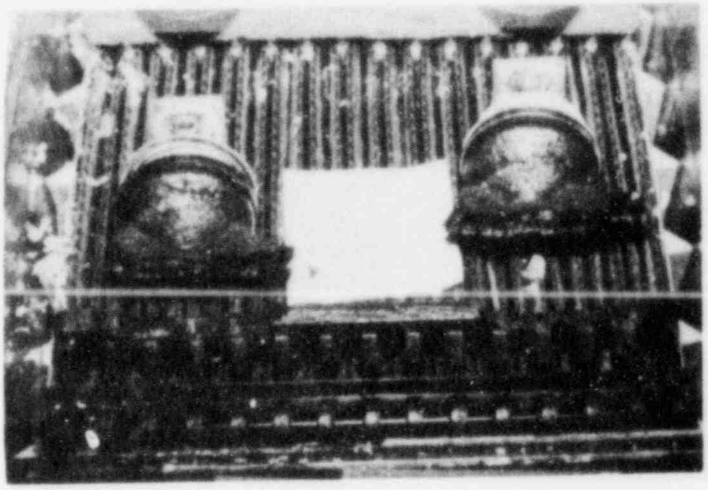
(1)



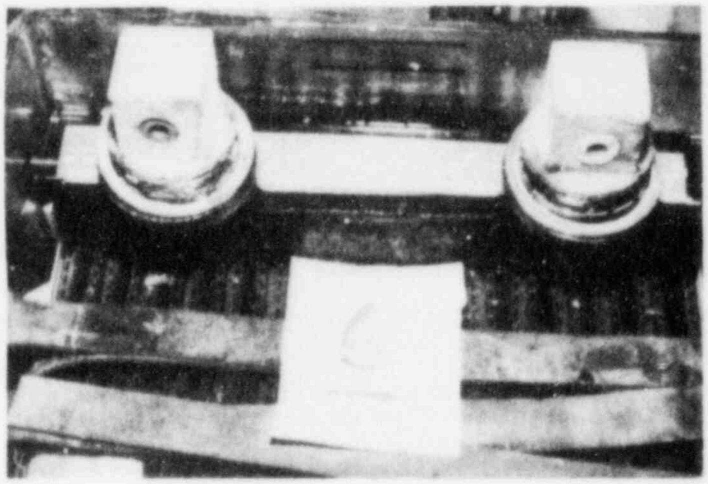
(2)



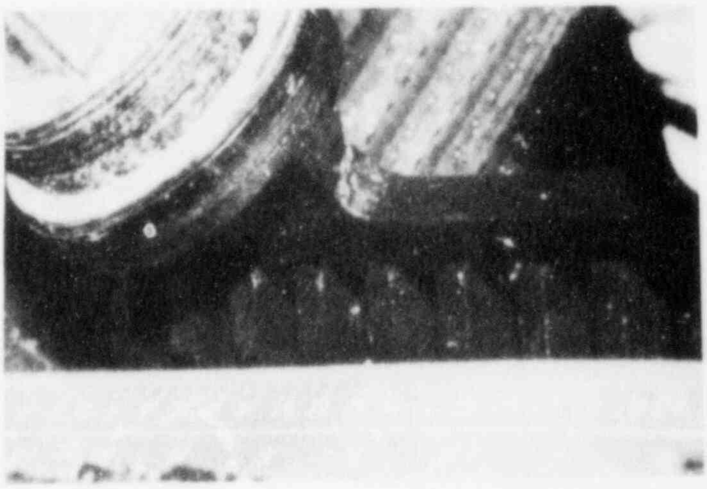
(3)



(4)

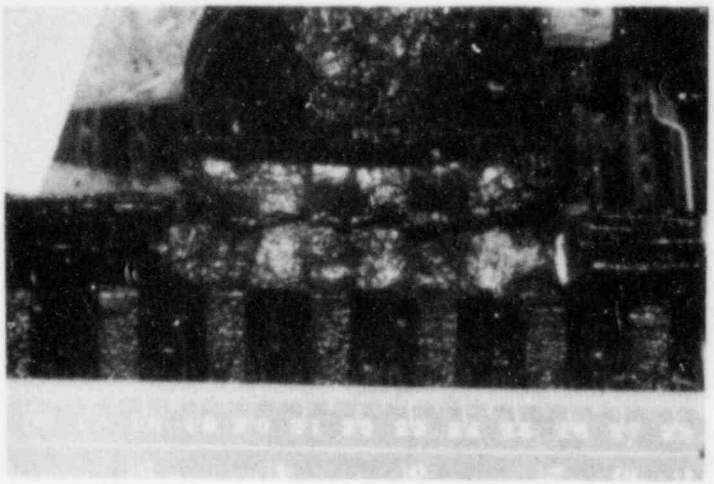


(5)

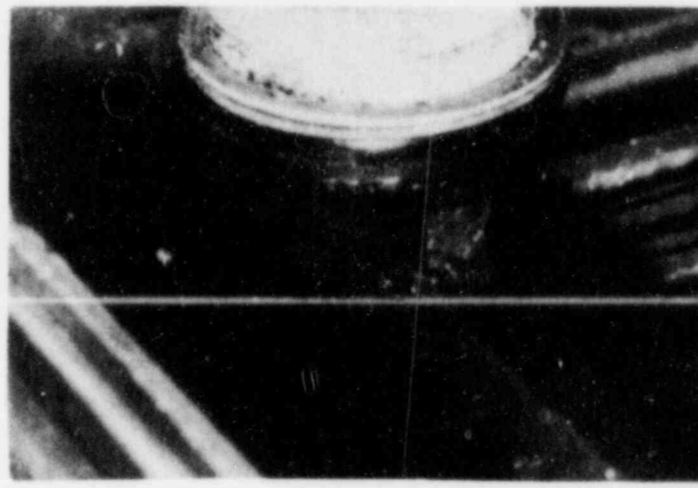


(6)

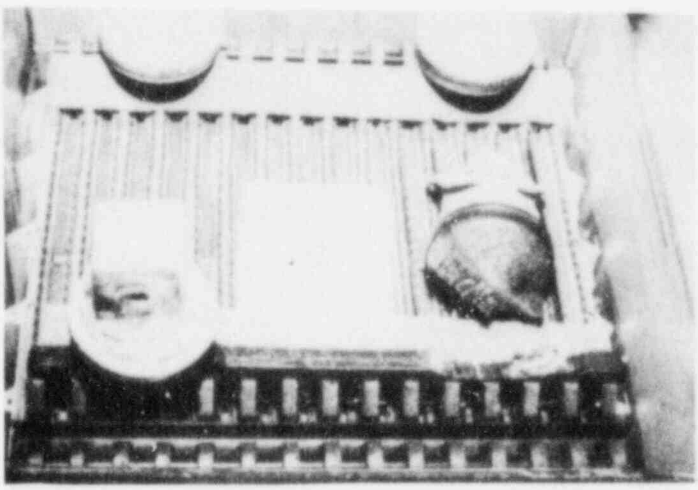
DOCUMENTATION PHOTOGRAPHS
FITZPATRICK LEAD-CALCIUM CELLS



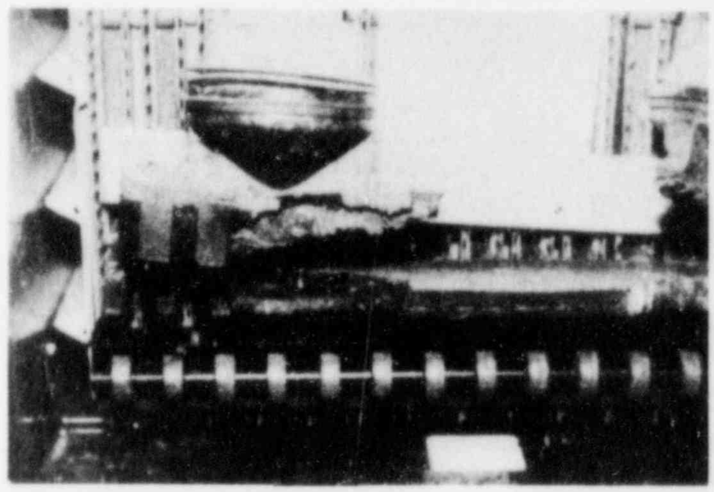
(7)



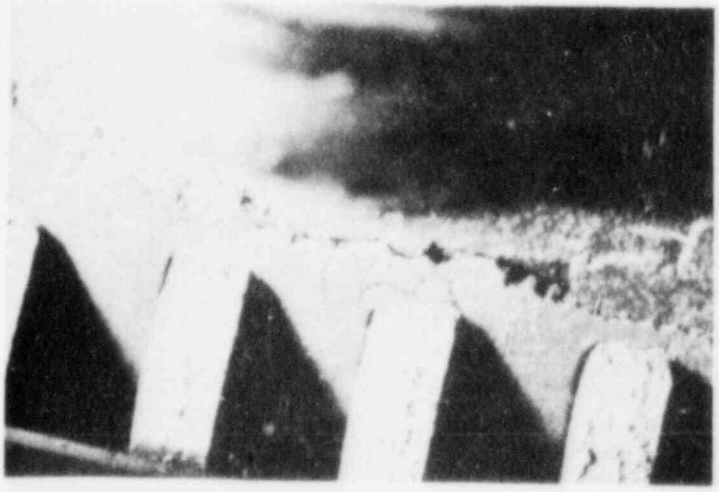
(10)



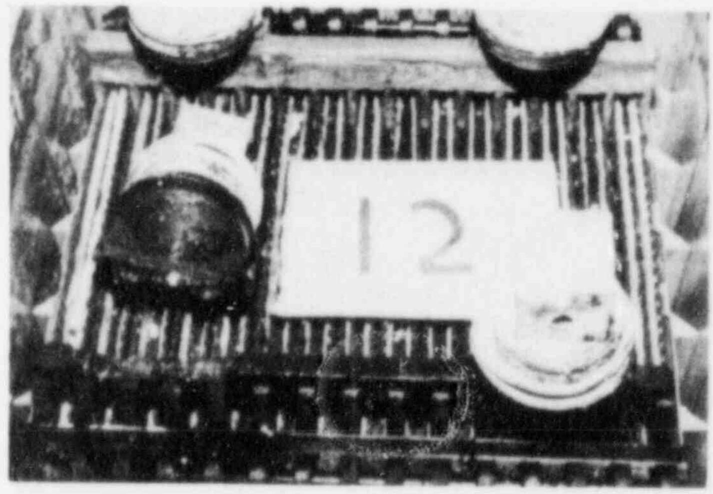
(8)



(11)

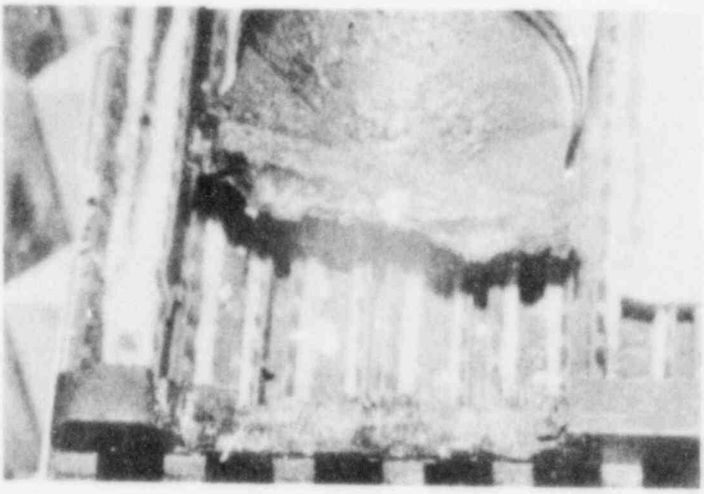


(9)

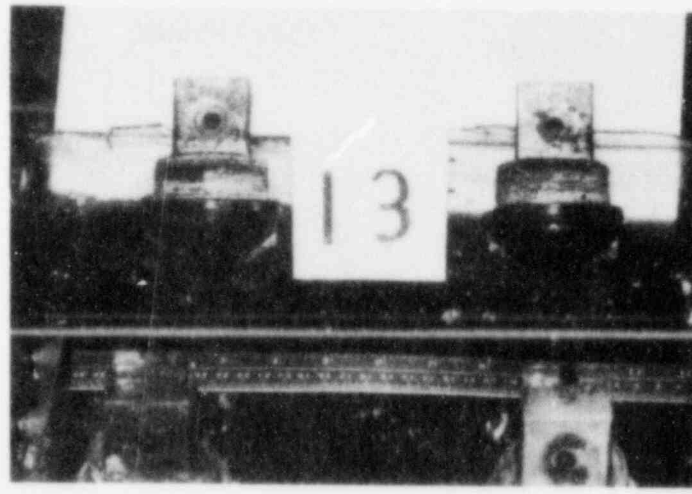


(12)

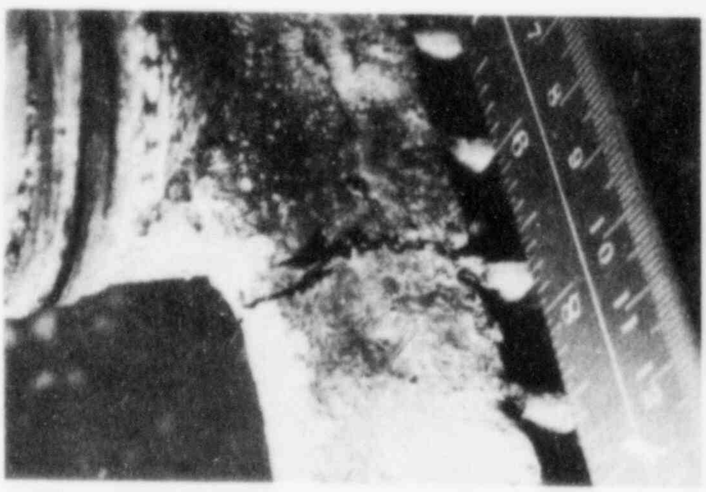
DOCUMENTATION PHOTOGRAPHS
FITZPATRICK LEAD-CALCIUM CELLS



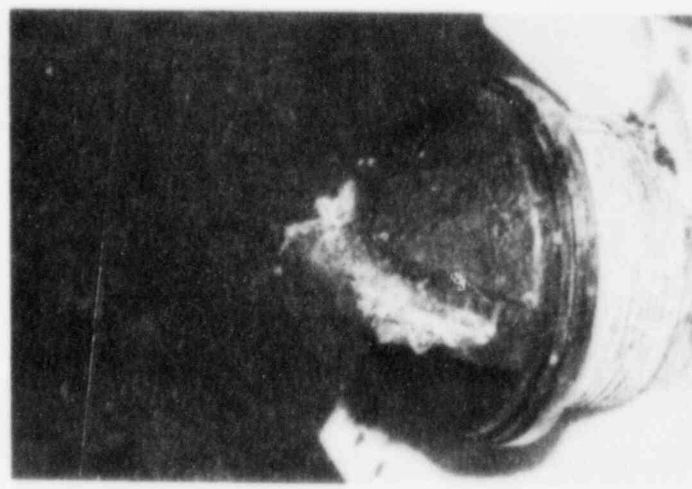
(13)



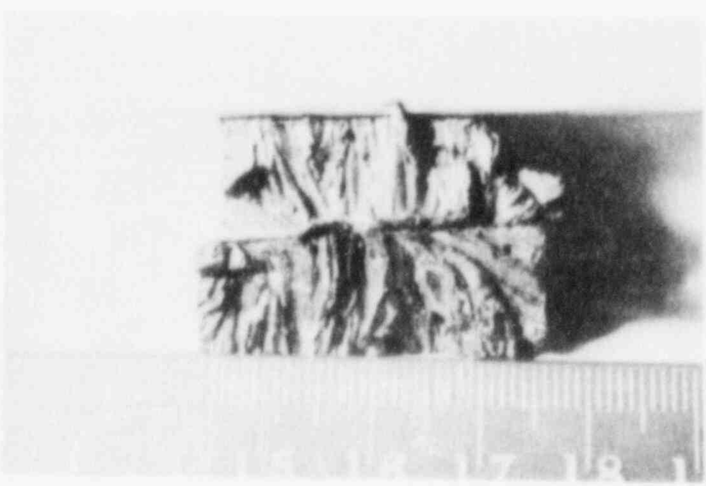
(16)



(14)



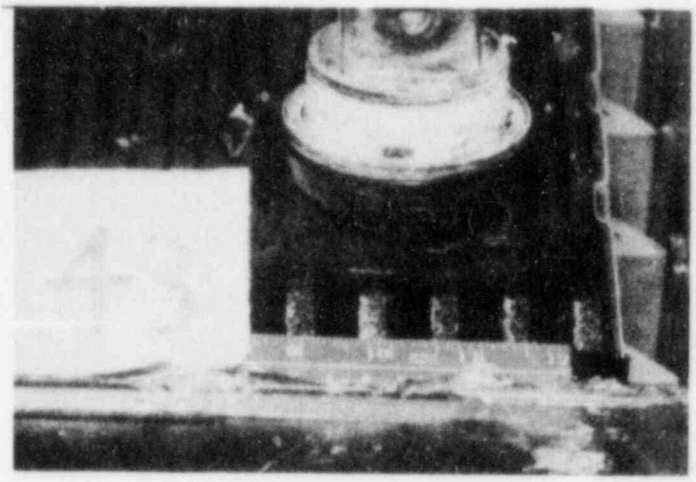
(17)



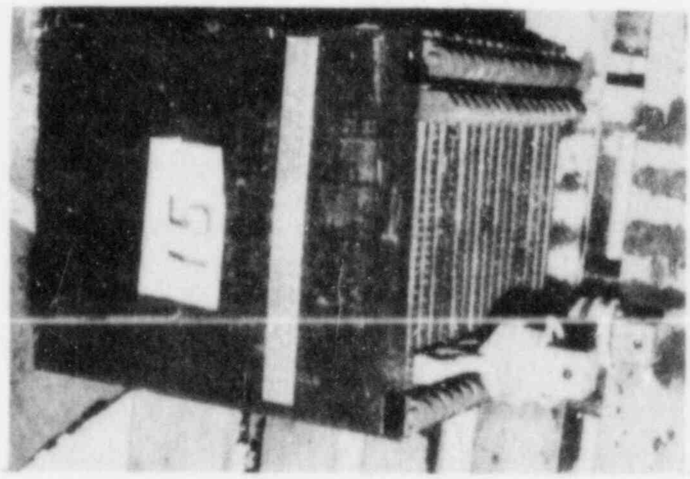
(15)

(18)

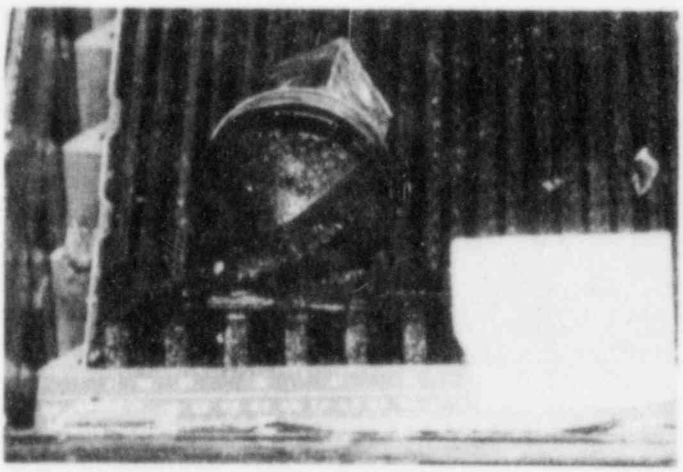
DOCUMENTATION PHOTOGRAPHS
FITZPATRICK LEAD-CALCIUM CELLS



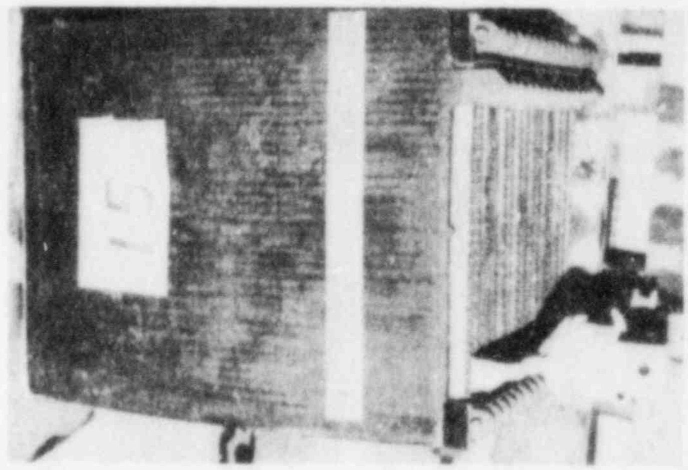
(19)



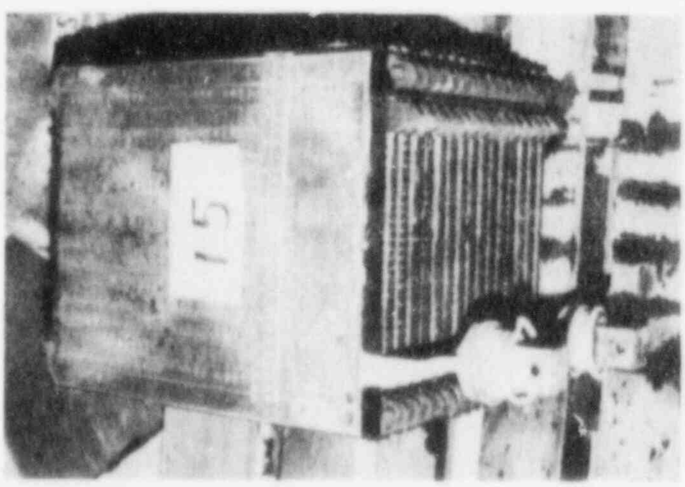
(22)



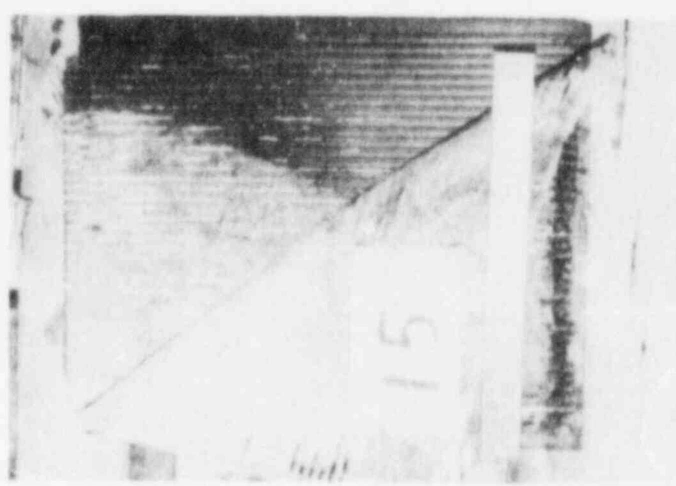
(20)



(23)



(21)



(24)

5.0 CONCLUSIONS

1. Six of nine 12-year old cells, selected at random from approximately 60 cells retired from service at Fitzpatrick NGS, failed under electrical load after repeated and violent shaking. One which did not fail electrically suffered significant internal damage.

2. Electrical failure of test cells was caused by severe cracking of abnormally brittle, positive bus material and/or disconnection of positive posts from the bus material.

3. Loss of cohesion, leading to fracture, occurred mostly along the boundaries of extremely large lead grains and was assisted by chemical corrosion. Coarse grain structure can be attributed to abnormalities in the cell bus casting process.

4. Internal components and connections in two cells without bus defects were extremely durable. Such cells survived violent seismic testing and were capable of meeting the acceptance criterion of 80% of rated capacity after the tests.

Approved: Submitted:

D. Harrison
Manager
Chemical Research Dept

W.J. Janis
Chemist
Organic Section

WJJ:km/kk

REFERENCES

1. Bellack, J.H. "IEEE Recommended Practice for Maintenance, Testing and Replacement of Large Lead Storage Batteries for Generating Stations and Substations". IEEE Std 450-1980. October 1980.

2. Stelter, M.K.G. "Battery Discharge Load for Seismic Tests". Ontario Hydro Research Division Report No E76-85--H. November 1976.

3. Vinal, G.S. Storage Batteries, Fourth Edition. J. Wiley and Sons, New York (1955).

APPENDIX 1

TEST CELL SPECIFICATIONS - NCX-2250 CELLS

(a) Capacity

Discharge Rate to 1.75 V Per Cell at 25°C (Amperes)				
For 8 h	For 5 h	For 3 h	For 1.5 h*	For 1 h*
281	405	585	989**	1336

* As calculated in Appendix 3, from manufacturer's data.
** For convenience in testing during seismic events a 1000 A discharge rate (1.48 h rate) was used as a nominal 1.5 h rate.

(b) Dimensions

	Height (cm)	Width (cm)	Length (cm)	Thickness (cm)
Overall	57.2	36.9	37.0	--
Positive Plate	38.1	31.8	--	0.81
Negative Plate	38.1	31.8	--	0.55

(c) Materials

Container	styrene-acrylonitrile copolymer (jar) styrene-acrylonitrile-butadiene terpolymer (cover)
Separators	unspecified microporous material
Positive Plate active material retainers	fiberglass mat
Electrodes	lead-calcium grid (31 positive, 32 negative,
Posts and Buses[1]	2 positive posts, 2 negative posts, 0.38 cm x 0.38 cm each, attached to to lead bus.
Electrolyte	1.215 specific gravity sulphuric acid (25°C)

[1] Note: Buses are sometimes refered to as straps.

APPENDIX 2

DISCHARGE DATA - SEISMIC EVENT TESTS

Notes

1. Seismic test event duration = 30 s in all cases.

2. A seismic event intensity setting of zero indicates that the cell was not shaken.

3. The cell failure criterion is a sharp cell potential drop to <1.75 VPC. Because cell 8 on discharge started the seismic test with a potential of 1.74 VPC the failure criterion for this cell was taken as a sharp cell potential drop to <1.70 VPC.

4. The maximum accelerations for the intensity settings are approximately as follows:

Intensity Setting	Maximum Acceleration (g)
2	2
3	3
4	4
5	5
6	6
6.8 (machine limit)	6.5

APPENDIX 2

Cell Number	Seismic Event Data				Cell Potential Data		
	Event Number	Intensity Setting	Relative Start Time (s)	Pass or Fail	At Start of Seismic Event (V)	At End of Sesimic Event (V)	Difference x 10^4 (V)
3	1	2	0	pass	1.8445	1.8347	98
	2	2	42	pass	1.8385	1.8509	-124
	3	4	91	pass	1.8509	1.8466	43
	4	4	196	pass	1.8518	1.8311	207
	5	5	231	pass	1.8312	1.8190	122
	6	6	280	fail	1.8053	1.7148	905
6	1	4	0	pass	1.8663	1.8797	-134
	2	5	63	pass	1.8883	1.8873	1
	3	6	147	pass	1.8904	1.8913	- 9
	4	6.8	231	pass	1.8920	1.8927	- 7
7	1	2	0	fail	1.7596	1.5683	1913
23**	1	3	0	pass	1.7391	1.7359	32
	2	4	160	pass	1.7373	1.7368	5
	3	5	240	fail	1.7291	1.5033	2258
12	1	5	0	pass	1.8200	1.8000	200
	2	6	60	fail	1.8000	1.7100	900
	3	5	135	fail	1.7100	1.6500	600
13	1	2	0	pass	1.9061	1.8228	833
	2	2	42	pass	1.8224	1.8338	-114
	3	4	84	pass	1.8338	1.8315	23
	4	4	126	pass	1.8315	1.8261	54
	5	5	182	fail	1.7807	1.7145	662
	6	6	266	fail	1.4879	1.1755	3124
14	1	5	0	pass	1.78	1.84	-600
	2	6	55	pass	1.85	1.85	0
	3	6.8	115	pass	1.85	1.85	0
8**	1	3	0	pass	1.8640	1.8630	10
	2	4	160	pass	1.8633	1.8629	4
	3	5	240	pass	1.8619	1.8709	-90
43	1	5	0	pass	1.8713	1.7750	963
	2	6	60	fail	1.7800	1.2850	495
48	1	5	0	reject from test program	2.060	1.5975	4625

** Multi-cell test.

APPENDIX 3

DISCHARGE TIME/RATE CALCULATIONS

(a) Discharge Current at 1.5 h and 1 h Rates

The most widely used and accepted equation relating discharge current and time is Peukert's equation/3/:

$$I^n t = C \quad [A3.1]$$

where I and t are the discharge current and time, respectively, and n and C are temperature dependent constants. The constants n and C may be evaluated by tests made on any cell or battery at at least two different rates of discharge at constant temperature.

Results of a linear regression analysis of $\log_e(t)$ versus $\log_e(I)$, using the I and t data of Appendix 1, are summarized in Table A3.1. An approximate empirical relation for the discharge rate, in amperes, as a function of the discharge time, in hours, is as follows:

$$I = (6.6854\times10^{-5} t)^{-0.7490} \quad [A3.2]$$

TABLE A3.1

LINEAR REGRESSION FIT - $LOG_e(t)$ VERSUS $LOG_e(I)$

t (h)	$\log_e(t)$	I (amperes)	$\log_e(I)$	Curve Fitting Parameters
8	2.079	281	5.638	Slope(-n)=-1.3352
5	1.609	405	6.004	y-intercept($\log_e$(c))=9.613
3	1.099	585	6.372	Correlation coefficient = -0.9998

Using Equation A3.2, the discharge current data of Table A.2 were calculated.

TABLE A3.2

APPROXIMATE DISCHARGE CURRENTS FOR GIVEN DISCHARGE TIMES

t (h)	I calculated (amperes)	I observed (amperes)	$I_{calc}-I_{obs}$ (amperes)
8	282	281	1
5	401	405	-4
3	588	585	3
1.5	989	-	-
1	1340	-	-

(b) Discharge Time at Nominal 1.5 h Rate-Converted to Discharge Time at Nominal 3 h Rate

From relation [A3.1], discharge currents at different discharge times are related by:

$$t_2 = \left(\frac{I_1}{I_2}\right)^n \cdot t_1 \qquad [A3.3]$$

where the subscripts refer to different (I,t) pairs.

Equation [A3.3], with n = 1.3352, was used to calculate 3 h rate data using 1.5 h rate data, and the results are shown in Table A3.3.

TABLE A3.3

DISCHARGE TIME CONVERSION (1.5 h RATE TO 3 h RATE)

Cell Number	1.5 h Rate Discharge		3 h Rate Discharge	
	Time (s)	Current (A) (nominal)	Time (s) (calculated)	Current (A) (nominal)
6	231	1000	473	585
14	115	1000	235	585

APPENDIX 4

CELL POST-MORTEM INFORMATION

(a) Observations Common to All Cells

- Minimal positive and negative plate pitting.
- Negative grid firm, active material porous.
- Separator and retainers intact.
- No plate hanger damage. All plates in proper position.
- Casting of negative bus not uniform.
- Minimal sediment. Tentatively identified as positive plate active material - little evidence of sulphate.
- All plate/bus interfaces appear intact although for some cells the buses are weak (see below).
- Postive active material normal (firm paste). No significant plate swelling evident.

(b) Cell 3

- Positive posts attached to bus but bus/post interface severely cracked. Bus is brittle.
- Negative terminals intact. Bus is brittle but not as bad as positive bus.
- Photos taken:
  - detail of positive post crack.
  - cell top-opened.
  - cell top-opened and with posts removed.

(c) Cell 6

- Positive bus solid - no movement when pushed with fingers.
- Bus/postive post interface fractured after several hammer blows.
- Metallic lead spots seen betwen plate hangers after positive post removed.

- Photos taken:
  - top view with cover removed.
  - positive post after hammer hits.
  - positive post after disconnection.

(d) Cell 7

- One positive post attached but bus area at point of attachment is fractured.
- Photos taken:
  - top view with cover removed.
  - detail of cracked positive post.
  - detail of broken post.

(e) Cell 12

- Negative bus fracture.
- One positive post attached but bus area at point of attachement is fractured.
- Photos taken:
  - positive post/bus detail.
  - cross-section of positive and negative bus material.
  - broken positive post/bus inteface.
  - cracked negative bus.

(f) Cell 13

- Both positive posts disconnected from bus.
- Positive bus extremely brittle and fragile.
- Photos taken:
  - positive posts detail.
  - positive bus pried away from plates.
  - plate/bus interface cross-section.

(g) Cell 14

- Both positive posts and bus extremely solid.
- Bus material ductile - did not fracture during repeated hammering.
- Bus cross-sections show no evidence of corrosion.
- Photos taken:
  - postive posts.
  - hammered posts (positive).

(h) Cell 15 (dummy cell)

- Cracked case - not seismically tested.
- Both positive posts disconnected from bus.
- Negative post/interface areas fractured.
- Photos taken:
  - broken positive terminals.
  - cracked negative bus.
  - plates removed from cell jar.
  - representative plate and separator detail.

(i) Cell 43

- Both positive post/bus areas fractured.
- Photos taken:
  - positive bus fractures.

(j) Cell 23

- One or both positive posts disconnected from bus material.

91600
new 82-10

APPENDIX 5

ontario hydro
research division

To Dr. R. Glass
Supervisor - Organic
Research Section
Chemical Research Dept

BRITTLE FRACTURE OF LEAD-ACID STORAGE BATTERY TERMINAL POSTS

G. Bellamy

Testing involving a simulated seismic event produced brittle fracture between certain terminal posts and plates. Subsequent destructive testing produced ductile failure at similar locations in cells that had survived the seismic procedure intact. Susceptibility to failure correlates well with the grain size of the lead post material; coarse grained material is failure prone. Further testing is required to clarify certain apsects of the failure mechanism.

INTRODUCTION

Laboratory based seismic event testing produced brittle fractures between certain terminal posts and plates; both positive and negative posts were involved. In cells that had survived the seismic test intact subsequent destructive testing produced ductile failure in the same general location as the previous brittle ones. Samples of ductile and brittle positive and negative posts were received for metallurgical failure analysis.

METALLURGICAL INVESTIGATION

Overall views of typical brittle and ductile failures appear in Figures 1a and 2a respectively. A long fracture zone of brittle, woody appearance is seen to the right of Figure 1a whilst the ductile failure occurred as a series of relatively short separations as evidenced by the bright areas of Figure 2a.

Longitudinal metallographic sections were cut to reveal microstructural detail associated with the two fracture types. Figure 1b shows the brittle fracture face of one failure extending vertically

job	file	date	report no.
740632-168-950	823.31	April 13, 1984	M84-54-K

up the right side. Both at and behind the fracture face extensive intergranular decohesion has taken place. Similar decohesion is seen between the post and plate components. All the grain boundary and component interfacial zones contain a continuous phase believed to be a corrosion product. Etching confirmed the intergranular fracture path and extremely coarse grain size which characterised the brittle material; Figure 1c shows a typical area. Fracture in ductile samples is typified by Figure 2b which illustrates a largely transgranular path through sound fine grained material.

Energy dispersive X-ray analysis was used in an attempt to identify the brittle plate matrix and grain boundary material. The technique detected only lead. Light elements such as carbon, oxygen and hydrogen are not detected; therefore the possibility exists for the presence of oxides, hydroxides or perhaps carbonates at the grain boundaries.

DISCUSSION AND CONCLUSIONS

1. Preliminary work has drawn a useful correlation between brittle fracture susceptibility and grain size in the plate material immediately beneath the cell terminal posts. Coarse grained material is susceptible.

2. The essentially pure lead components which failed by brittle fracture also exhibit extensive intergranular decohesion behind the fracture face and interfacial decohesion between plate and post material.

3. All the grain boundary and interfacial zones of the brittle component contained an unidentified phase believed to be a corrosion product of the oxide, hydroxide or possibly carbonate variety.

4. Coarse grain size almost certainly originated with the cell manufacturers casting process; it is extremely unlikely that in-service conditions would precipitate this condition.

5. The precise failure mechanism remains obscure. Creep is a possibility but this normally requires a sustained tensional loading regime rather than the oscillatory vibrations of a seismic event. Intergranular corrosion may be a very significant contributor to failure.

6. Clarification of the failure mechanism will require examination of coarse grained unused cell components.

ACKNOWLEDGEMENTS

Metallographic services were provided by Mr. T.R. Ryans. Ms. S.V. Sandloehken was responsible for X-ray analyses.

Approved By:	Prepared By:
B. Mukherjee	G. Bellamy
(Ag) Supervising E-ngineer	Senior Engineer
Metallurgy Section	Metallurgy Section
Metallurgical Research Dept	

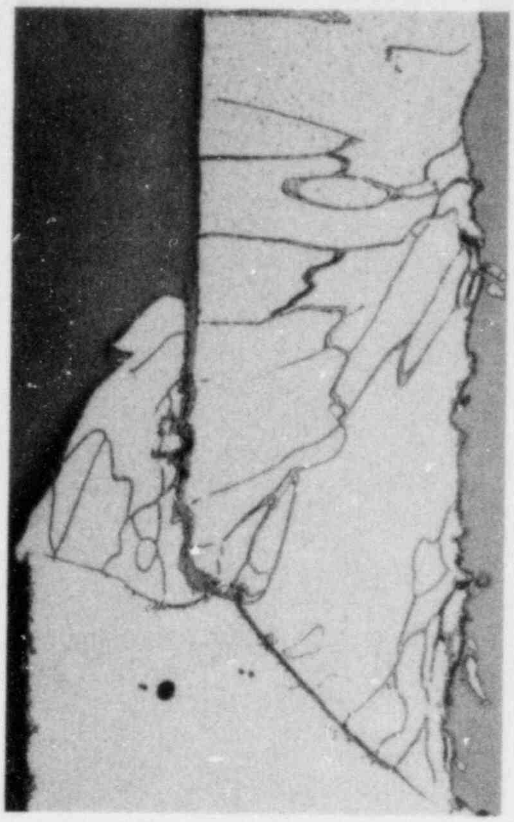
GB:dr

DISTRIBUTION

Dr. R. Glass	Chemical Research
Mr. W.J. Janis (2)	Chemical Research
Mr. R.J. Strickert	TTS, A7-E1
Mr. B. Montford	TTS, A7-H8
Mr. W. Sokolski	TTS, A7-H2
Dr. B. Mukherjee	Metallurgical Research
Dr. M.A. Clark	Metallurgical Research
Mr. P.J. King	Metallurgical Research
Mr. T.R. Ryans	Metallurgical Research
Dr. G. Bellamy	Metallurgical Research

Official Record
Office Copy
Extra Copies (3)

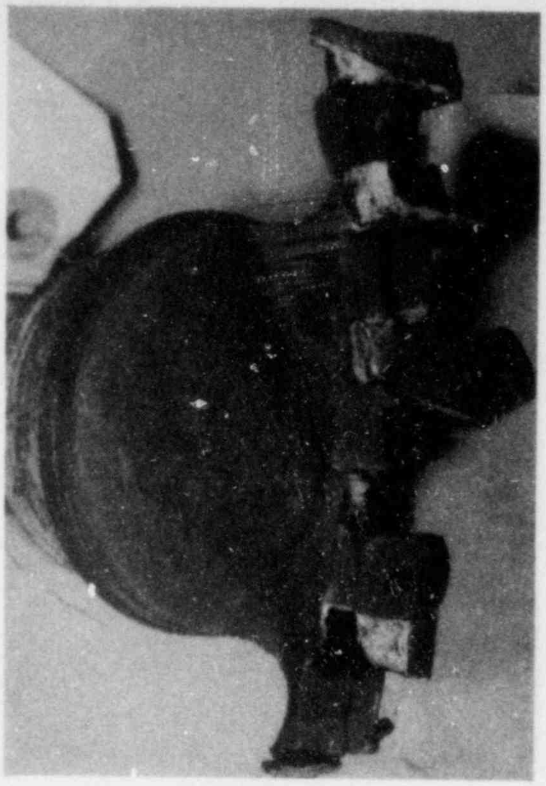
a) X 0.9 mag



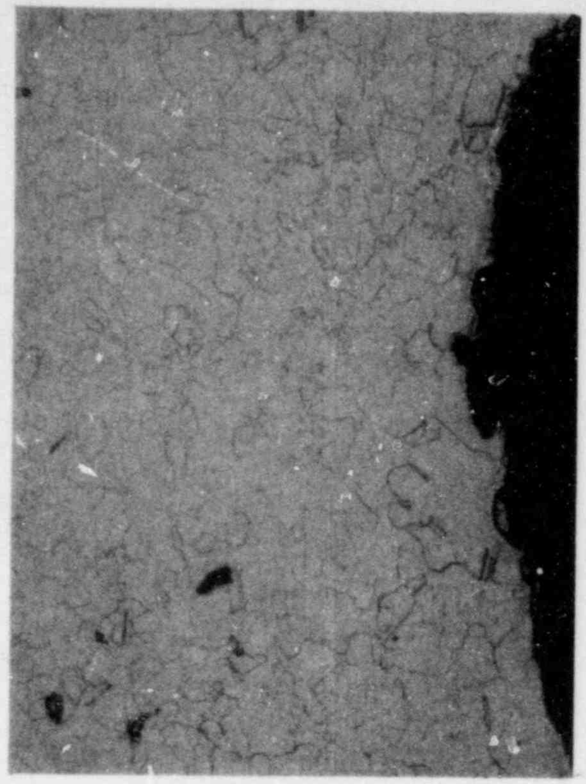
b) X 4.5 mag

c) X 400 mag

FIGURE 1 - DETAILS OF BRITTLE POST



a) X 0.8 mag



b) X 200 mag

FIGURE 2 - DETAILS OF DUCTILE POST

DISTRIBUTION

Mr. F.J. Kee	Director of Research
Mr. B.A. Oliver	Electrical Design, H12G3
Mr. J. Schendel	Electrical Design, H12E5
Mr. D.A. Black	Mechanical Research
Mr. J.D. Tulk (10)	Mechanical Research
Mr. B.D. Aucoin	Chemical Research
Mr. J.S. Ferrie	Chemical Research
Mr. W.J. Janis	Chemical Research

Official Record
Office Copy
Extra Copy

- last page -

84-49

APPENDIX C

SEISMIC TESTING OF FITZPATRICK NUCLEAR GENERATING STATION BATTERIES (GOULD MODEL NCX-2250)

D. A. Black

G. D. Paulsen

Ontario Hydro Research Division

9160C
new 82-10

ontario hydro
research division

To Mr. B.A. Oliver
Manager
Electrical Design
Design & Development

SEISMIC TESTING OF FITZPATRICK NUCLEAR GENERATING STATION BATTERIES (GOULD MODEL NCX 2250)

D.A. Black and G.D. Paulsen

Ten Gould station cells were seismically tested to IEEE specifications. This report describes the test procedure followed, the test equipment used and interprets the results of the tests. The cells were from Fitzpatrick nuclear generating station and part of a study of the effects of the aging process of batteries on their ability to withstand seismic events.

1.0 INTRODUCTION

The ten Gould cells were tested to IEEE 344/1/ and IEEE 501/2/ specifications. Date of test, specimen description, test facility name and location, test data and test temperature, humidity and pressure are recorded on each of the response spectrum curves. These curves also show the conditions of the test, the type of analysis, the accelerometers used, the direction of the test, and the axis analysed. All tests were analysed using 5% damping and the maximax shock spectrum. The tests performed were tri-axial tests as defined in IEEE 344. All technical terms used in this report are defined by Harris/3/.

2.0 SAMPLE

The 12-year old cells tested were described as follows:

1)	Gould, Model NCX 2250, Cell No	13; Serial No	00144
2)		3;	00155
3)		6;	K-1148
4)		7;	00154
5)		15;	00158
6)		25;	00143
7)		43;	00141
8)		12;	00130
9)		14;	00022
10)		48;	00032

job	file	date	report no.
740624-268-450	824.46		B84-39-P

3.0 TEST EQUIPMENT

3.1 Equipment Used

3.1.1 Shaker Control Equipment

1. MTS 436 control units
2. MTS 406.11 controllers
3 MTS hydraulic pumps
4. Ontario Hydro noise generators and filters
5. Ontario Hydro tri-axial shaker table.

3.1.2 Analysis

1. Columbia Model 9000 amplifiers and matching Wilcoxon M-408 accelerometers.

Amplifier Serial No	Accelerometer Serial No
368 1632	S893
368 1633	S297
368 1634	S901
368 1635	S369
368 1636	S753
368 1637	S754
369 1638	S756
369 1639	S757
369 1640	S759
369 1641	S760
369 1642	S761
369 1643	S771

2. SE tape recorder Model 7000A, Serial No 547.

3. Tektronix 5113 dual beam storage oscilloscope, KS3681.

4. Spectral Dynamics 13231 Shock Spectrum Analyser, Serial No 27.

5. Spectral Dynamics 13191 Transient Memory, Serial No 29.

6. Ontario Hydro transmissibility circuit.

7. Watanabe WX4400 X-Y Recorder, Serial No 83010070.

8. Hewlett-Packard 7046A X-Y1-Y2 Recorder, Serial No 1914A05842.

9. Spectral Dynamics 50121L Tracking Filter, Serial No 171.

10. Spectral Dynamics SD122L Tracking Filter, Serial No 370.

11. Honeywell 1858 oscillograph, Serial No 2649JF78.

12. Nicolet Scientific Corp, Model 660A Dual Channel FFT Analyzer, Serial No 9866226.

13. Hewlett-Packard Model 7470A Plotter, Serial No 2210A-12990.

3.1.3 Calibration Equipment

1. Bruel and Kjaer Type 3506, Serial No 877022 Accelerometer Calibration Set which includes Type 2626, Serial No 842947 and Type 83055, Serial No 858627, traceable to NBS.

2. General Radio 1557-A vibration calibrator, Serial No 2379.

3. Data Precision 2440 digital voltmeter, Serial No 8583, traceable to NBS.

4. Data Precision 248 digital voltmeter, Serial No 8583, traceable to NBS.

4.0 TESTS AND PROCEDURES

4.1 Calibration Procedure

Accelerometers and amplifiers are calibrated using the backto-back calibration procedure. The reference accelerometer was mounted on the vibration calibrator with the Wilcoxon accelerometer. Using 100 Hz sine wave vibration of approximately 1 g, the sensitivity of the Columbia amplifiers was set to give 500 mV/g output. The outputs were measured using the digital voltmeter. By using the same voltmeter for both the reference and the Columbia amplifiers, slight differences in voltmeters need not be considered. Since the voltmeter measures true RMS voltages, the waveshapes of the 100 Hz signals were compared on the oscilloscope. This ensures that the signals are equivalent.

4.2 Test Setup and Procedures

Each cell was clamped in a special fixture (Figure 01A) which clamped the cell jar at the corners. Each corner clamp consisted of two half-inch threaded rods and angle iron backed with rubber strips (Shore A50). The cell to be tested was connected to a resistive load (1.5 hour rate) and monitored for voltage drop and current by Chemical Research/4/. Continuous recordings of the cell voltage were separately taken for some of the cells. Accelerometers were attached to the base plate of the fixture and to a cell terminal post. Instrumented impact tests were performed on the first cell to determine if natural frequencies could be found in the seismic range (ie, 1 to 33 Hz). Two cracked cells were tested to determine if crack propagation was significant.

4.3 Vibration Tests

The shaker consists of random generators and hydraulic actuators which are capable of driving the shaker in three directions simultaneously. The shaker has the following limitation in each axis:

Displacement limit	152 mm
Velocity limit	820 m/s
Acceleration limit	4 g (no load)
Acceleration limit	1.6 g (fully loaded)
Maximum load	2000 kg

Simultaneous random inputs were applied in three axes and the coherence between axes was negligible. The vibration levels in the two horizontal and vertical directions were individually controlled to nominally give similar levels. These levels were set by adjusting a "span" potentiometer. The span setting used is of no significance in itself except equivalent span settings nominally indicate equivalent vibration levels. The vibration is never the same from one test to the next since a different random signal is used for each test.

5.0 TEST RESULTS

The instrumented impact tests showed that the mounting and cell should be considered as being rigid in the seismic frequency range. A test log for each of the cells is given in Table I. The results are given in Table II and Figures 01C to 60. The ZPA values were determined by using the standard curve of IEEE 501. Two of the 8 cells tested did not fail as a result of the seismic tests. Continuous recording of the voltage showed that when a cell begins to break down, the normally smooth trace begins to oscillate randomly. The amount of this voltage drop increases until a full excursion of the cell voltage appears. This was likely due to the change in resistance between the bus bar and the positive terminal posts (as reported in reference report/4/).

5.1 Results of the Cell Jar Crack Propagation Test

Two cells were selected from the cells with cracked cases. The two selected cells were each capable of holding water without leaking and each had a larger bottom crack and several small side cracks. The selected cells were filled with a water/sodium bicarbonate solution and the outputs shorted to completely neutralize the acid. Each crack was marked with a scribe to aid in determining crack growth. Cracks were photographed (Figures 01B, 01B1 and 01B2), and any that grew were measured. In the photographing of one of the cracks the cell jar in the vicinity of the crack was cleaned with trichlorethylene 2 while heated by the photography lamps. This caused sudden and unexpected crack growth on cell #15. The clamps in these single cell tests place the cracks in compression which should help suppress crack growth. It is hypothesized that a side crack in cell 15 grew for the following reasons:

1. The trichlorethylene 2 caused a relatively small crack to grow to roughly 100 mm.

2. This larger crack was beyond a postulated critical size. Smaller cracks did not grow.

3. The le d plates impacted the sides of the cell with sufficient force to cause considerable bending. This was sufficient to overcome the compression due to the clamps.

4. The crack tended to grow faster with the clamps loose.

5. Leakage from the cracks was negligible.

6.0 CONCLUSIONS

From the two cells tested for crack growth, the tests indicated that small cracks in cell jars are not likely to grow. Large cracks will only grow at repeated high amplitude shaking. The cracks tend to propagate faster when the cell is not rigidly clamped in position. This condition is expected when station racks are used. The eight live cells tested indicate that electrical failures on this type of cell could occur at high seismic inputs. There was a considerable range in the amount of vibration the cells could withstand. This is likely due to the handmade nature of the original manufacture. One cell showed typical signs of rapid loss of voltage. However, the cell later proved to be capable of holding charge. The loss of voltage was attributed to loose connections on the terminal posts. Five other cells failed internally and would not hold charge. Two cells did not fail and the shaker limit was reached.

Approved:	Submitted:
H A Ewing for	Gordon Paulsen per DAE
D.B. Craig	G.D. Paulsen
Section Head	Technologist
Mechanical Testing and	Mechanical Testing and
Development Section	Development Section
Mechanical Research Dept	
	D.A. Black
	D.A. Black
	Engineer
GDP:DAB:sf	Mechanical Testing and Development Section

B84-39

REFERENCES

1. The Institute of Electrical and Electronic Engineers Inc. IEEE 344. Qualification of Class 1E Equipment for Nuclear Power Generating Stations. New York. 1975.

2. The Institute of Electrical and Electronic Engineers Inc. IEEE 501. IEEE Recommended Practices for Seismic Qualification of Relays.

3. Harris, Cyril M., and Charles E. Crede. "Shock and Vibration Handbook". Second Edition. McGraw Hill Book Company. Toronto. 1976.

4. W.J. Janis. "Seismic Testing of Fitzpatrick Nuclear Generation Station Batteries - Cell Inspection and Capacity Tests." Ontario Hydro Research Report C84-49-P.

TABLE I

SUMMARY OF TESTING STATION CELLS

Cell	Date	Time	Run	Span	Plotted	Comments
#13	16/01/84	2:22	1	2	No	
#13	16/01/84	2:23	2	3	No	
#13	16/01/84	2:23	3	4	No	
#13	16/01/84	2:24	4	5	Yes	Loss of voltage
#13	16/01/84	2:25	5	6	No	Considerable loss of electrolyte. Seal gave out around top of case.
#3	16/01/84	3:17	1	2	No	
#3	16/01/84	3:18	2	3	No	Voltage increasing.
#3	16/01/84	3:20	3	4	No	Voltage lost; then returned.
#3	16/01/84	3:21	4	4	No	
#3	16/01/84	3:21	5	5	No	
#3	16/01/84	3:22	6	6	Yes	Voltage steadily decreasing past failure point.
#6	17/01/84	11:32	1	4	No	
#6	17/01/84	11:32	2	5	No	
#6	17/01/84	11:33	3	6	No	
#6	17/01/84	11:34	4	6.8	Yes	No failure.
#7	17/01/84	2:01	1	4	Yes	Rapid loss of voltage.
#15	18/01/84	10:48	1	3	No	Crack propagation; clamps tight.
#15	18/01/84	11:02	2	4	No	Clamps tight.
#15	18/01/84	11:08	3	4	No	Clamps loose; side crack grew 3 mm.
#15	18/01/84	11:15	4	5	No	Clamps loose.
#15	18/01/84	11:26	5	5	No	Clamps tight.
#15	18/01/84	11:36	6	6	No	Clamps tight; 103 mm crack spread to 140 mm.
#15	18/01/84	11:42	7	6	Yes	Clamps tight; 140 mm crack spread to 310 mm. Bottom crack also spread. Note: Trichlorethylene 2 plus heat results in rapid and dramatic crack propagation.
#25	18/01/84	2:17	1	4	No	Crack propagation; clamps loose.
#25	18/01/84	2:19	2	5	No	Run cancelled because clamps fell off
#25	18/01/84	2:38	3	5	No	No apparent crack propagation.
#25	18/01/84	2:52	4	6.8	Yes	
#43	20/01/84	9:10	1	5	No	
#43	20/01/84	9:12	2	6	Yes	Loss of voltage - cell will not hold current.
#12	23/01/84	11:08	1	5	No	Rapid loss in voltage, but not to failure.
#12	23/01/84	11:10	2	6	Yes	Cell lost more voltage, still not to failure.
#12	23/01/84	11:14	3	5	No	Voltage loss to failure.
#14	23/01/84	1:52	1	5	No	
#14	23/01/84	1:54	2	6	No	
#14	23/01/84	1:56	3	6.8	Yes	No failure.
#48	23/01/84	2:58	1	5	Yes	Cell lost voltage almost as soon as load was applied.

TABLE II

SUMMARY OF TEST RESULTS

Cell No	Direction	ZPA (g)	Span	Comments
13	X - Base	1.13	5.0	Fragility level.
	Y - Base	0.98		Loss of voltage.
	Z - Base	1.42		
	X - Top	0.98		
	Y - Top	1.31		
	Z - Top	1.54		
3	X - Base	1.46	6.0	Fragility level.
	Y - Base	1.17		
	Z - Base	1.65		
	X - Top	1.50		
	Y - Top	1.93		
	Z - Top	1.94		
6	X - Base	1.48	6.8	Shaker limit.
	Y - Base	2.52		No failure of cell, ie, no
	Z - Base	1.83		loss of voltage.
	X - Top	1.78		
	Y - Top	1.85		
	Z - Top	2.22		
7	X - Base	1.22	4.0	Fragility level.
	Y - Base	0.92		
	Z - Base	1.19		
	X - Top	1.25		
	Y - Top	1.31		
	Z - Top	1.19		
15	X - Base	1.25	6.0	Crack propagation test.
	Y - Base	0.89		Clamps tight.
	Z - Base	1.48		
	X - Top	1.93		Large side crack grew from
	Y - Top	1.71		100 mm to 103 mm at span=4.
	Z - Top	2.41		
				103 mm crack grew to 140 mm at span=6.
				140 mm bottom crack spread to 310 mm at span=6.
25	X - Base	2.00	6.8	Crack propagation.
	Y - Base	2.34		Clamps loosened.
	Z - Base	1.80		Bottom crack grew 5 mm when
	X - Top	2.17		battery was lifted.
	Y - Top	1.50		No other apparent damage
	Z - Top	2.74		occurred as a result of the tests.
43	X - Base	1.34	6.0	Fragility level.
	Y - Base	1.53		
	Z - Base	1.22		
	X - Top	1.69		
	Y - Top	1.89		
	Z - Top	2.52		
12	X - Base	1.22	6.0	Fragility level.
	Y - Base	1.66		
	Z - Base	1.46		
	X - Top	1.47		
	Y - Top	1.59		
	Z - Top	1.83		
14	X - Base	1.32	6.8	Shaker limit.
	Y - Base	1.47		
	Z - Base	1.60		
	X - Top	1.79		
	Y - Top	2.17		
	Z - Top	2.49		
48	X - Base	1.19	5.0	Cell lost voltage as soon
	Y - Base	0.89		as load was applied and
	Z - Base	1.22		shake test began.
	X - Top	1.31		Failure may have been due
	Y - Top	1.53		to loose connections.
	Z - Top	1.46		

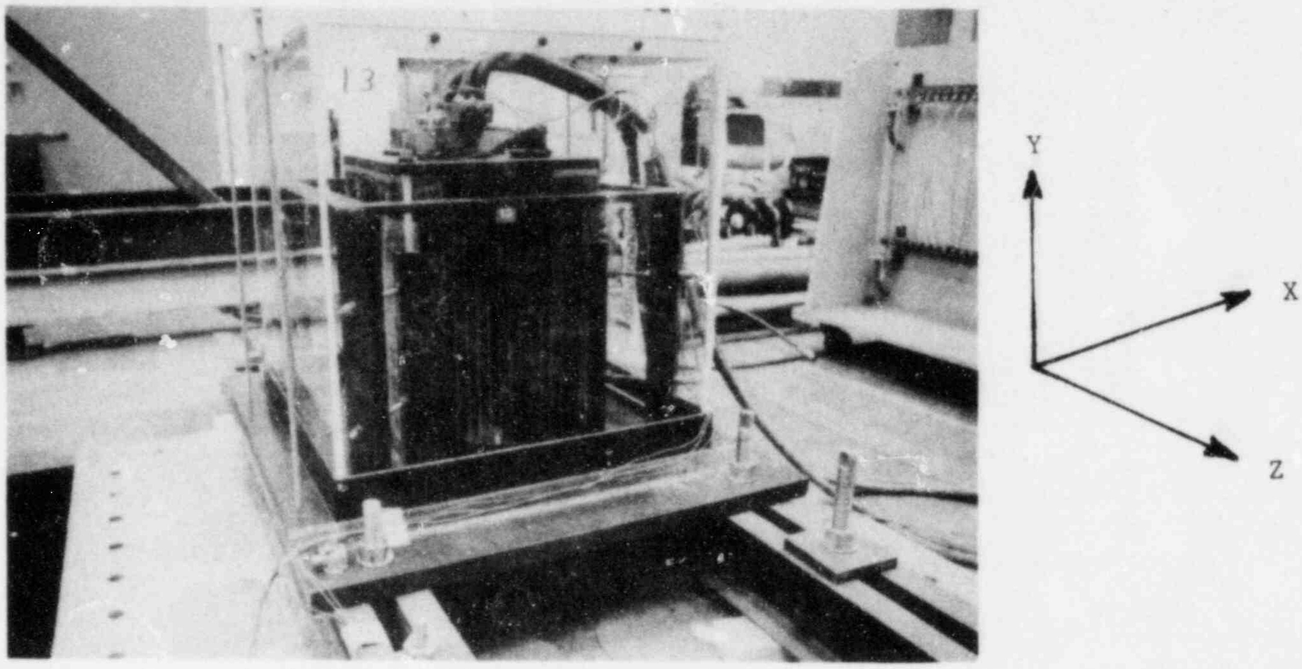


FIGURE 01A
Typical set-up of cell in test jig. Accelerometers are located on the base plate and one terminal post. The axes of vibration are shown.

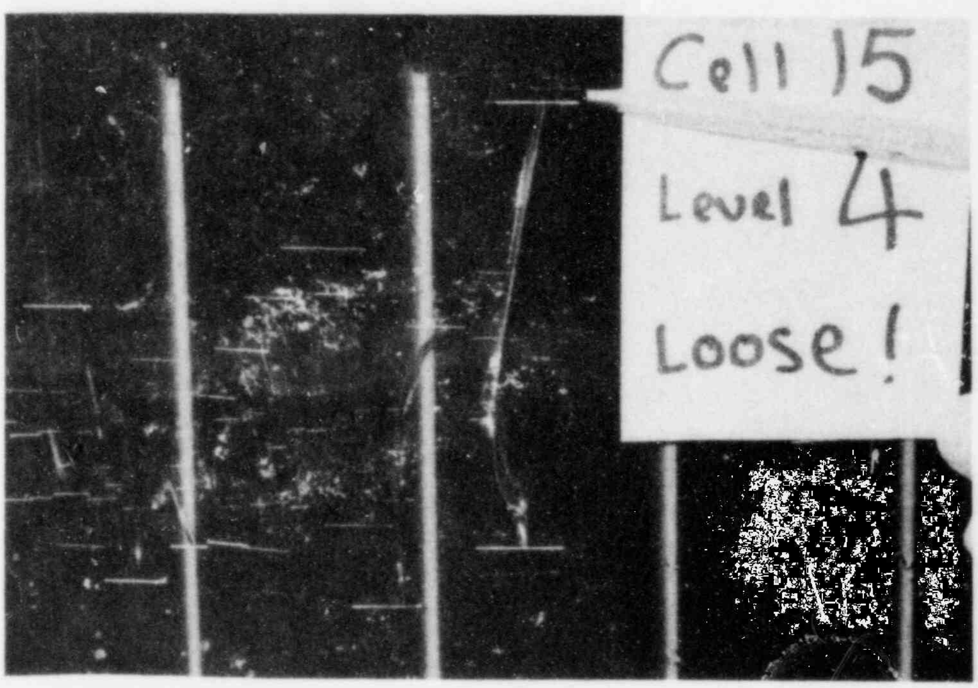


FIGURE 01B
Growth of cracks in all jars as a result of seismic testing. The side cracks were originally due to the clamping in a battery rack. The crack indicated was lengthened using trichlorethylene 2 from its original length marked. The small amount of growth at the pencil was due to vibration.

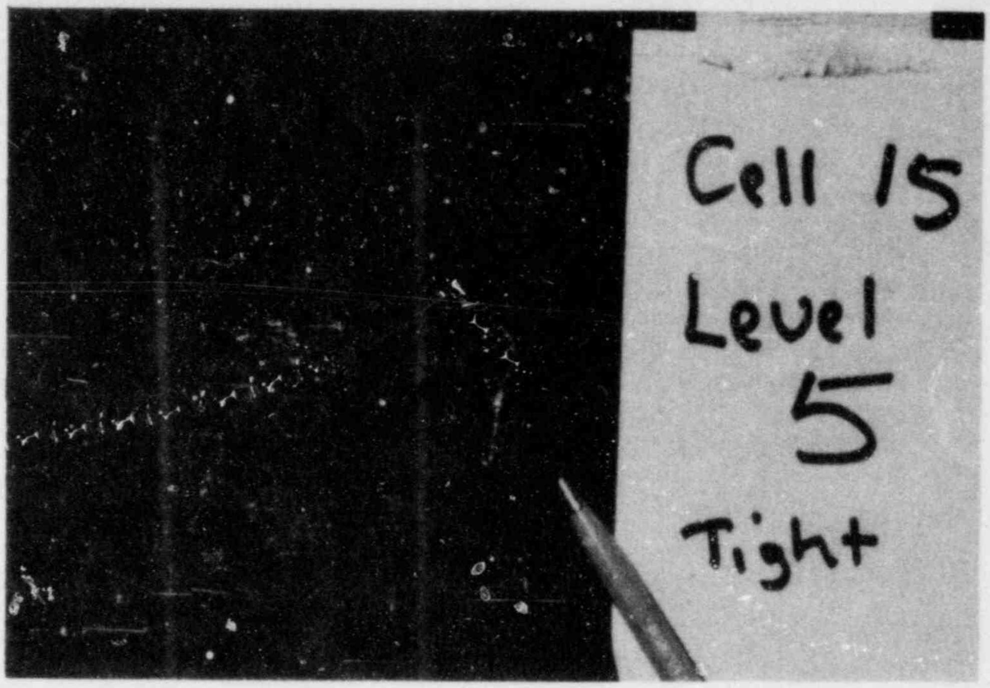


Figure 01B1
Very little additional crack growth is shown over previous Figure. Note the scribe marks to indicate the crack length.

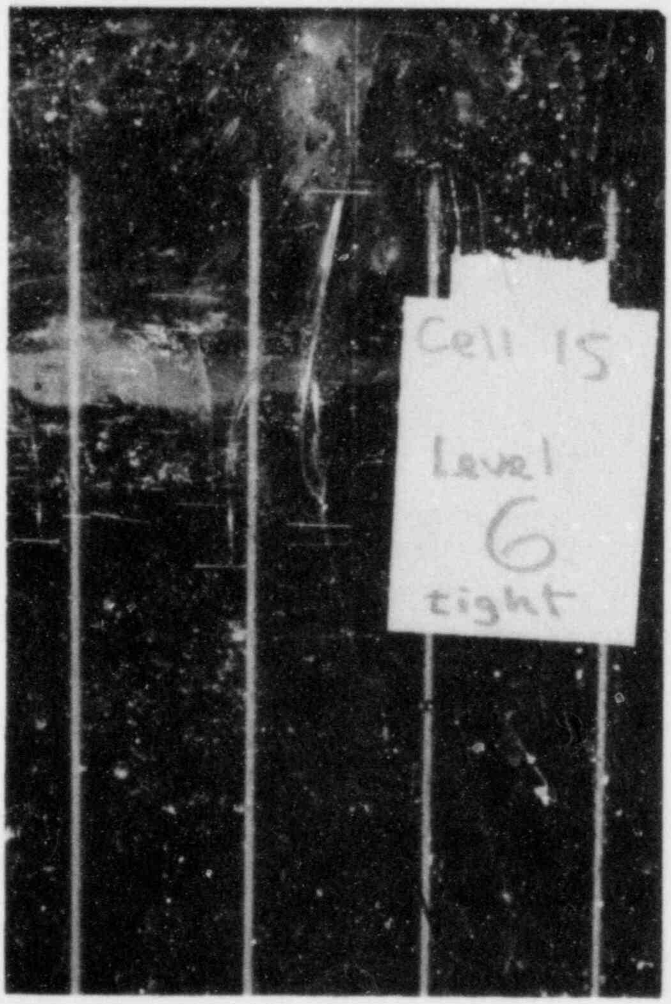
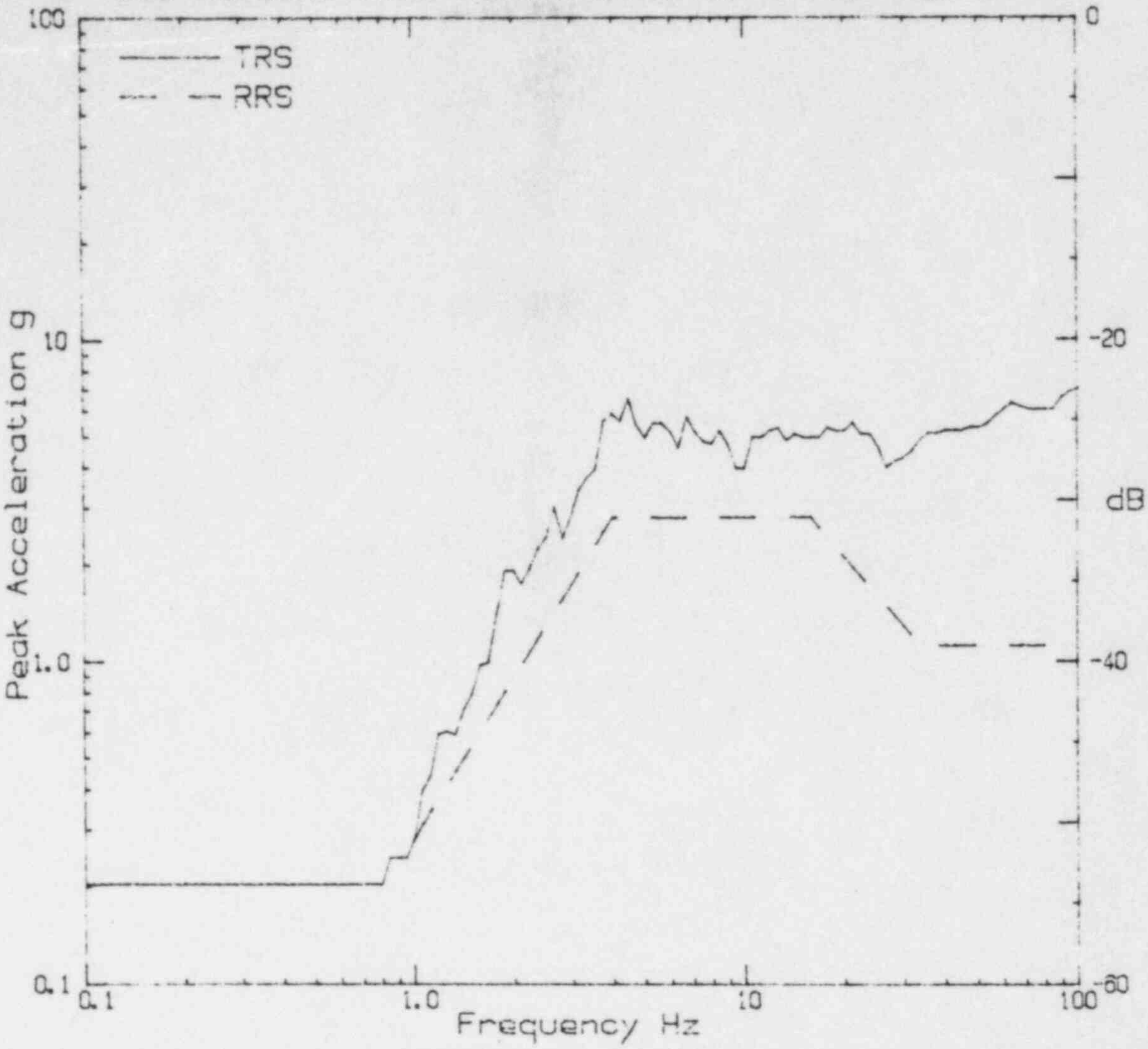


Figure 01B2
The crack above grew at the larger seismic levels. Note that the smaller cracks did not appear to grown significantly.

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 01C

TEST ITEM
station cells, Gould, Modal NCX 2250, #13

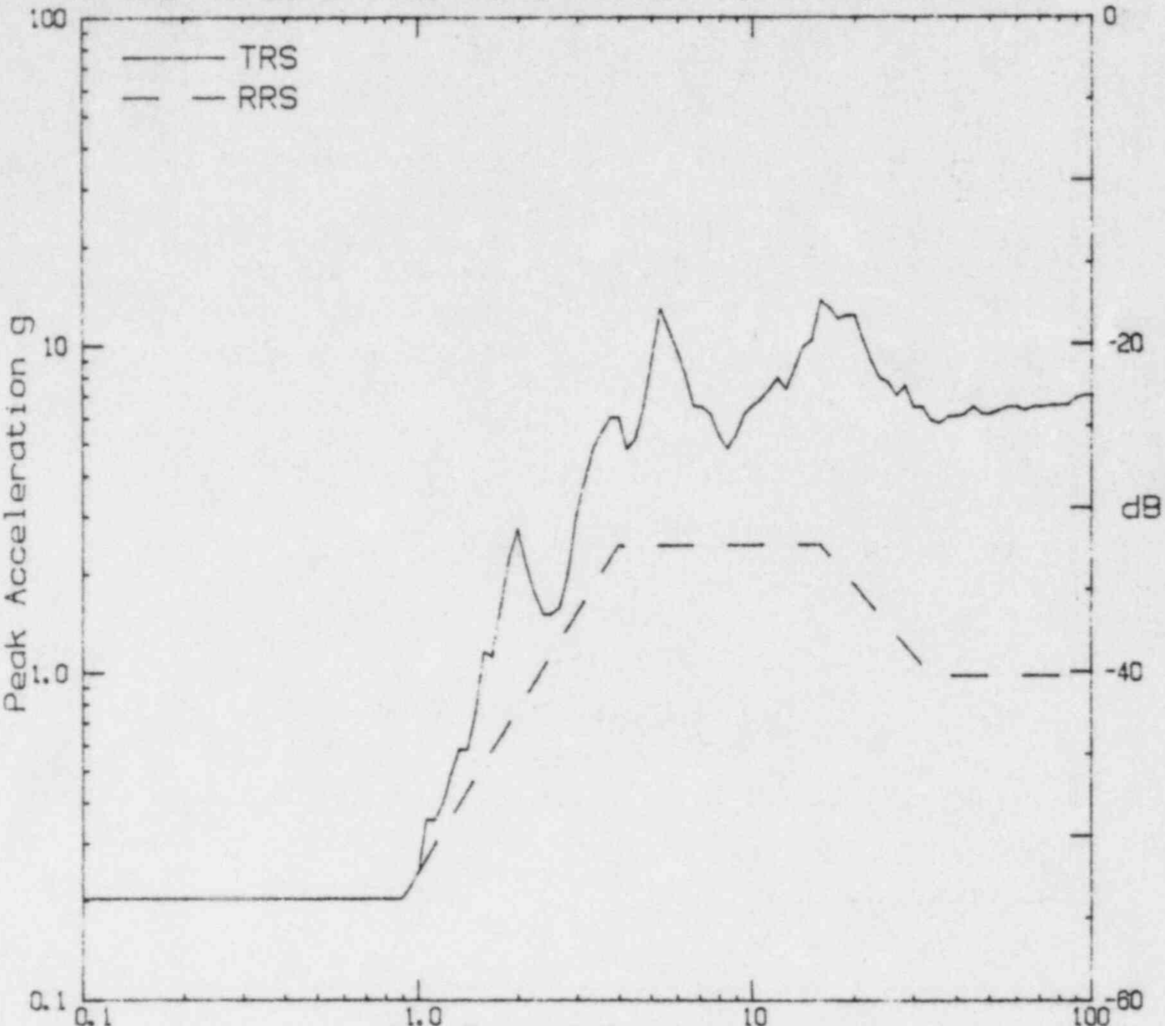
PARTICULARS
Jan 16/84, Time 1:35, Temp('C) 23, Humidity(%) 22, Press (kPa)100.3,
Graph 4963

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.13g

ACCELEROMETER
Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 558, Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 02

TEST ITEM
station cells, Gould, Model NCX 2250, #13

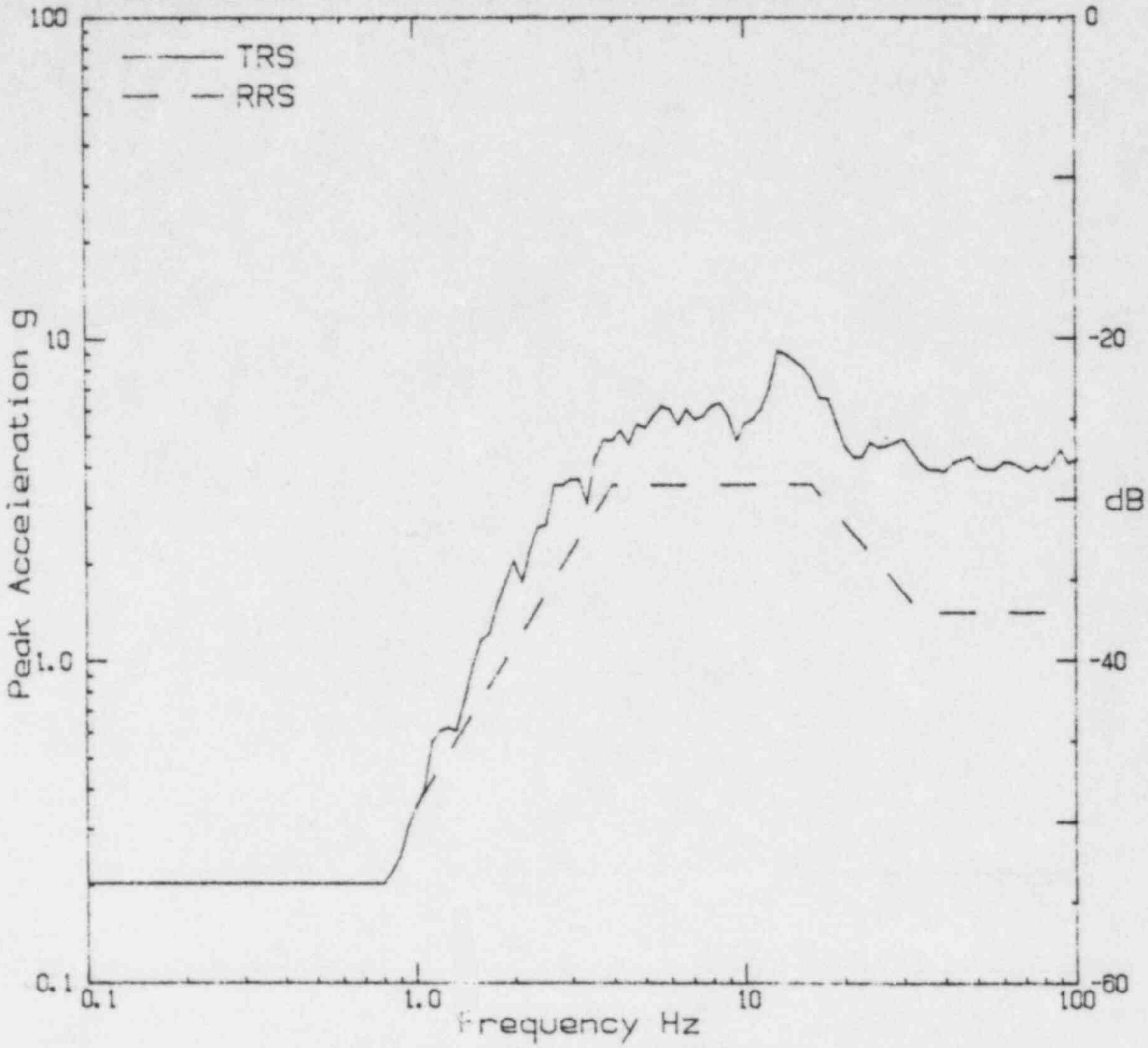
PARTICULARS
Jan 16/84, Time 1:35, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.3,
Graph 4964

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=.98g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB58, Location base-mounting jig,
TT 558, Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 03

TEST ITEM
station cells. Gould. Model NCX 2250. #13

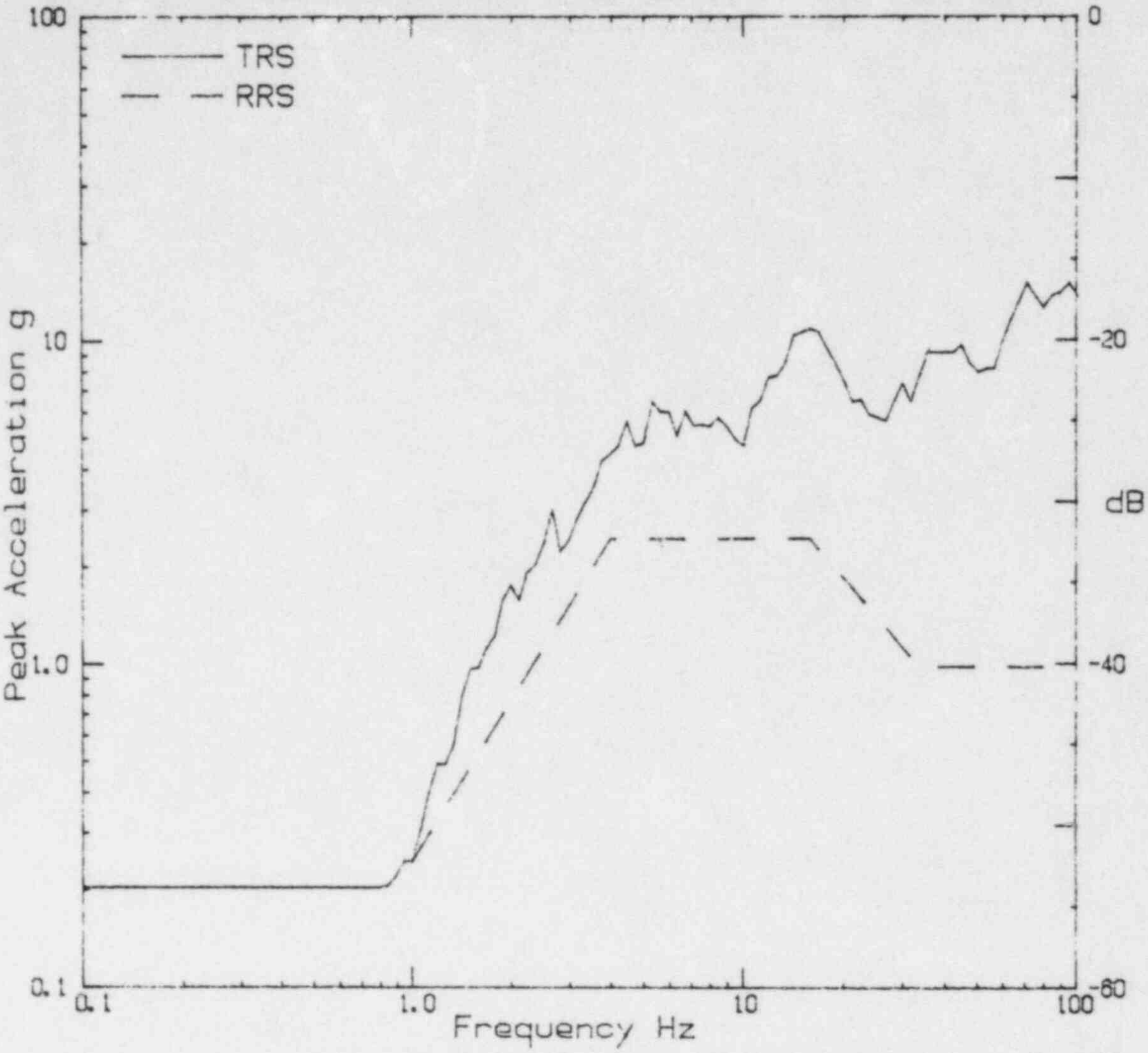
PARTICULARS
Jan 16/84. Time 1:35. Temp('C) 23. Humidity(%) 22. Press (kPa)100.3.
Graph 4965

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.42g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 558. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 04

TEST ITEM
station cells, Gould, Model NCX 2250, #13

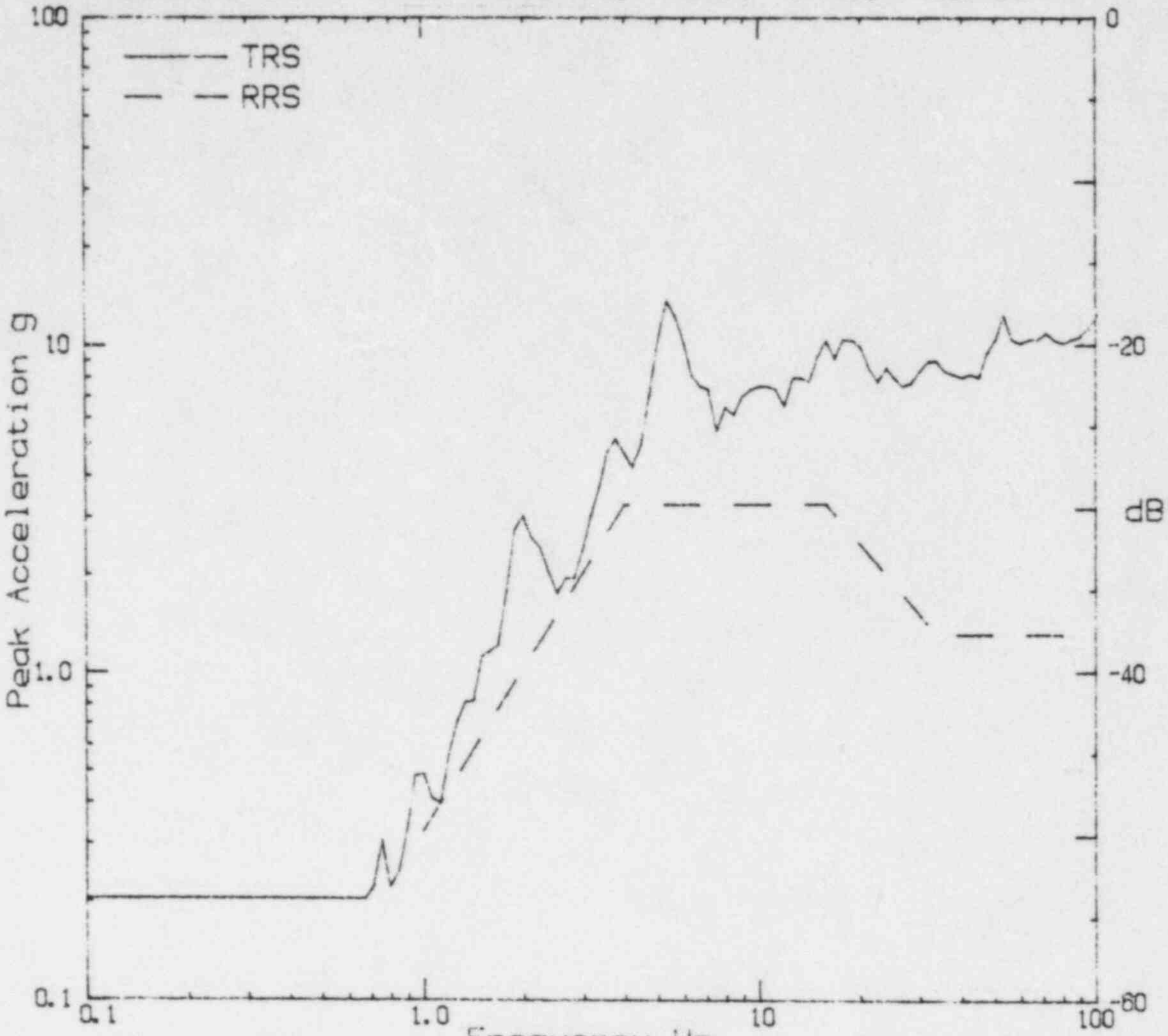
PARTICULARS
Jan 16/84, Time 1:35, Temp('C) 23, Humidity(%) 22, Press (kPa)100.3,
Graph 4966

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=.98g

ACCELEROMETER
Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 558, Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 05

TEST ITEM
station cells. Gould. Model NCX 2250. #13

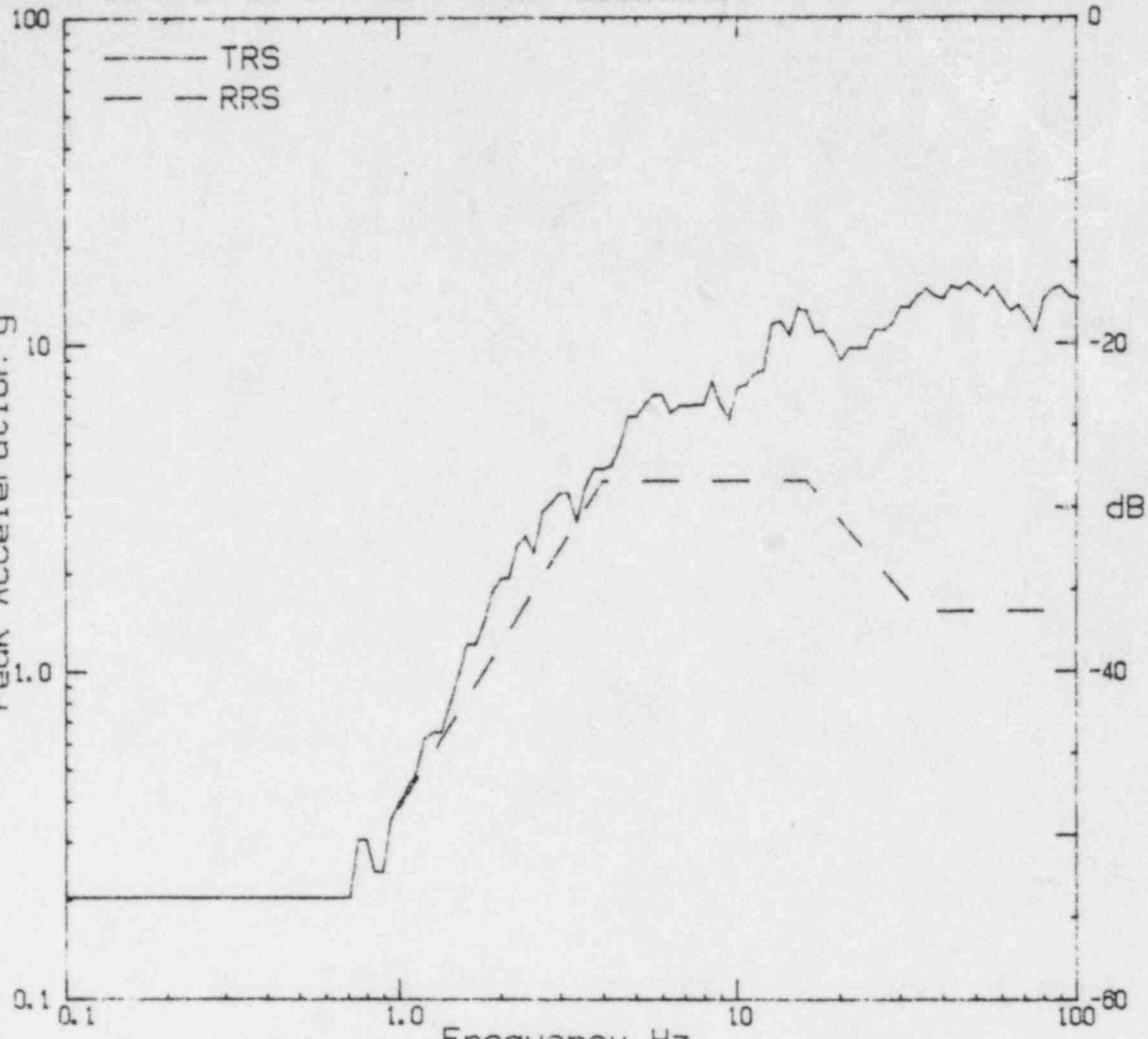
PARTICULARS
Jan 16/84. Time 1:35. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.3.
Graph 4967

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.31g

ACCELEROMETER
Wilcoxon. Serial S771. Range dB58. Location top-cell terminal.
TT 558. Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 06

TEST ITEM
station cells, Gould, Model NCX 2250, #13

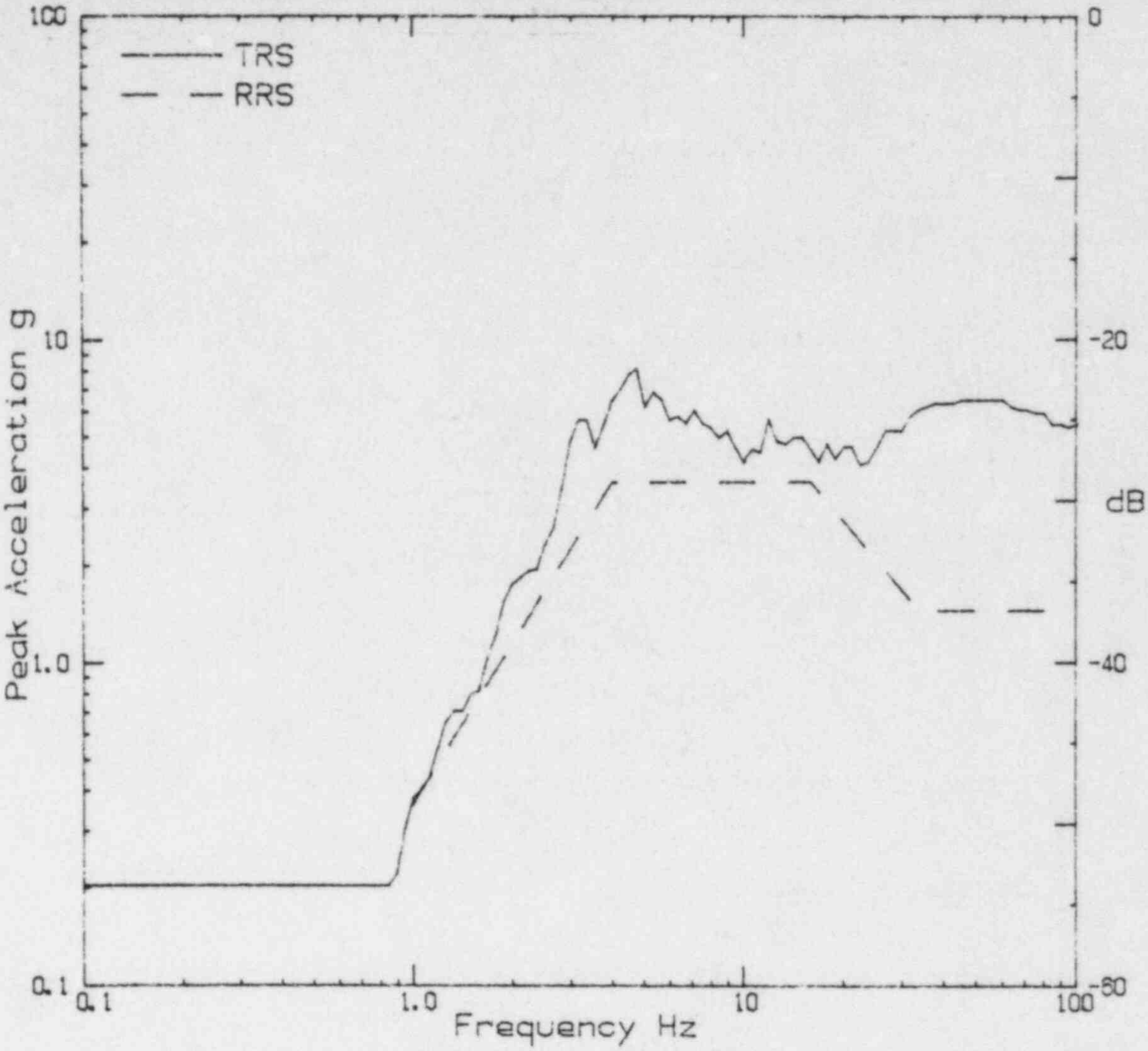
PARTICULARS
Jan 16/84, Time 1:35, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.3,
Graph 4968

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.54g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 558, Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 07

TEST ITEM
station cells. Gould. Model NCX 2250. #3

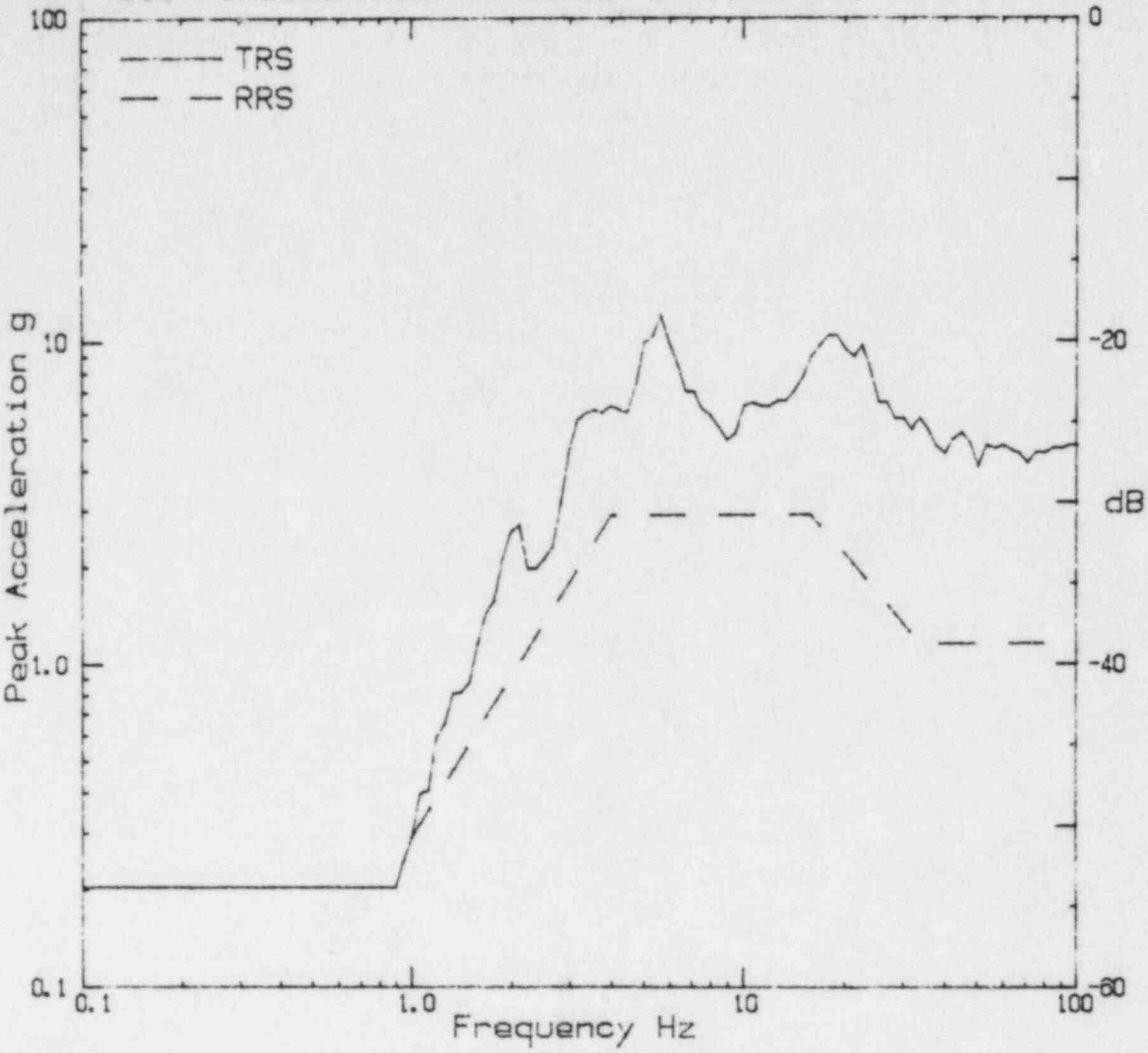
PARTICULARS
Jan 16/84. Time 3:20. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.3. Graph 4969

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X. Shaker tri-axial. ZPA=1.46g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig. TT 575. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 08

TEST ITEM
station cells. Gould. Model NCX 2250. #3

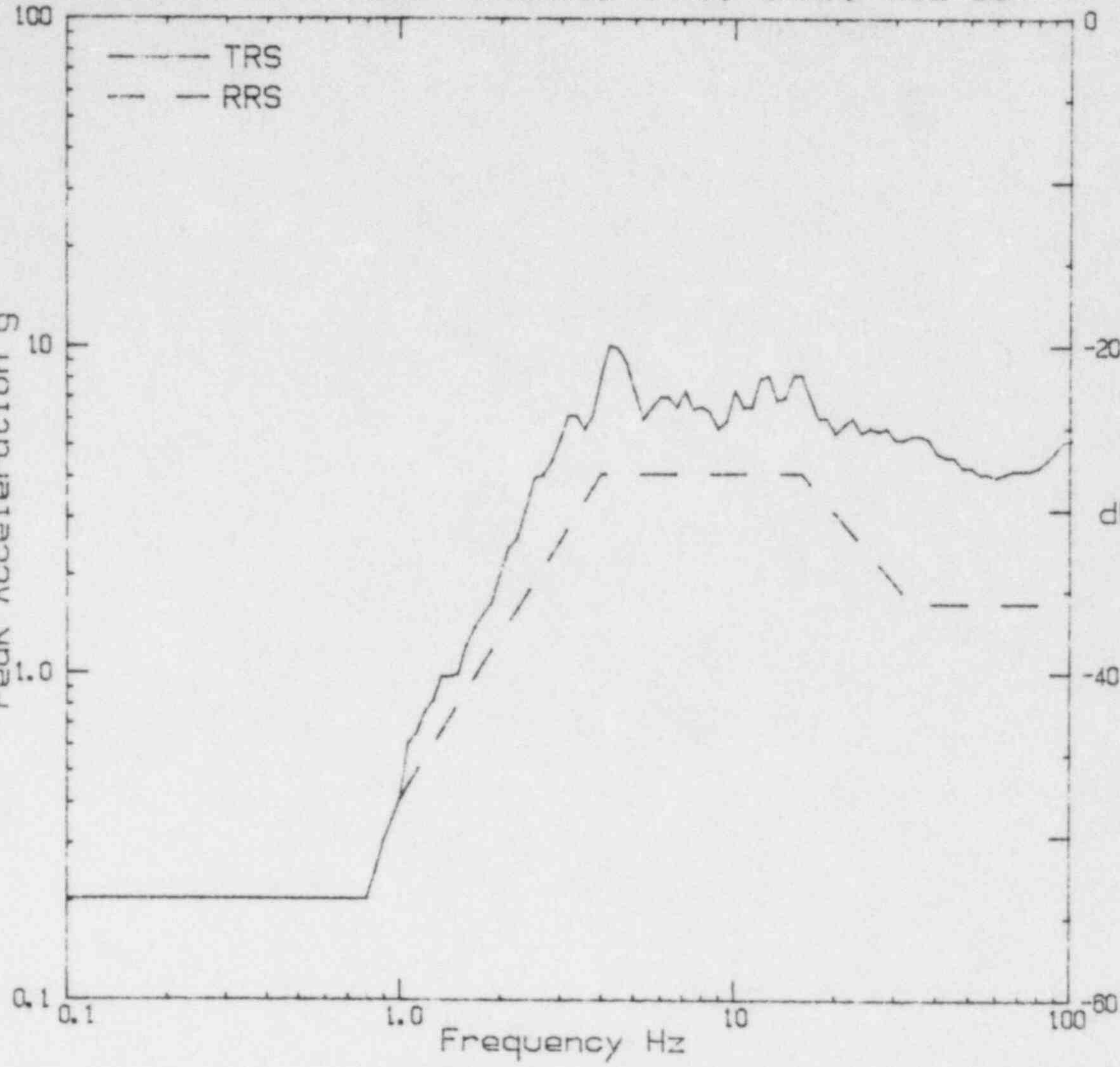
PARTICULARS
Jan 16/84. Time 3:20. Temp('C) 23. Humidity(%) 22. Press (kPa)100.3. Graph 4970

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour raté. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W. = 1/12 Octaves. Axis Y. Shaker tri-axial. ZPA=1.17g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig. TT 575. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 09

TEST ITEM
station cells, Gould, Model NCX 2250, #3

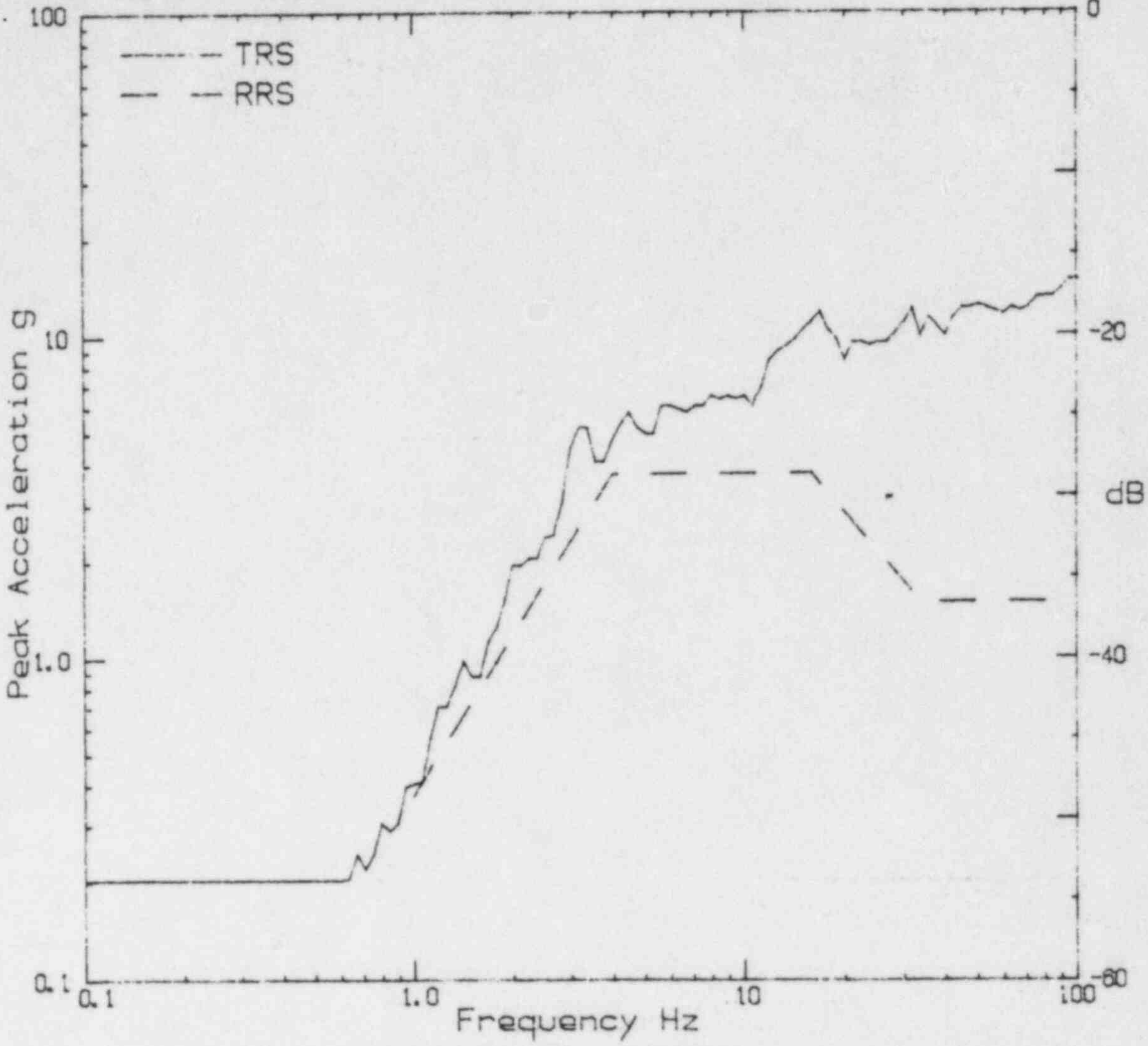
PARTICULARS
Jan 16/84, Time 3:20, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.3,
Graph 4971

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.65g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 575, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 10

TEST ITEM
station cells. Gould. Model NCX 2250. #3

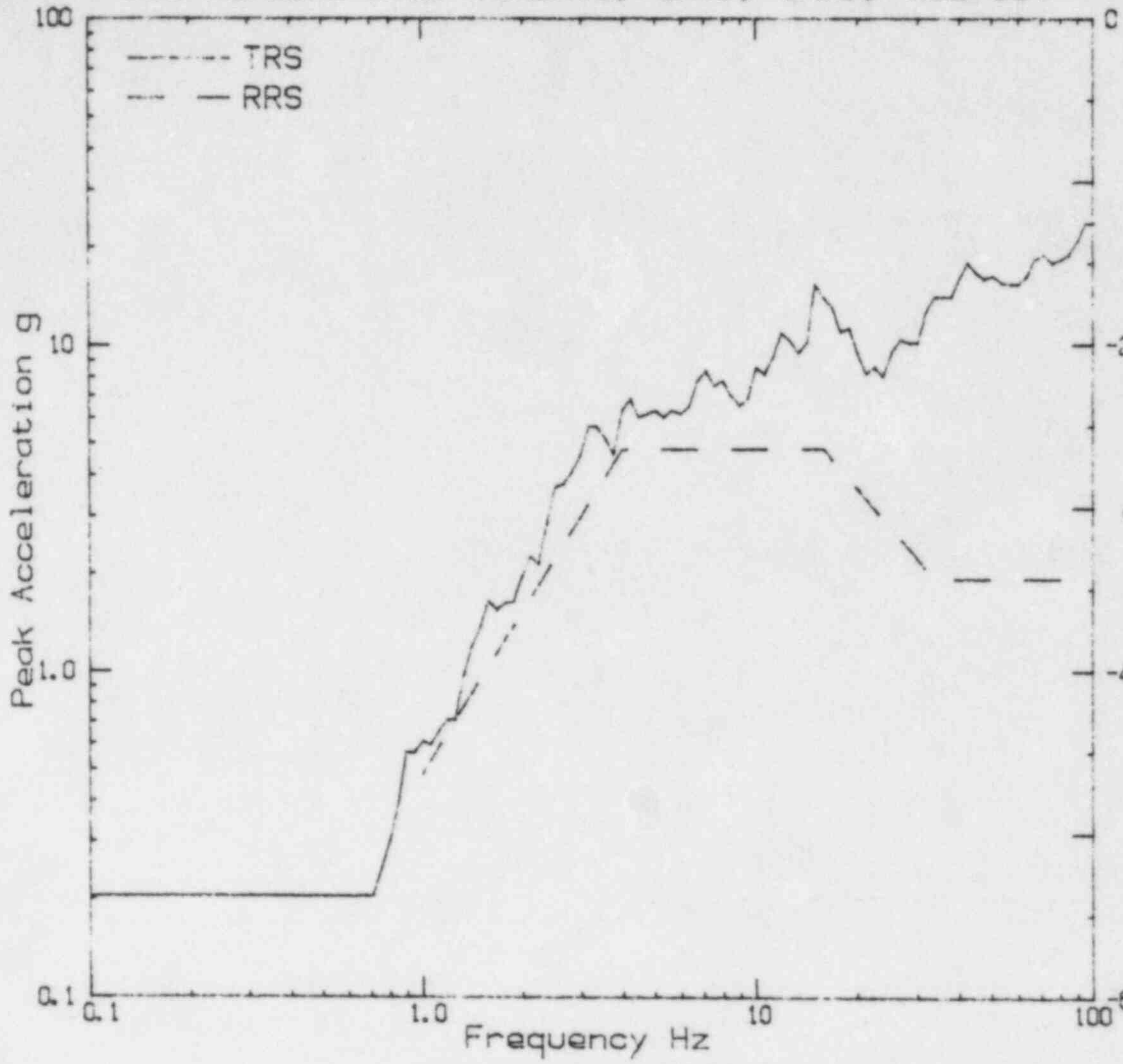
PARTICULARS
Jan 16/84. Time 3:20. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.3.
Graph 4972

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.5g

ACCELEROMETER
Wilcoxon. Serial S754. Range dB58. Location top-cell terminal.
TT S75. Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 11

TEST ITEM
station cells, Gould, Model NCX 2250, #3

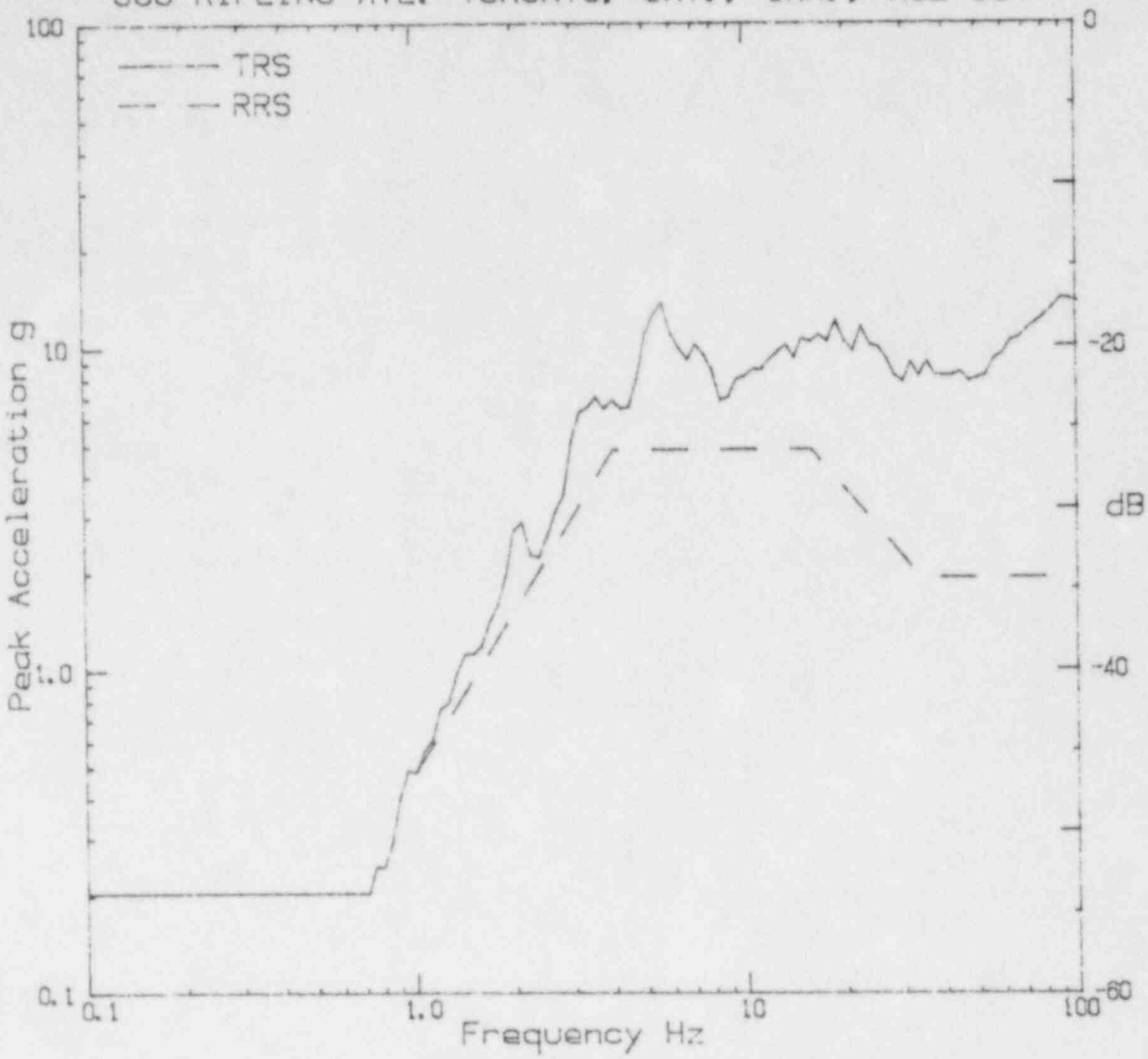
PARTICULARS
Jan 16/84, Time 3:20, Temp('C) 23, Humidity(%) 22, Press (kPa)100.3,
Graph 4973

SPECIFICATIONS
Specs IEEE 501, Conditions operating,8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.93g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB58, Location top-cell terminal,
TT 575, Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 12

TEST ITEM
station cells. Gould. Model NCX 2250. #3

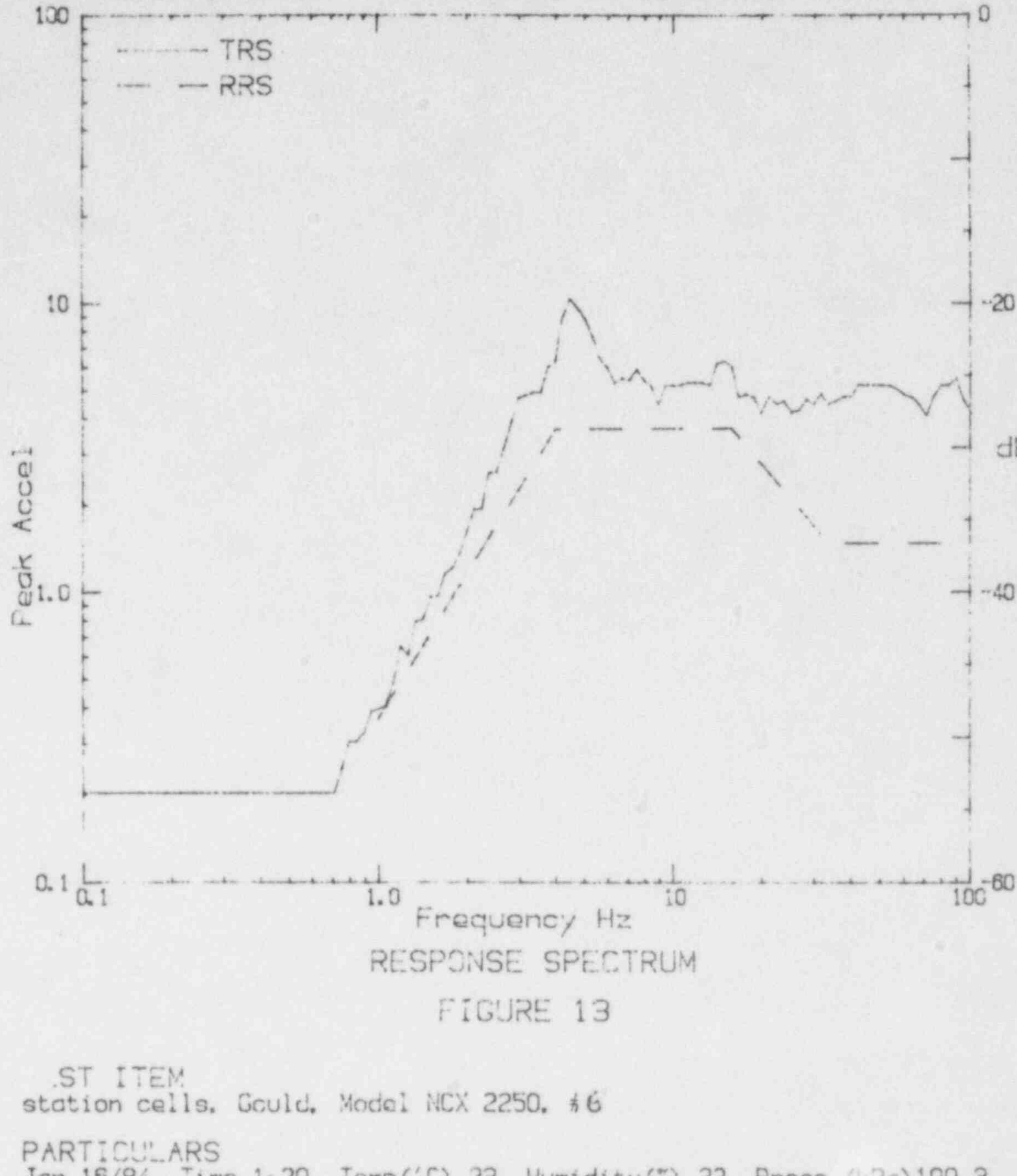
PARTICULARS
Jan 16/84. Time 3:20. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.3. Graph 4974

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.94g

ACCELEROMETER
Wilcoxon. Serial S297. Range dB58. Location top-cell terminal.
TT 575. Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 13

.ST ITEM
station cells, Gould, Model NCX 2250, #6

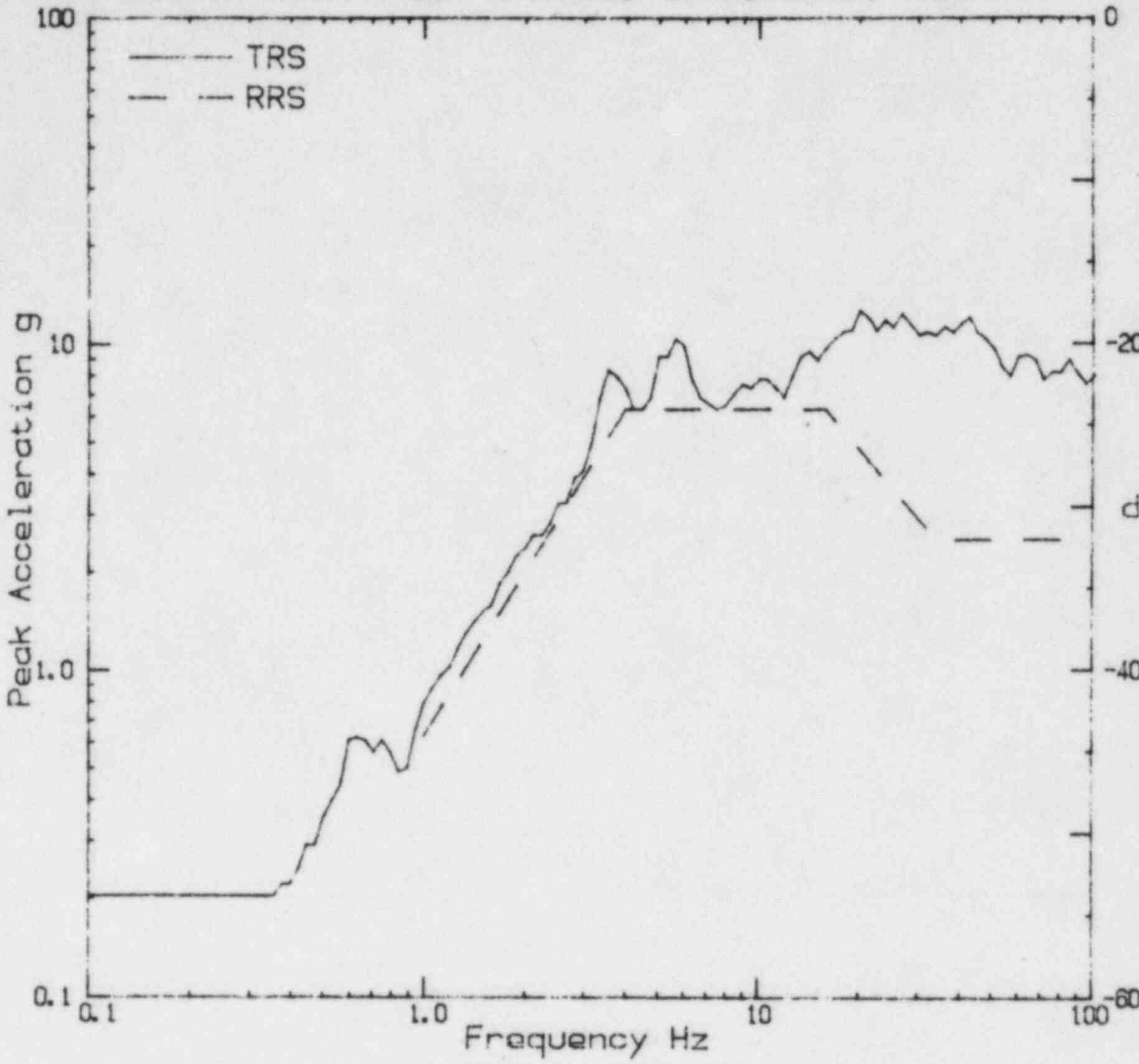
PARTICULARS
Jan 16/84, Time 1:20, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.3,
Graph 4975

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, shaker limit

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.48g

ACCELEROMETER
Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 584, Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 14

TEST ITEM
station cells, Gould, Model NCX 2250, #6

PARTICULARS
Jan 16/84, Time 1:20, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.3,
Graph 4976

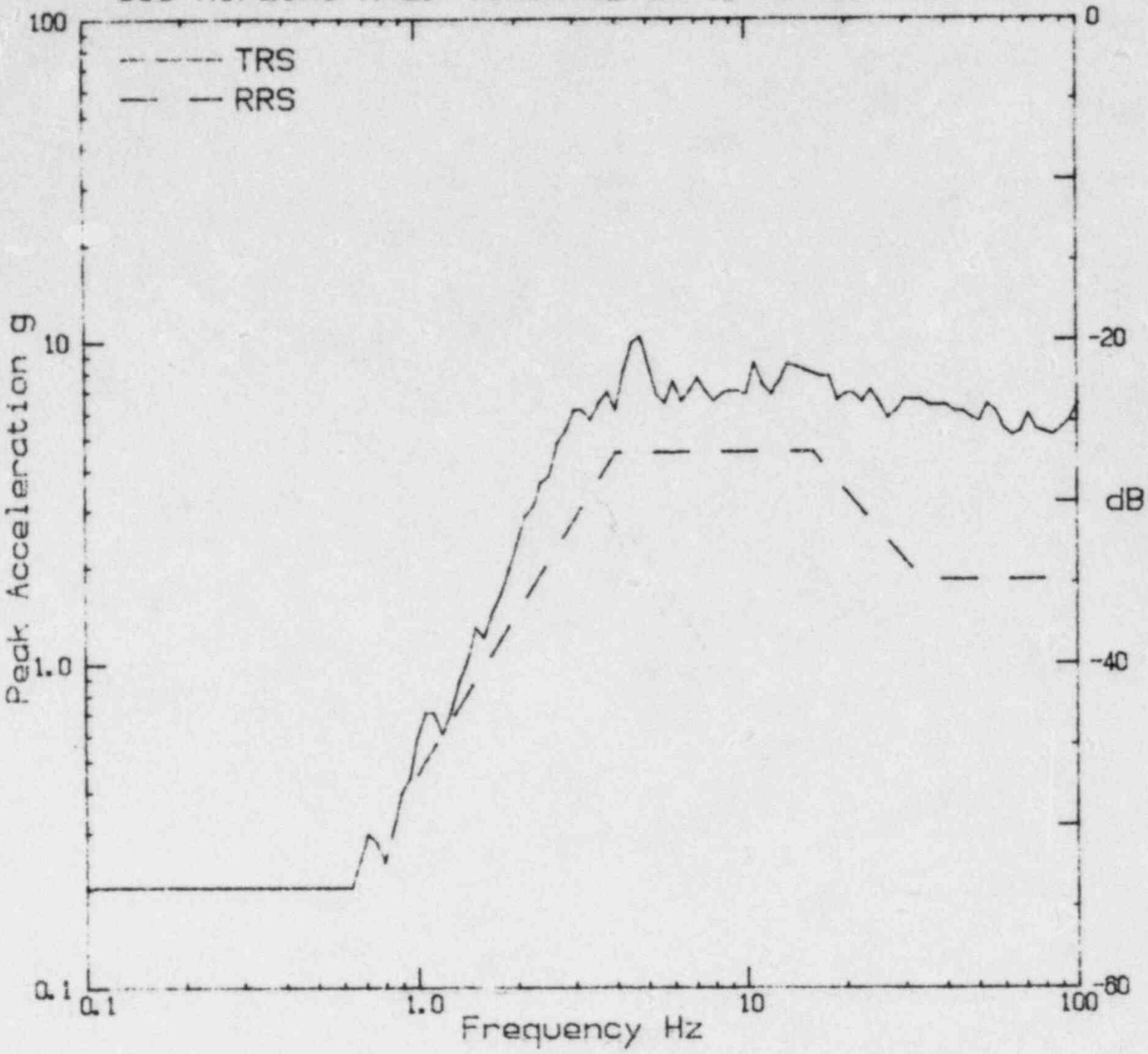
SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, shaker limit

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=2.52g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB58, Location base-mounting jig,
TT 584, Channel 2

-142-

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 15

TEST ITEM
station cells. Gould. Mo 40 50. #6

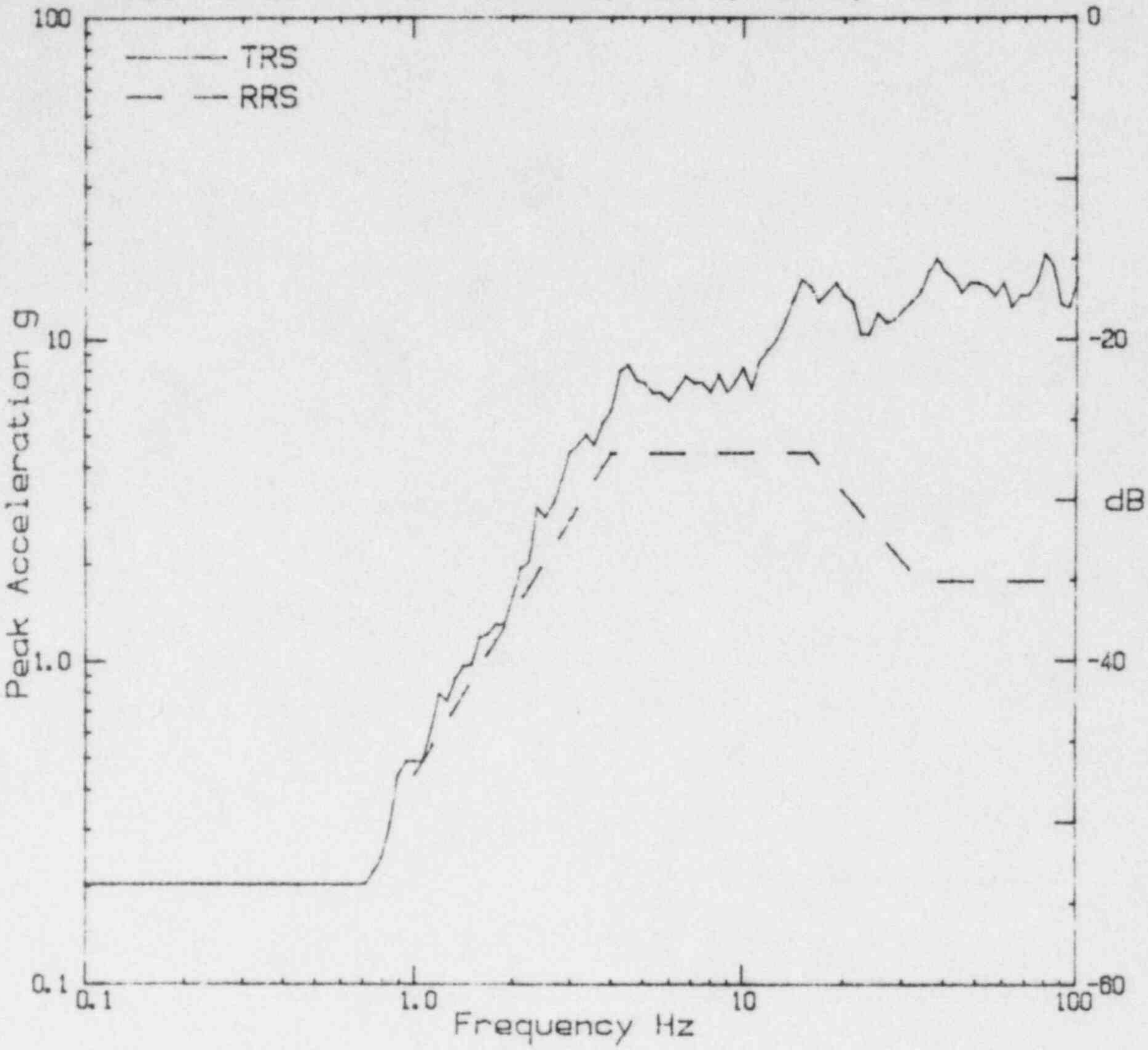
PARTICULARS
Jan 16/84. Time 1:20. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.3.
Graph 4977

SPECIFICATIONS
Specs IEEE 501. Conditions operating. 8-hour rate. shaker limit

ANALYSIS
Type Maximax. Damping (%)5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.83g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 584. Channel 3

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 16

TEST ITEM
station cells, Gould, Model NCX 2250, #6

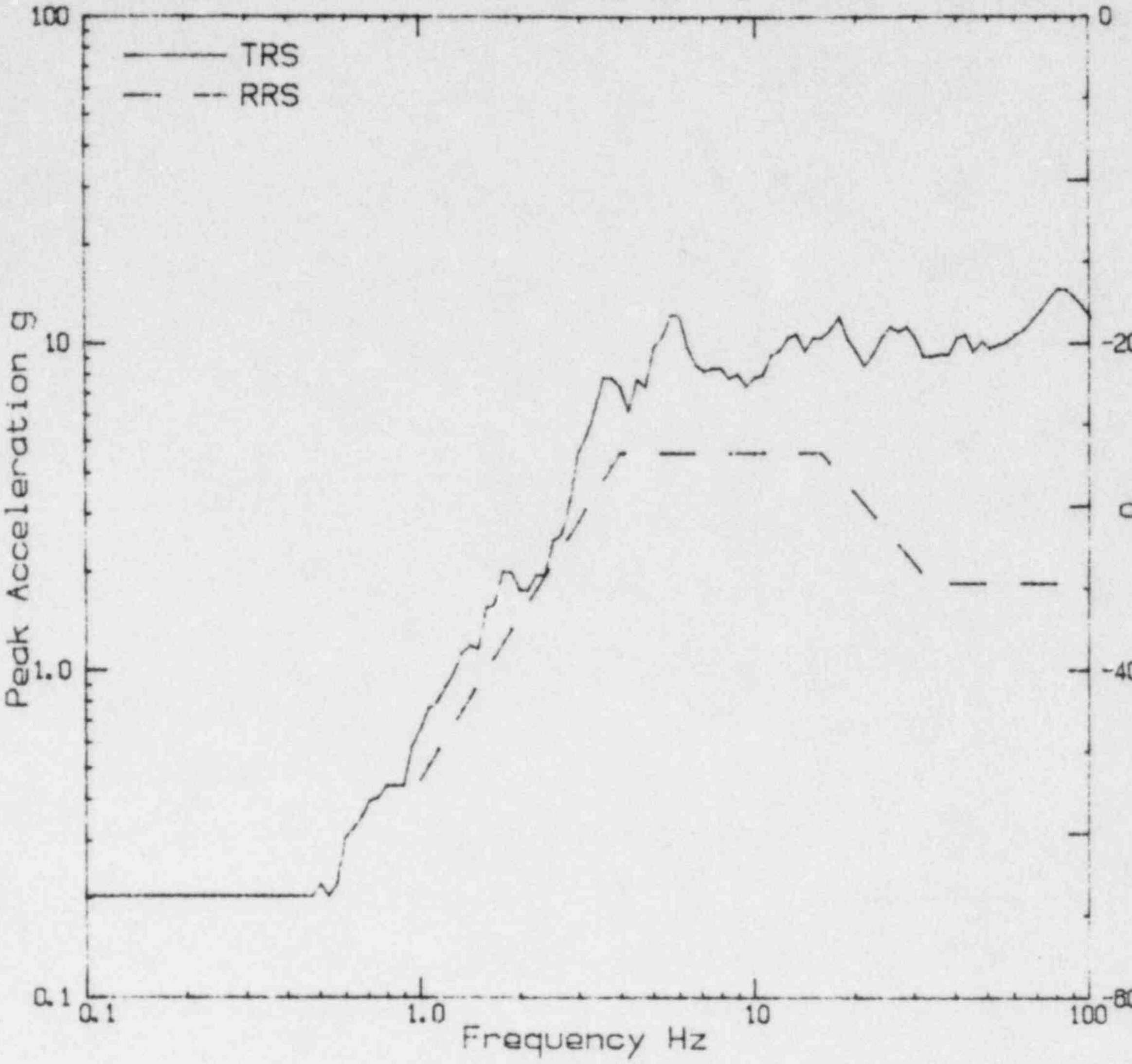
PARTICULARS
Jan 16/84, Time 1:20, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.3, Graph 4978

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, shaker limit

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X, Shaker tri-axial, ZPA=1.78g

ACCELEROMETER
Wilcoxon, Serial S754, Range dB58, Location top-cell terminal, TT 584, Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 17

TEST ITEM
station cells, Gould, Model NCX 2250, #6

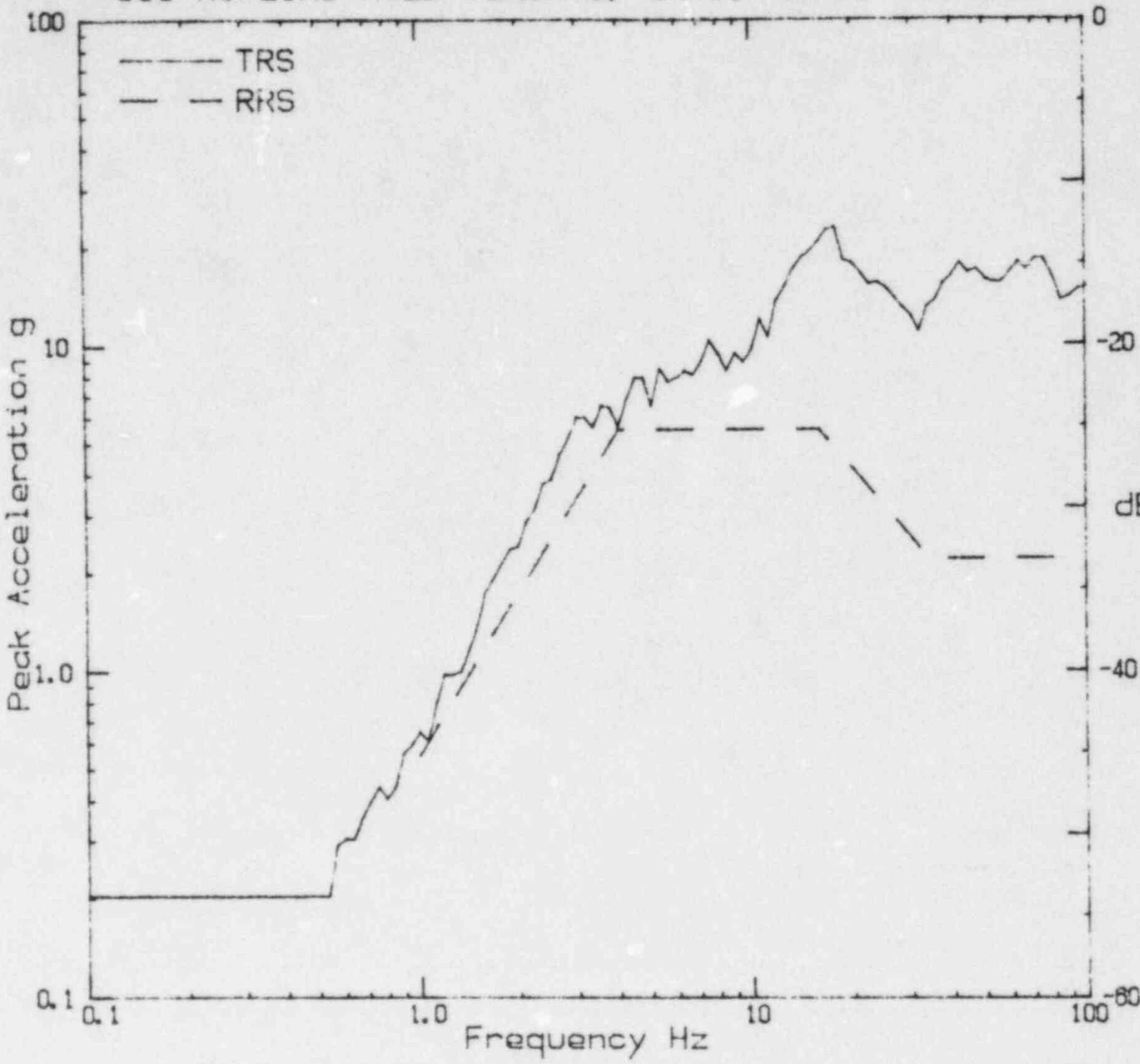
PARTICULARS
Jan 16/84, Time 1:20, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.3,
Graph 4979

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, shaker limit

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.85g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB58, Location top-cell terminal,
TT 584, Channel 5

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 18

TEST ITEM
station cells, Gould, Model NCX 2250, #6

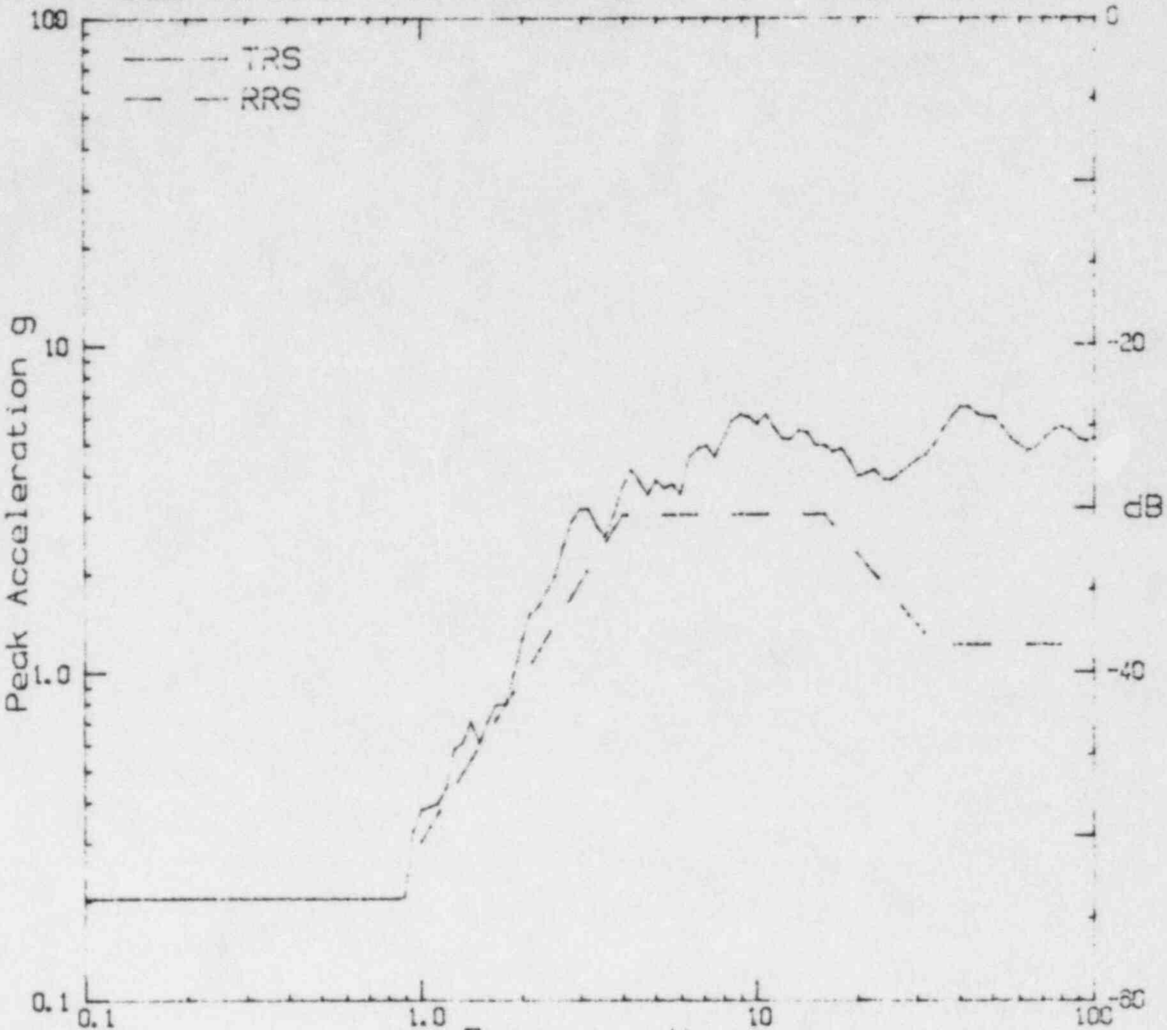
PARTICULARS
Jan 16/84, Time 1:20, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.3,
Graph 4980

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 8-hour rate, shaker limit

ANALYSIS
Type Maximax, Damping (%) 5, B. W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=2.22g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 584, Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 19

TEST ITEM
station cell, Gould, Model NCX 2250, sample 7

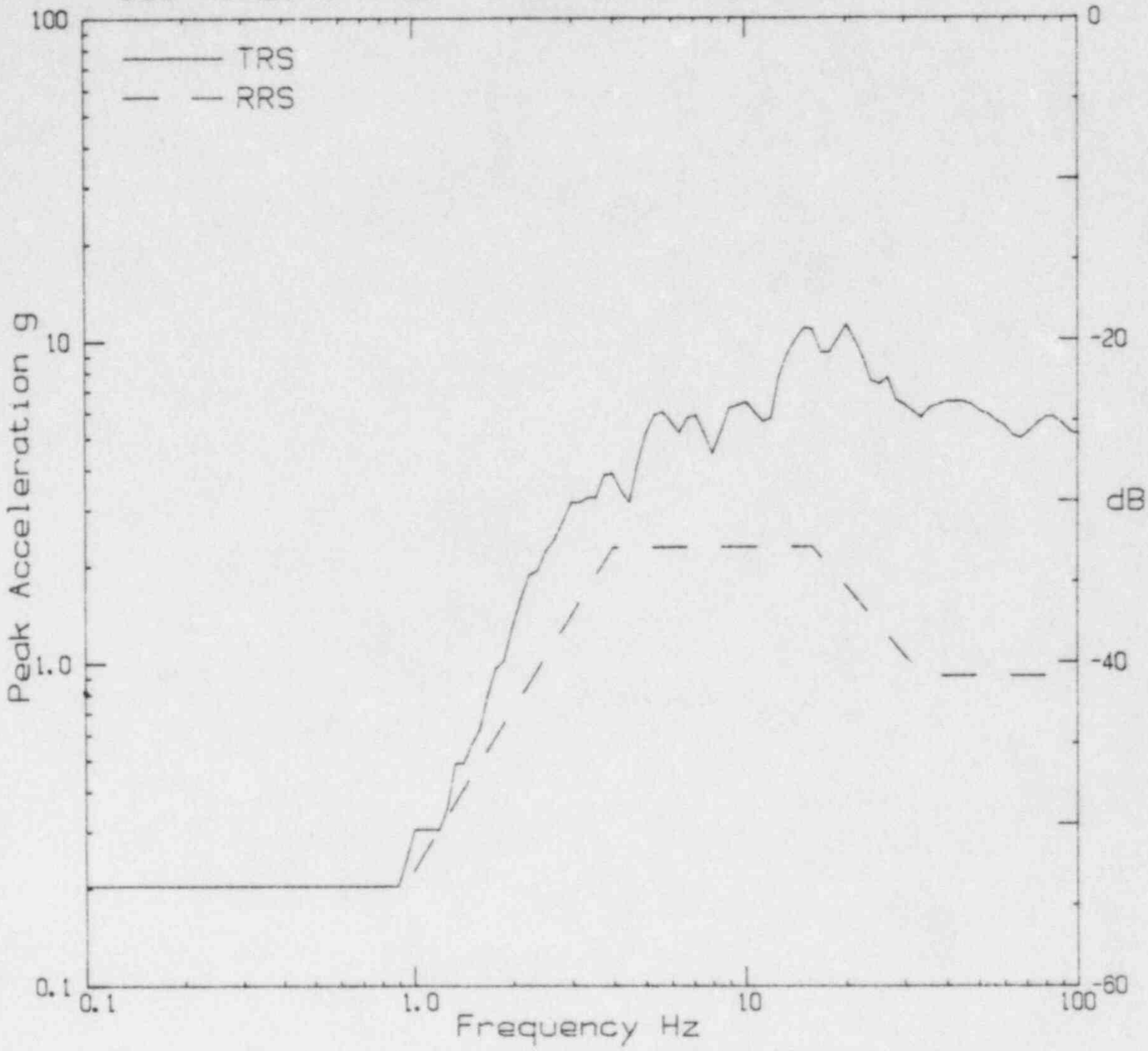
PARTICULARS
Jan 17/84, Time 2:02, Temp('C) 23, Humidity(%) 24, Press (kPa)100.5,
Graph 4981

SPECIFICATIONS
Specs IEEE 501, Conditions operating 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.22g

ACCELEROMETER
Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 586, Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 20

TEST ITEM
station cell, Gould, Model NCX 2250, sample 7

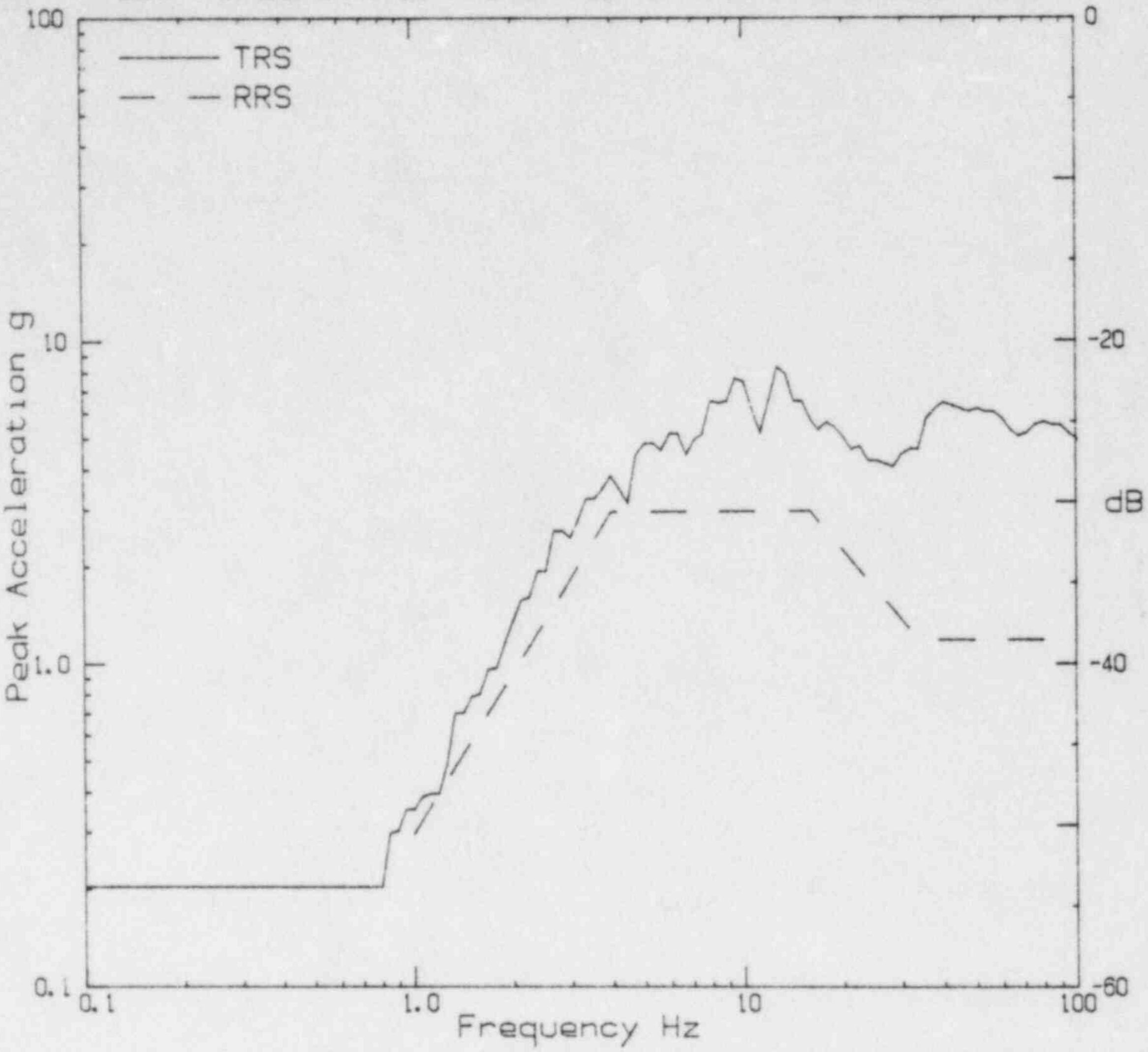
PARTICULARS
Jan 17/84, Time 2:02, Temp('C) 23, Humidity(%) 24, Press (kPa)100.5, Graph 4982

SPECIFICATIONS
Specs IEEE 501, Conditions operating 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y, Shaker tri-axial, ZPA=.92g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB58, Location base-mounting jig, TT 586, Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 21

TEST ITEM
station cell, Gould, Model NCX 2250, sample 7

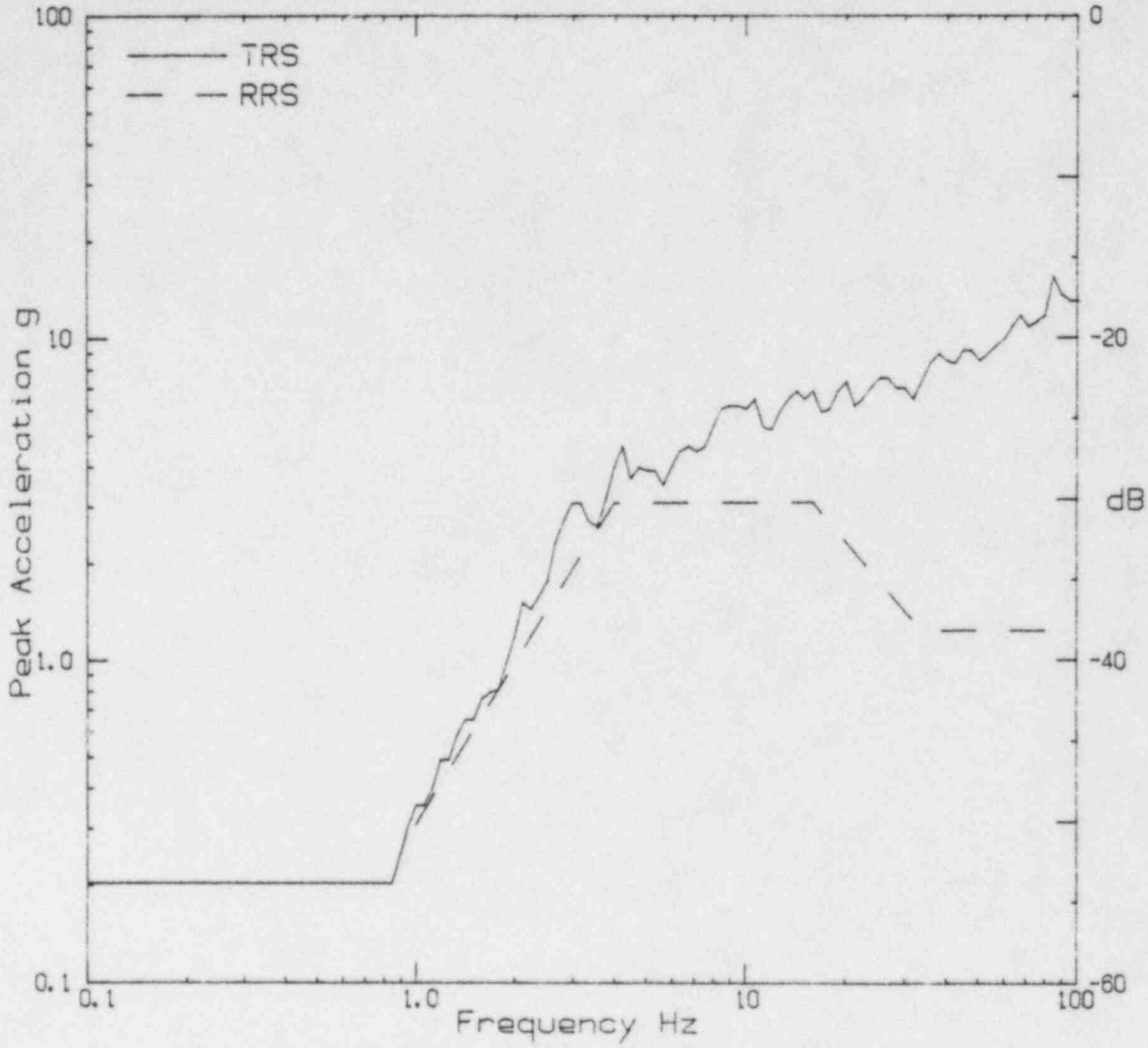
PARTICULARS
Jan 17/84, Time 2:02, Temp('C) 23, Humidity(%) 24, Press (kPa)100.5, Graph 4983

SPECIFICATIONS
Specs IEEE 501, Conditions operating 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z, Shaker tri-axial, ZPA=1.19g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting jig, TT 586, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 22

TEST ITEM
station cell, Gould, Model NCX 2250, sample 7

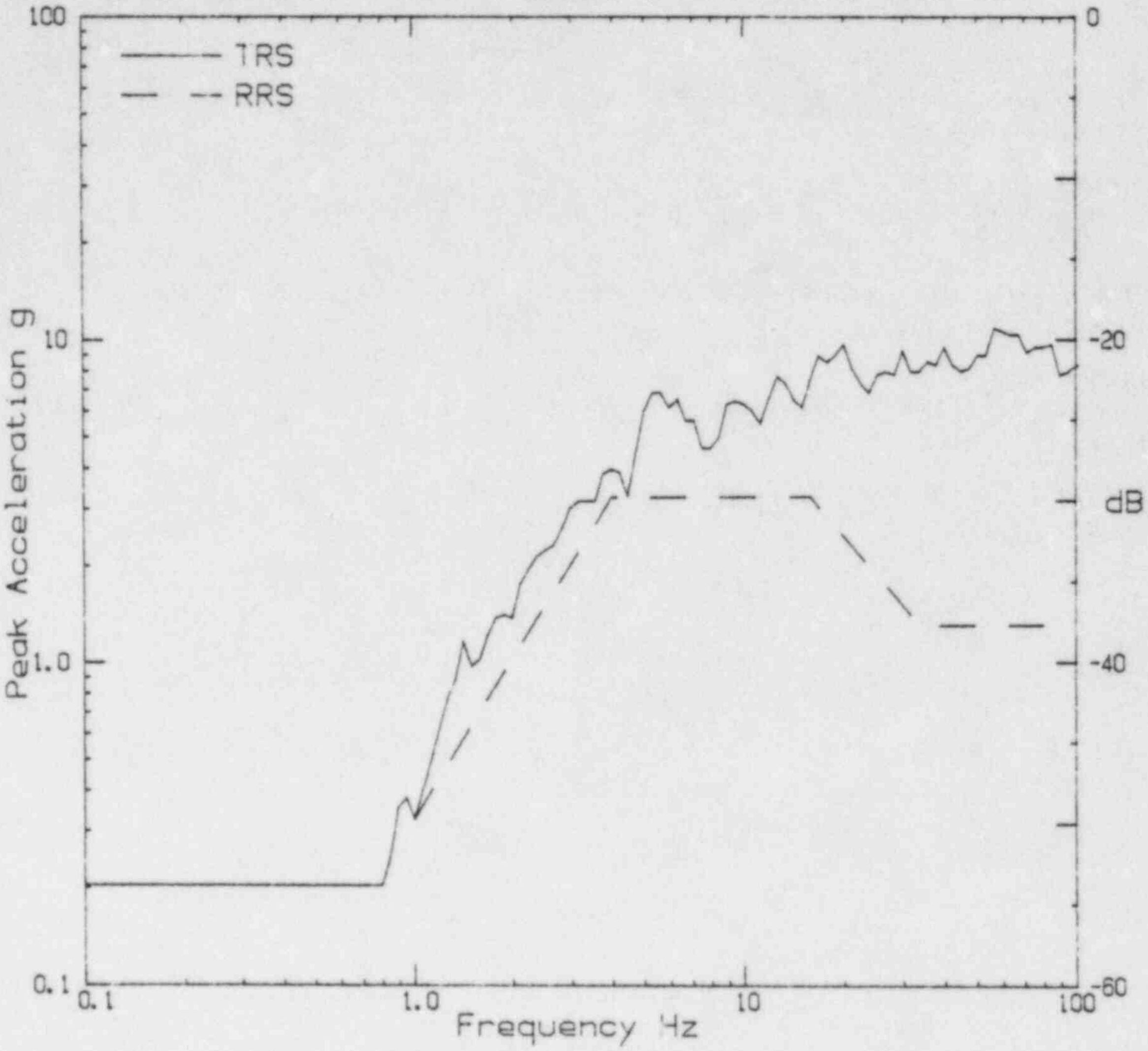
PARTICULARS
Jan 17/84, Time 2:02, Temp('C) 23, Humidity(%) 24, Press (kPa)100.5,
Graph 4984

SPECIFICATIONS
Specs IEEE 501, Conditions operating 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.25g

ACCELEROMETER
Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 586, Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 23

TEST ITEM
station cell, Gould, Model NCX 2250, sample 7

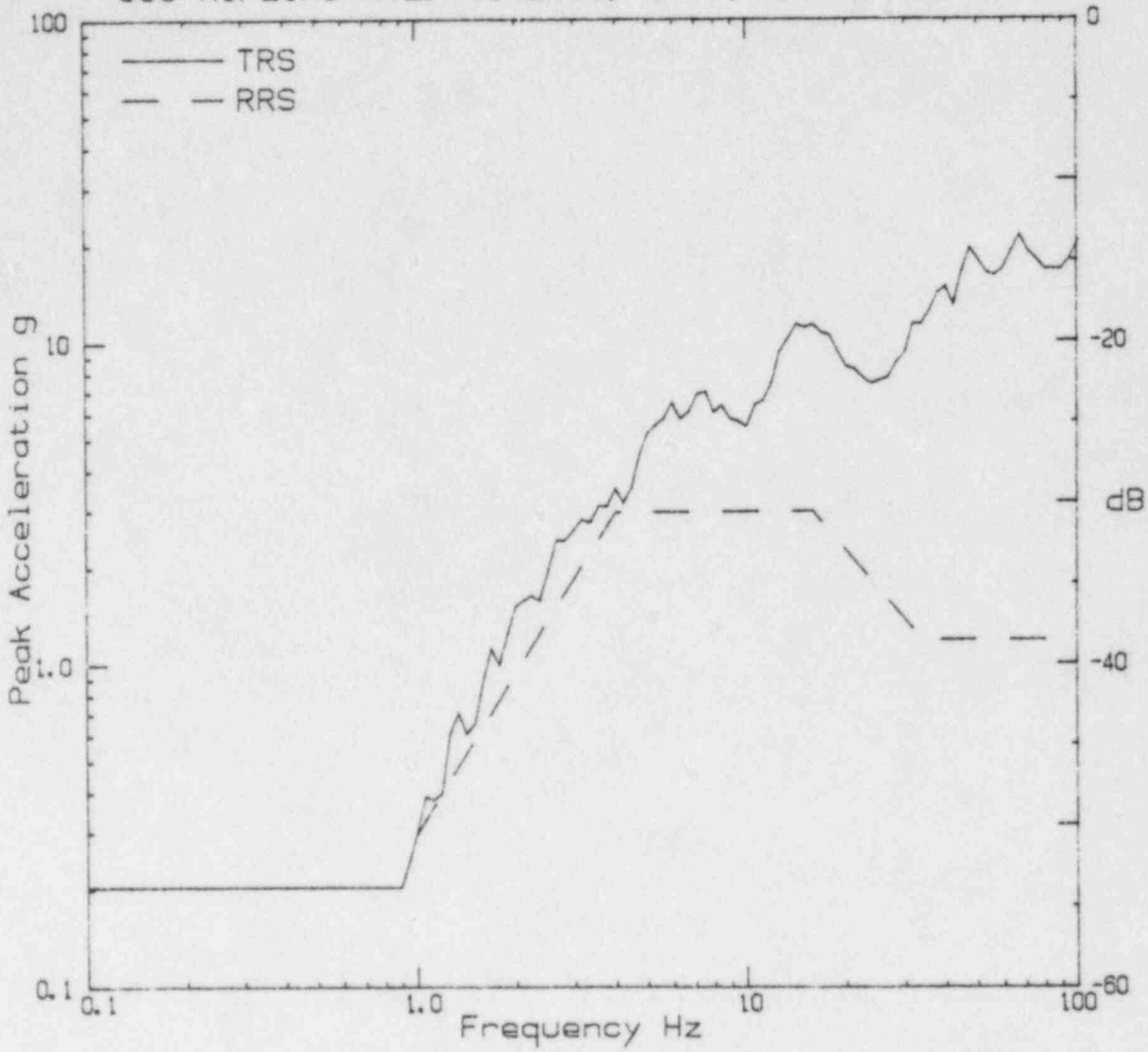
PARTICULARS
Jan 17/84, Time 2:02, Temp('C) 23, Humidity(%) 24, Press (kPa)100.5, Graph 4985

SPECIFICATIONS
Specs IEEE 501, Conditions operating 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y, Shaker tri-axial, ZPA=1.31g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB58, Location top-cell terminal, TT 586, Channel 5

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 24

TEST ITEM
station cell, Gould, Model NCX 2250, sample 7

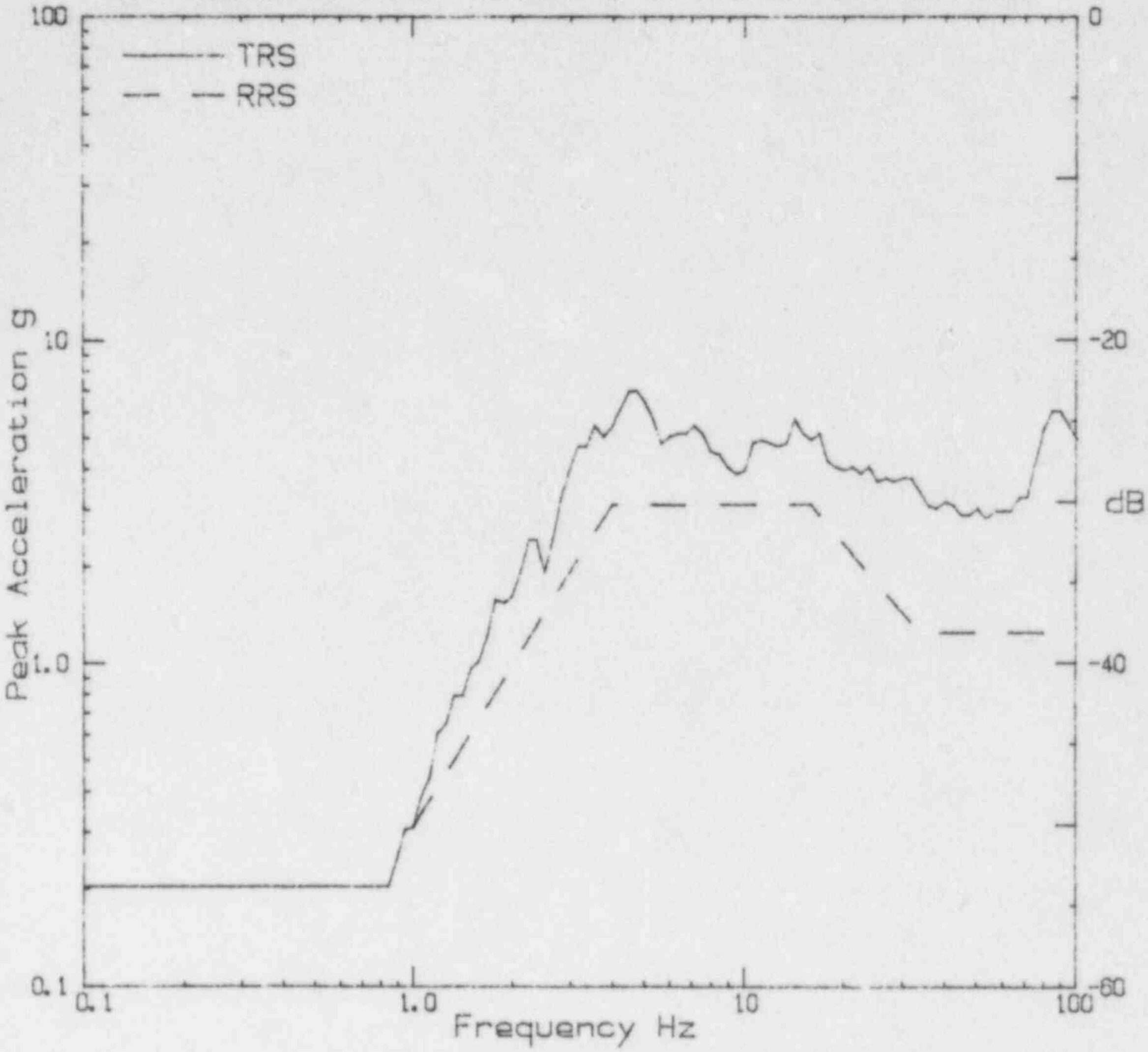
PARTICULARS
Jan 17/84, Time 2:02, Temp('C) 23, Humidity(%) 24, Press (kPa)100.5,
Graph 4986

SPECIFICATIONS
Specs IEEE 501, Conditions operating 8-hour rate, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.19g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 586, Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 25

TEST ITEM
station cell, Gould, Model NCX 2250, sample 15

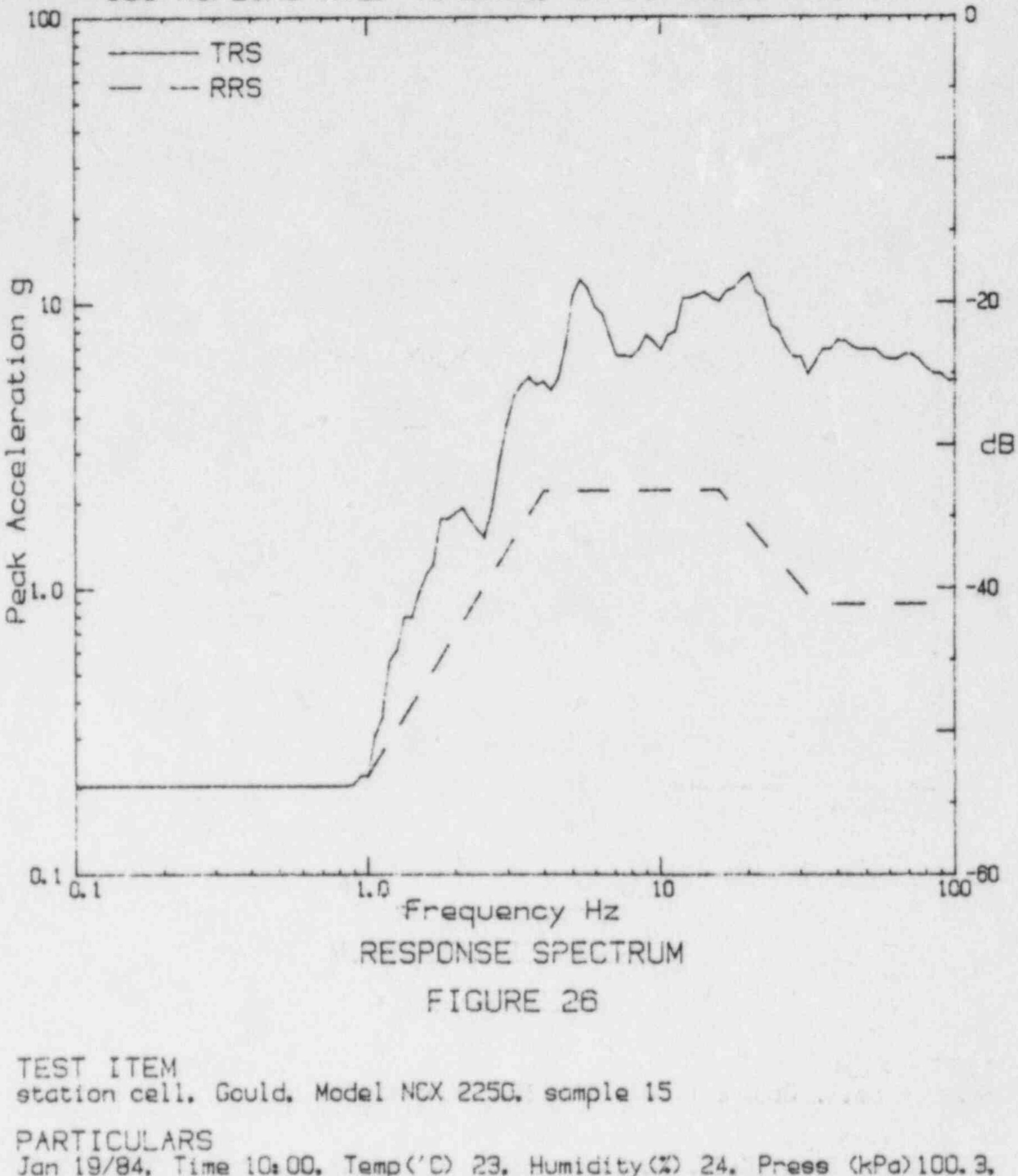
PARTICULARS
Jan 19/84, Time 10:00, Temp('C) 23, Humidity(%) 24, Press (kPa)100.3, Graph 4987

SPECIFICATIONS
Specs IEEE 501, Conditions not operating; crack propagation, clamps tight

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X, Shaker tri-axial, ZPA=1.25g

ACCELEROMETER
Wilcoxon, Serial S757, Range dB58, Location base-mounting jig, TT 604, Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 26

TEST ITEM
station cell, Gould, Model NCX 2250, sample 15

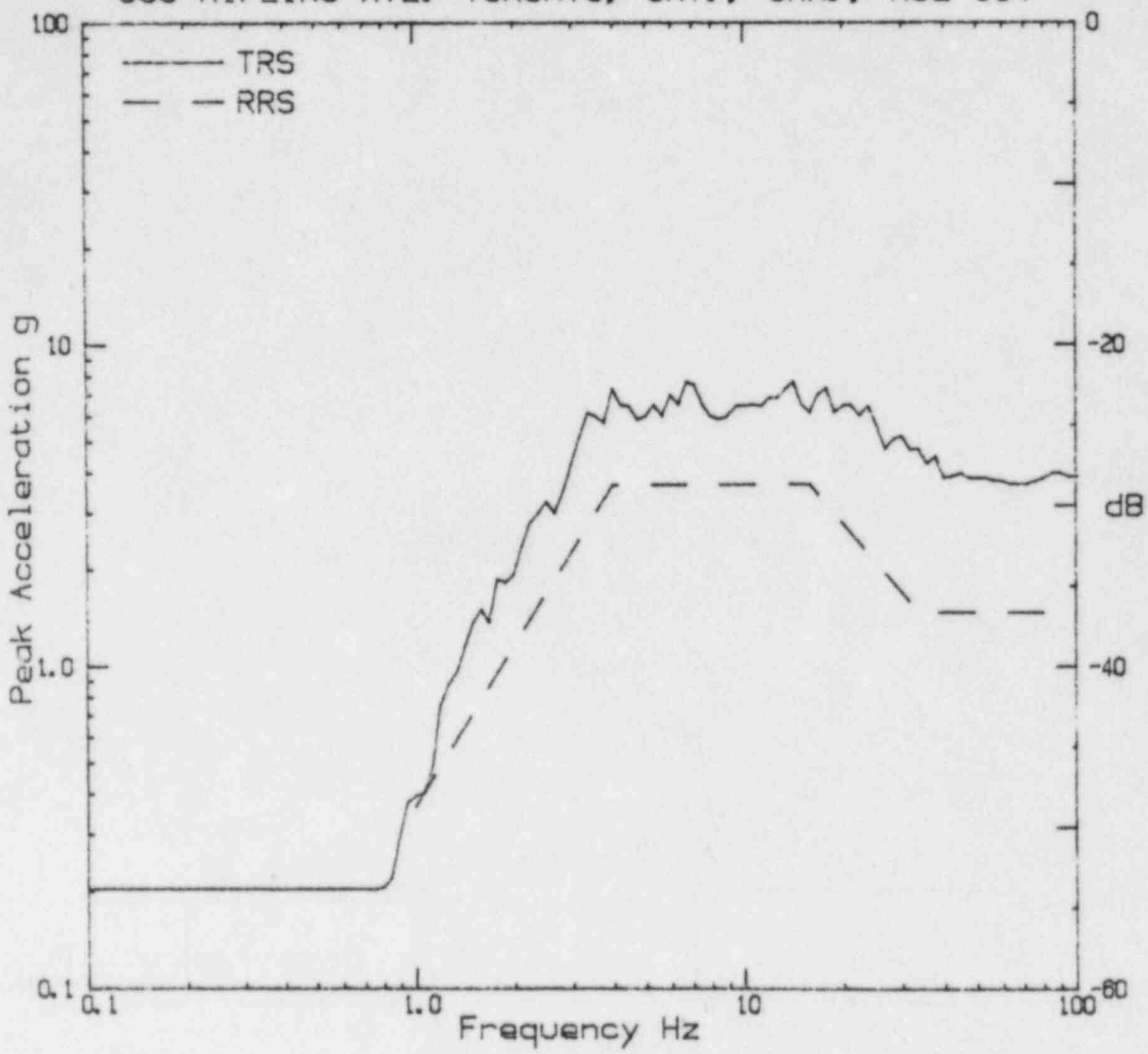
PARTICULARS
Jan 19/84, Time 10:00, Temp('C) 23, Humidity(%) 24, Press (kPa) 100.3,
Graph 4988

SPECIFICATIONS
Specs IEEE 501, Conditions not operating; crack propagation,
clamps tight

ANALYSIS
Type Maximax, Damping (%) 5, B.W.= 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=.89g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB58, Location base-mounting jig,
TT 604, Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 27

TEST ITEM
station cell, Gould, Model NCX 2250, sample 15

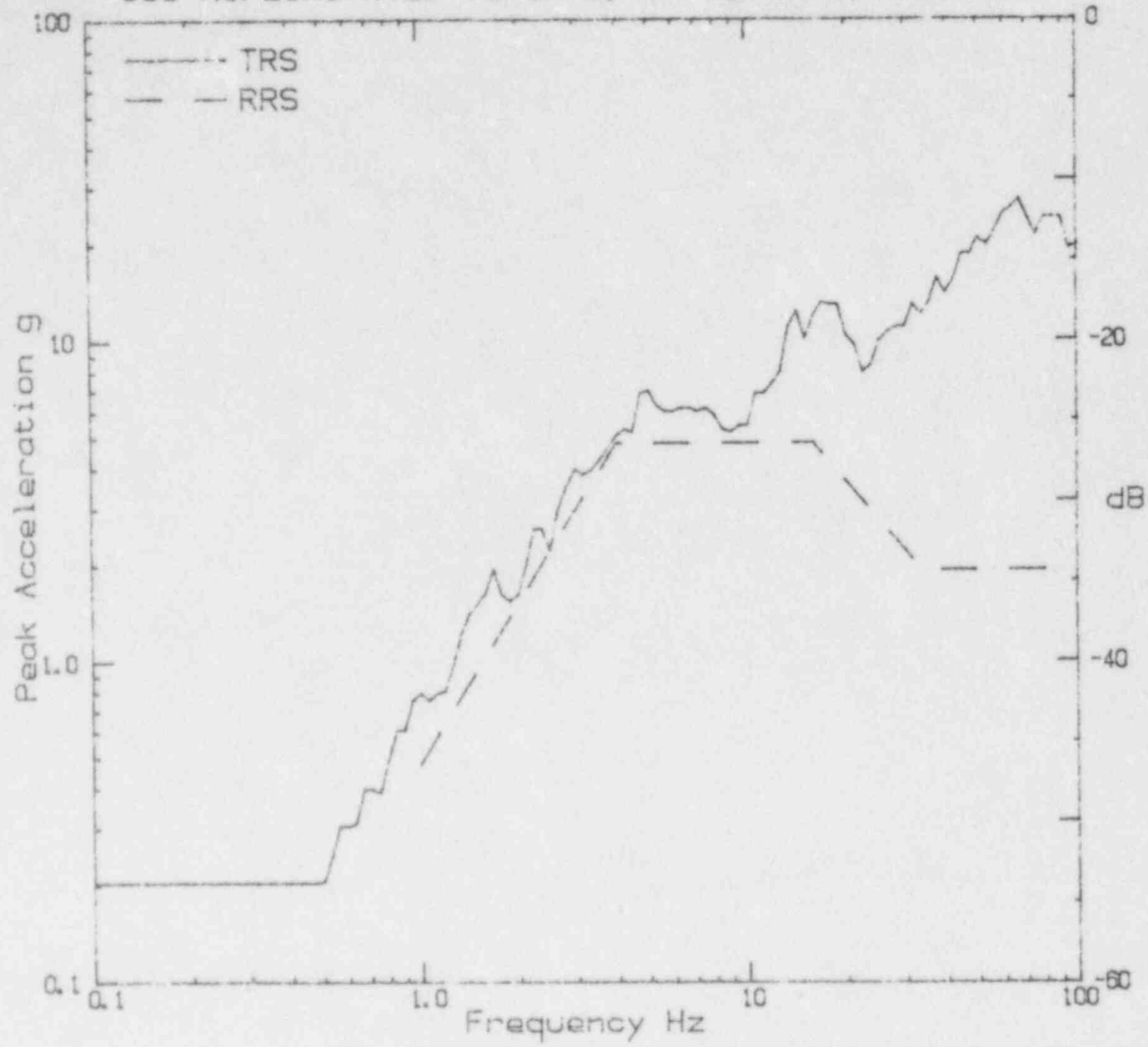
PARTICULARS
Jan 19/84, Time 10:00, Temp('C) 23, Humidity(%) 24, Press (kPa) 100.3, Graph 4989

SPECIFICATIONS
Specs IEEE 501, Conditions not operating; crack propagation, clamps tight

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z, Shaker tri-axial, ZPA=1.48g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting jig, TT 604, Channel 3

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 28

TEST ITEM
station cell, Gould, Model NCX 2250, sample 15

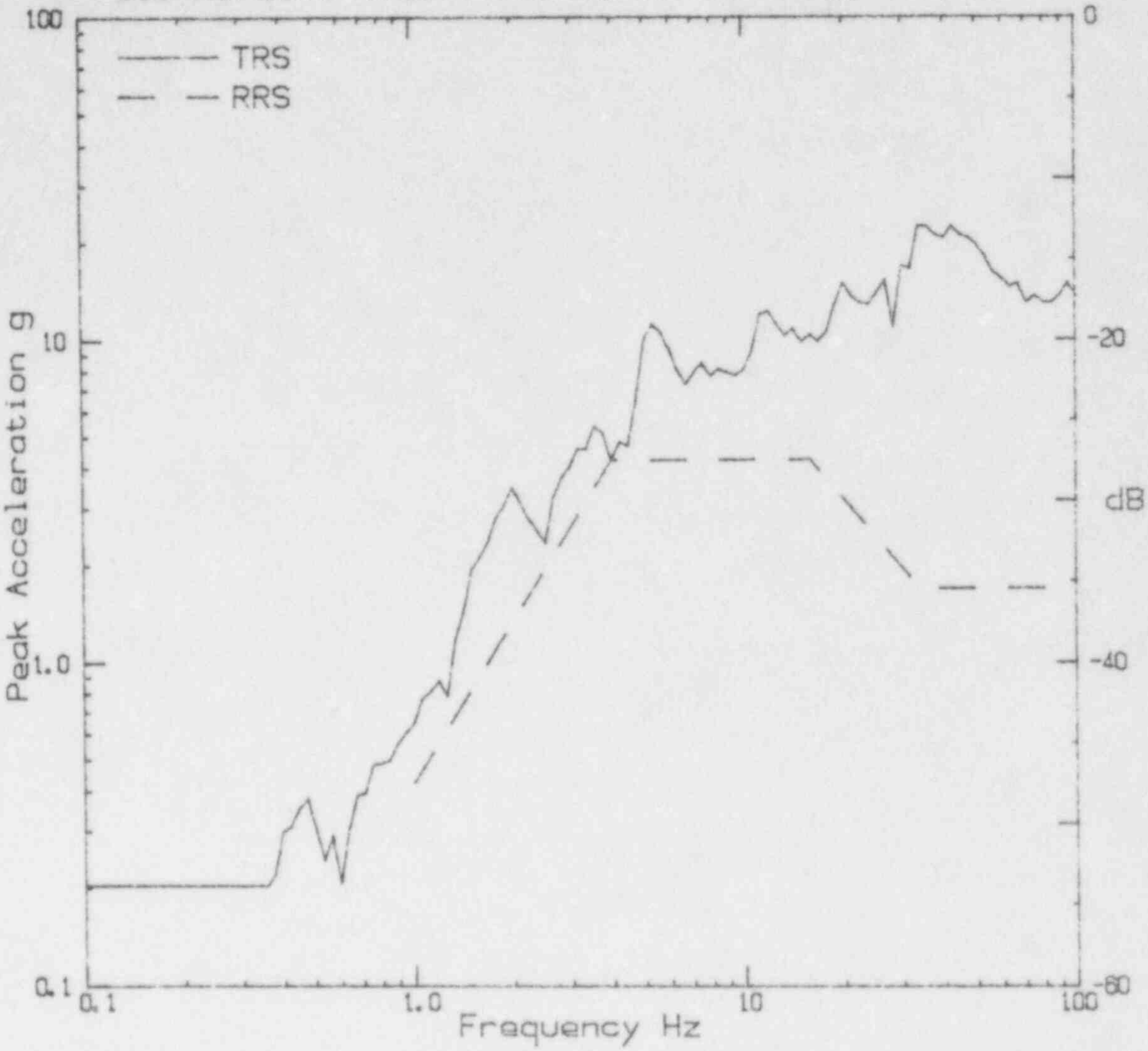
PARTICULARS
Jan 19/84, Time 10:00, Temp('C) 23, Humidity(%) 24, Press (kPa)100.3,
Graph 4990

SPECIFICATIONS
Specs IEEE 501, Conditions not operating; crack propagation,
clamps tight

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.93g

ACCELEROMETER
Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 604, Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 29

TEST ITEM
station cell, Gould, Model NCX 2250, sample 15

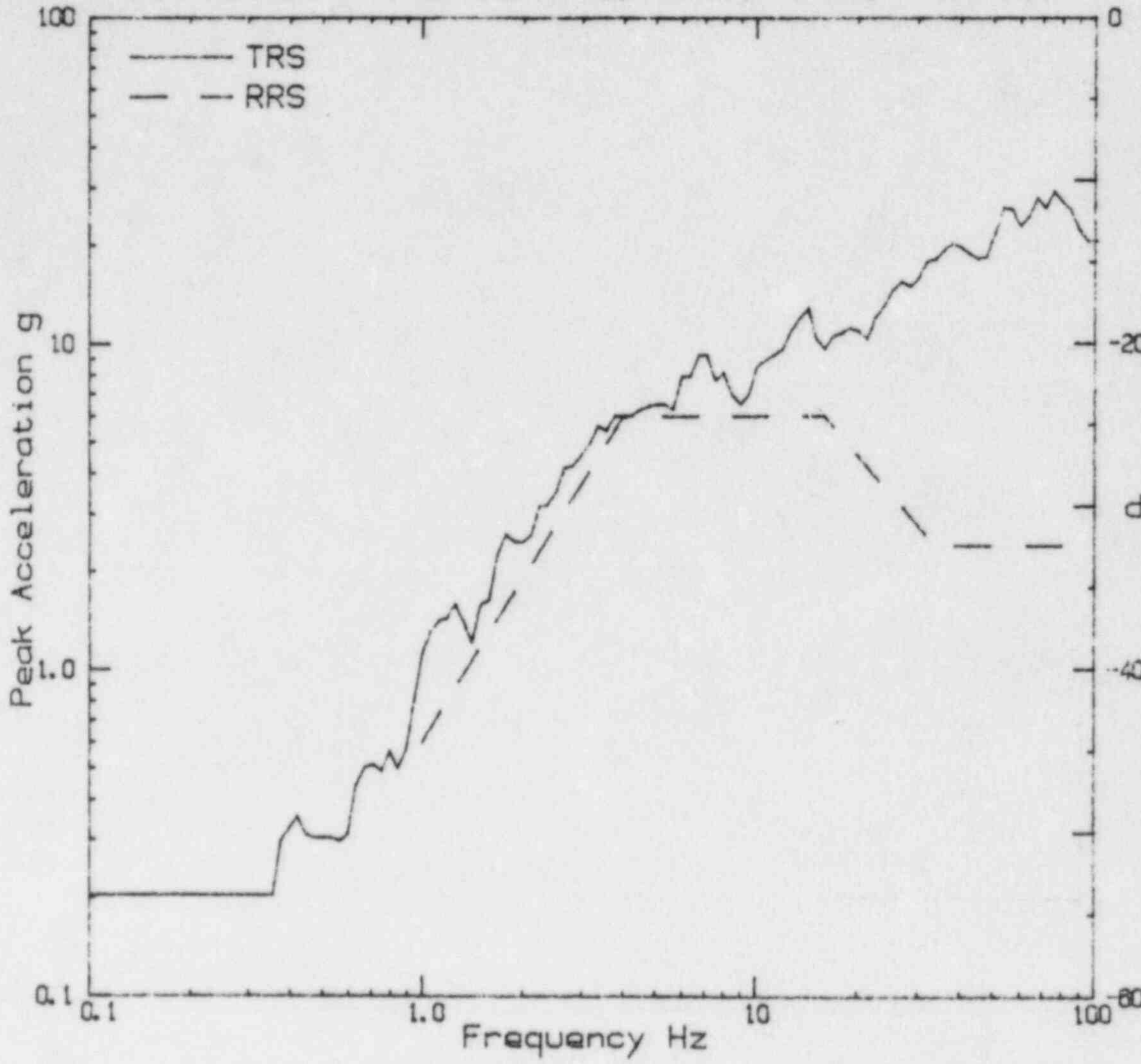
PARTICULARS
Jan 19/84, Time 10:00, Temp('C) 23, Humidity(%) 24, Press (kPa)100.3, Graph 4991

SPECIFICATIONS
Specs IEEE 501, Conditions not operating: crack propagation, clamps tight

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y, Shaker tri-axial, ZPA=1.71g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB58, Location top-cell terminal, TT 604, Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 30

TEST ITEM
station cell, Gould, Model NCX 2250, sample 15

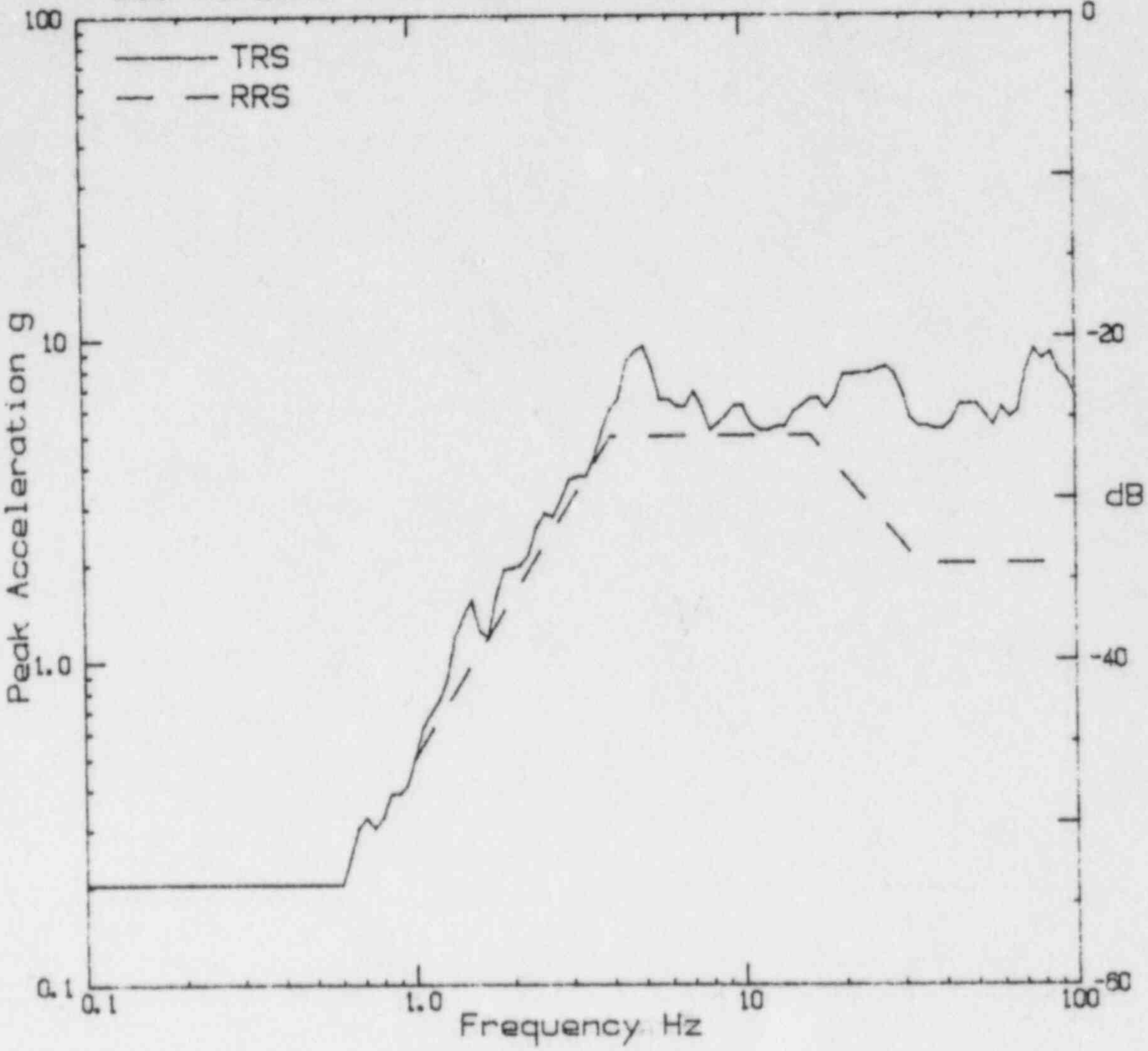
PARTICULARS
Jan 19/84, Time 10:00, Temp('C) 23, Humidity(%) 24, Press (kPa) 100.3,
Graph 4992

SPECIFICATIONS
Specs IEEE 501, Conditions not operating: crack propagation,
clamps tight

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=2.41g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 604, Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 31

TEST ITEM
station cell. Gould. Model NCX 2250. sample 25

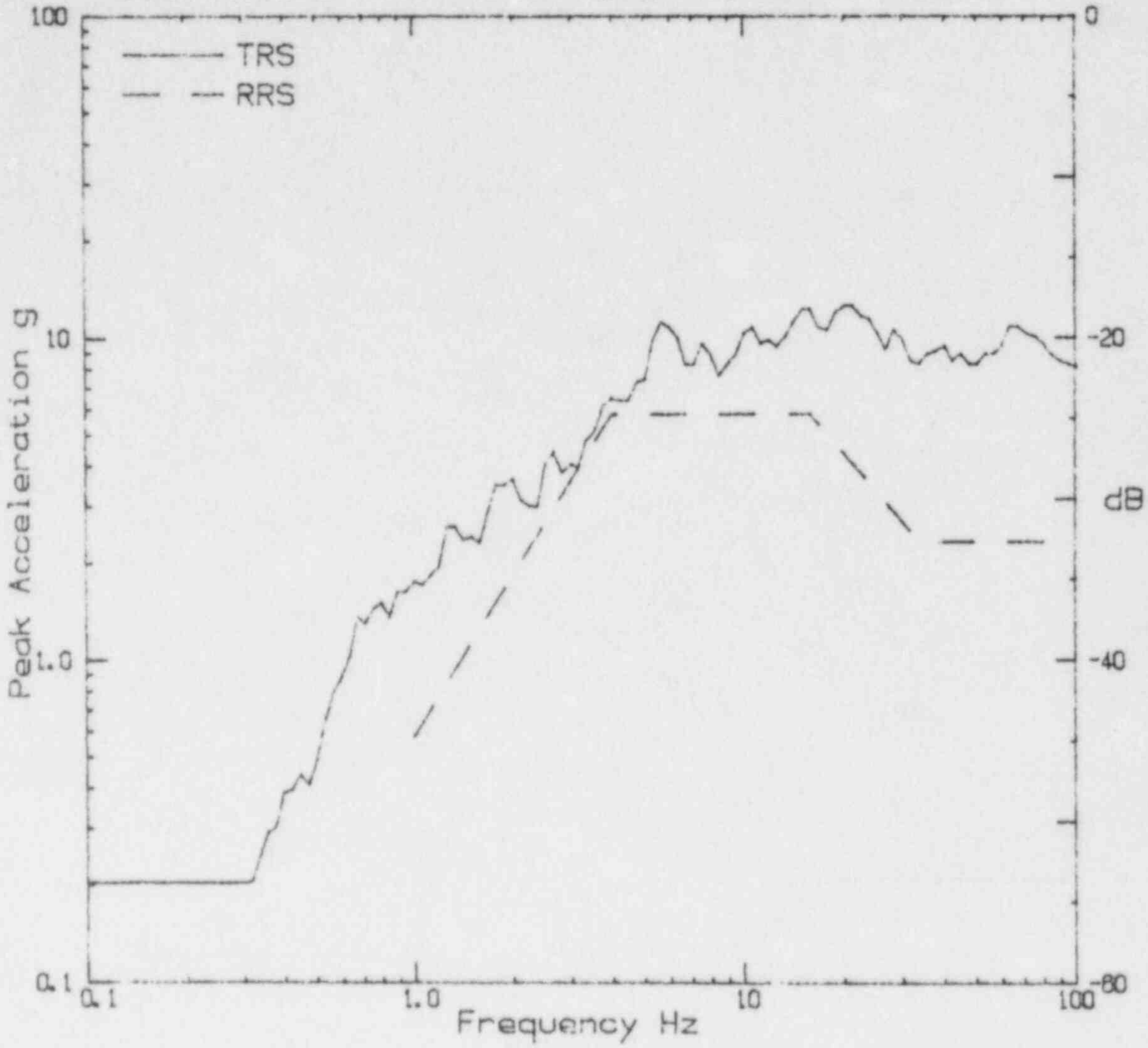
PARTICULARS
Jan 19/84. Time 2:30. Temp('C) 23. Humidity(%) 24. Press (kPa)100.3.
Graph 4993

SPECIFICATIONS
Specs IEEE 501. Conditions not operating: crack propagation.
clamps loosened

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=2g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 618. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 32

TEST ITEM
station cell. Gould. Model NCX 2250. sample 25

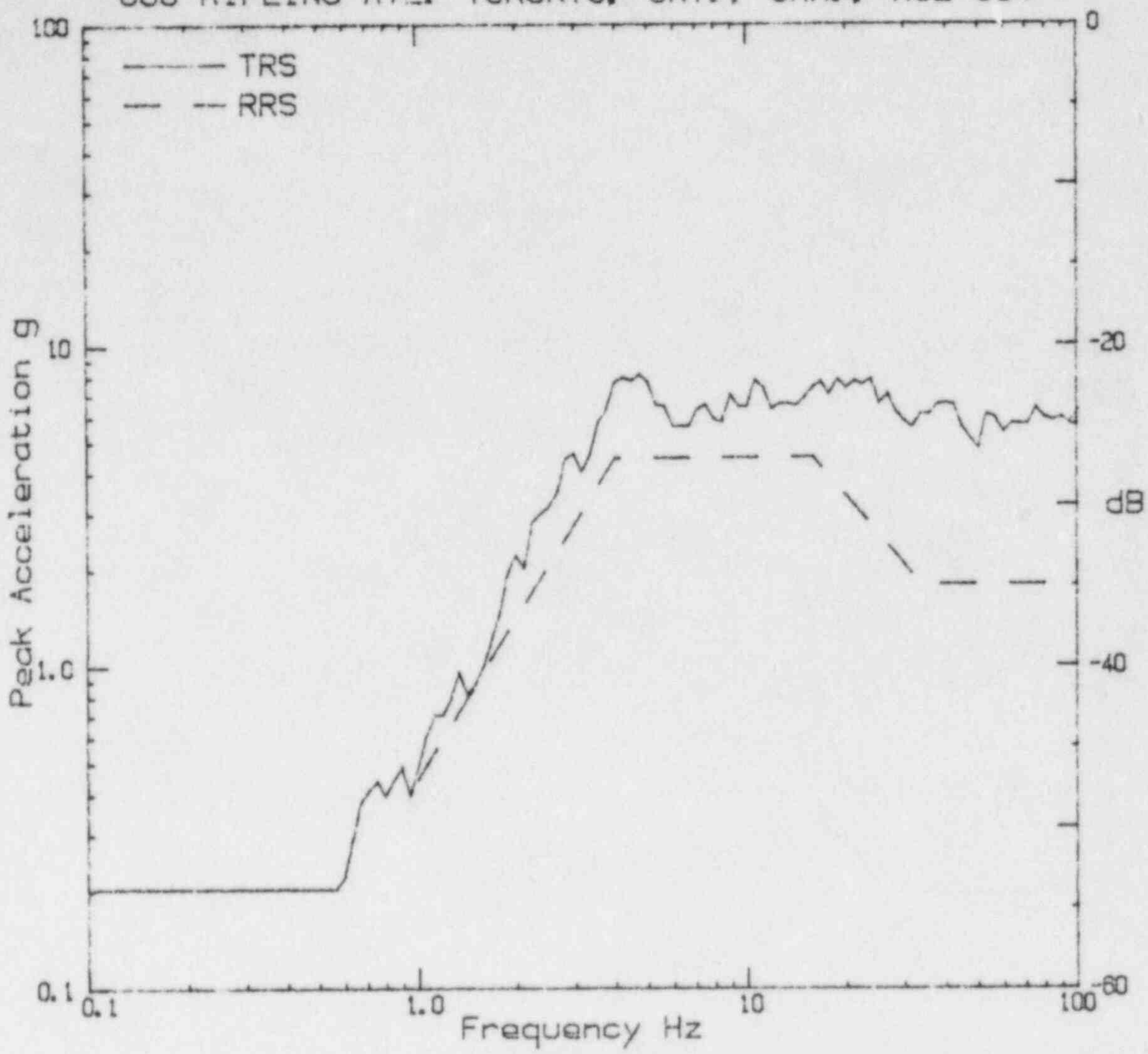
PARTICULARS
Jan 19/84. Time 2:30. Temp('C) 23. Humidity(%) 24. Press (kPa)100.3. Graph 4994

SPECIFICATIONS
Specs IEEE 501. Conditions not operating: crack propagation. clamps loosened

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y. Shaker tri-axial. ZPA=2.34g

ACCELEROMETER
Wilcoxon. Serial 5771. Range dB58. Location base-mounting jig. TT 816. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 33

TEST ITEM
station cell. Gould. Model NCX 2250. sample 25

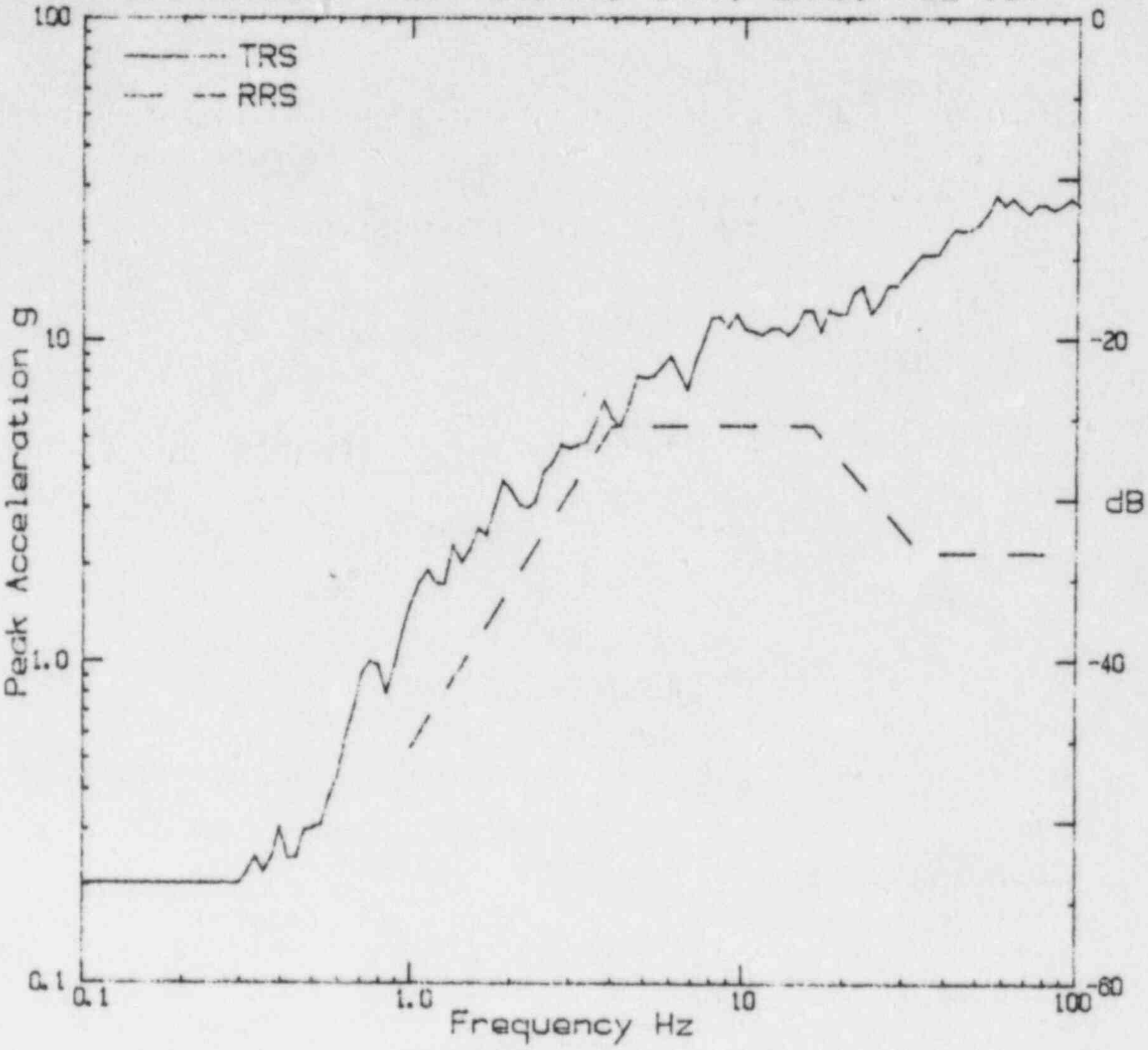
PARTICULARS
Jan 19/84. Time 2:30. Temp('C) 23. Humidity(%) 24. Press (kPa) 100.3.
Graph 4995

SPECIFICATIONS
Specs IEEE 501. Conditions not operating: crack propagation.
clamps loosened

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.8g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 616. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 34

TEST ITEM
station cell, Gould, Model NCX 2250, sample 25

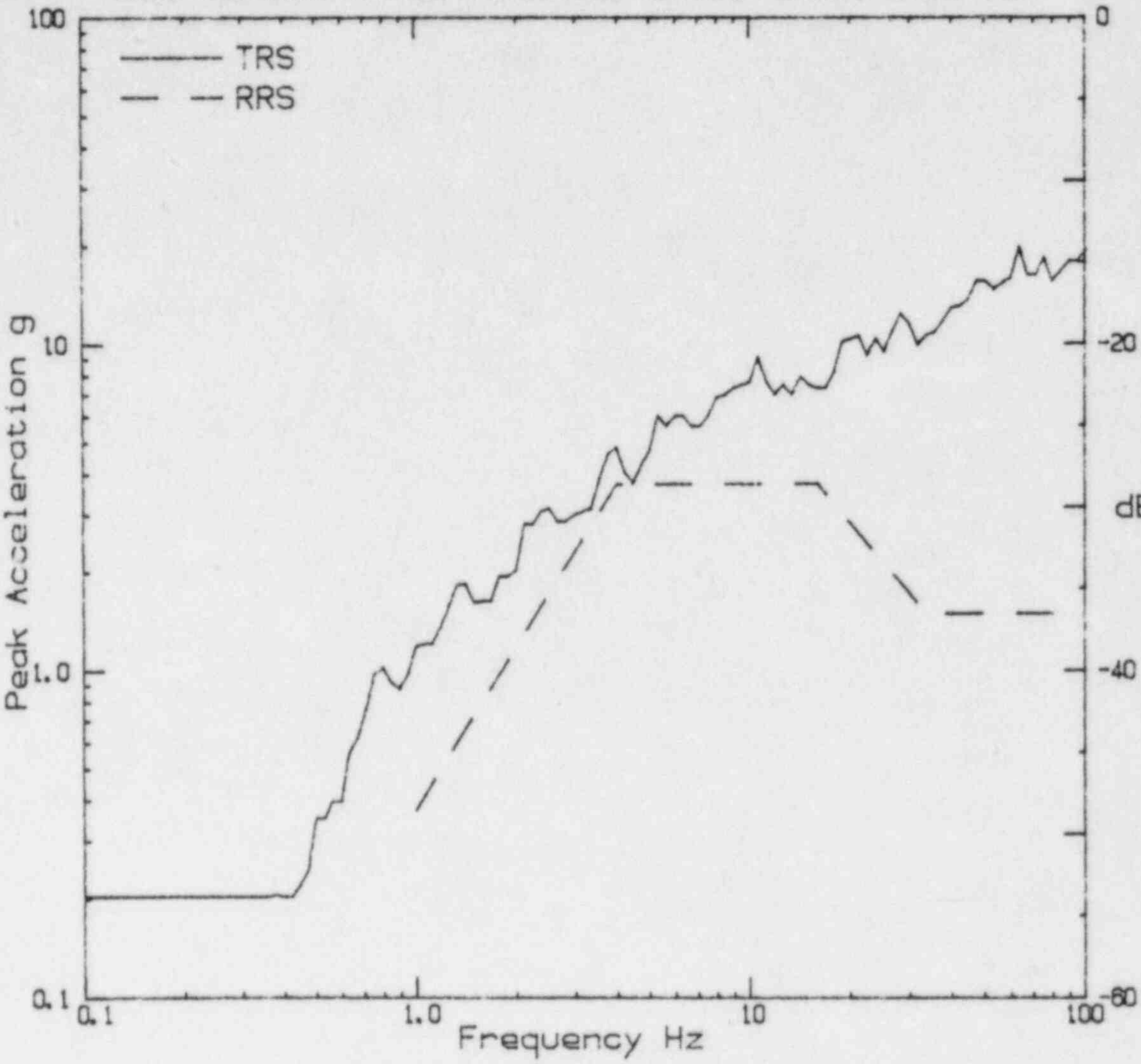
PARTICULARS
Jan 19/84, Time 2:30, Temp('C) 23, Humidity(%) 24, Press (kPa) 100.3, Graph 4996

SPECIFICATIONS
Specs IEEE 501, Conditions not operating: crack propagation, clamps loosened

ANALYSIS
Type Maximax, Damping (%)5, B.W. = 1/12 Octaves, Axis X, Shaker tri-axial, ZPA=2.17g

ACCELEROMETER
Wilcoxon, Serial S754, Range d858, Location top-cell terminal, TT 616, Channel 4

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 35

TEST ITEM
station cell, Gould, Model NCX 2250, sample 25

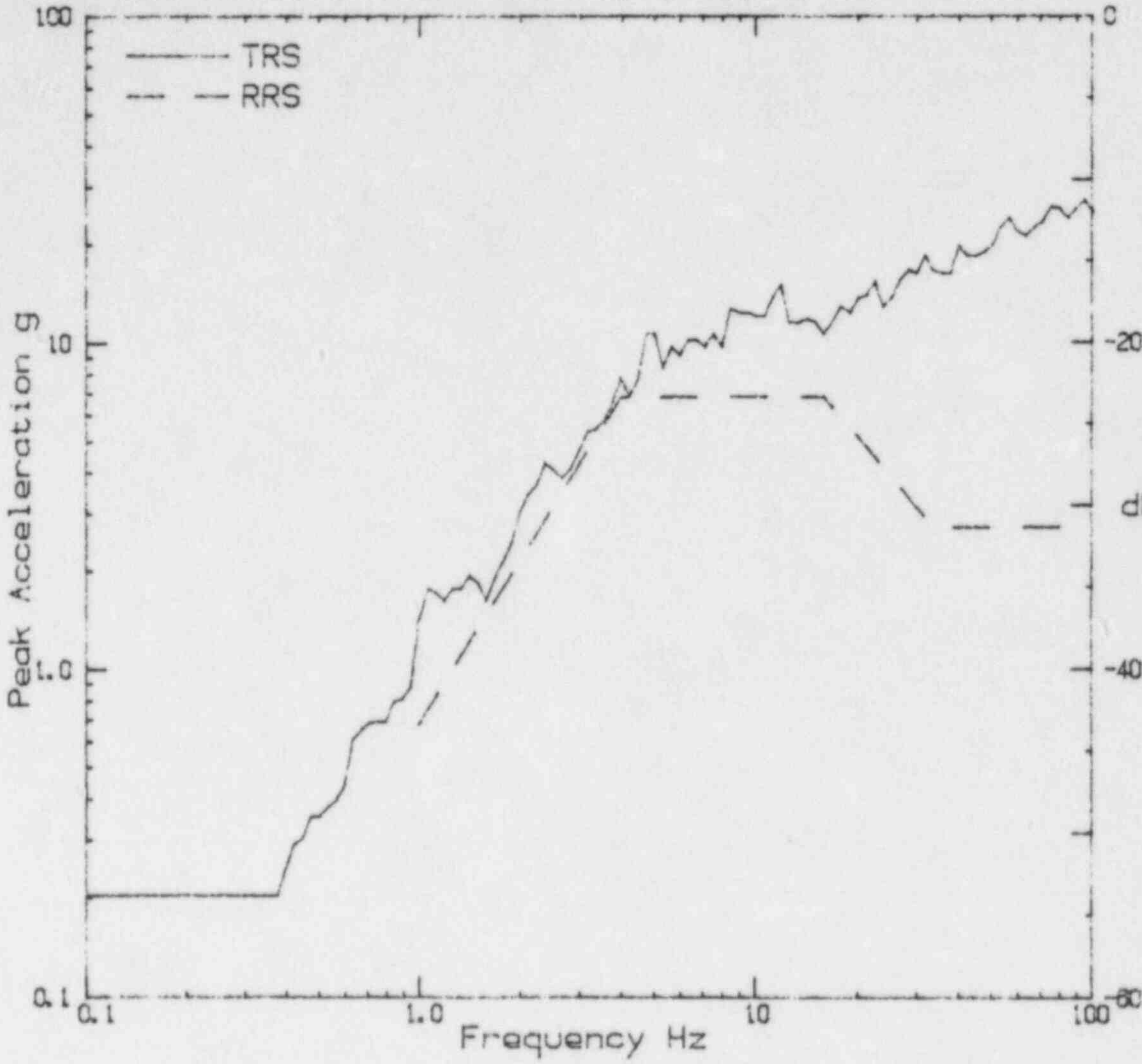
PARTICULARS
Jan 19/84, Time 2:30, Temp('C) 23, Humidity(%) 24, Press (kPa) 100.3,
Graph 4997

SPECIFICATIONS
Specs IEEE 501, Conditions not operating: crack propagation,
clamps loosened

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.5g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB58, Location top-cell terminal,
TT 616, Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 36

TEST ITEM
station cell, Gould, Model NCX 2250, sample 25

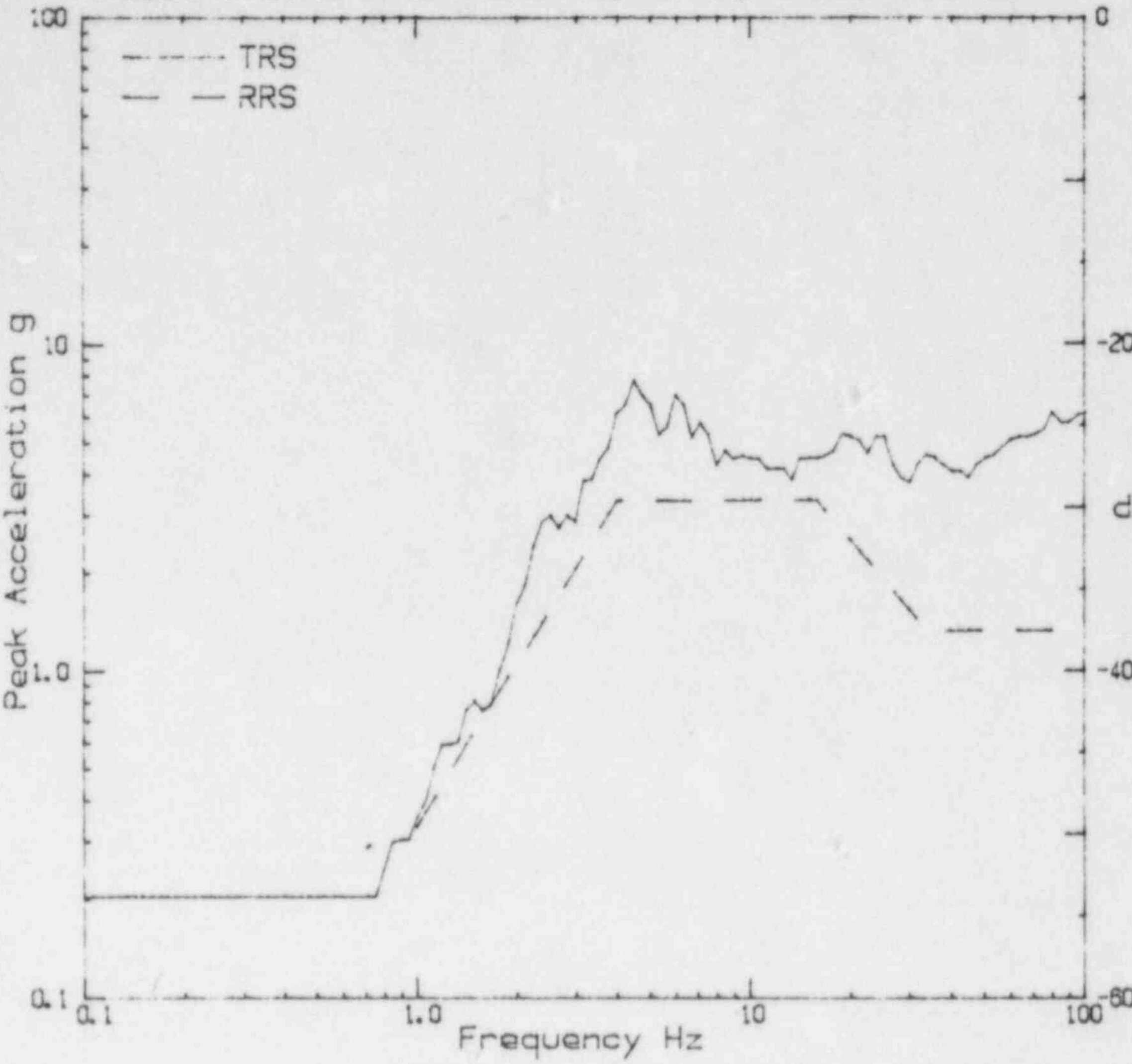
PARTICULARS
Jan 19/84, Time 2:30, Temp('C) 23, Humidity(%) 24, Press (kPa)100.3,
Graph 4998

SPECIFICATIONS
Specs IEEE 501, Conditions not operating; crack propagation,
clamps loosened

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=2.74g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 616, Channel 6

ONTARIO HYDRO
W. F. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 37

TEST ITEM
station cells. Gould. Model NCX 2250. sample #43

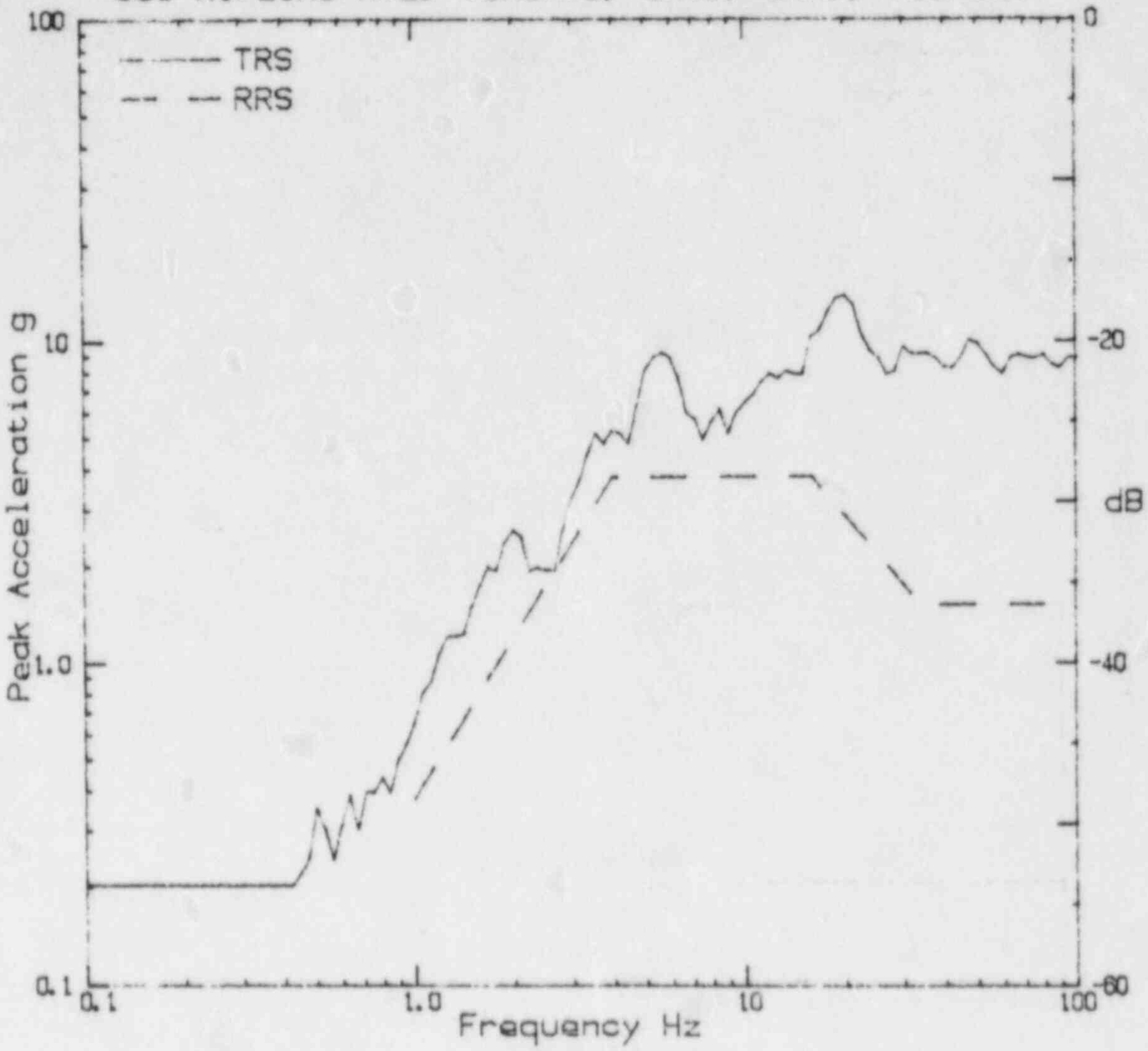
PARTICULARS
Jan 20/84. Time 9:15. Temp('C) 23. Humidity(%) 25. Press (kPa) 101.2.
Graph 4999

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.34g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 628. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 38

TEST ITEM
station cells, Gould, Model NCX 2250, sample #43

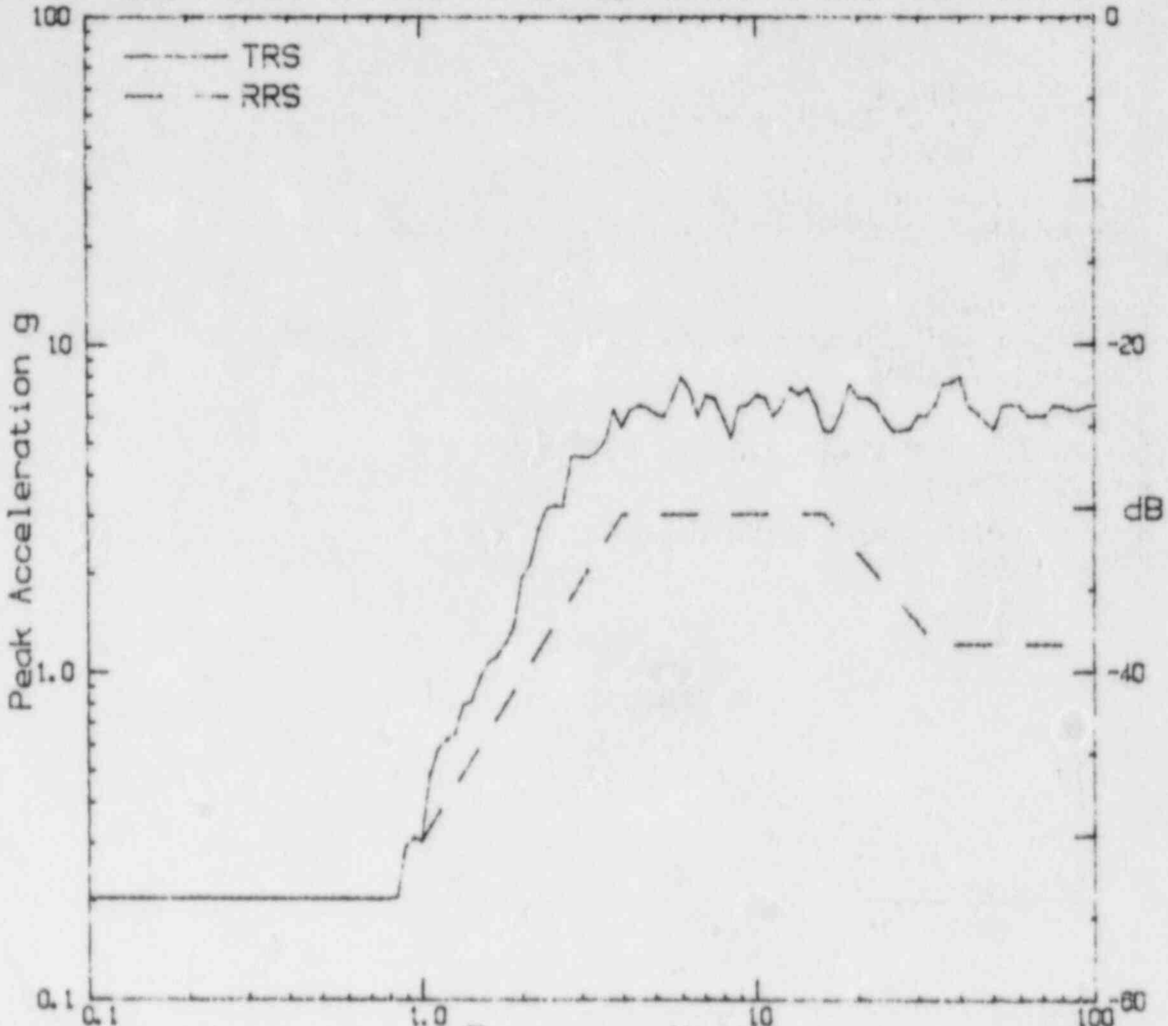
PARTICULARS
Jan 20/84, Time 9:15, Temp(°C) 23, Humidity(%) 25, Press (kPa)101.2,
Graph 5000

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate,
span 6: fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.53g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB58, Location base-mounting jig,
TT 628, Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 39

TEST ITEM
station cells, Gould, Model NCX 2250, sample #43

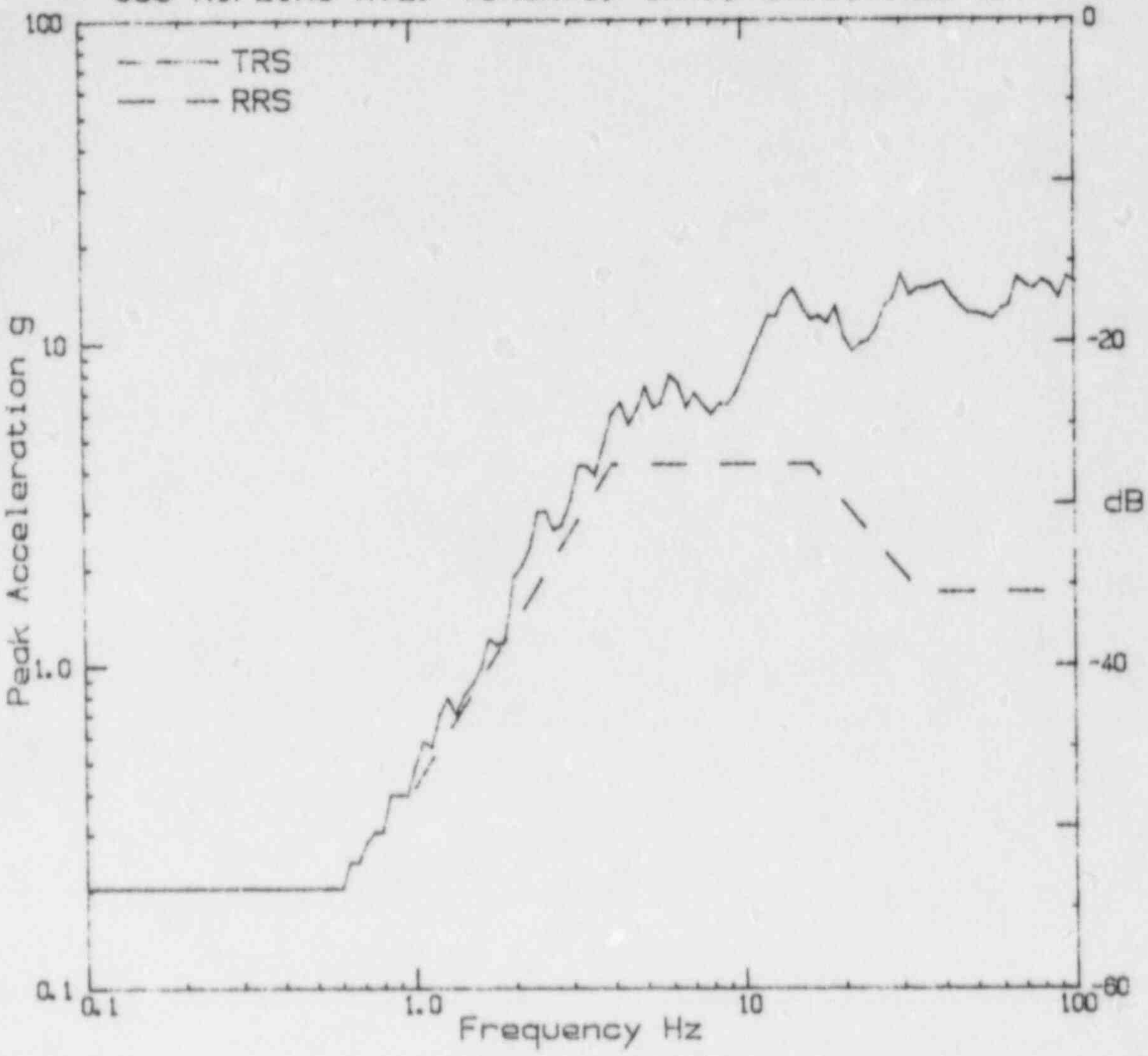
PARTICULARS
Jan 20/84, Time 9:15, Temp('C) 23, Humidity(%) 25, Press (kPa)101.2,
Graph 5001

SPECIFICATIONS
Specs IEEE 501, Conditions operating; 8-hour rate,
span 6: fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.22g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 628, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 40

TEST ITEM
station cells. Gould. Model NCX 2250. sample #43

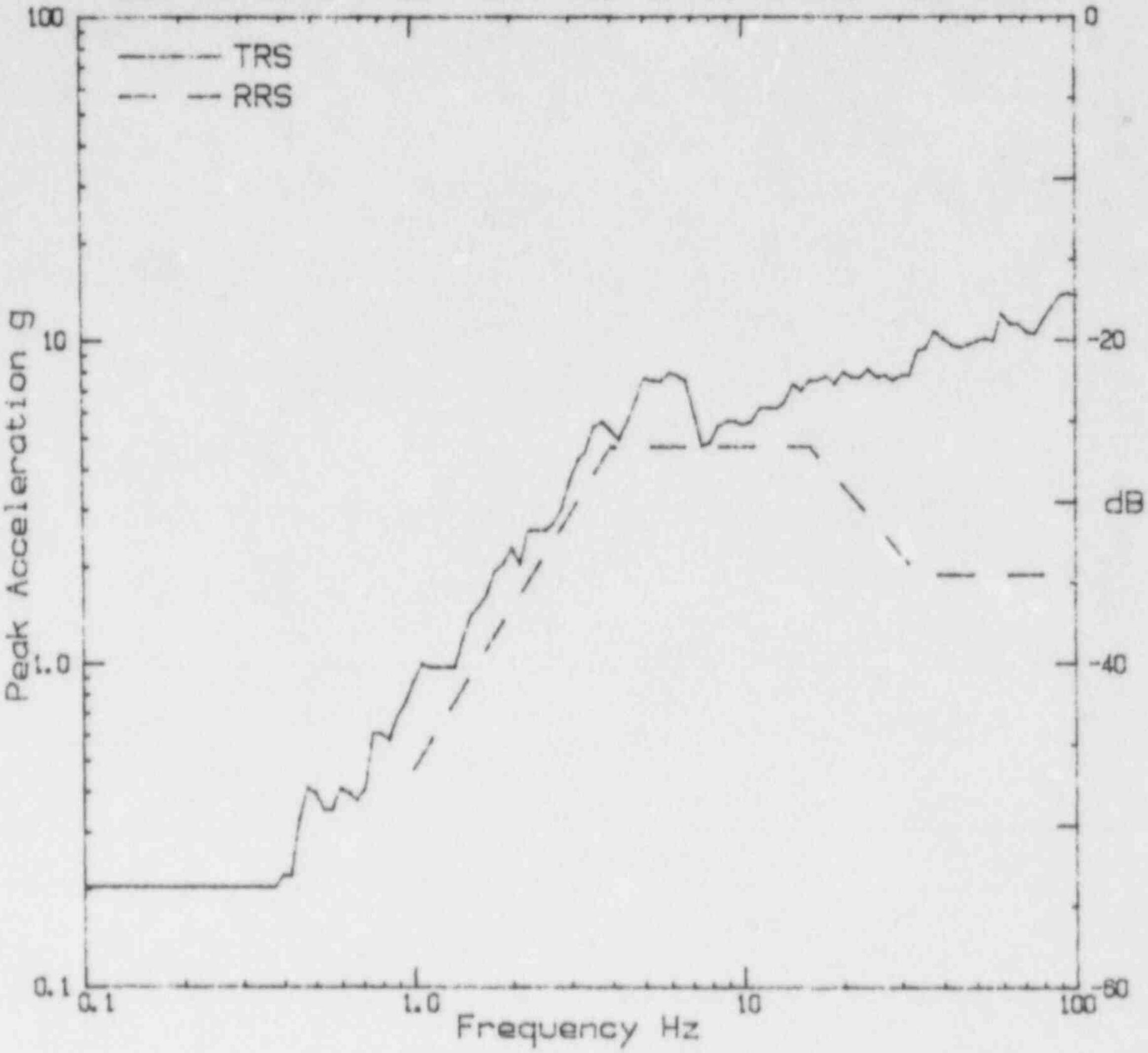
PARTICULARS
Jan 20/84. Time 9:15. Temp('C) 23. Humidity(%) 25. Press (kPa)101.2.
Graph 5002

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.69g

ACCELEROMETER
Wilcoxon. Serial S754. Range dB58. Location top-cell terminal.
TT 628. Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 41

TEST ITEM
station cells. Gould. Model NCX 2250. sample #43

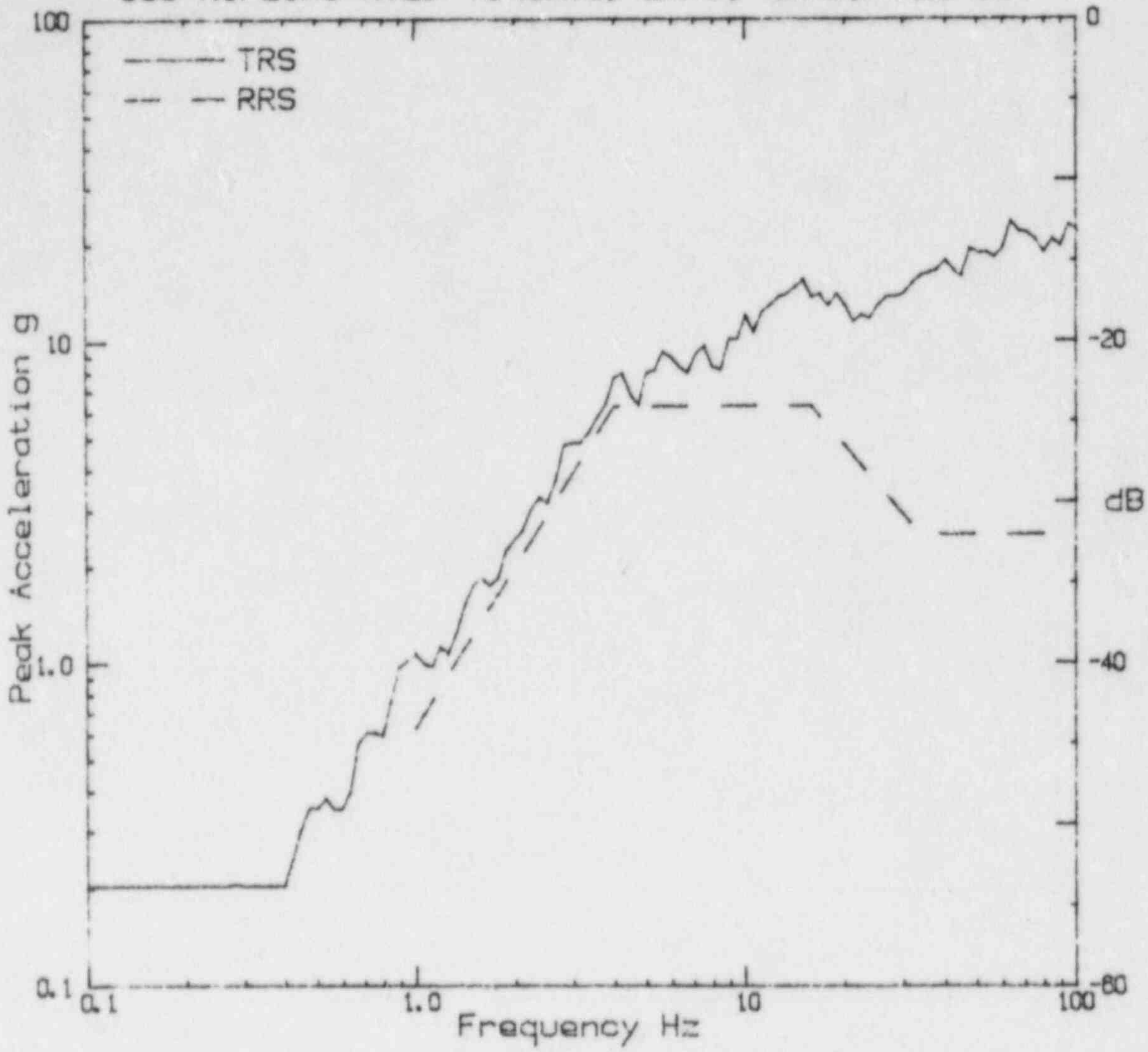
PARTICULARS
Jan 20/84. Time 9:15. Temp('C) 23. Humidity(%) 25. Press (kPa)101.2.
Graph 5003

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.89g

ACCELEROMETER
Wilcoxon. Serial S771. Range d858. Location top-cell terminal.
TT 828. Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 42

TEST ITEM
station cells, Gould, Model NCX 2250, sample #43

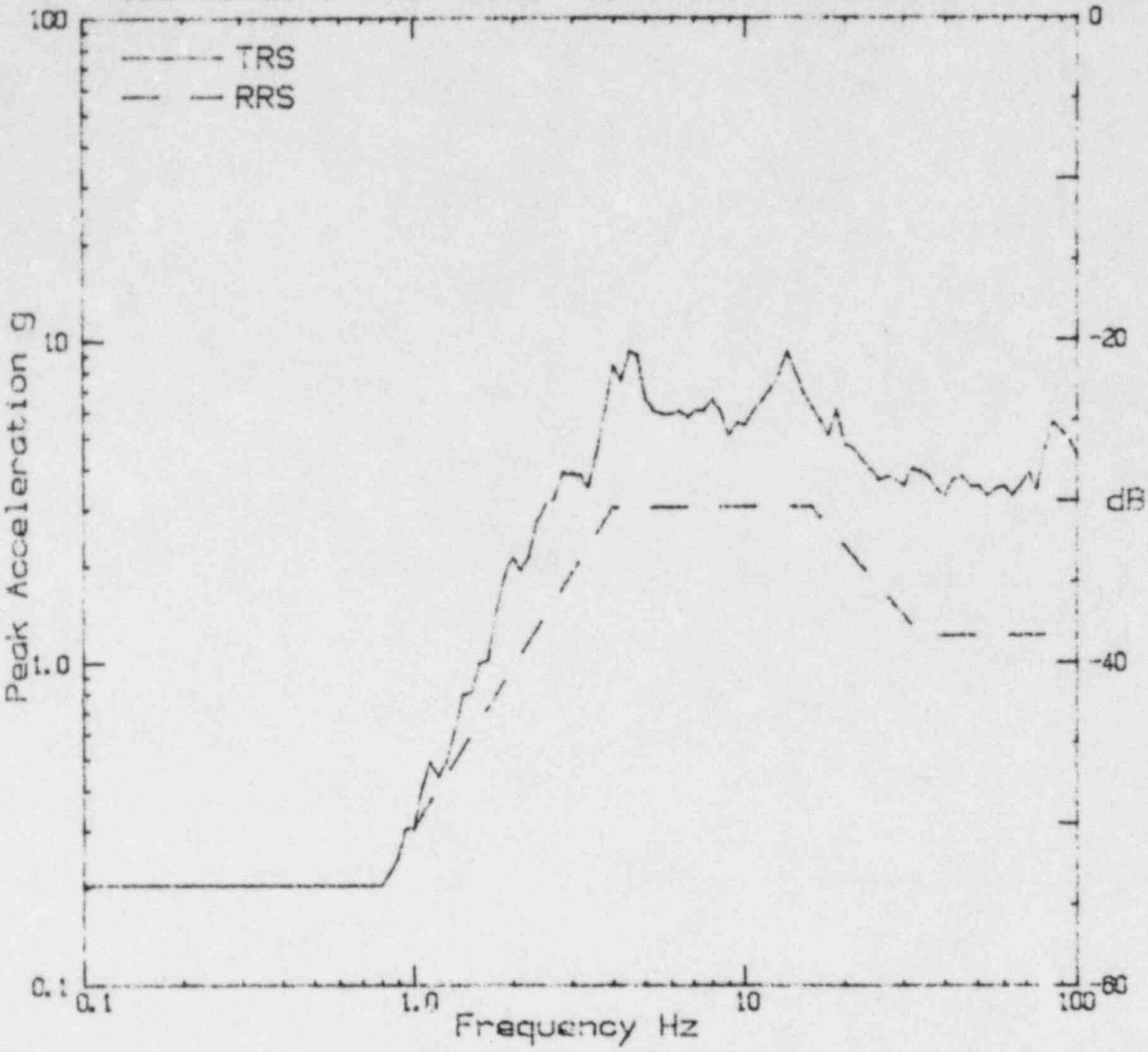
PARTICULARS
Jan 20/84, Time 9:15, Temp('C) 23, Humidity(%) 25, Press (kPa)101.2,
Graph 5004

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate,
span 6: fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=2.52g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 828, Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 43

TEST ITEM
station cells. Gould. Model NCX 2250. sample #12

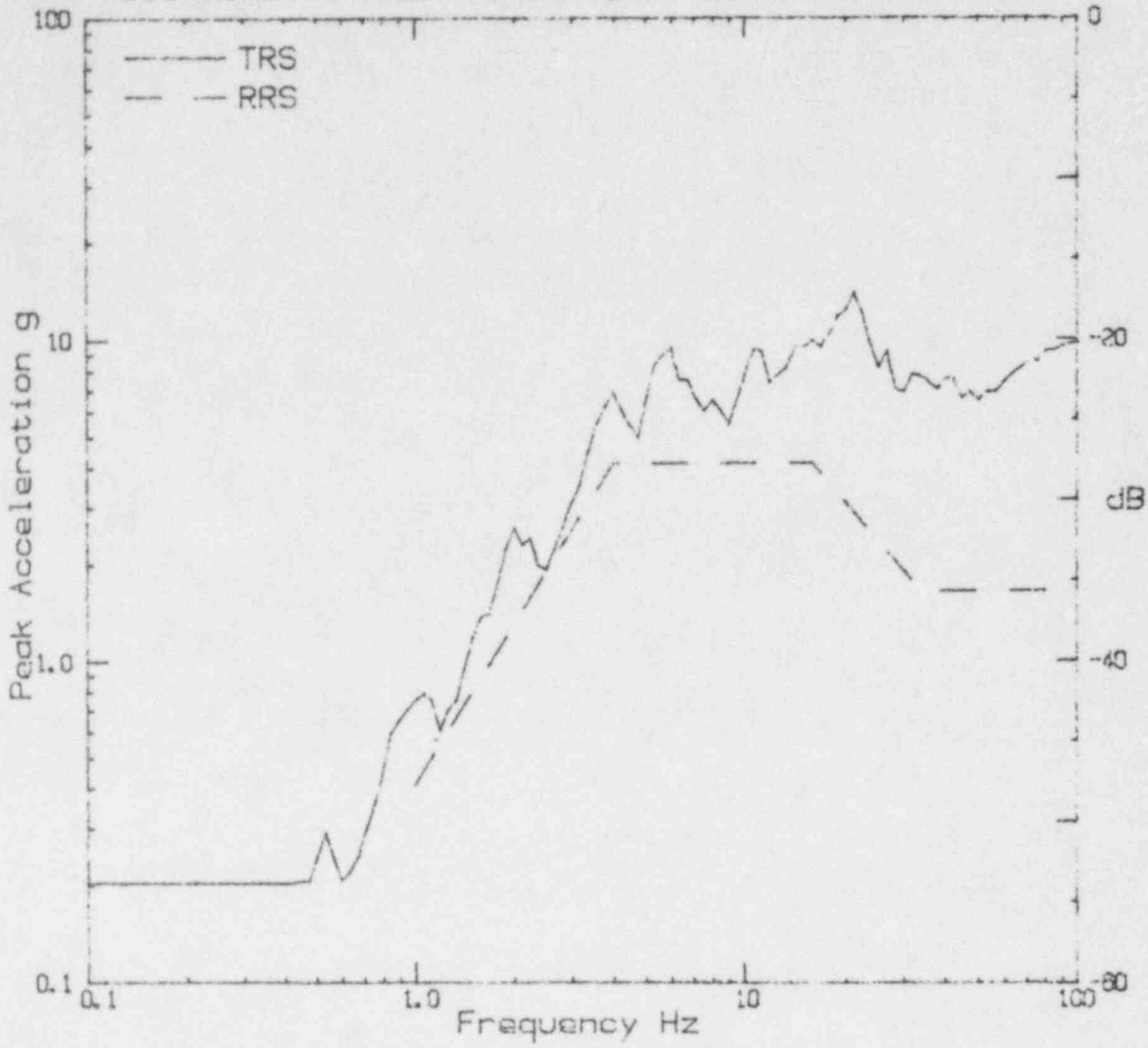
PARTICULARS
Jan 23/84. Time 11:10. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.4.
Graph 5005

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.22g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 634. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 44

TEST ITEM
station cells, Gould, Model NCX 2250, sample #12

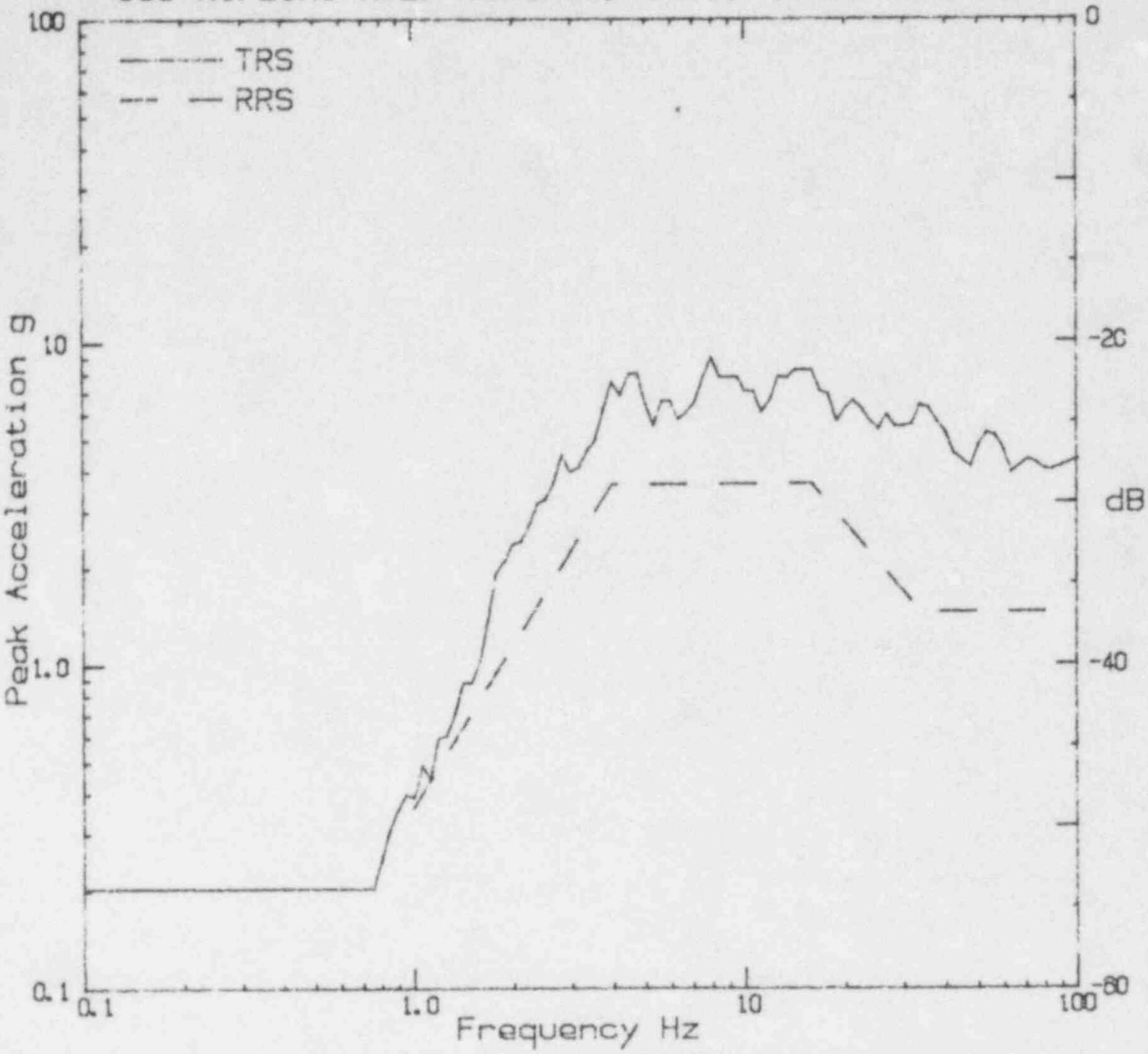
PARTICULARS
Jan 23/84, Time 11:10, Temp('C) 23, Humidity(%) 22, Press (kPa)100.4,
Graph 5006

SPECIFICATIONS
Specs IEEE 501, Conditions operating; 8-hour rate,
span 6; fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.66g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB58, Location base-mounting jig,
TT 634, Channel 2

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 45

TEST ITEM
station cells, Gould, Model NCX 2250, sample #12

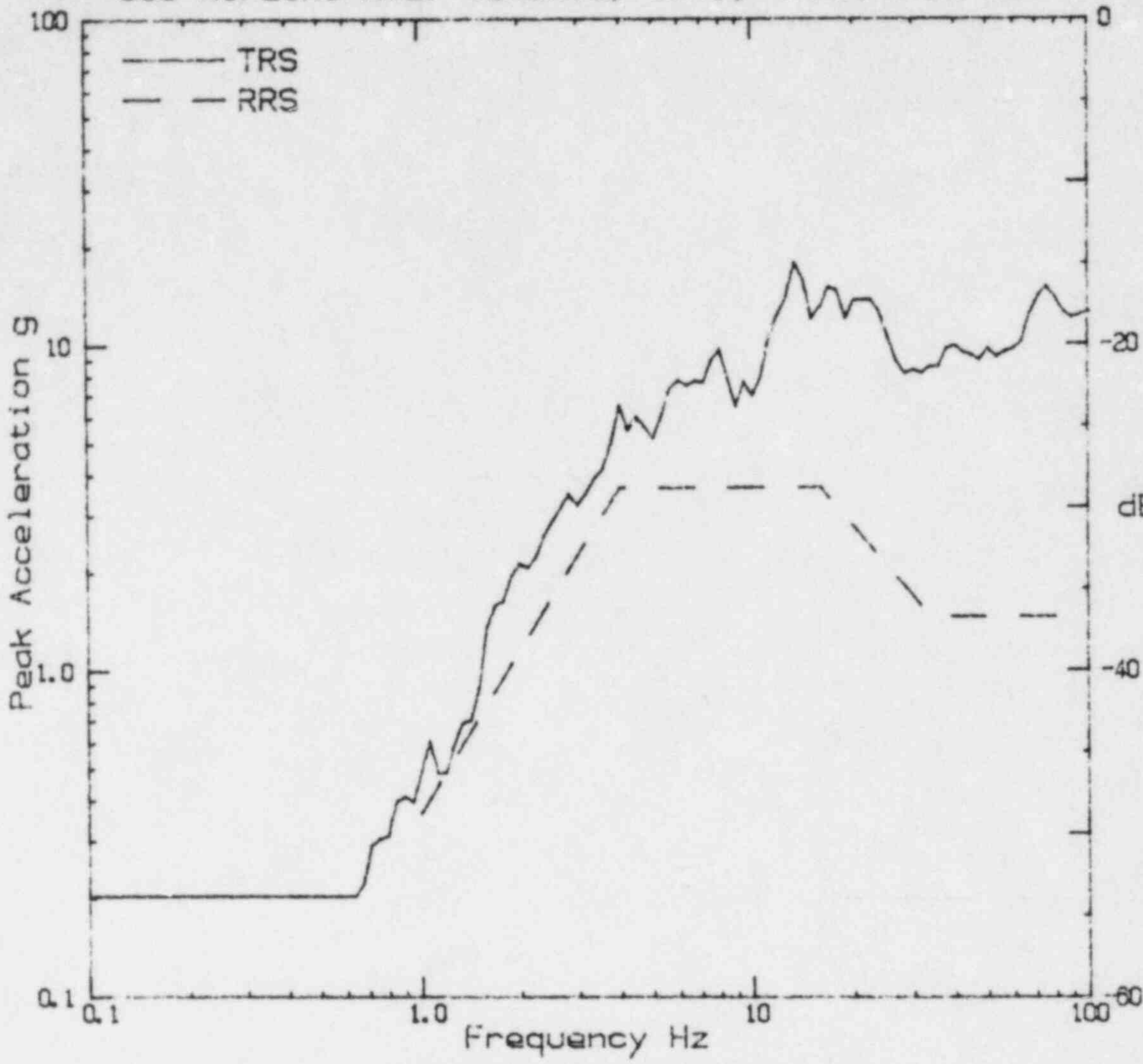
PARTICULARS
Jan 23/84, Time 11:10, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.4,
Graph 5007

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate,
span 6: fragility level

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.46g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 634, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 46

TEST ITEM
station cells, Gould, Model NCX 2250, sample #12

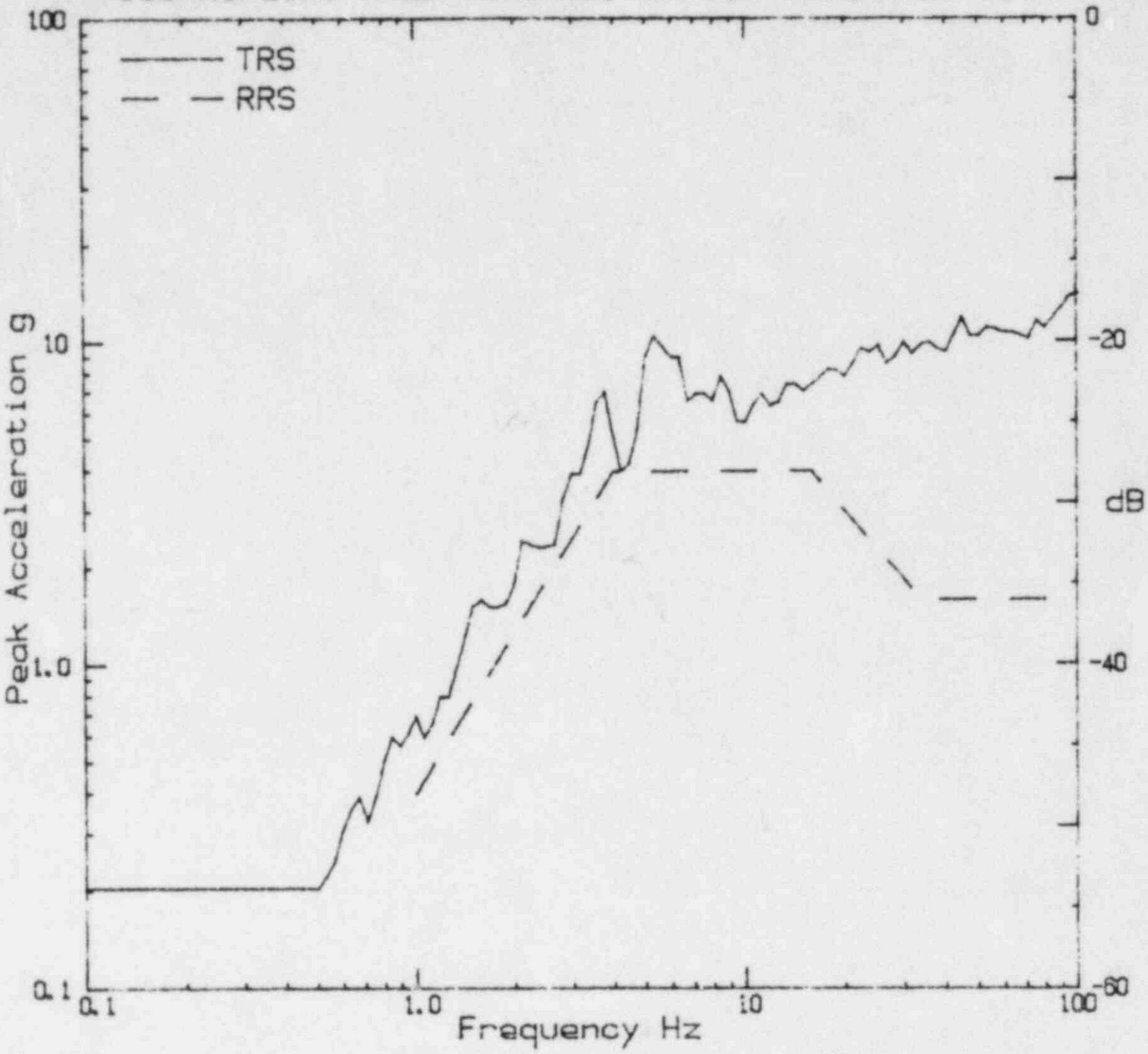
PARTICULARS
Jan 23/84, Time 11:10. Temp('C) 23, Humidity(%) 22, Press (kPa) 100.4,
Graph 5008

SPECIFICATIONS
Specs IEEE 501, Conditions operating; 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.47g

ACCELEROMETER
Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 634, Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 47

TEST ITEM
station cells. Gould. Model NCX 2250. sample #12

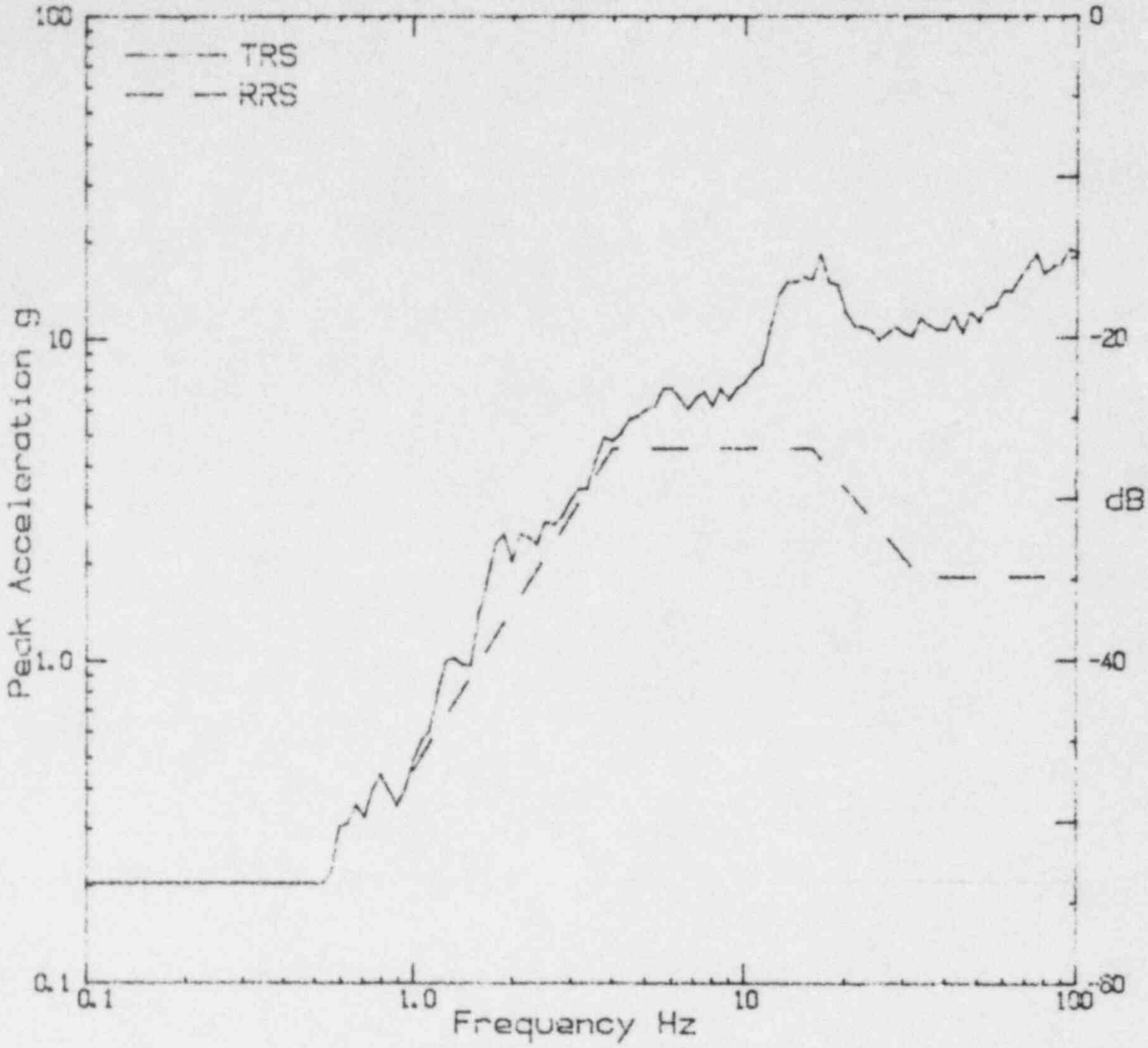
PARTICULARS
Jan 23/84. Time 11:10. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.4.
Graph 5009

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6: fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.59g

ACCELEROMETER
Wilcoxon. Serial S771. Range dB58. Location top-cell terminal.
TT 634. Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 48

TEST ITEM
station cells, Gould, Model NCX 2250, sample #12

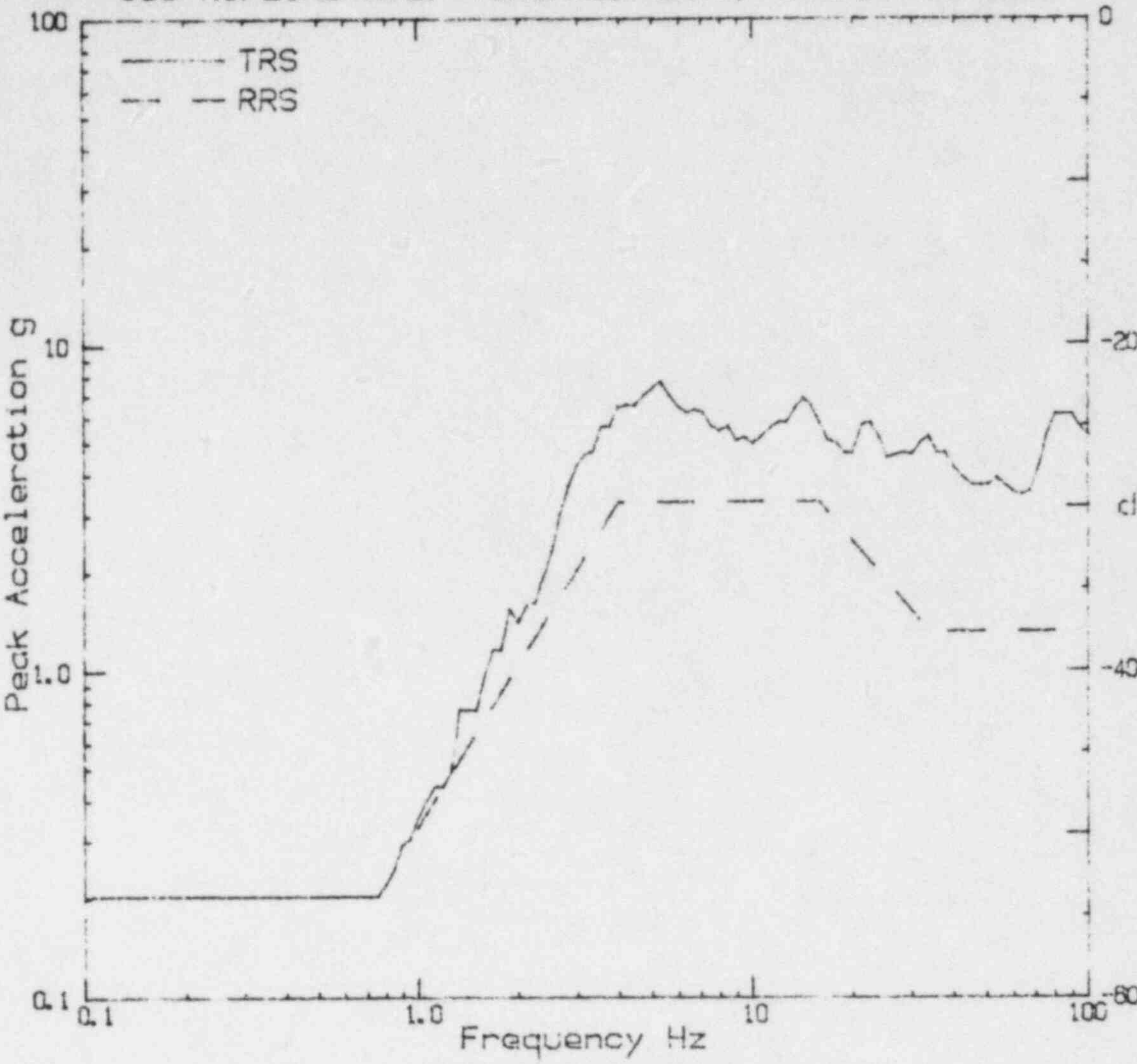
PARTICULARS
Jan 23/84, Time 11:10, Temp('C) 23, Humidity(%) 22, Press (kPa)100.4,
Graph 5010

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate,
span 6: fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.83g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB58, Location top-cell terminal,
TT 634, Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 49

TEST ITEM
station cells. Gould. Model NCX 2250. sample-#14

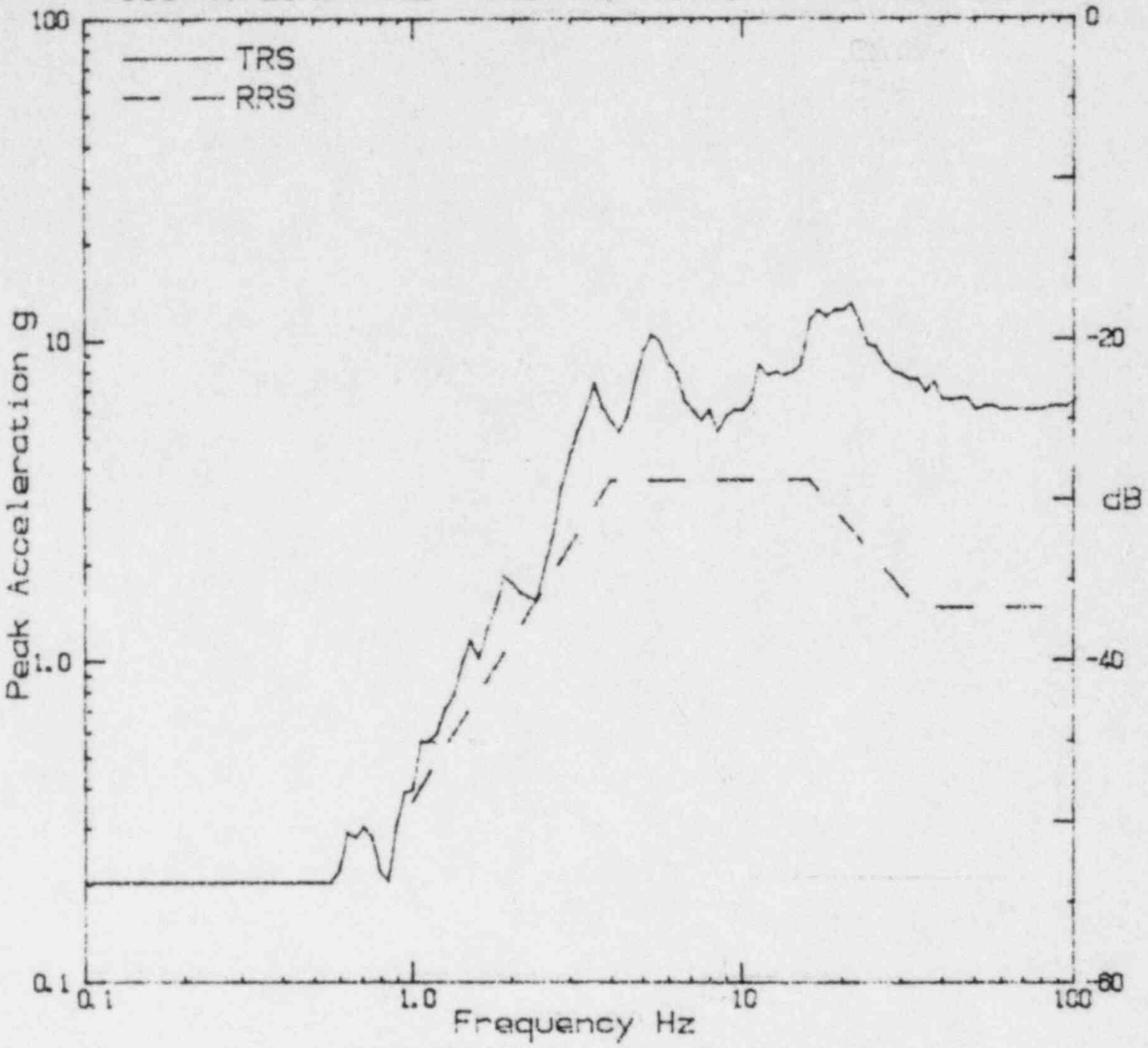
PARTICULARS
Jan 23/84. Time 2:15. Temp('C) 23. Humidity(%) 22. Press (kPa)100.4.
Graph 5011

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 6.8: shaker limit

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.32g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting jig.
TT 644. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 50

TEST ITEM
station cells, Gould, Model NCX 2250, sample-#14

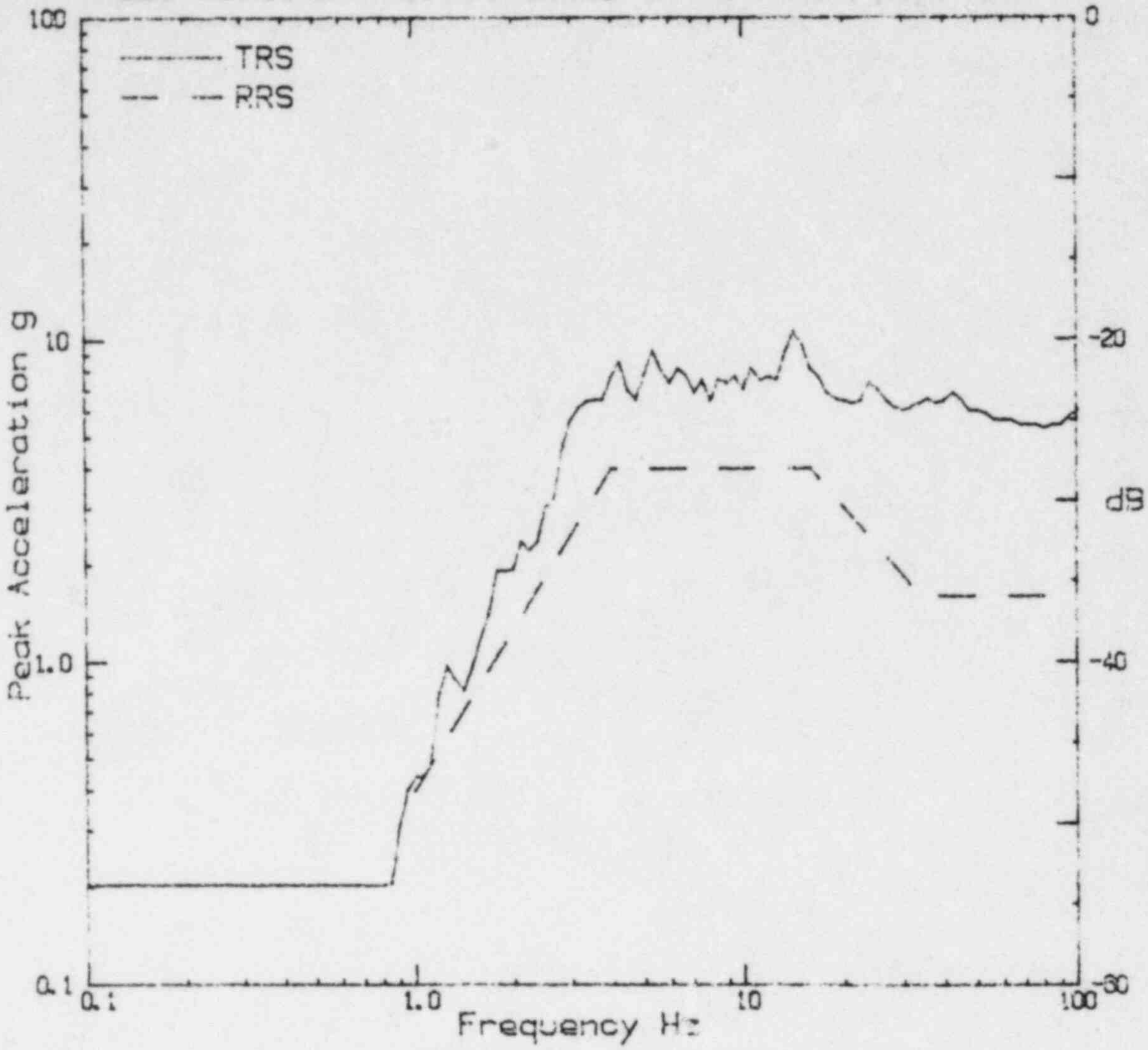
PARTICULARS
Jan 23/84, Time 2:15, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.4,
Graph 5012

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate,
span 6.8: shaker limit

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.47g

ACCELEROMETER
Wilcoxon, Serial S781, Range dB58, Location base-mounting jig.
TT 644, Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 51

TEST ITEM
station cells. Gould. Model NCX 2250. sampleH#14

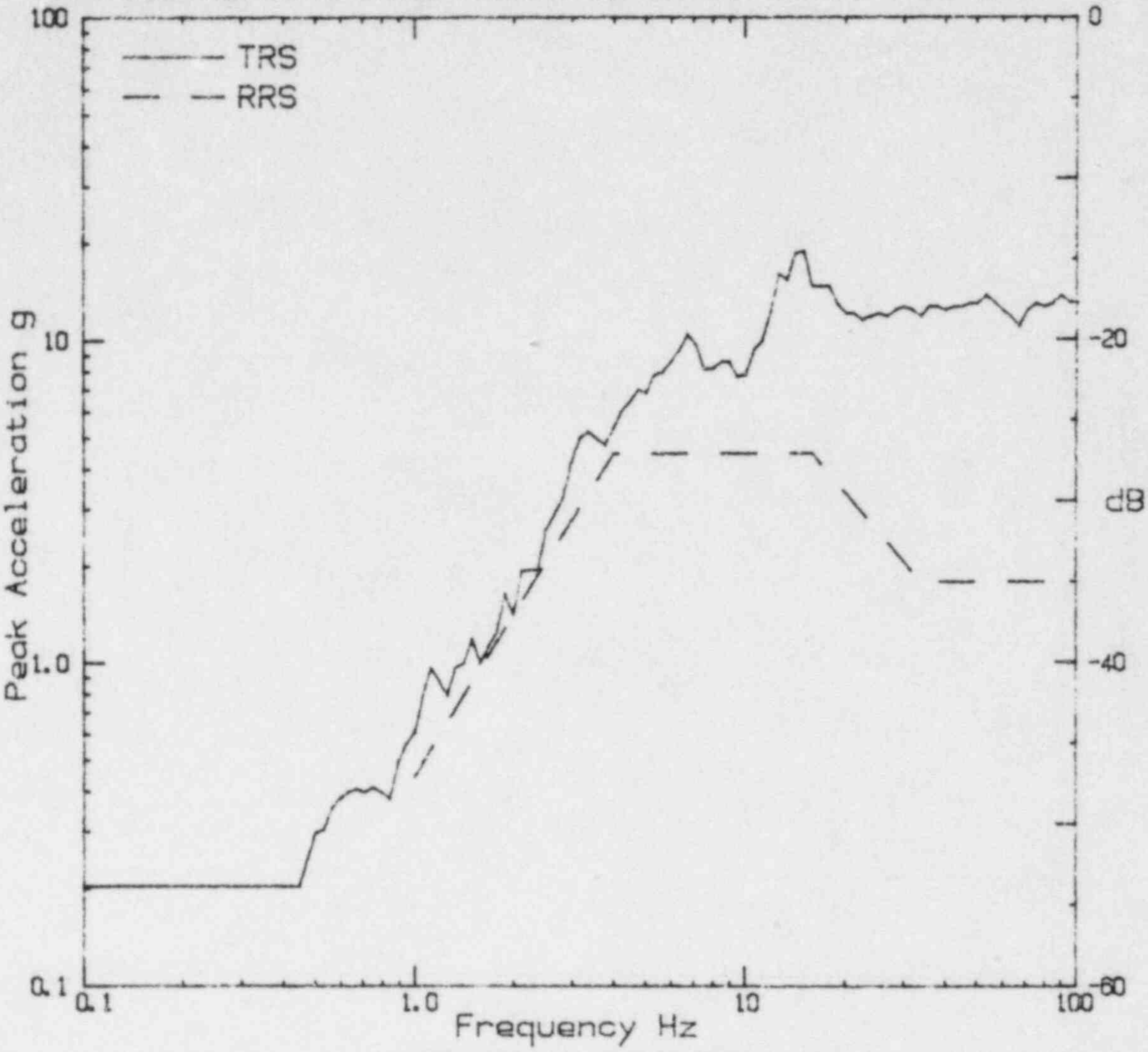
PARTICULARS
Jan 23/84. Time 2:15. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.4.
Graph 5013

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate.
span 8.8: shaker limit

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.6g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting jig.
TT 644. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 52

TEST ITEM
station cells, Gould, Model NCX 2250, sample-#14

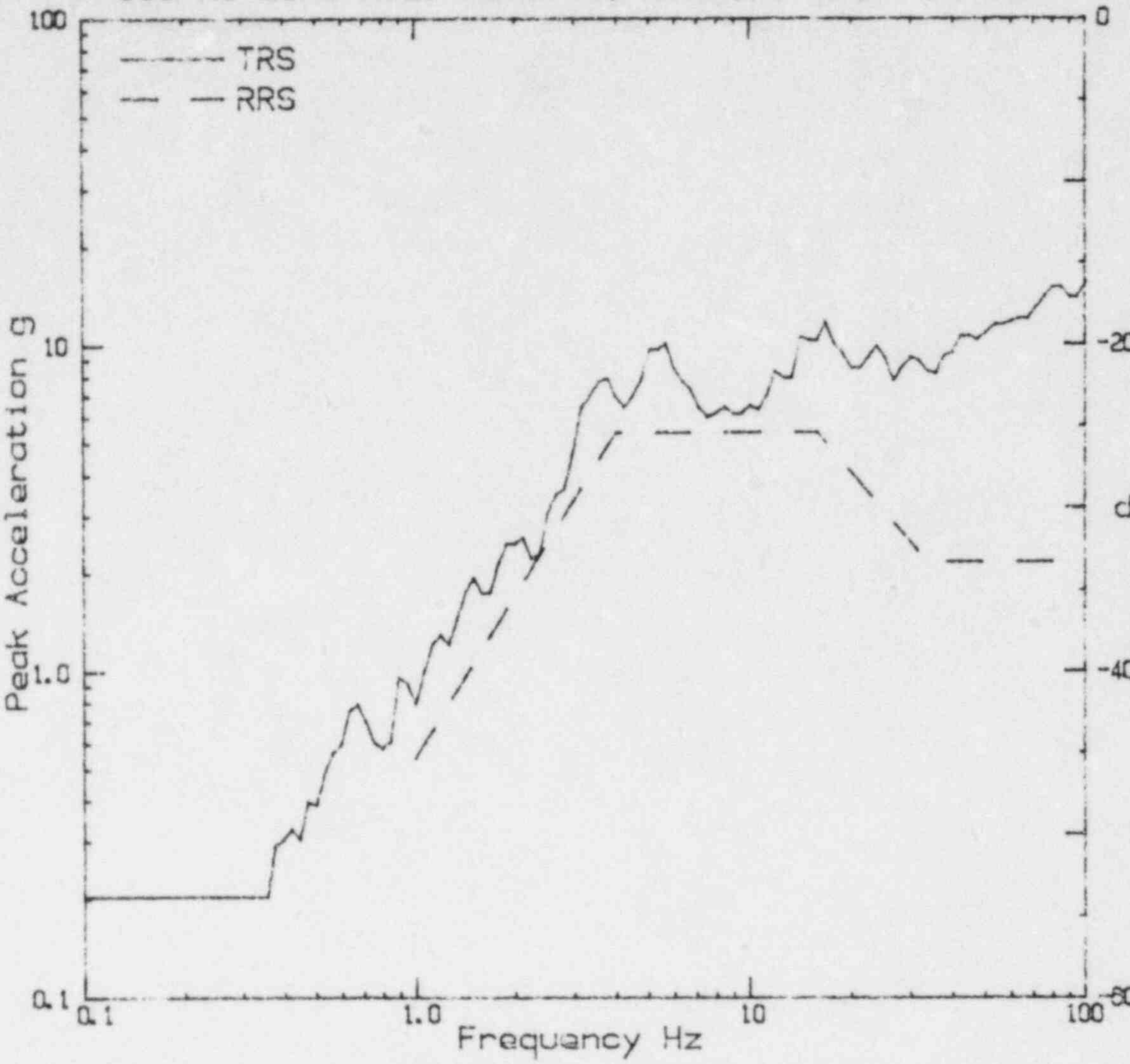
PARTICULARS
Jan 23/84, Time 2:15, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.4,
Graph 5014

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate,
span 6.8: shaker limit

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.79g

ACCELEROMETER
Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 644, Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 53

TEST ITEM
station cells, Gould, Model NCX 2250, sample!-#14

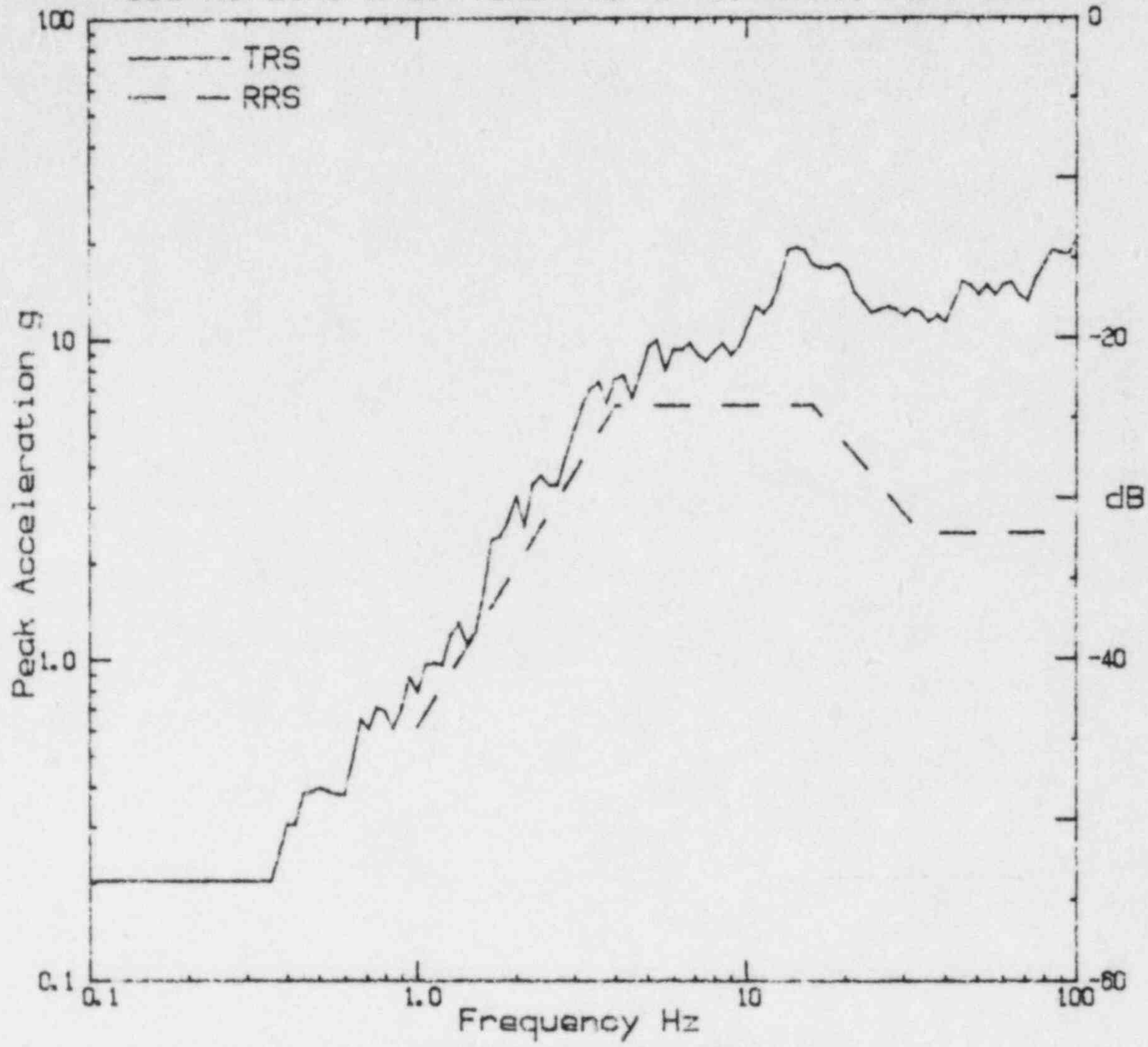
PARTICULARS
Jan 23/84, Time 2:15, Temp('C) 23, Humidity(%) 22, Press (kPa)100.4,
Graph 5015

SPECIFICATIONS
Specs IEEE 501, Conditions operating; 8-hour rate,
span 6.8; shaker limit

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=2.17g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB58, Location top-cell terminal,
TT 644, Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 54

TEST ITEM
station cells, Gould, Model NCX 2250, sample#14

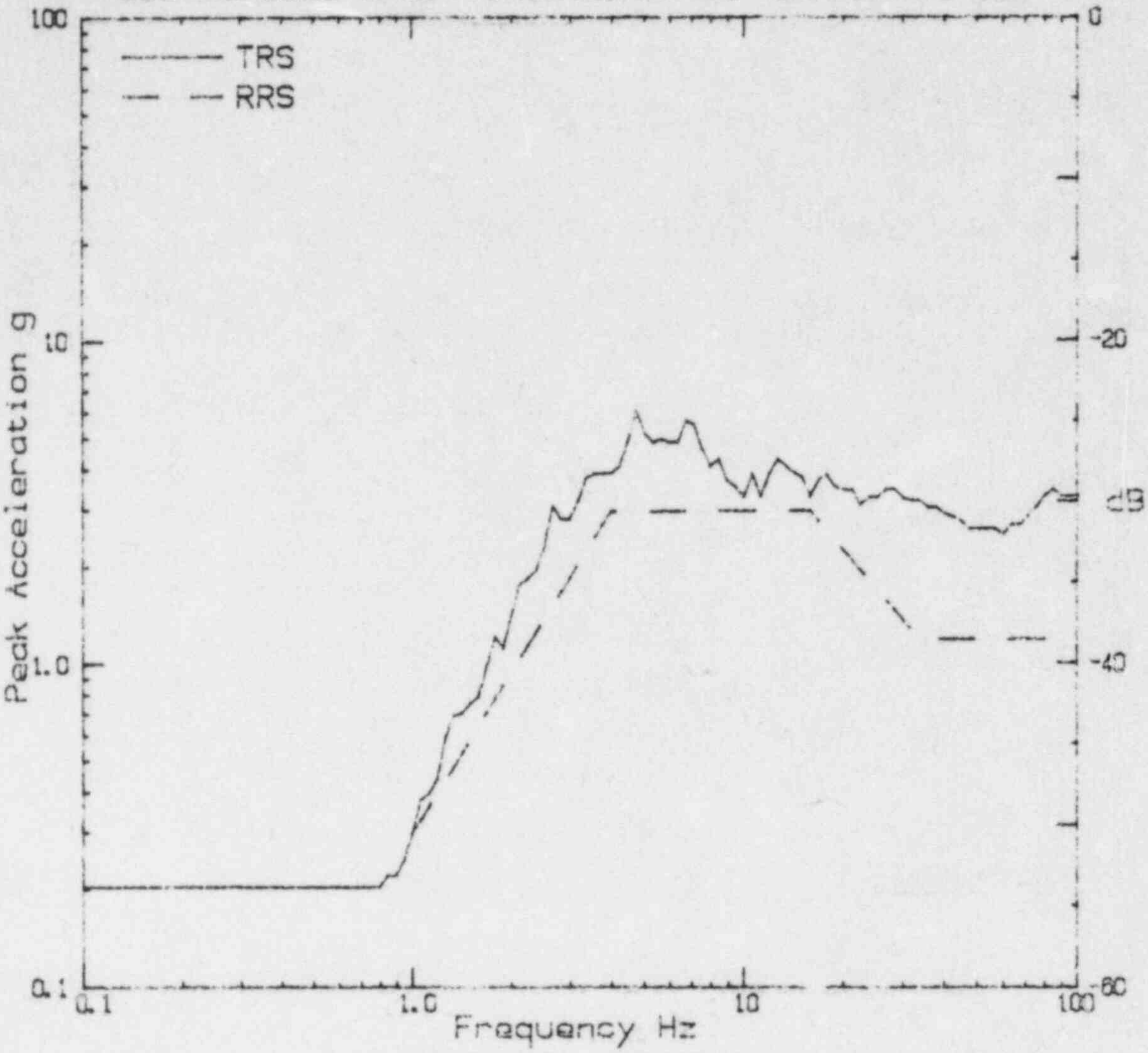
PARTICULARS
Jan 23/84, Time 2:15, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.4, Graph 5016

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate, span 6.8: shaker limit

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z, Shaker tri-axial, ZPA=2.49g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB58, Location top-cell terminal, TT 644, Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 55

TEST ITEM
station cells, Gould, Model NCX 2250, sample#48

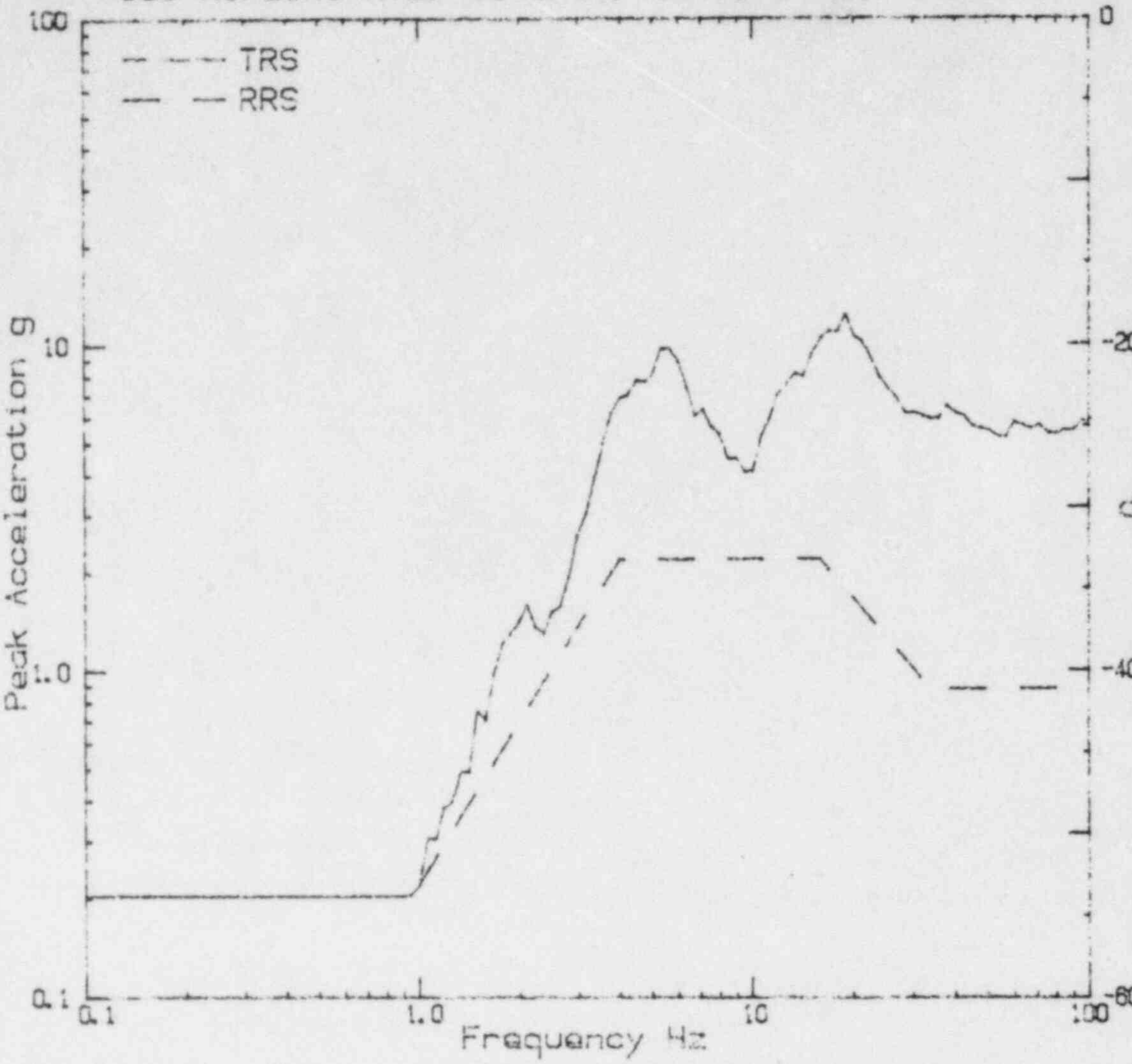
PARTICULARS
Jan 23/84, Time 3:00, Temp('C) 23, Humidity(%) 22, Press (kPa)100.4,
Graph 5017

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate, span 5

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.19g

ACCELEROMETER
Wilcoxon, Serial S757, Range dB58, Location base-mounting jig,
TT 647, Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 56

TEST ITEM
station cells. Gould. Model NCX 2250. sample#48

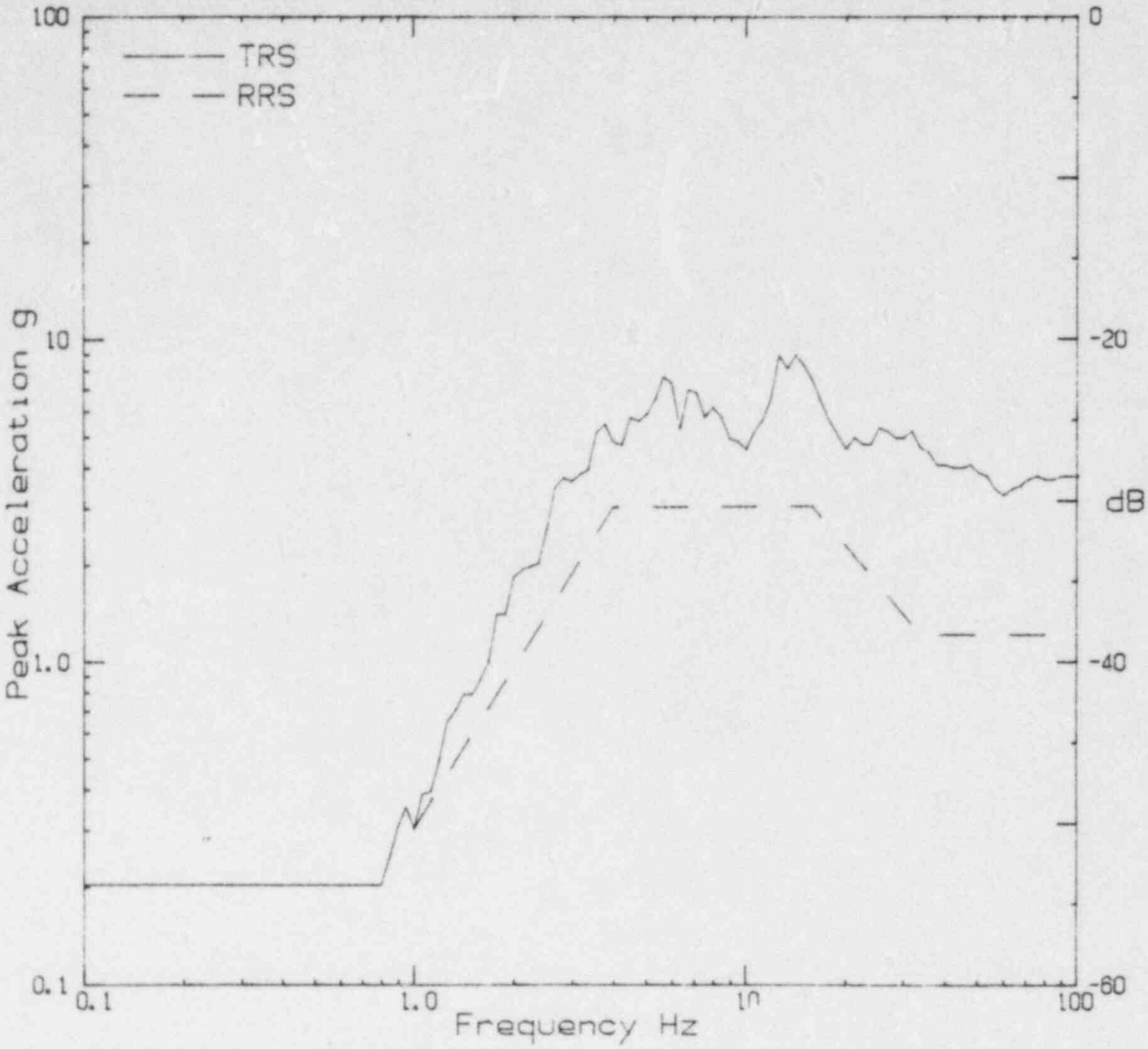
PARTICULARS
Jan 23/84. Time 3:00. Temp('C) 23. Humidity(%) 22. Press (kPa)100.4.
Graph 5018

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate. span 5

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=.89g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting jig.
TT 647. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 57

TEST ITEM
station cells, Gould, Model NCX 2250, sample+#48

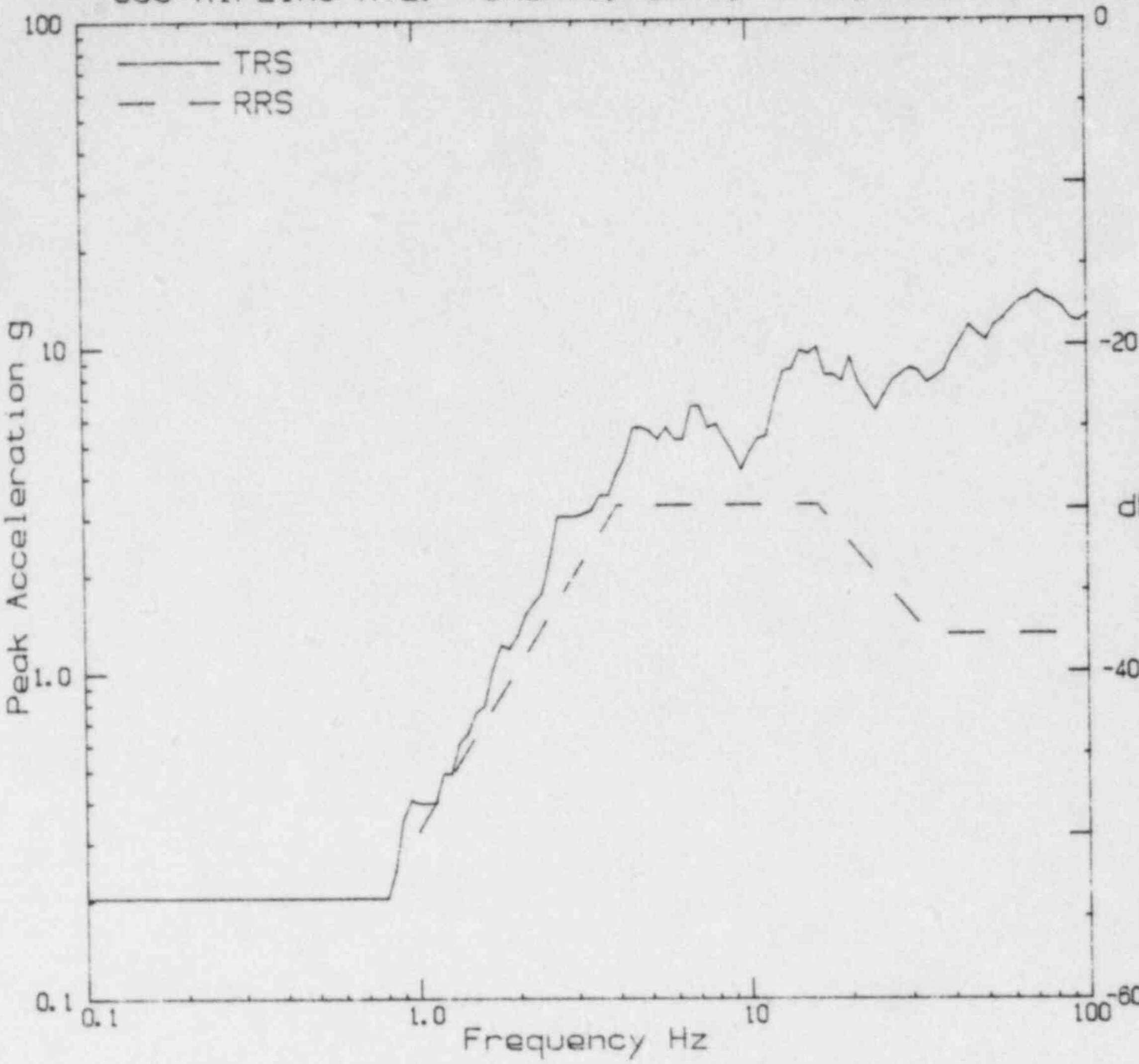
PARTICULARS
Jan 23/84, Time 3:00, Temp('C) 23, Humidity(%) 22, Press (kPa)100.4,
Graph 5019

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate, span 5

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.22g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting jig,
TT 647, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 58

TEST ITEM
station cells, Gould, Model NCX 2250, sample #48

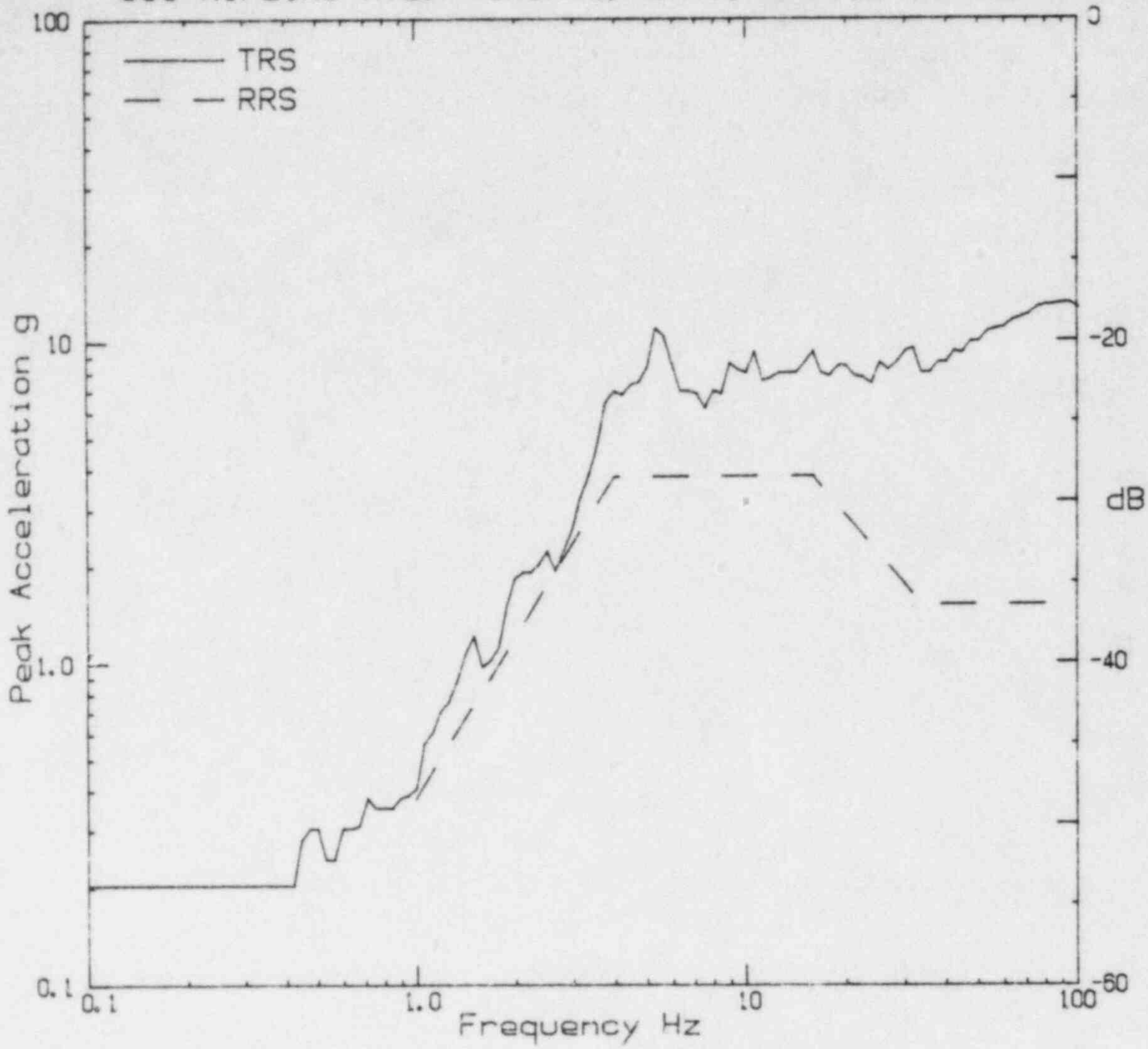
PARTICULARS
Jan 23/84, Time 3:00, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.4,
Graph 5020

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate, span 5

ANALYSIS
Type Maximax, Damping (%) 5, B.W.= 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.31g

ACCELEROMETER
Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 647, Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 59

TEST ITEM
station cells, Gould, Model NCX 2250, sample#48

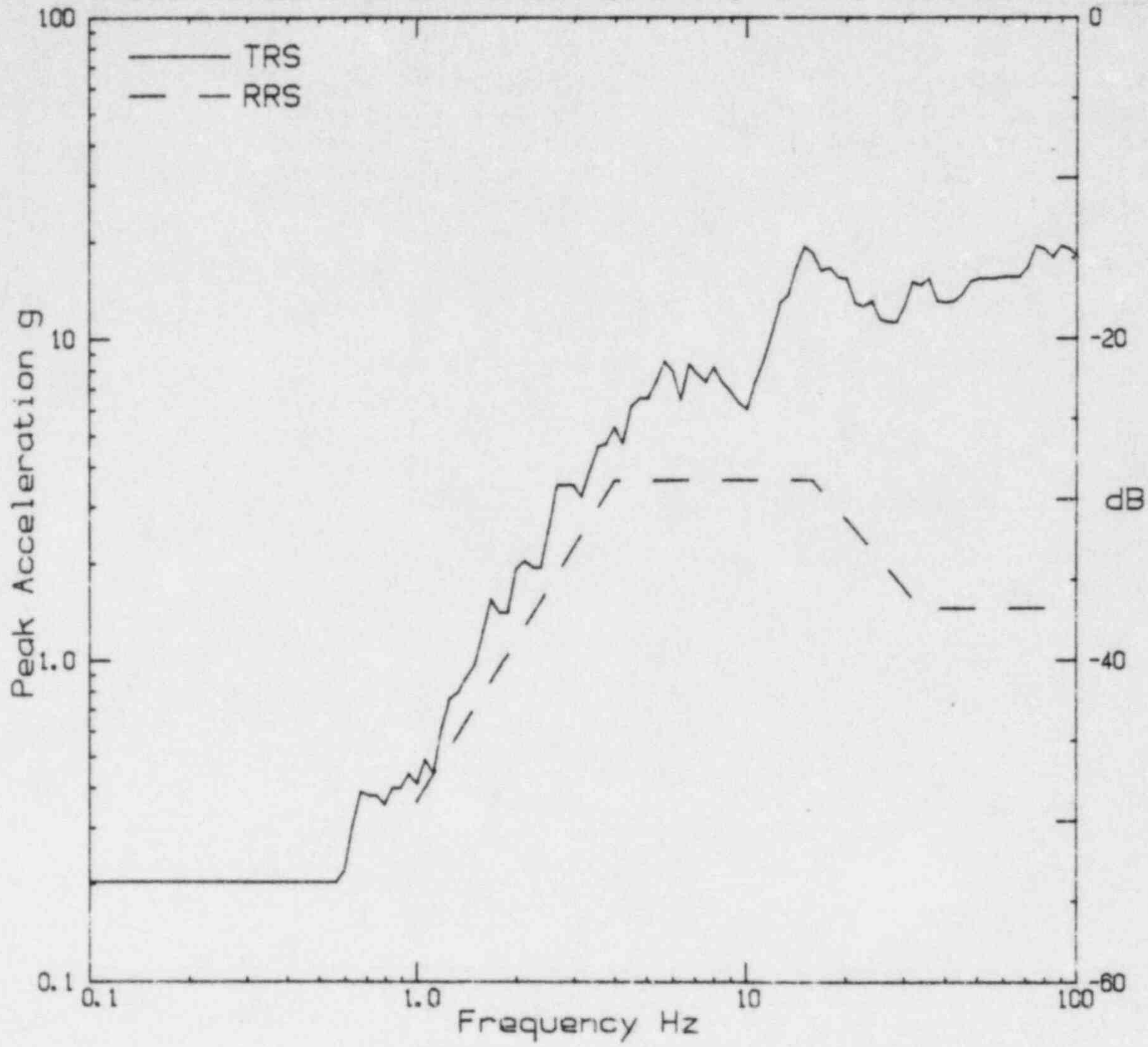
PARTICULARS
Jan 23/84, Time 3:00, Temp('C) 23, Humidity(%) 22, Press (kPa) 100.4,
Graph 5021

SPECIFICATIONS
Specs IEEE 501, Conditions operating: 8-hour rate, span 5

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.53g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB58, Location top-cell terminal,
TT 647, Channel 5

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 60

TEST ITEM
station cells. Gould. Model NCX 2250. sample-#48

PARTICULARS
Jan 23/84. Time 3:00. Temp('C) 23. Humidity(%) 22. Press (kPa) 100.4.
Graph 5022

SPECIFICATIONS
Specs IEEE 501. Conditions operating: 8-hour rate. span 5

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.46g

ACCELEROMETER
Wilcoxon. Serial S297. Range dB58. Location top-cell terminal.
TT 647. Channel 6

DISTRIBUTION

Mr. B.A. Oliver (2)	Design & Development, H12G5
Mr. W.J. Janis	Chemical Research
Mr. J.D. Tulk (10)	Mechanical Research
Mr. G.D. Paulsen	Mechanical Research
Mr. D.A. Black	Mechanical Research

Official Record

APPENDIX D

SEISMIC TESTING OF FITZPATRICK NUCLEAR GENERATING STATION SIMULATED BATTERY RACK WITH CELLS

D. A. Black

G. D. Paulsen

Ontario Hydro Research Division

91600
new 82-10

ontario hydro
research division

To Mr. B.A. Oliver
Manager
Electrical Design
Design & Development

SEISMIC TESTING OF FITZPATRICK NUCLEAR GENERATING STATION SIMULATED BATTERY RACK WITH CELLS

D.A. Black and G.D. Paulsen

Seismic tests were performed on two sets of 3 cells in a simulated battery rack. This report describes the test procedure, methods and equipment, and interprets the test results. The tests are part of a study to determine how aged batteries will withstand seismic events.

1.0 INTRODUCTION

Two sets of three cells were tested in a simulated rack. The assembly was tested to IEEE 344/1/and IEEE 501/2/ Specifications. Date of test, specimen description, test facility name and location, test data and test temperature, humidity and pressure are recorded on each of the response spectrum curves. These curves also show the conditions of the test, the type of analysis, the accelerometers used, the direction of the test, and the axis analysed. All tests were analysed using 5% damping and the maximax shock spectrum. The tests performed were tri-axial tests as defined in IEEE 344. The shaker inputs were pseudo-random with a duration of 30 seconds. In addition, impact tests were performed in order to determine the natural frequency of the unit. All technical terms used in this report are defined by Harris/3/.

2.0 SAMPLE

The 12-year old cells tested were described as follows:

Test 1 - Three cells, Gould, Model NCX 2250 numbered 49, 42 and 25 were filled with water and neutralized. They were mounted on a rack made from 1-5/8 channel.

Test 2 - Three cells, Gould Model NCX 2250 numbered 30 (filled with water), 23 and 8 (live and connected to electrical load) were mounted in the same rack as above.

job	file	date	report no.
740624-268-450	824.46	July 19, 1984	B84-37-P

3.0 TEST EQUIPMENT

3.1 Equipment Used

3.1.1 Shaker Control Equipment

1. MTS 436 control uni s
2. MTS 406.11 controllers
3 MTS hydraulic pumps
4. Ontario Hydro noise generators and filters
5. Ontario Hydro tri-axial shaker table.

3.1.2 Analysis

1. Columbia Model 9000 amplifiers and matching Wilcoxon M-408 accelerometers.

Amplifier Serial No	Accelerometer Serial No
368 1632	S893
368 1633	S297
368 1634	S901
368 1635	S369
368 1636	S753
368 1637	S754
369 1638	S756
369 1639	S757
369 1640	S759
369 1641	S760
369 1642	S761
369 1643	S771

2. SE tape recorder Model 7000A, Serial No 547.

3. Tektronix 5113 dual beam storage oscilloscope, KS3681.

4. Spectral Dynamics 13231 Shock Spectrum Analyser, Serial No 27.

5. Spectral Dynamics 13191 Transient Memory, Serial No 29.

6. Ontario Hydro transmissibility circuit.

7. Watanabe WX4400 X-Y Recorder, Serial No 83010070.

8. Hewlett-Packard 7046A X-Y1-Y2 Recorder, Serial No 1914A05842.

9. Spectral Dynamics 50121L Tracking Filter, Serial No 171.

10. Spectral Dynamics SD122L Tracking Filter, Serial No 370.

11. Honeywell 1858 oscillograph, Serial No 2649JF78.

12. Nicolet Scientific Corp, Model 660A Dual Channel FFT Analyzer, Serial No 9866226.

13. Hewlett-Packard Model 7470A Plotter, Serial No 2210A-12990.

3.1.3 Calibration Equipment

1. Bruel and Kjaer Type 3506, Serial No 877022 Accelerometer Calibration Set which includes Type 2626, Serial No 842947 and Type 83055, Serial No 858627, traceable to NBS.

2. General Radio 1557-A vibration calibrator, Serial No 2379.

3. Data Precision 2440 digital voltmeter, Serial No 8583, traceable to NBS.

4. Data Precision 248 digital voltmeter, Serial No 8583, traceable to NBS.

4.0 TESTS AND PROCEDURES

4.1 Calibration Procedure

Accelerometers and amplifiers are calibrated using the back-to-back calibration procedure. The reference accelerometer was mounted on the vibration calibrator with the Wilcoxon accelerometer. Using 100 Hz sine wave vibration of approximately 1 g, the sensitivity of the Columbia amplifiers was set to give 500 mV/g output. The outputs were measured using the digital voltmeter. By using the same voltmeter for both the reference and the Columbia amplifiers, slight differences in voltmeters need not be considered. Since the voltmeter measures true RMS voltages, the waveshapes of the 100 Hz signals were compared on the oscilloscope. This ensures that the signals are equivalent.

4.2 Test Setup and Procedures

Cells 49, 42 and 25 were selected from the cells which had cracked cases. They were water filled and mounted in the rack as shown in Figure 01A. Cells 30, 23 and 8 were selected for the second test. Cell #30 was a cracked case and was neutralized for the test. Cells 8 and 23 were connected to electrical load and monitored for voltage and current by Chemical Research (at the 1.5 hour rate). Separately, the voltage was continuously recorded on the Honeywell 1858 Oscillograph.

Instrumented impact tests were performed on the rack with cells. The entire rack used half inch bolts which were tighened to 34 Nm (300 in-lb).

Displacement limit	152 mm
Velocity limit	820 m/s
Acceleration limit	4 g (no load)
Acceleration limit	1.6 g (fully loaded)
Maximum load	2000 kg

Simultaneous random inputs were applied in three axes and the coherence between axes was negligible. The vibration levels in the two horizontal and vertical directions were individually controlled to nominally give similar levels. These levels were set by adjusting a "span" potentiometer. The span setting used is of no significance in itself except equivalent span settings nominally indicate equivalent vibration levels. The vibration is never the same from one test to the next since a different random signal is used for each test.

5.0 TEST RESULTS

The instrumented impact tests showed a side to side resonant frequency of 10.8 Hz and damping of 3.5%. The lengthwise natural frequency was 12.8 Hz with a damping of 5.4%. These tests were done on cells 49, 42 and 25. These cells were run through the sequence of tests given in Table 1. The tests were taken to the shaker limit after cell 49 failed and lost its electrolyte. The other rack of three cells was tested until electrical failure of cell number 23. Cell 23 was connected in series with cell 8 which was located at the end of the rack. Table 1 shows the sequence of testing. During the tests, bolts on the rack loosened and were retightened to 34 Nm except the bolts at the end of the 1-5/8-inch channel fence which were tightened to 68 Nm. The test response spectra for the rack tests are given in Figures 01C through 24. The ZPA values for the graphs plotted are given in Table 2.

6.0 OBSERVATIONS

The three cells tested tended to move together as one unit. This probably accounts for the rack failure (run 3, cells 49, 42 and 25, see Table 1). The end rail of the rack came loose, allowing the cells to slide in the longitudinal direction. For long racks the forces on the end rails could be very large. This may also be a factor in the observed tendency for the end cells to fail before the centre cell. Insufficient testing of multicell racks makes the above trend inconclusive. The end cell failures may be coincidences. Vertical vibrations tended to be very hard on these cells. In some cases the cell bounced on the rack. This may have caused the failure of the case (cell #49).

7.0 CONCLUSIONS

The rack tests showed the necessity of properly holding down the cells. Some sort of vertical clamping arrangement would eliminate bouncing of the cells. Restraint between the cells would help prevent the cells from marching off the end of the rack. Two sets of three cells were tested on the same rack. In the first test the rack failed as the bolts came loose. The case of cell #49 failed after repeated high level tests. Cell #23 failed electrically in the second rack test.

Approved:

D.B. Craig
Section Head
Mechanical Testing and
Development Section
Mechanical Research Dept

Submitted:

G.D. Paulsen
Technologist
Mechanical Testing and
Development Section

D.A. Black
Engineer
Mechanical Testing and
Development Section

GDP:DAB:sf

REFERENCES

1. The Institute of Electrical and Electronic Engineers Inc. IEEE 344. Qualification of Class 1E Equipment for Nuclear Power Generating Stations. New York. 1975.

2. The Institute of Electrical and Electronic Engineers Inc. IEEE 501. IEEE Recommended Practices for Seismic Qualification of Relays.

3. Harris, Cyril M., and Charles E. Crede. "Shock and Vibration Handbook". Second Edition. McGraw Hill Book Company. Toronto. 1976.

TABLE I

SUMMARY OF TESTING SETS OF
THREE STATION CELLS IN A RACK

Cell Numbers	Date	Time	Run	Span	Plotted	Comments
49, 42 & 25	Mar 12/84	10:46	1	3	No	Some leakage from cell 25 bottom crack.
49, 42 & 25	Mar 12/84	10:52	2	4	No	Some loss of neutralized electrolite from caps.
49, 42 & 25	Mar 12/84	10:54	3	5	Yes	Cells move together in rack. End bar of fence loosened, readjusted and torqued to 68 Nm. Cells shifted in the longitudinal direction.
49, 42 & 25	Mar 12/84	11:00	4	6	Yes	Considerable bouncing of cells. Failure of cell jar #49 at bottom lower corner. No apparent previous cracks in failure zone. Centre cell #42 terminal posts showed signs of lifting. Bolts on cross bars and frame lost considerable tension. Less than 1/3 of original remained.
49, 42 & 25	Mar 12/84	11:06	5	6.8	No	Considerable bouncing due to vertical input exceeding 1 g. Cell 49 jar bottom broke off completely. Cell 42 posts and plate hanger broke off.
30, 23 & 8	Mar 12/84	3:39	1	3	No	No apparent change.
30, 23 & 8	Mar 12/84	3:42	2	4	Yes	Some loss of load in bolts. Retightened to original values. First signs of impending electrical failure.
30, 23 & 8	Mar 12/84	4:00 pm	3	5	Yes	Electrical failure of cell #23.

TABLE II

SUMMARY OF TEST RESULTS

Cell Number	Direction	ZPA (g)	Span	Comments
49, 42 & 25	X - Base	1.08	5	Highest level before case failure.
	Y -	1.28		
	Z -	0.90		
	X - Terminal	1.29		
	Y -	-		
	Z -	2.16		
49, 42 & 25	X - Base	1.42	6	Case failed at this level.
	Y -	1.59		
	Z -	1.04		
	X - Terminal	1.59		
	Y -	-		
	Z -	2.20		
30, 23 & 8	X - Base	1.10	4	First signs of electrical breakdown.
	Y -	0.68		
	Z -	0.74		
	X - Terminal	1.08		
	Y -	1.44		
	Z -	1.37		
30, 23 & 8	X - Base	1.47	5	Failure of cell #23
	Y -	0.82		
	Z -	0.93		
	X - Terminal	1.22		
	Y -	1.29		
	Z -	2.12		

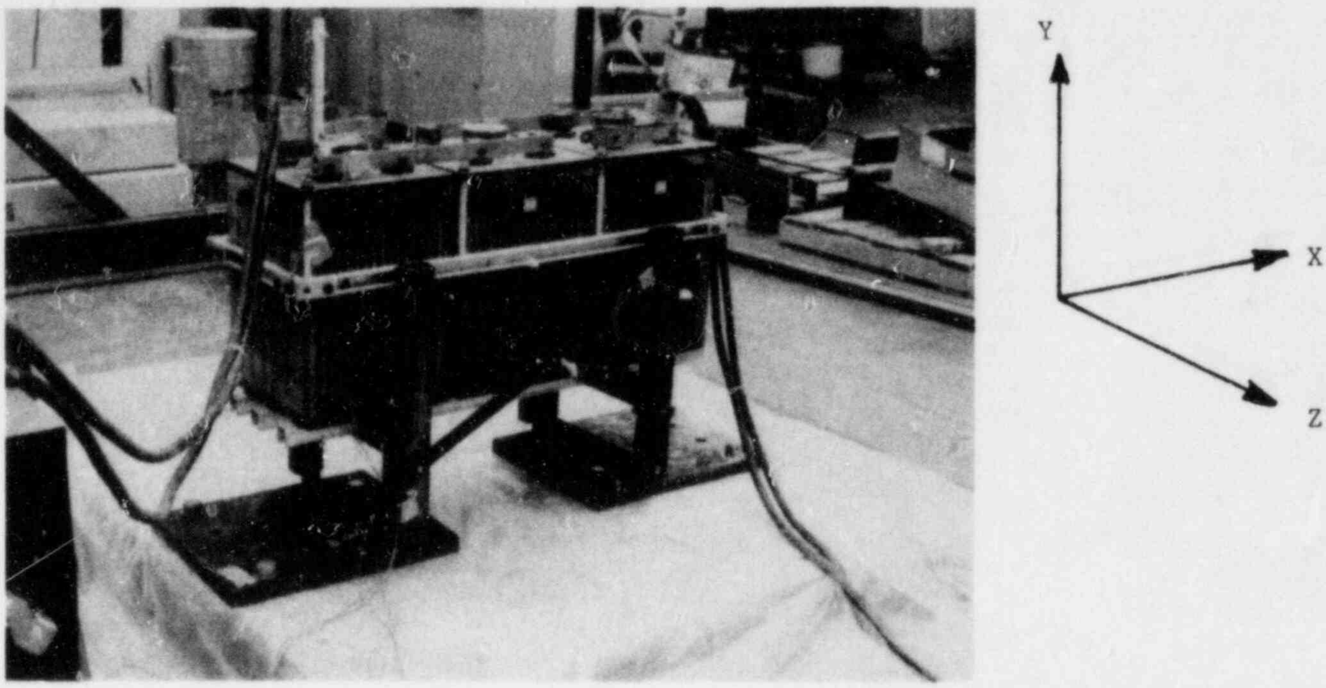
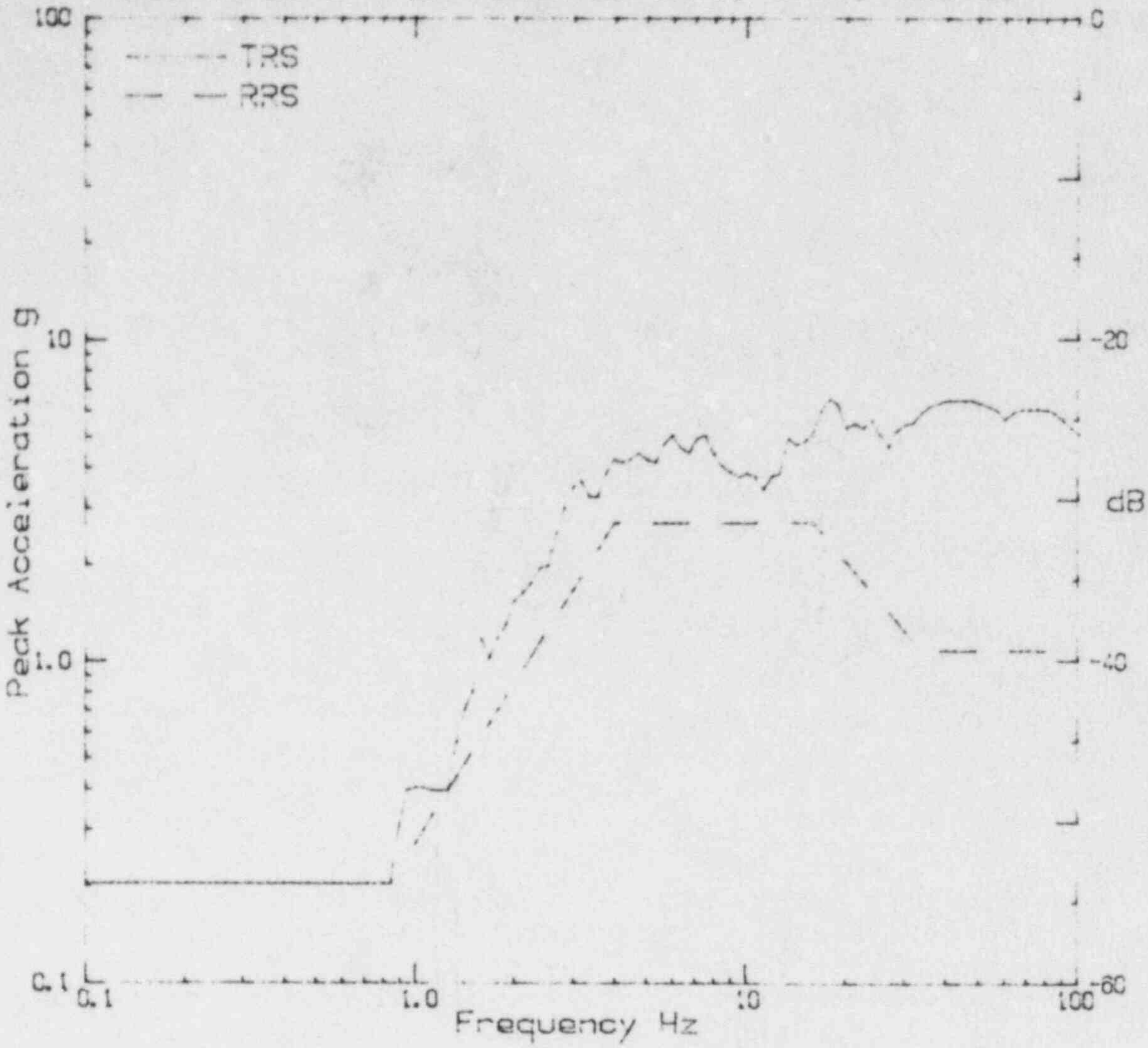


FIGURE 01A

Battery rack with three cells connected to simulate part of a typical battery rack. In the tests the left end cell jar failed at the bottom releasing the neutralized electrolyte. This rack only contains three cells; normal racks contain many more cells with this section replicated several times. The axes of vibration are shown.

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 01B

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part 49: 42: 25

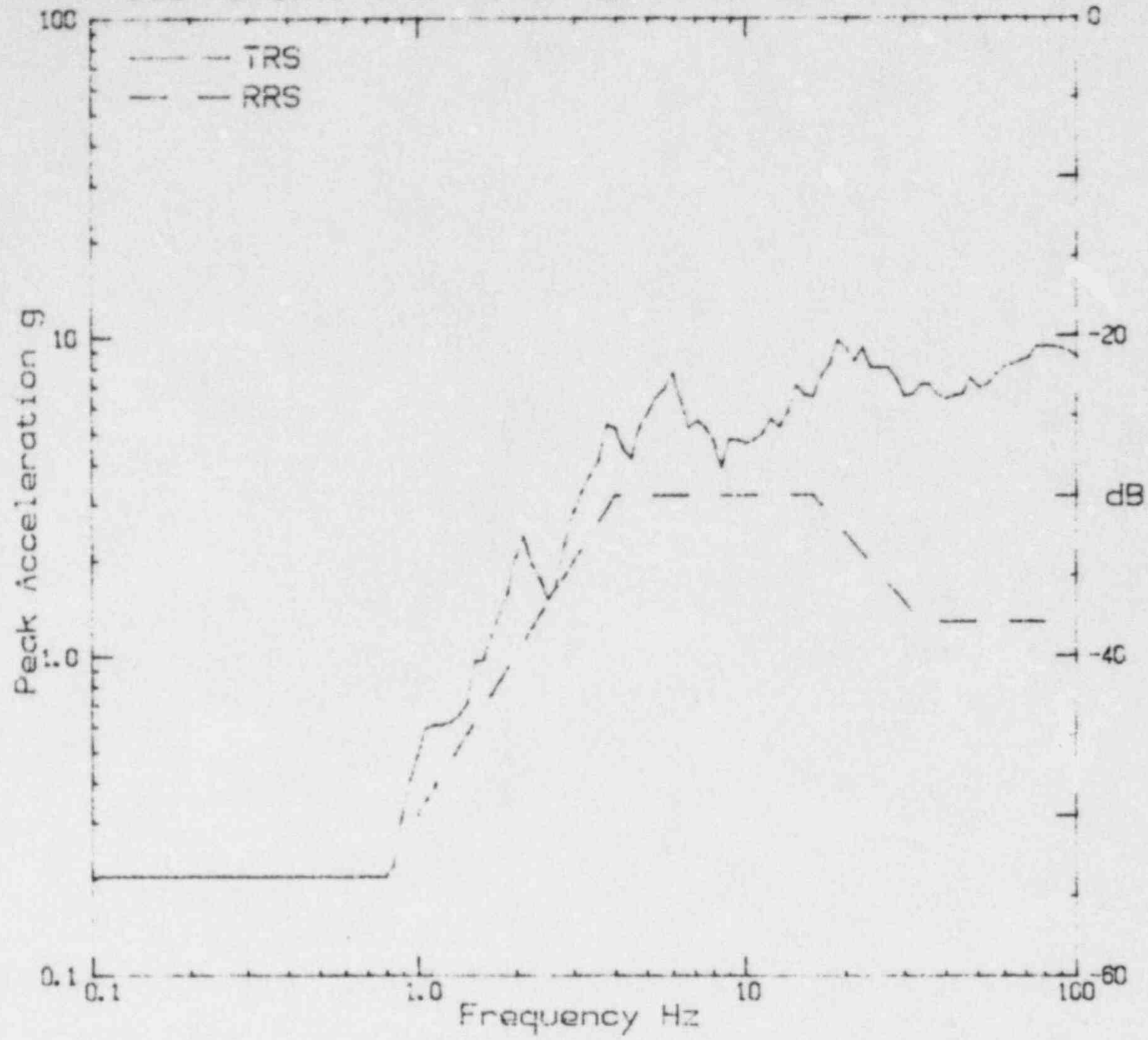
PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5080

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 5. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.08g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting plate.
TT 668. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 02

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part 49: 42: 25

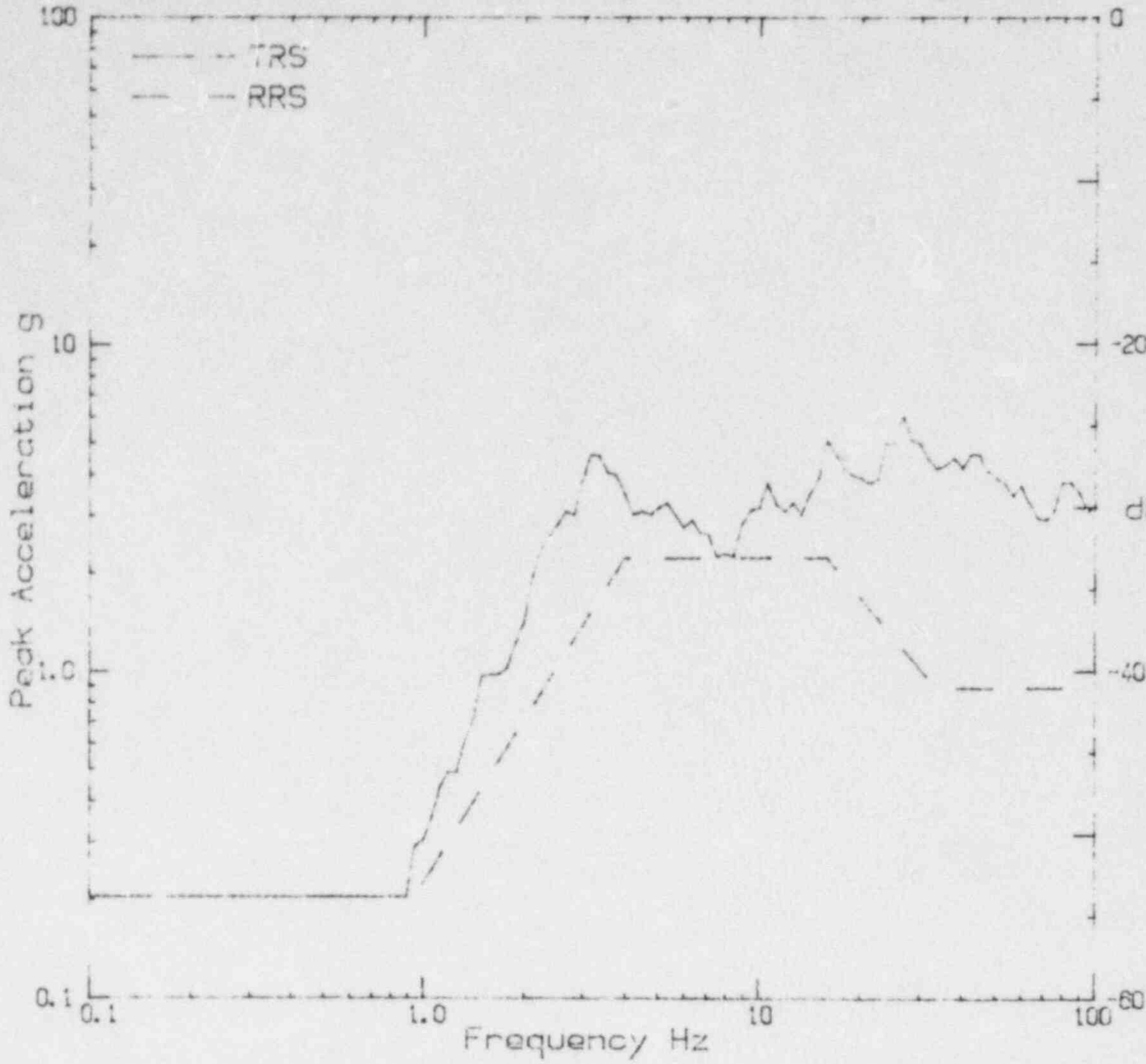
PARTICULARS
March 12/84. Time 10:48. Temp(°C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5081

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 5. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.28g

ACCELEROMETER
Wilcoxon. Serial S761 Range dB58. Location base-mounting plate.
TT 668. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 03

TEST ITEM
Station Cells & rack, Gould, Model NCX2250 & Gould type rack,
Part 49; 42; 25

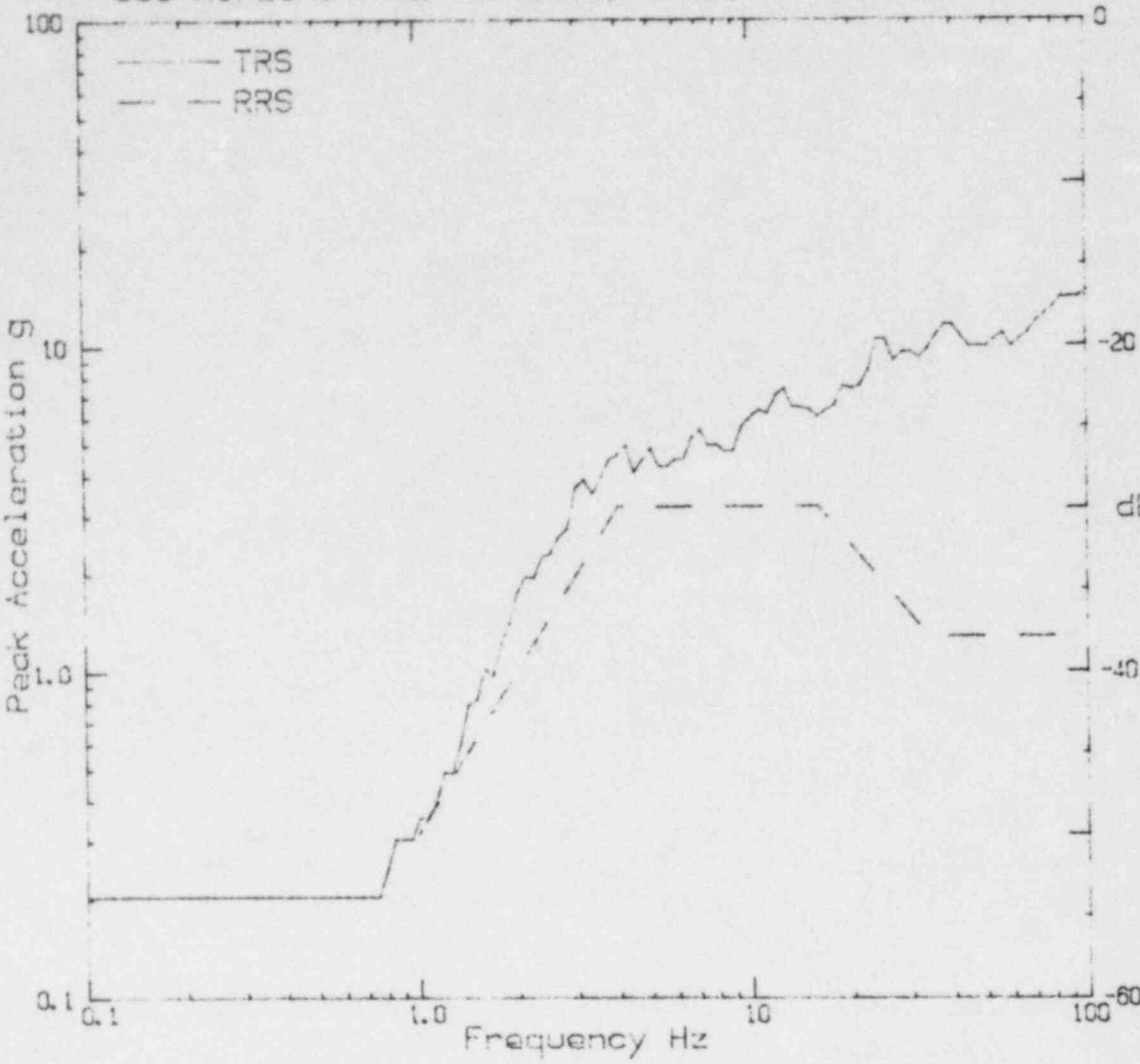
PARTICULARS
March 12/84, Time 10:46, Temp('C) 24, Humidity(%) 39,
Press (kPa)100.9, Graph 5082

SPECIFICATIONS
Specs IEEE 501, Conditions 3 dummy cells ; span 5, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Z,
Shaker tri-axial. ZPA=.9g

ACCELEROMETER
Wilcoxon, Serial S901, Range dB58, Location base-mounting plate,
TT 668, Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 04

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part 49:42:25

PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5083

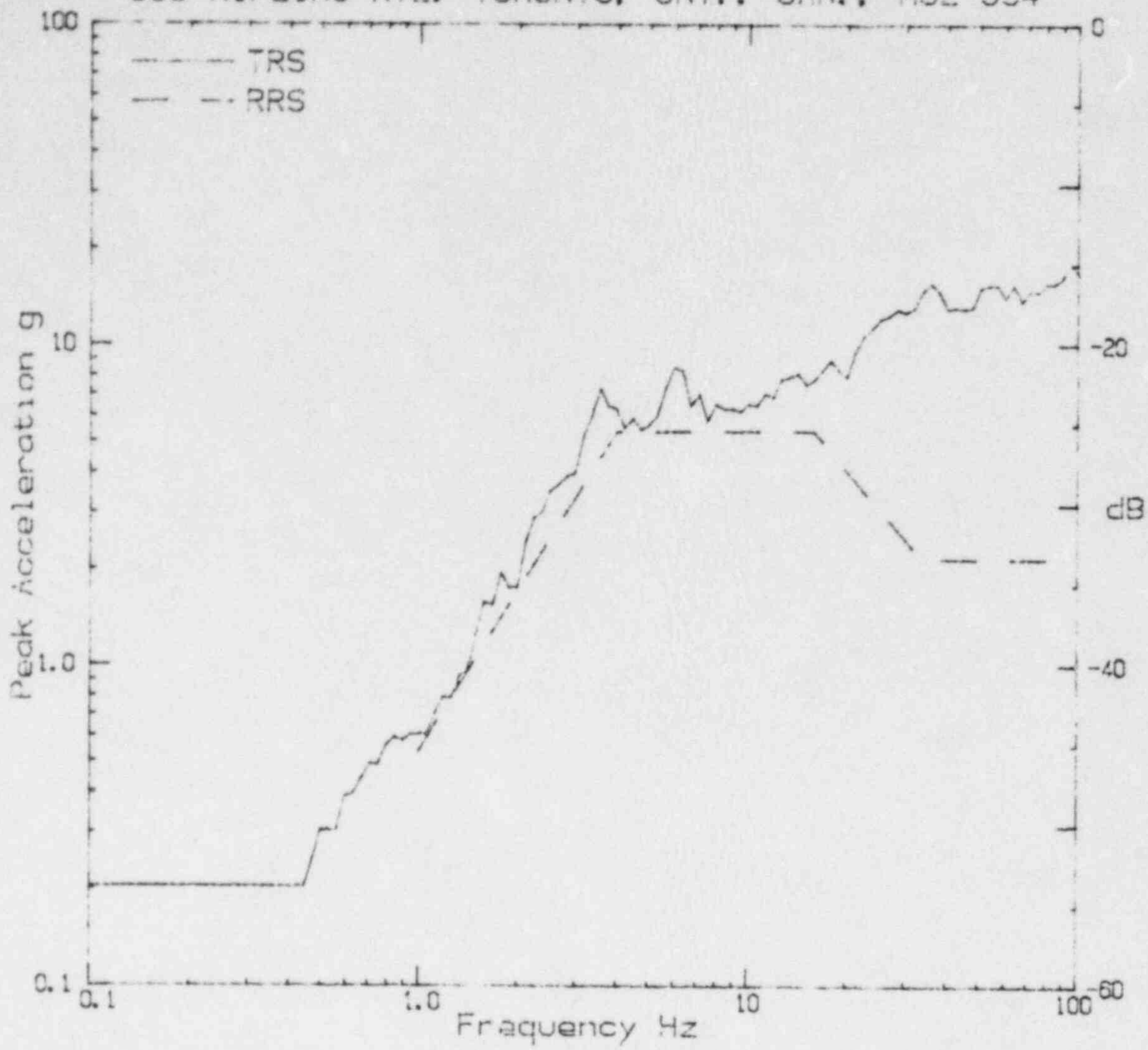
SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 5. fragility level

ANALYSIS
Type Maximax. Damping (%) 5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.29g

ACCELEROMETER
Wilcoxon. Serial S771. Range dB58. Location top-cell terminal.
TT 668. Channel 4

B84-37

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 06

TEST ITEM
Station Cells & rack, Gould, Model NCX2250 & Gould type rack.
Part 49:42:25

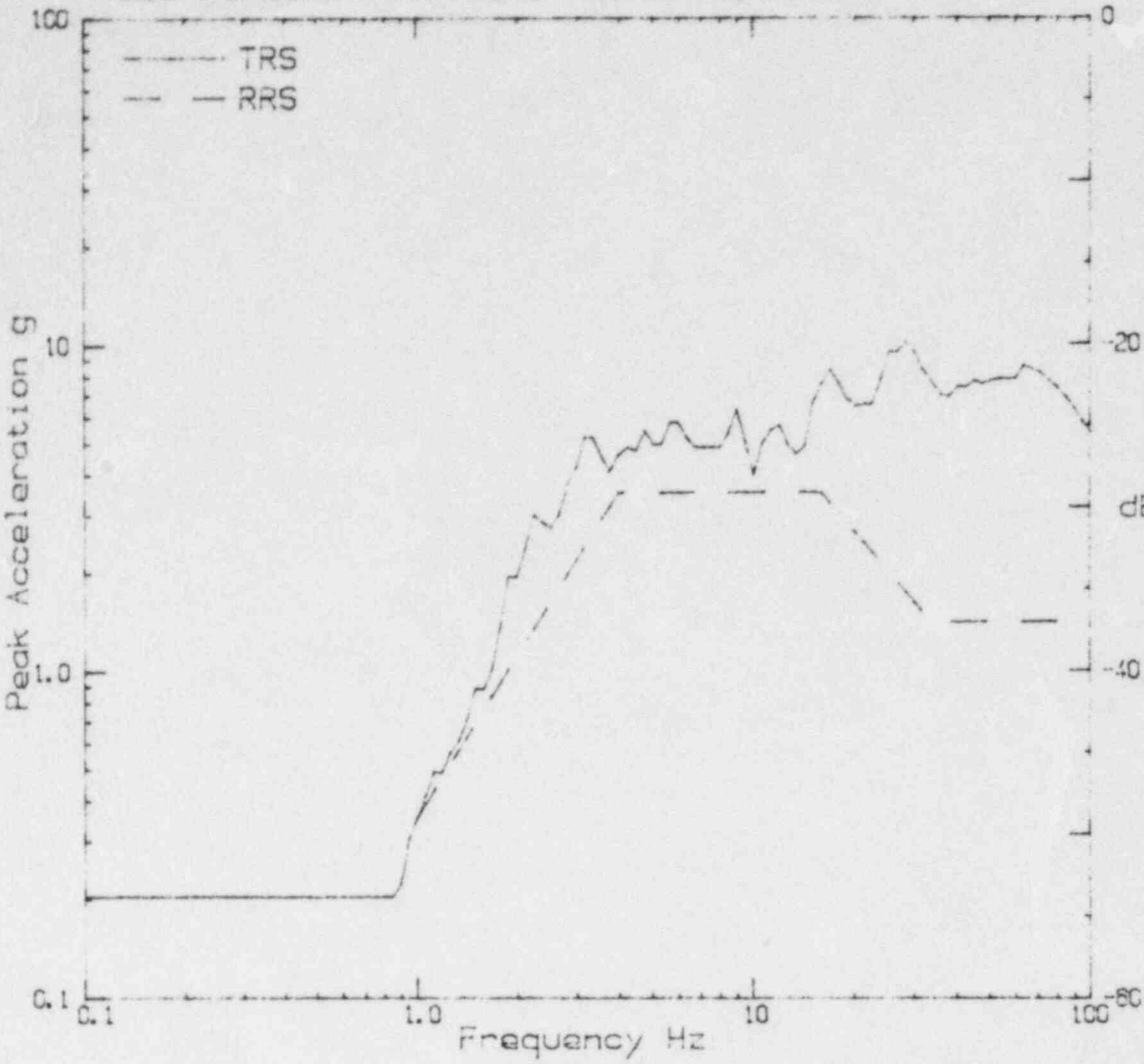
PARTICULARS
March 12/84, Time 10:46, Temp('C) 24, Humidity(%) 39,
Press (kPa) 100.9, Graph 5085

SPECIFICATIONS
Specs IEEE 501, Conditions 3 dummy cells ; span 5, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=2.16g

ACCELEROMETER
Wilcoxon, Serial S754, Range dB58, Location top-cell terminal,
TT 668, Channel 6

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 07

TEST ITEM
Station Cells & rack, Gould, Model NCX2250 & Gould type rack,
Part 49; 42; 25

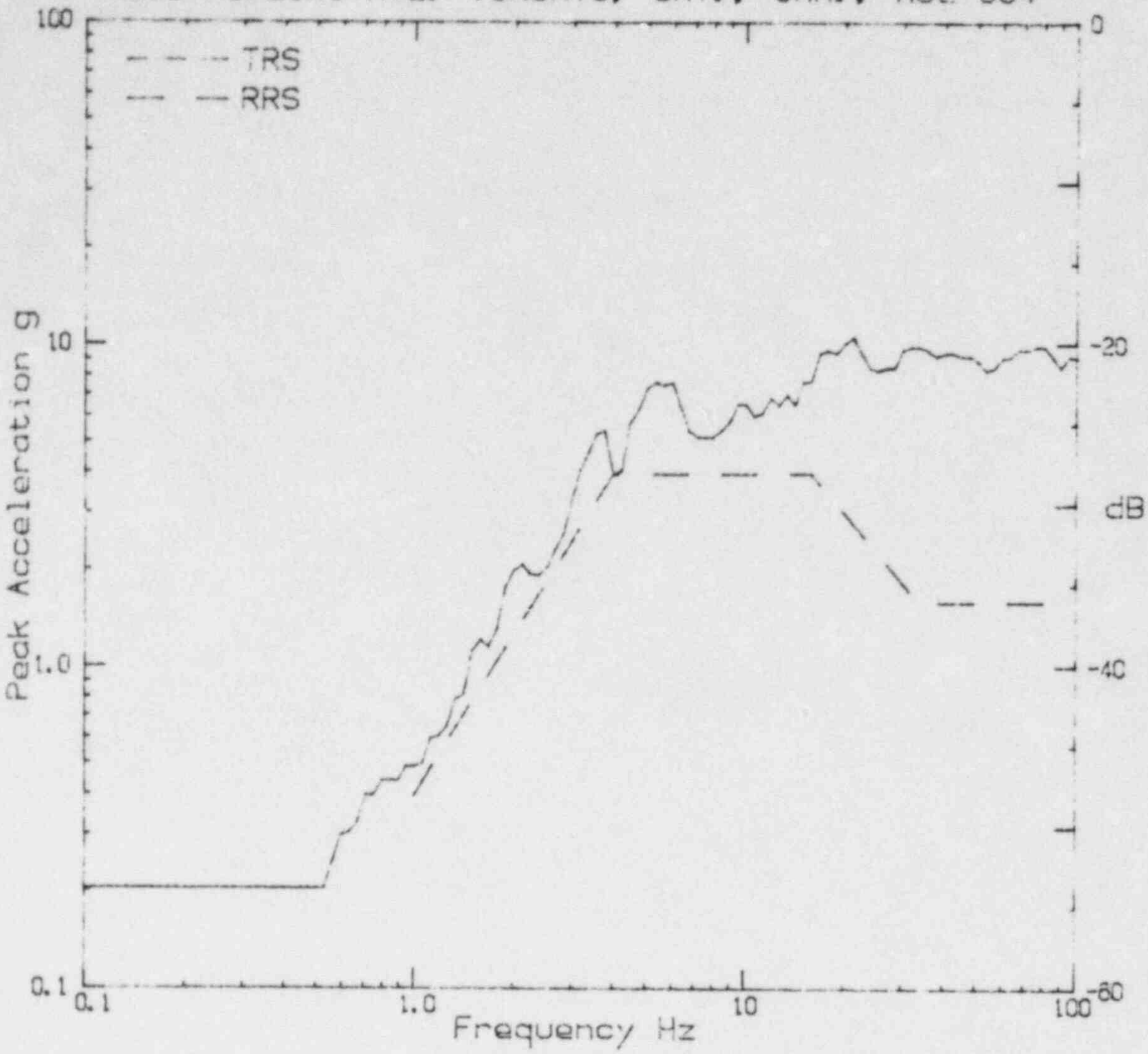
PARTICULARS
March 12/84, Time 10:46, Temp('C) 24, Humidity(%) 39,
Press (kPa) 100.9, Graph 5086

SPECIFICATIONS
Specs IEEE 501, Conditions 3 dummy cells ; span 6, one cell broken

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.42g

ACCELEROMETER
Wilcoxon, Serial 5757, Range dB58, Location base-mounting plate,
TT 670, Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 08

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part 49: 42: 25

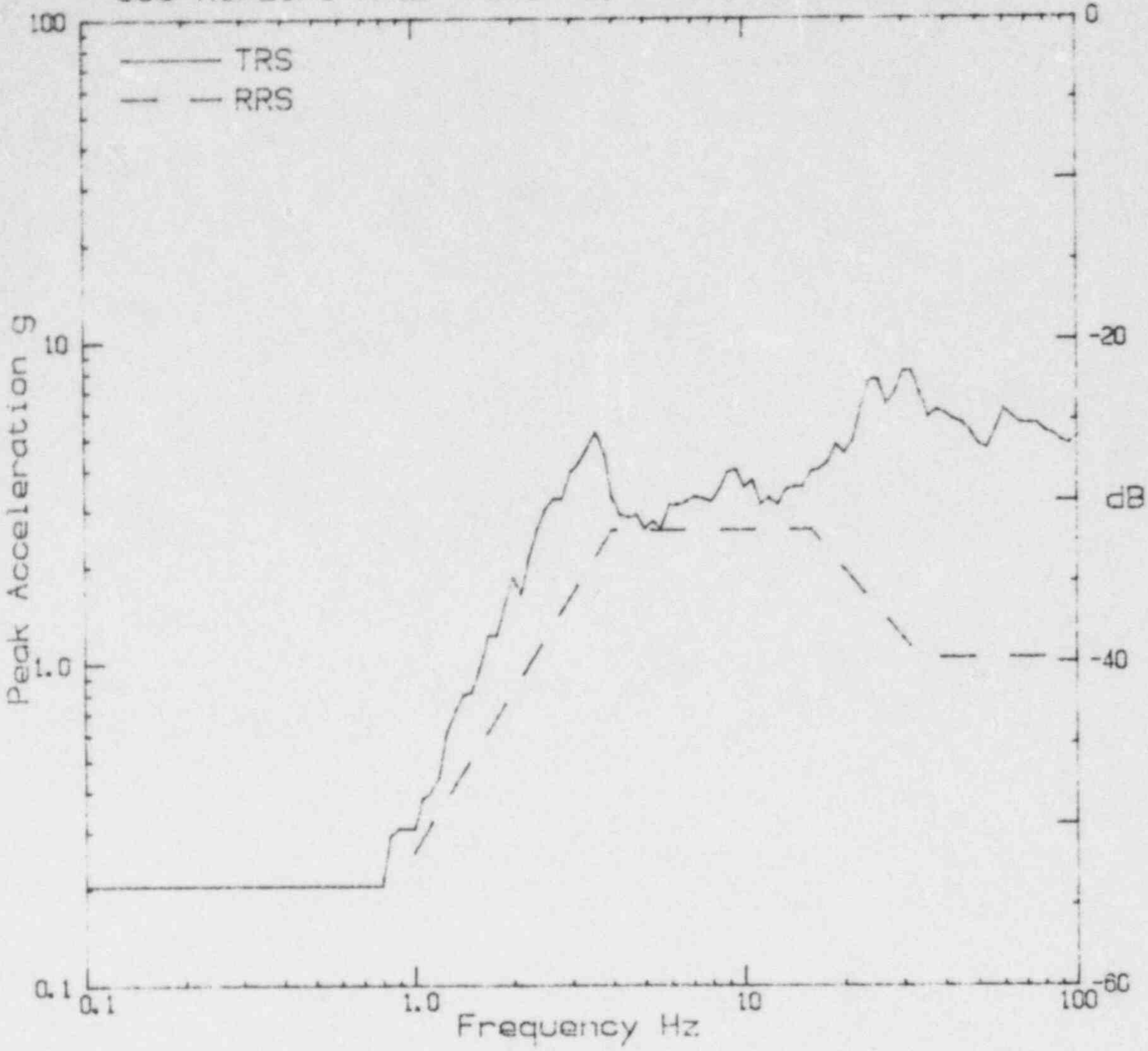
PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5087

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 8. one cell broken

ANALYSIS
Type Maximax. Damping (%)5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.59g

ACCELEROMETER
Wilcoxon. Serial S761. Range dB58. Location base-mounting plate.
TT 670. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 09

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part 49;42;25

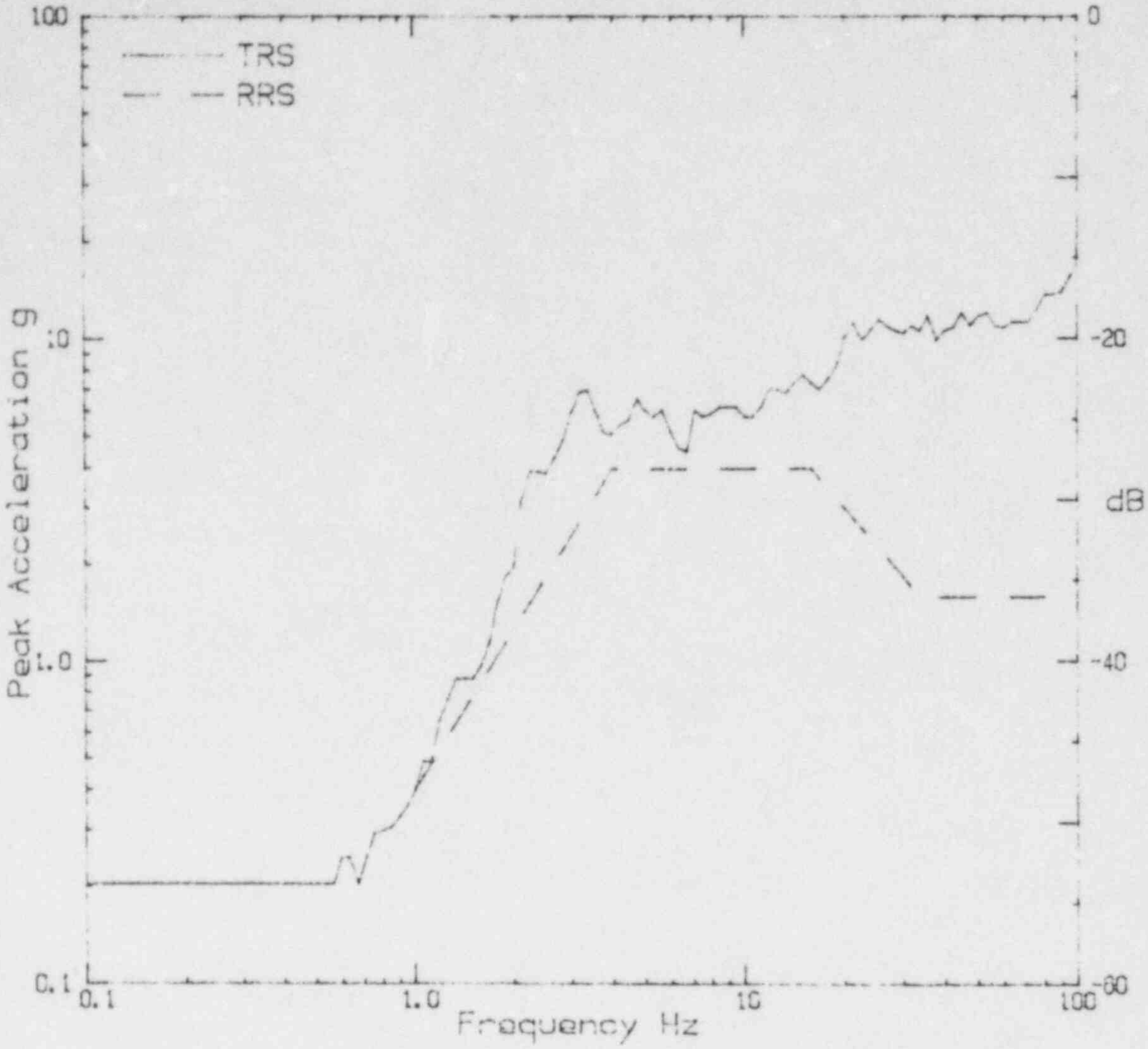
PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5088

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 6. one cell broken

ANALYSIS
Type Maximax. Damping (%) 5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.04g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting plate.
TT 670. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 10

TEST ITEM
Station Cells & rack, Gould, Model NCX2250 & Gould type rack.
Part 49:42:25

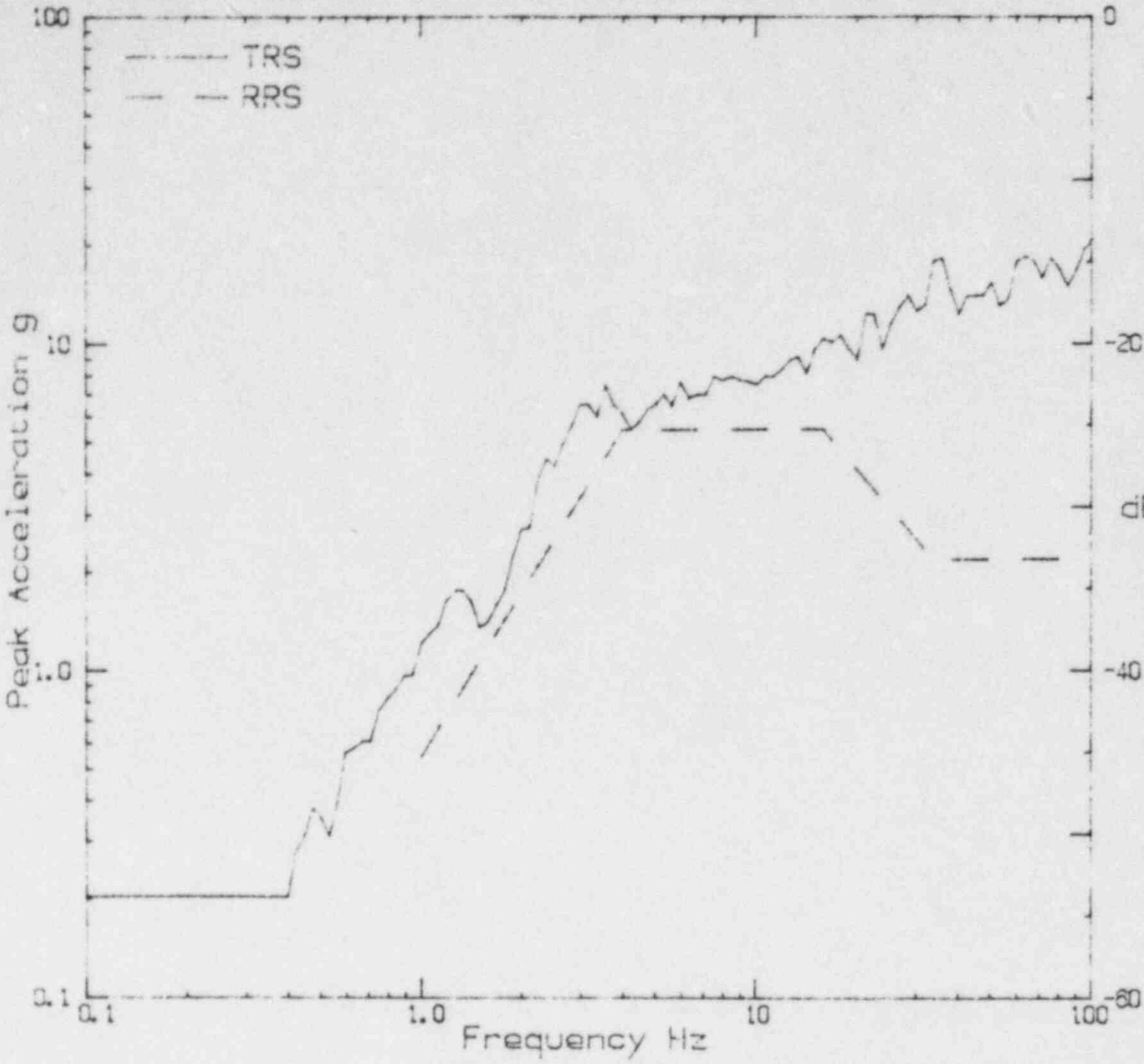
PARTICULARS
March 12/84, Time 10:46, Temp('C) 24, Humidity(%) 39,
Press (kPa)100.9, Graph 5089

SPECIFICATIONS
Specs IEEE 501, Conditions 3 dummy cells ; span 6, one cell broken

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.59g

ACCELEROMETER
Wilcoxon, Serial 5771, Range dB58, Location top-cell terminal,
TT 670, Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 12

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part 49; 42; 25

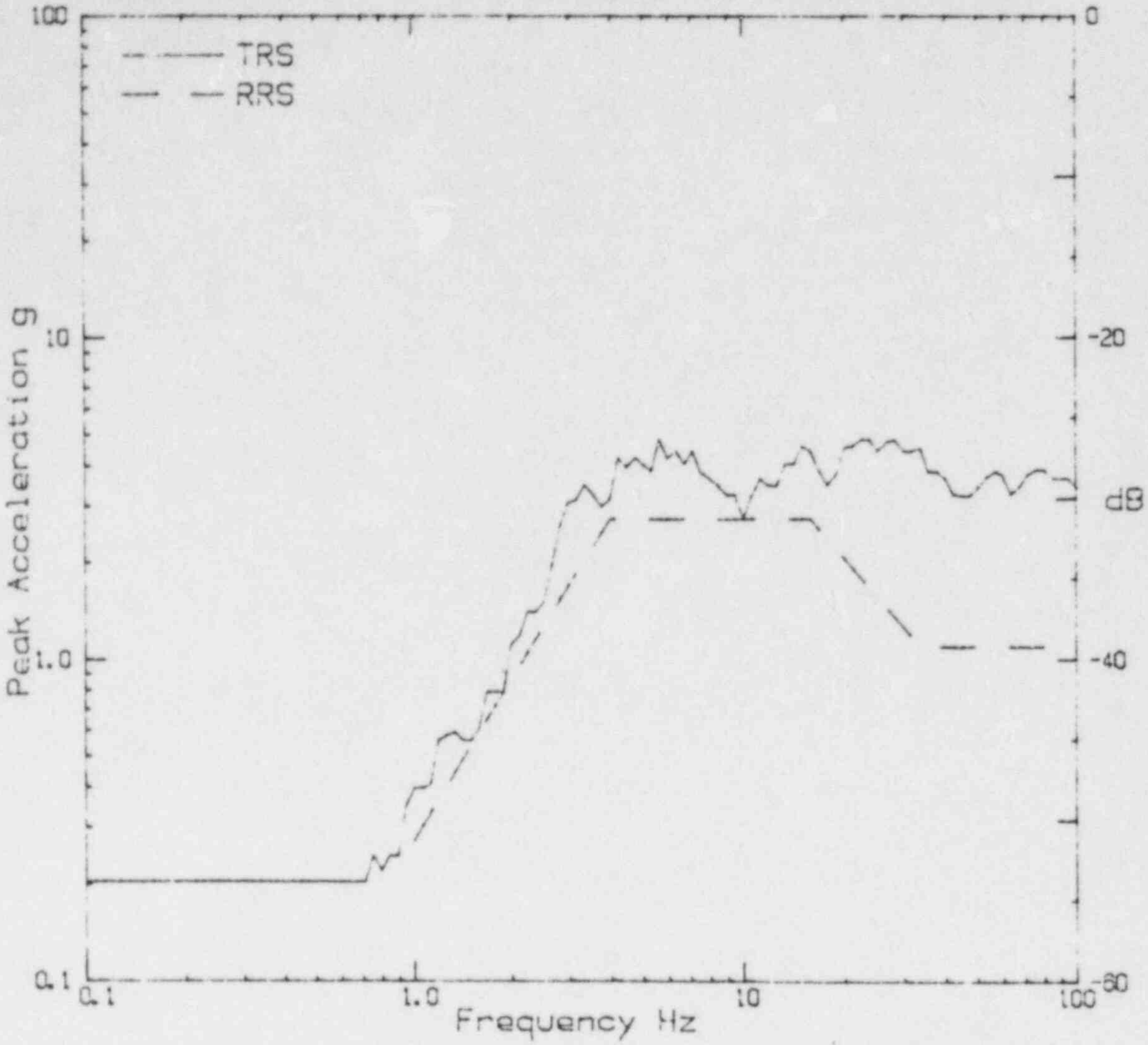
PARTICULARS
March 12/84. Time 10:46. Temp('C) 24. Humidity(%) 39.
Press (kPa) 100.9. Graph 5091

SPECIFICATIONS
Specs IEEE 501. Conditions 3 dummy cells : span 6. one cell broken

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=2.2g

ACCELEROMETER
Wilcoxon. Serial S754. Range dB58. Location top-cell terminal.
TT 670. Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 13 -

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells #30:23:8

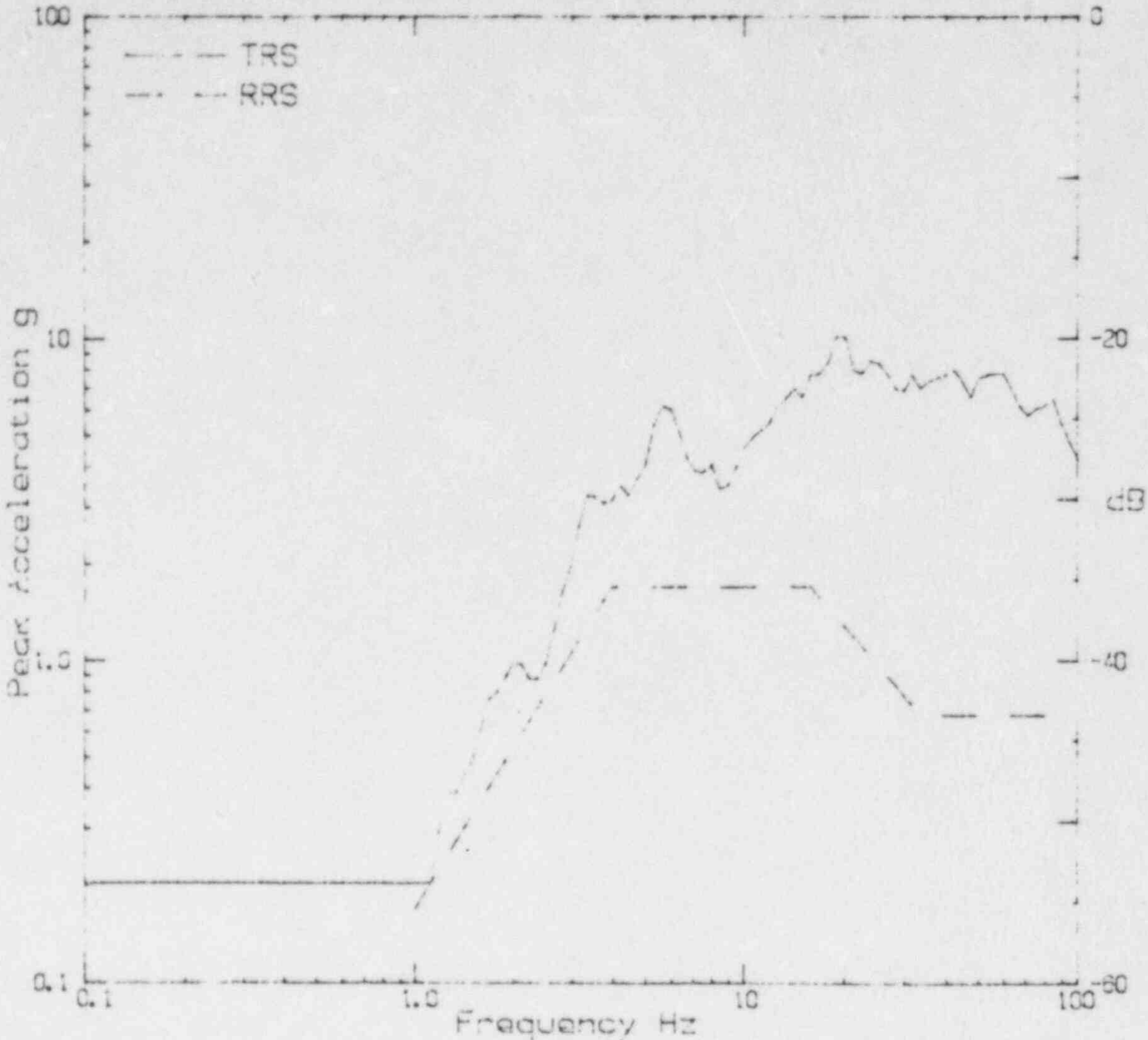
PARTICULARS
March 12/84. Time 9:42. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5092. Record 0

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells :1 dummy. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.1g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting plate.
TT 678. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 14

TEST ITEM
Station Cells & rack, Gould, Model NCX2250 & Gould type rack.
Part cells #30;23;6

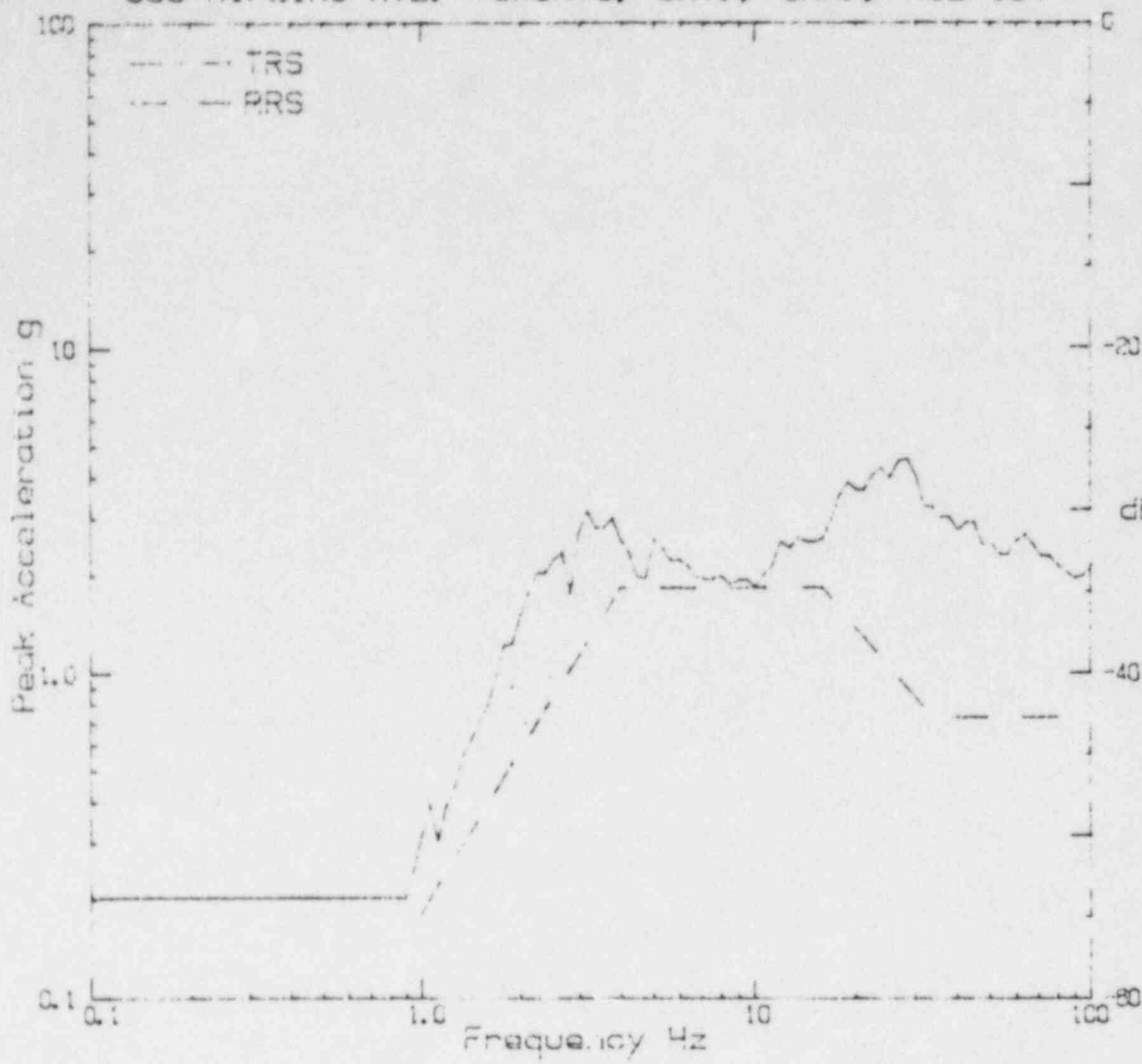
PARTICULARS
March 12/84, Time 3:42, Temp('C) 24, Humidity(%) 39.
Press (kPa)100.9, Graph 5093, Record 0

SPECIFICATIONS
Specs IEEE 501, Conditions 2 live cells ;1 dummy, fragility level

ANALYSIS
Type Maximax, Damping (%)5, B.W.= 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=.68g

ACCELEROMETER
Wilcoxon, Serial 9781, Range dB58, Location base-mounting plate,
TT 678, Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 15

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells #30:23:8

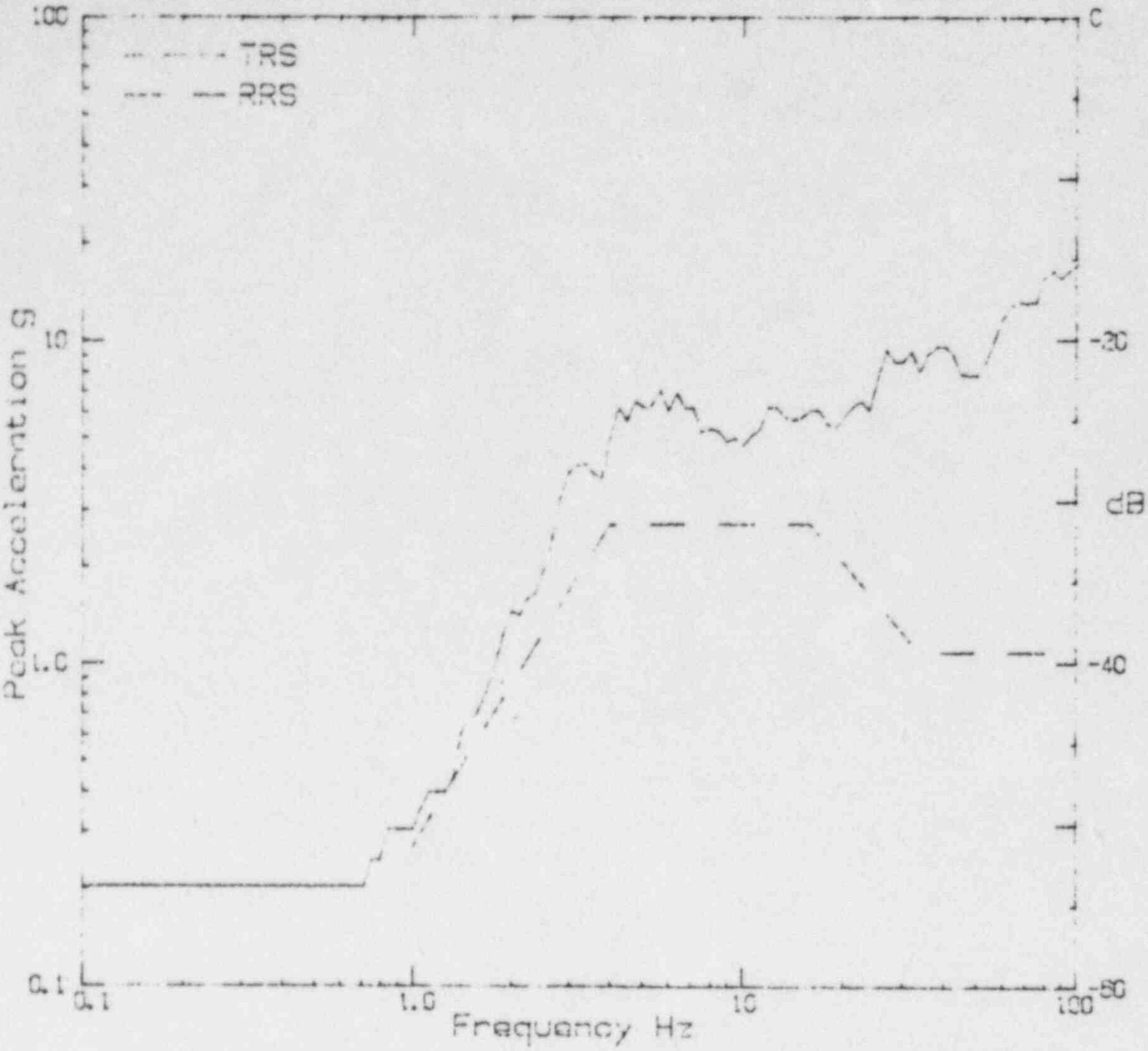
PARTICULARS
March 12.84. Time 3:42. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5094. Record 0

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells :1 dummy. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=.74g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting plate.
TT 578. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 16

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells #30:23:8

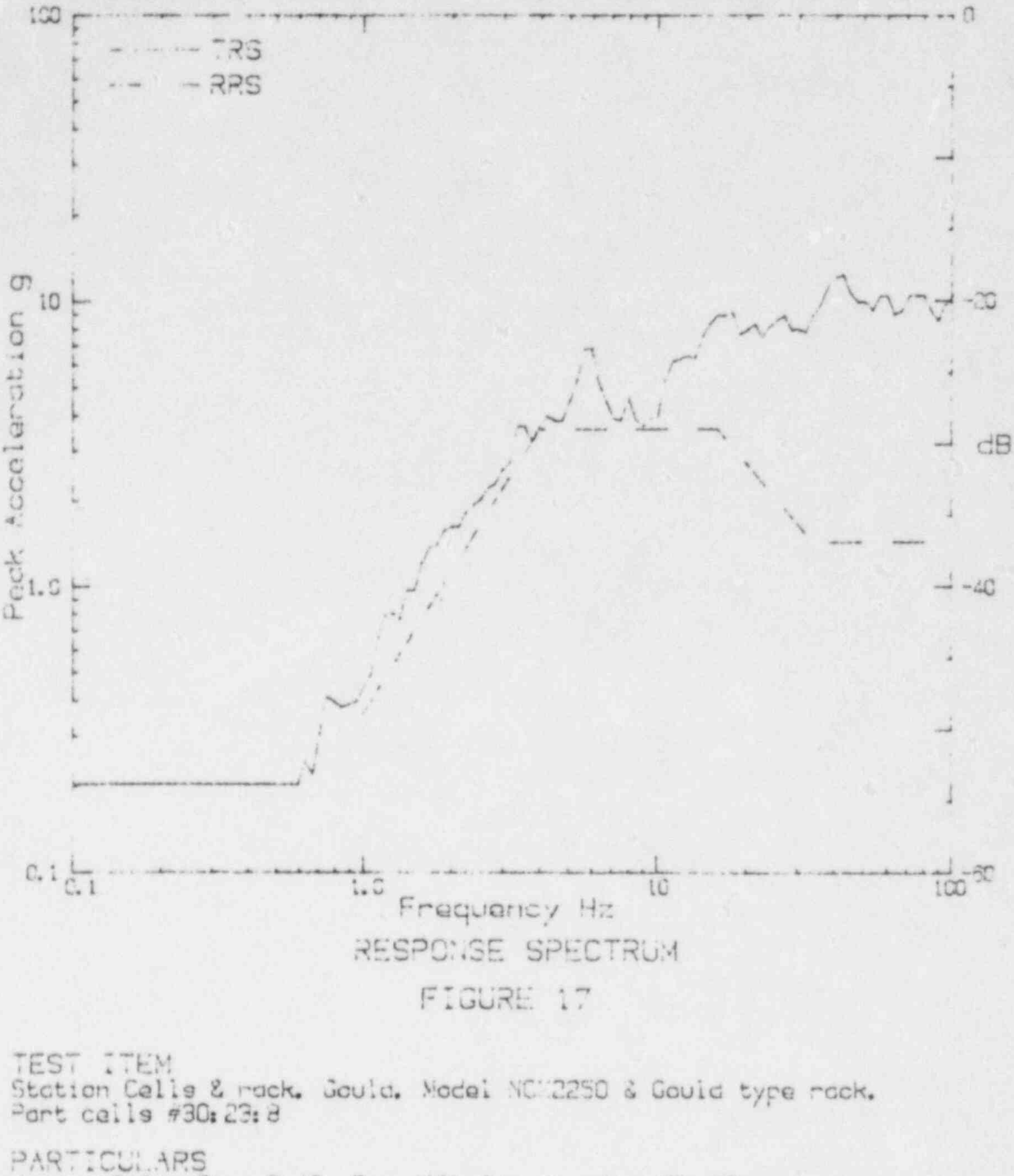
PARTICULARS
March 12/84. Time 3:42. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5095. Record 0

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells :1 dummy. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1.12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.08g

ACCELEROMETER
Wilcoxon. Serial S771. Range dB58. Location top-cell terminal.
TT 678. Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 17

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells #30:23:8

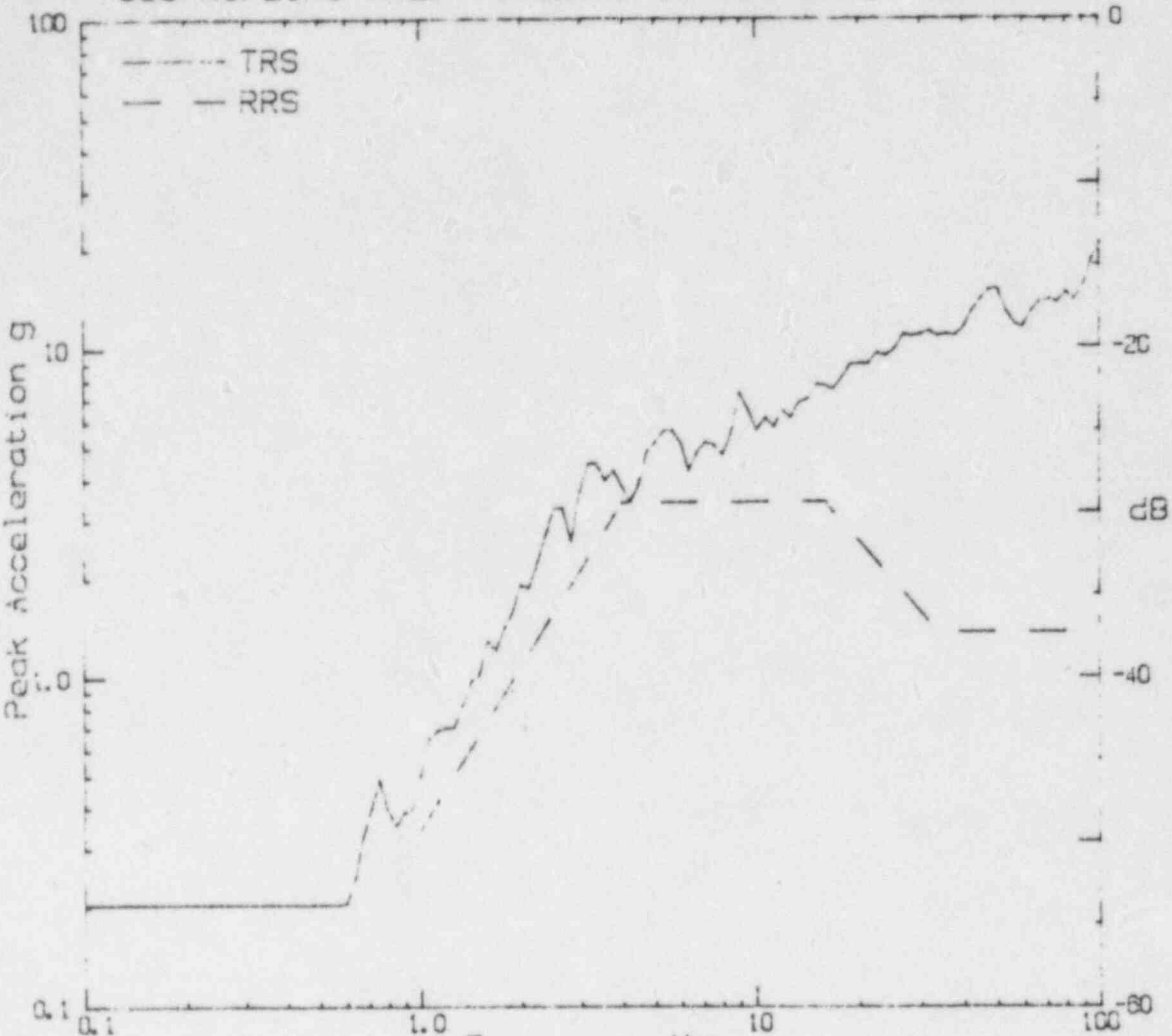
PARTICULARS
March 12/84. Time 3:42. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5096. Record 0

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells :1 dummy. fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.44g

ACCELEROMETER
Wilcoxon. Serial S297. Range 0858. Location top-cell terminal.
TT 378. Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 18

TEST ITEM
Station Cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells #30; 23; 8

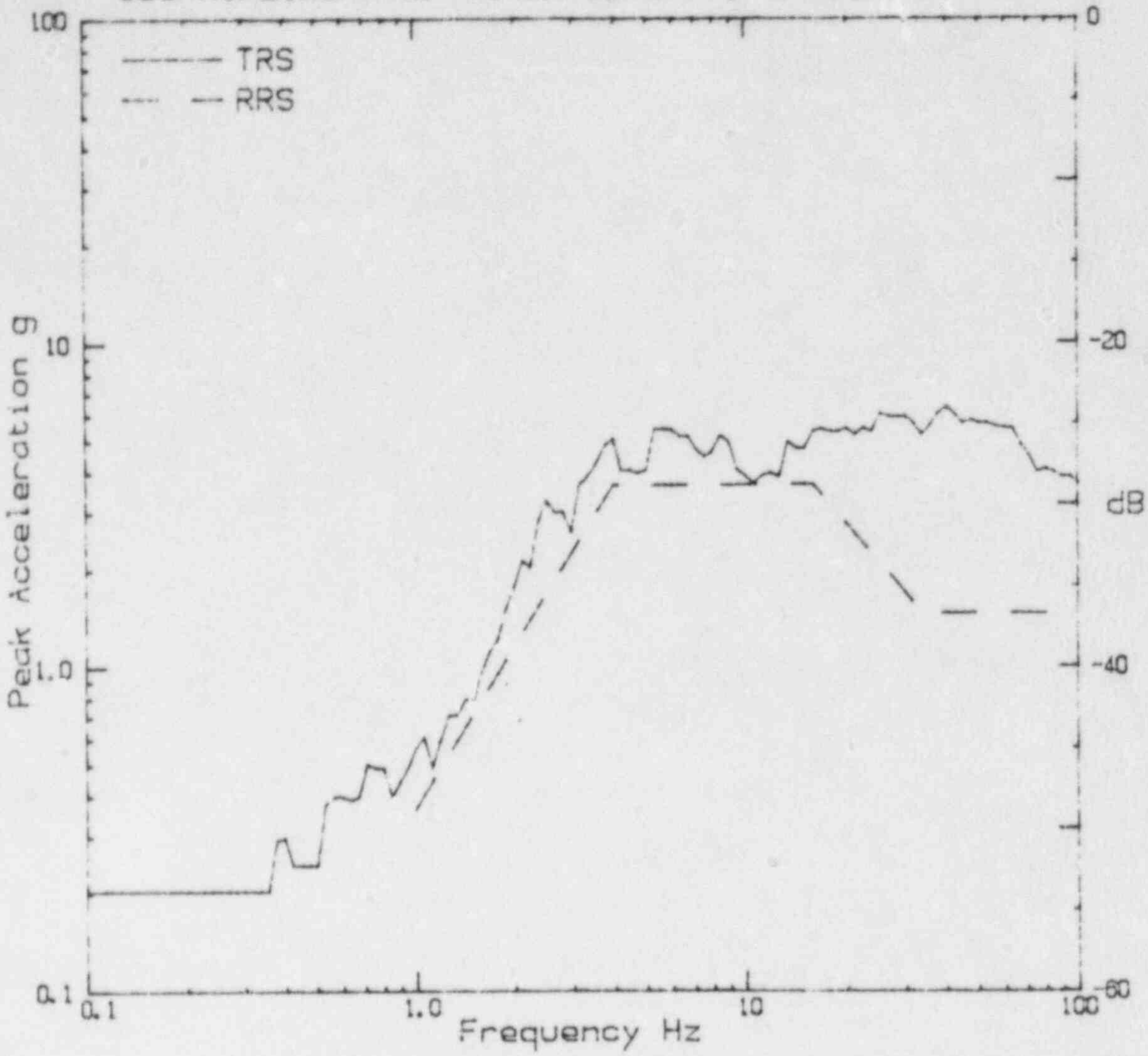
PARTICULARS
March 12/84. Time 9:42. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5097. Record 0

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. Fragility level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=1.37g

ACCELEROMETER
Wilcoxon. Serial S754. Range dB58. Location top-cell terminal.
TT 678. Channel 6

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 19

TEST ITEM
Station cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells 30 . 23 . 8.

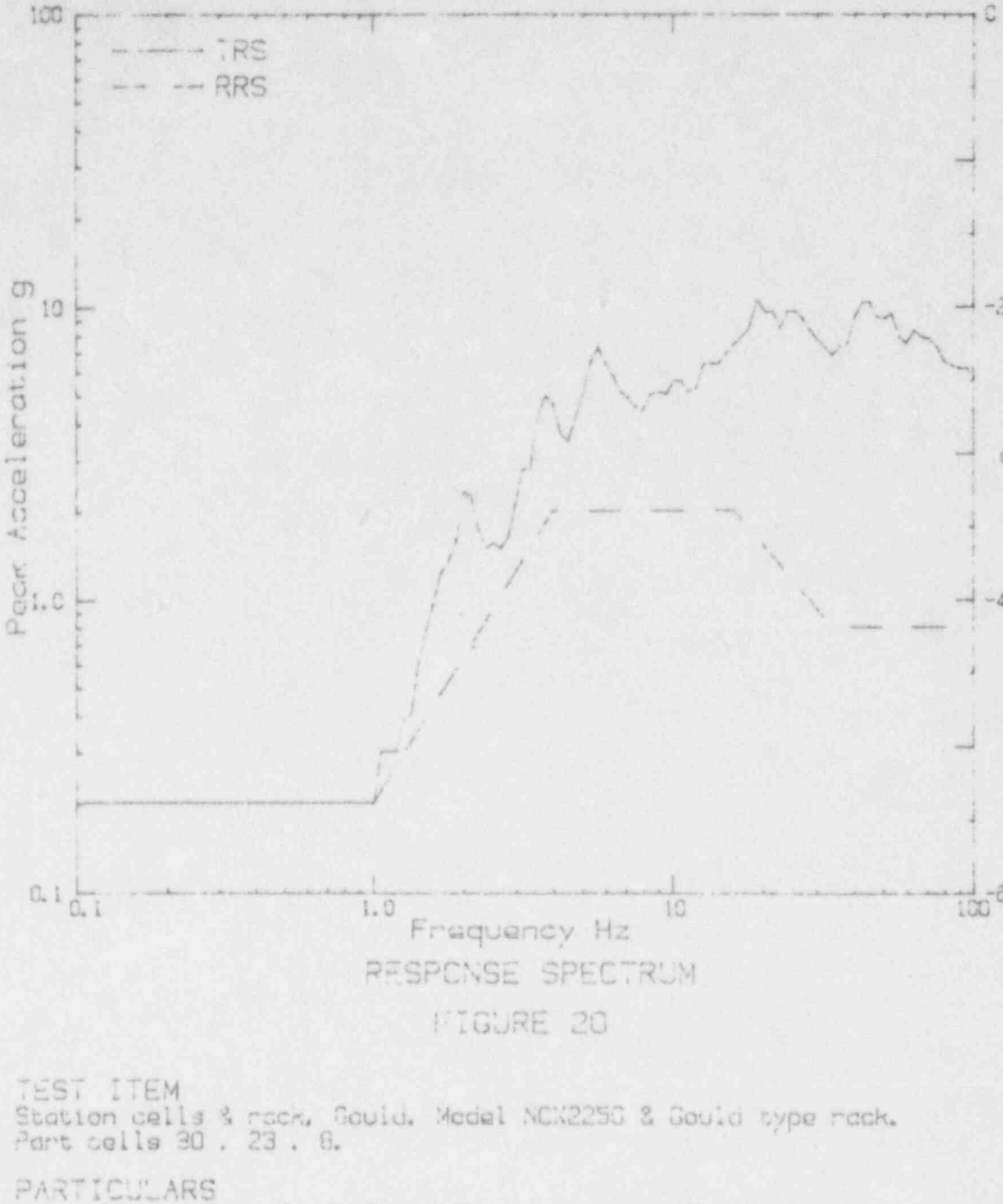
PARTICULARS
March 12/84. Time 3:45. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5098

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. failure level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.47g

ACCELEROMETER
Wilcoxon. Serial S757. Range dB58. Location base-mounting plate.
TT 680. Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 20

TEST ITEM
Station cells & rack, Gould. Model NCX2250 & Gould type rack.
Part cells 30 . 23 . 8.

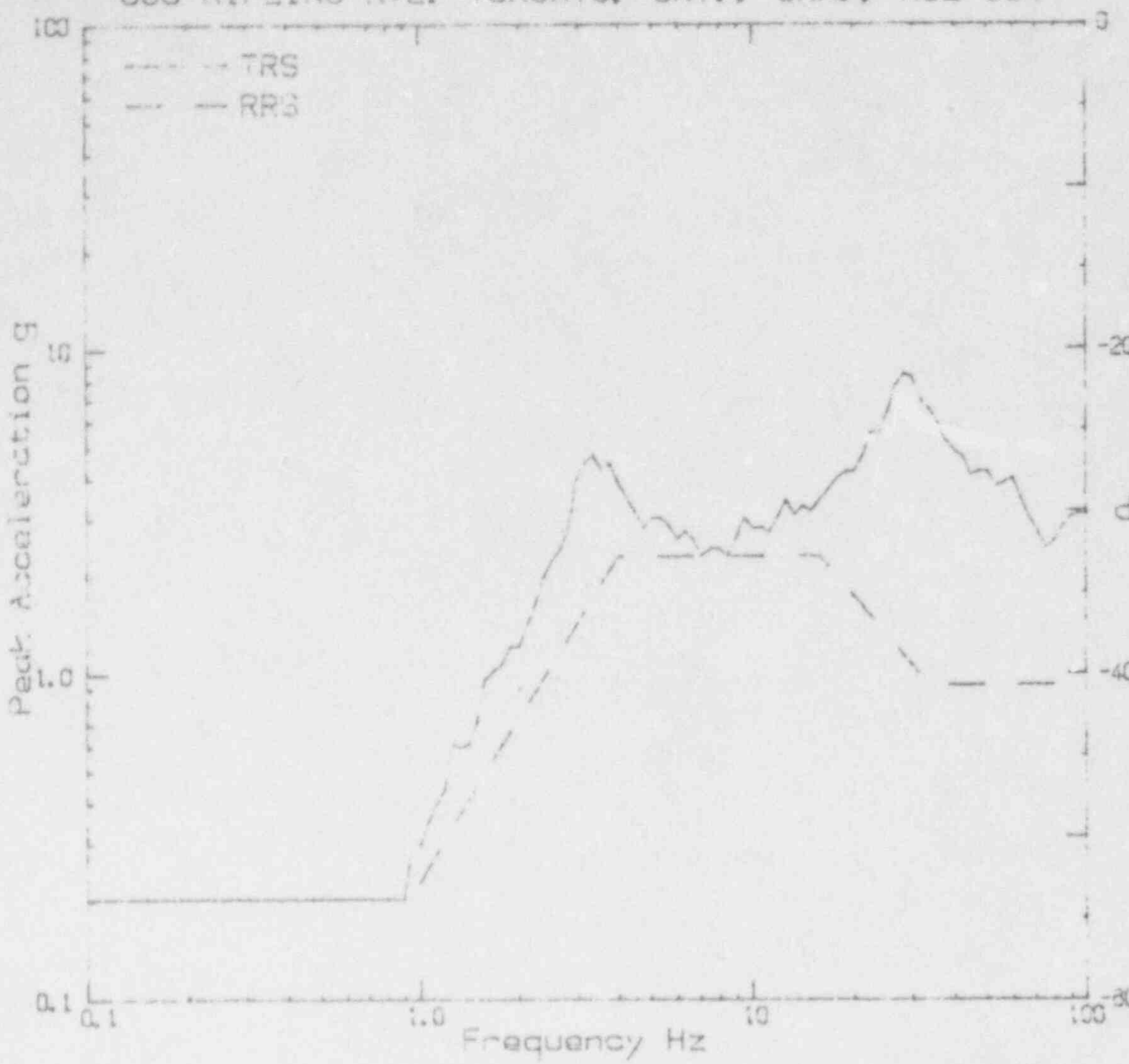
PARTICULARS
March 12/84. Time 3:45. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5099

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. Failure level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=.82g

ACCELEROMETER
Wilcoxon. Serial 3761. Range dB58. Location base-mounting plate.
TT 680. Channel 2

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 21

TEST ITEM
Station cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells 30 , 23 , 8.

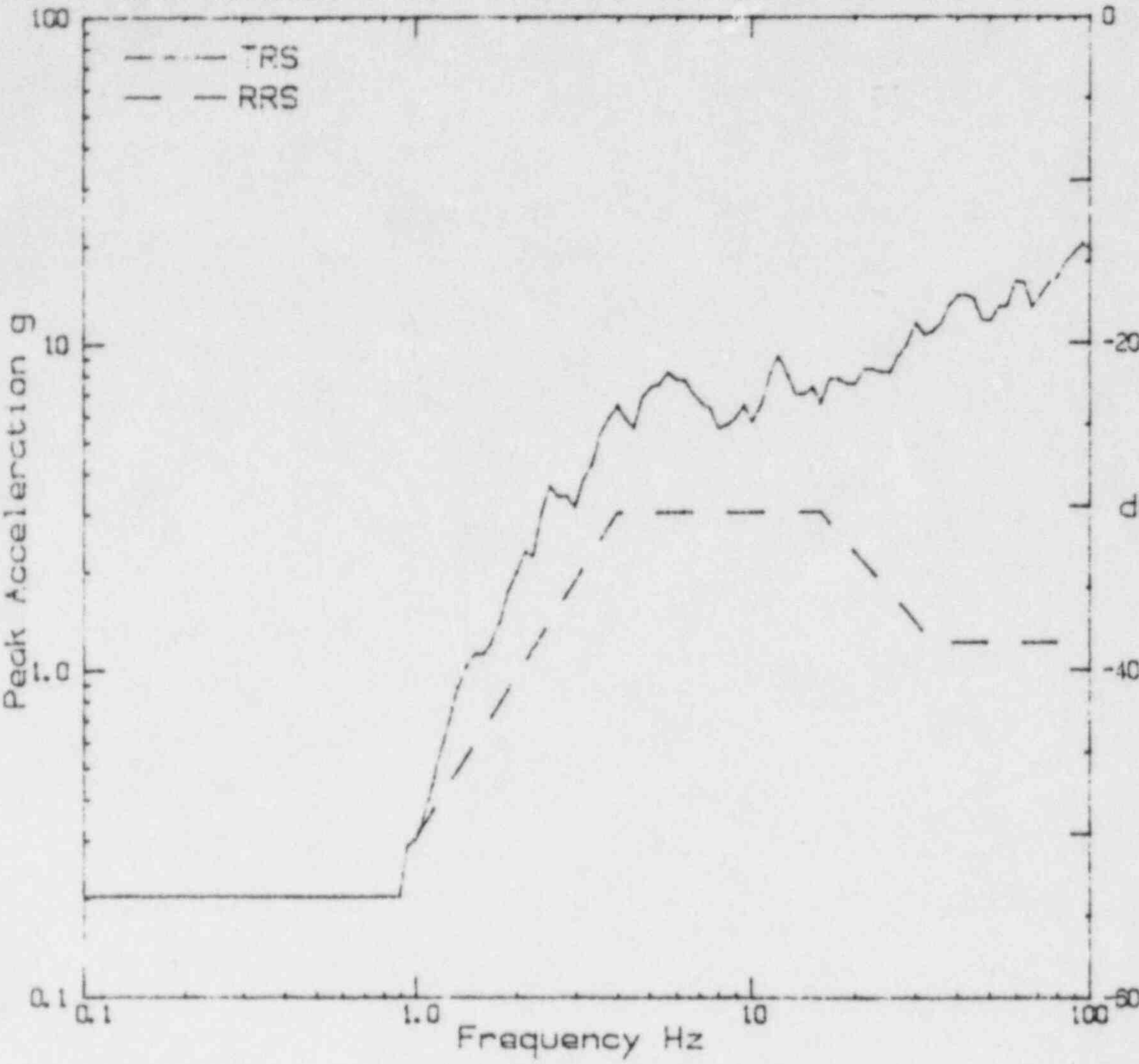
PARTICULARS
March 12/84. Time 9:45. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5100

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. failure level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=.93g

ACCELEROMETER
Wilcoxon. Serial S901. Range dB58. Location base-mounting plate.
TT 680. Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 22

TEST ITEM
Station cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells 30 . 23 . 8.

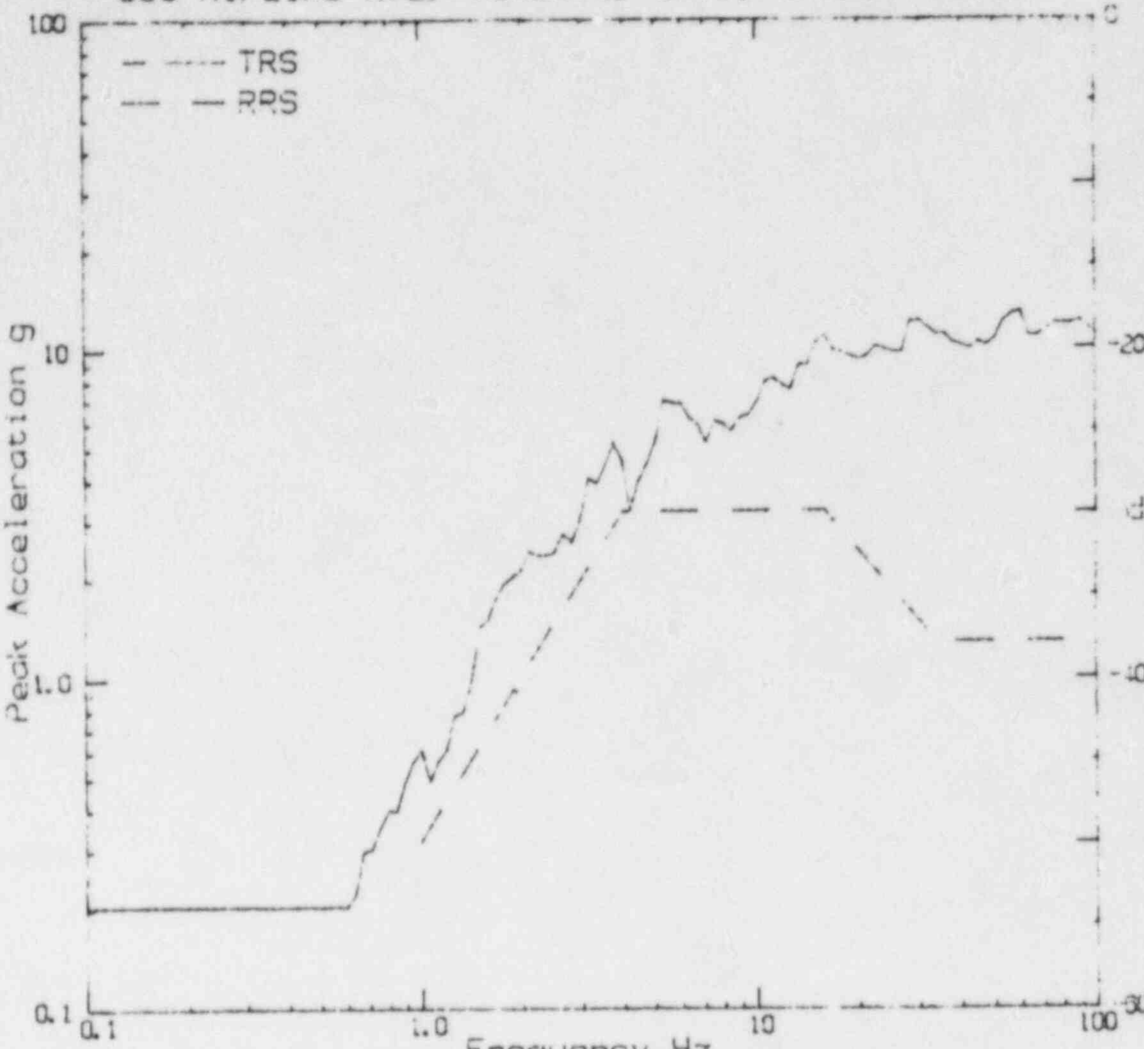
PARTICULARS
March 12/84. Time 3:45. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph S101

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. failure level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis X.
Shaker tri-axial. ZPA=1.22g

ACCELEROMETER
Wilcoxon. Serial S771. Range dB58. Location top-cell terminal.
TT 680. Channel 4

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO. ONT.. CAN.. M8Z 5S4



RESPONSE SPECTRUM

FIGURE 23

TEST ITEM
Station cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells 30 . 23 . 8.

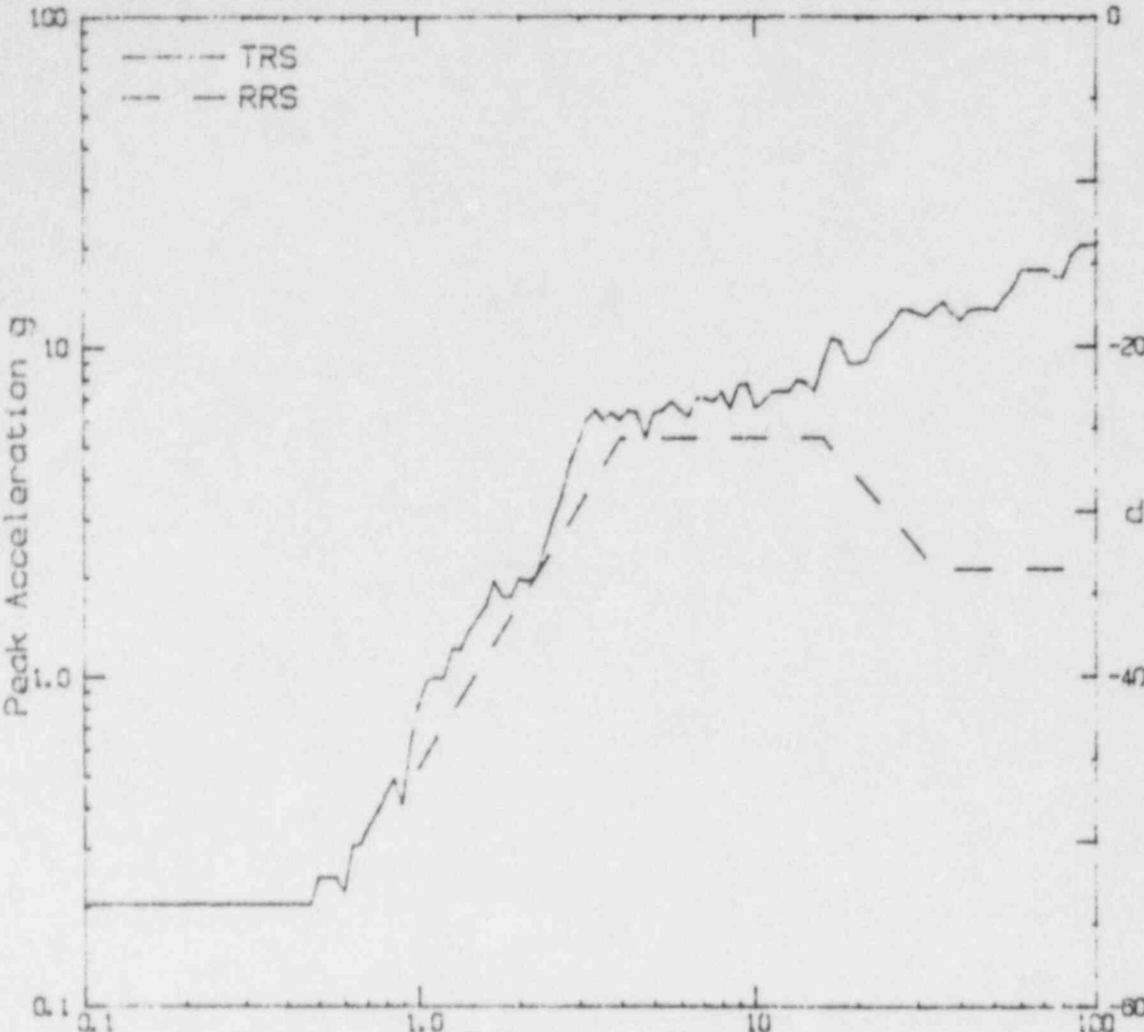
PARTICULARS
March 12/84. Time 3:45. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5102

SPECIFICATIONS
Space IEEE 501. Conditions 2 live cells : 1 dummy. failure level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.29g

ACCELEROMETER
Wilcoxon. Serial 3297. Range dB58. Location top-cell terminal.
TT 680. Channel 5

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 24

TEST ITEM
Station cells & rack. Gould. Model NCX2250 & Gould type rack.
Part cells 30 , 23 , 8.

PARTICULARS
March 12 84. Time 3:45. Temp('C) 24. Humidity(%) 39.
Press (kPa)100.9. Graph 5103

SPECIFICATIONS
Specs IEEE 501. Conditions 2 live cells : 1 dummy. Failure level

ANALYSIS
Type Maximax. Damping (%)5. B.W.= 1/12 Octaves. Axis Z.
Shaker tri-axial. ZPA=2.12g

ACCELEROMETER
Wilcoxon. Serial S754. Range dB58. Location top-cell terminal.
TT 680. Channel 6

DISTRIBUTION

Mr. B.A. Oliver (2)	Design & Development, H12G5
Mr. W.J. Janis	Chemical Research
Mr. J.D. Tulk (10)	Mechanical Research
Mr. D.A. Black	Mechanical Research
Mr. G.D. Paulsen	Mechanical Research

Official Record

DISTRIBUTION:

U.S. NRC Distribution Contractor
15700 Crabbs Branch Way
Rockville, MD 20850
375 copies for RV

Ansaldo Impianti
Centro Sperimentale del Boschetto
Corso F.M. Perrone, 118
16161 Genova
ITALY
Attn: C. Bozzolo

Ansaldo Impianti
Via Gabriele D'Annunzio, 113
16121 Genova
ITALY
Attn: S. Grifoni

ASEA-ATOM
Department KRD
Box 53
S-721 04
Vasteras
SWEDEN
Attn: A. Kjellberg

ASEA-ATOM
Department TQD
Box 53
S-721 04
Vasteras
SWEDEN
Attn: T. Granberg

ASEA KABEL AB
P.O. Box 42 108
S-126 12
Stockholm
SWEDEN
Attn: B. Dellby

Atomic Energy of Canada, Ltd.
Chalk River Nuclear Laboratories
Chalk River, Ontario KOJ 1JO
CANADA
Attn: G. F. Lynch

Atomic Energy of Canada, Ltd.
1600 Dorchester Boulevard West
Montreal, Quebec H3H 1P9
CANADA
Attn: S. Nish

Atomic Energy Research Establishment
Building 47, Division M.D.D.
Harwell, Oxfordshire
OX11 ORA,
ENGLAND
Attn: S. G. Burnay

Bhabha Atomic Research Centre
Health Physics Division
BARC
Bombay-85
INDIA
Attn: S. K. Mehta

British Nuclear Fuels Ltd.
Springfields Works
Salwick, Preston
Lancs
ENGLAND
Attn: W. G. Cunliff, Bldg 334

Brown Boveri Reaktor GMBH
Postfach 5143
D-6800 Mannheim 1
WEST GERMANY
Attn: R. Schemmel

Bundesanstalt fur Materialprufung
Unter den Eichen 87
D-1000 Berlin 45
WEST GERMANY
Attn: K. Wundrich

CEA/CEN-FAR
Departement de Surete Nucleaire
Service d'Analyse Fonctionnelle
B.P. 6
92260 Fontenay-aux-Roses
FRANCE
Attn: M. Le Meur
J. Henry

CERN
Laboratorie 1
CH-1211 Geneve 23
SWITZERLAND
Attn: H. Schonbacher

Canada Wire and Cable Limited
Power & Control Products Division
22 Commercial Road
Toronto, Ontario
CANADA M4G 1Z4
Attn: Z. S. Paniri

Centro Elettrotecnico
Sperimentale Italiano
Research and Development
Via Rubattino 54
20134 Milan,
ITALY
Attn: Carlo Masetti

Commissariat a l'Energie Atomique
ORIS/LABRA
BP N° 21
91190 Gif-Sur-Yvette
FRANCE
Attn: G. Gaussens
J. Chenion
F. Carlin

Commissariat a l'Energie Atomique
CEN Cadarche DRE/STRE
BP N° 1
13115 Saint Paul Lez Durance
FRANCE
Attn: J. Campan

Conductores Monterrey, S. A.
P.O. Box 2039
Monterrey, N. L.
MEXICO
Attn: P. G. Murga

Electricite de France
Service Etudes et Projets Thermiques
et Nucleaires (S.E.P.T.E.N.)
Tour EDF GDF
Cedex N° 8
92080 Paris - La Defense
FRANCE
Attn: M. Herouard
M. Hermant

Electricite de France
Direction des Etudes et Recherches
1, Avenue du General de Gaulle
92141 CLAMART CEDEX
FRANCE
Attn: J. Roubault
L. Deschamps

Electricite de France
Direction des Etudes et Recherches
Les Renardieres
Boite Postale n° 1
77250 MORET SUR LORING
FRANCE
Attn: Ph. Roussarie
V. Deglon
J. Ribot

EURATOM
Commission of European Communities
C.E.C. J.R.C.
21020 Ispra (Varese)
ITALY
Attn: G. Mancini

FRAMATOME
Tour Fiat - Cedex 16
92084 Paris La Defense
FRANCE
Attn: G. Chauvin
E. Raimondo

Furukawa Electric Co., Ltd.
Hiratsuka Wire Works
1-9 Higashi Yawata - 5 Chome
Hiratsuka, Kanagawa Pref
JAPAN 254
Attn: E. Oda

Gesellschaft fur Reaktorsicherheit (GRS) mbH
Glockengasse 2
D-5000 Koln 1
WEST GERMANY
Attn: Library

Health & Safety Executive
Thames House North
Milbank
London SW1P 4QJ
ENGLAND
Attn: W. W. Ascroft-Hutton

ITT Cannon Electric Canada
Four Cannon Court
Whitby, Ontario L1N 5V8
CANADA
Attn: B. D. Vallillee

Imatran Voima Oy
Electrotechn. Department
P.O. Box 138
SF-00101 Helsinki 10
FINLAND
Attn: B. Regnell
K. Koskinen

Institute of Radiation Protection
Department of Reactor Safety
P.O. Box 268
00101 Helsinki 10
FINLAND
Attn: L. Reiman

Instituto de Desarrollo y Diseno
Ingar - Santa Fe
Avellaneda 3657
C.C. 34B
3000 Santa Fe
REPUBLICA ARGENTINA
Attn: N. Labath

Japan Atomic Energy Research Institute
Takasaki Radiation Chemistry
Research Establishment
Watanuki-machi
Takasaki, Gunma-ken
JAPAN
Attn: N. Tamura
K. Yoshida
T. Seguchi

Japan Atomic Energy Research Institute
Tokai-Mura
Naka-Gun
Ibaraki-Ken
319-11
JAPAN
Attn: Y. Koizumi

Japan Atomic Energy Research Institute
Osaka Laboratory for Radiation Chemistry
25-1 Mii-Minami machi,
Neyagawa-shi
Osaka 572
JAPAN
Attn: Y. Nakase

Kraftwerk Union AG
Department R361
Hammerbacherstrasse 12 + 14
D-8524 Erlangen
WEST GERMANY
Attn: I. Terry

Kraftwerk Union AG
Section R541
Postfach: 1240
D-8757 Karlstein
WEST GERMANY
Attn: W. Siegler

Kraftwerk Union AG
Hammerbacherstrasse 12 + 14
Postfach: 3220
D-8520 Erlangen
WEST GERMANY
Attn: W. Morell

Motor Columbus
Parkstrasse 27
CH-5401
Baden
SWITZERLAND
Attn: H. Fuchs

National Nuclear Corporation
Cambridge Road
Whetstone
Leicester LE8 3LH
ENGLAND
Attn: A. D. Hayward
J. V. Tindale

NOK AG Baden
Beznau Nuclear Power Plant
CH-5312 Doettingen
SWITZERLAND
Attn: O. Tatti

Norsk Kabelfabrik
3000 Drammen
NORWAY
Attn: C. T. Jacobsen

Nuclear Power Engineering Test Center
6-2, Toranomon, 3-Chome
Minato-ku
No. 2 Akiyana Building
Tokyo 105
JAPAN
Attn: S. Maeda

Ontario Hydro
700 University Avenue
Toronto, Ontario M5G 1X6
CANADA
Attn: R. Wong
B. Kukreti

Oy Stromberg Ab
Helsinki Works
Box 118
FI-00101 Helsinki 10
FINLAND
Attn: P. Paloniemi

Rappini
ENEA-PEC
Via Arcoveggio 56/23
Bologna
ITALY
Attn: Ing. Ruggero

Rheinisch-Westfallscher
Technischer Uberwachunge-Vereln e.V.
Postfach 10 32 61
D-4300 Essen 1
WEST GERMANY
Attn: R. Sartori

Sydkraft
Southern Sweden Power Supply
21701 Malmo
SWEDEN
Attn: O. Grondalen

UKAEA
Materials Development Division
Building 47
AERE Harwell
OXON OX11 ORA
ENGLAND
Attn: D. C. Phillips

United Kingdom Atomic Energy Authority
Safety & Reliability Directorate
Wigshaw Lane
Culcheth
Warrington WA3 4NE
ENGLAND
Attn: M. A. H. G. Alderson

Waseda University
Department of Electrical Engineering
4-1 Ohkubo-3, Shinjuku-ku
Tokyo
JAPAN
Attn: K. Yahagi

1800 R. L. Schwoebel
1810 R. G. Kepler
1811 R. L. Clough
1812 L. A. Harrah
1812 K. T. Gillen
1813 J. G. Curro
1815 R. T. Johnson
2155 J. E. Gover
2155 O. M. Stuetzer
2525 R. P. Clark
6200 V. L. Dugan
6300 R. W. Lynch
6400 A. W. Snyder
6410 J. W. Hickman
6417 D. D. Carlson
6420 J. V. Walker
6440 D. A. Dahlgren
6442 W. A. Von Riesemann
6444 S. L. Thompson
6445 J. H. Linebarger
6445 L. D. Bustard
6445 C. M. Craft
6446 L. L. Bonzon (20)
6446 W. H. Buckalew
6446 J. W. Grossman
6446 D. B. Hente
6446 F. V. Thome
6446 F. J. Wyant
6447 D. L. Berry
6449 K. D. Bergeron
6450 J. A. Reuscher
8024 M. A. Pound
3141 C. M. Ostrander
3151 W. L. Garner

NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1 REPORT NUMBER (Assigned by TIDC, add Vol No., if any)
NUREG/CR-3923
SAND84-1737

2 TITLE AND SUBTITLE
Test Series 1: Seismic-Fragility Tests of Naturally-Aged Class 1E Gould NCX-2250 Battery Cells

3 LEAVE BLANK

4 DATE REPORT COMPLETED
MONTH: August YEAR: 1984

5 AUTHOR(S)
Lloyd L. Bonzon
Donald B. Hente

6 DATE REPORT ISSUED
MONTH: September YEAR: 1984

7 PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Qualification Methodology Assessment Division 6446
Sandia National Laboratories
Albuquerque, New Mexico 87185

8 PROJECT/TASK/WORK UNIT NUMBER

9 FIN OR GRANT NUMBER
NRC FIN No. A-1051

10 SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)
Electrical Engineering, Instrumentation and Control Branch
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a TYPE OF REPORT

b PERIOD COVERED (Inclusive dates)

12 SUPPLEMENTARY NOTES

13 ABSTRACT (200 words or less)

The seismic-fragility response of naturally-aged, nuclear station, safety-related batteries is of interest for two reasons: 1) to determine actual failure modes and thresholds and 2) to determine the validity of using the electrical capacity of individual cells as an indicator of the "end-of-life" of a battery, given a seismic event. This report covers the first test series of an extensive program using 12-year old, lead-calcium, Gould NCX-2250 cells, from the James A. Fitzpatrick Nuclear Power Station operated by the New York Power Authority.

Seismic tests with three cell configurations were performed using a triaxial shake table: single-cell tests, rigidly mounted; multi-cell (three) tests, mounted in a typical battery rack; and single-cell tests specifically aimed towards examining propagation of pre-existing case cracks. In general the test philosophy was to monitor the electrical properties including discharge capacity of cells through a graduated series of g-level step increases until either the shake-table limits were reached or until electrical "failure" of the cells occurred.

Of nine electrically active cells, six failed during seismic testing over a range of imposed g-level loads in excess of a 1-g ZPA. Post-test examination revealed a common failure mode, the cracking at the abnormally brittle, positive lead bus-bar/post interface; further examination showed that the failure zone was extremely coarse grained and extensively corroded. Presently accepted accelerated-aging methods for qualifying batteries, per IEEE Std. 535-1979, are based on plate growth, but these naturally-aged 12-year old cells showed no significant plate growth.

While cracks were propagated and leaks were observed in the propagation tests at high g-levels, it appears that this failure mechanism was less significant than the bus-bar/post interface failures.

14 DOCUMENT ANALYSIS - a KEYWORDS/DESCRIPTORS

b IDENTIFIERS/OPEN-ENDED TERMS

15 AVAILABILITY STATEMENT
Unlimited

16 SECURITY CLASSIFICATION
(This page) U
(This report) U

17 NUMBER OF PAGES
226

18 PRICE

☆U.S. GOVERNMENT PRINTING OFFICE:1984—776-027/4380

120555078877 1 LANIRV
US NRC
ADM-DIV OF TIDC
POLICY & PUB MGT BR-PDR NUREG
W-501
WASHINGTON DC 20555