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An Evaluation of Methodology for Seismic Qualification of Equipment, Cable Trays, and Ducts in ALWR Plants by Use of Experience Data

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Prepared by
K. K. Bandyopadhyay, D. D. Kaña, R. P. Kennedy, A. J. Schiff

Brookhaven National Laboratory

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Prepared by
K. K. Bandyopadhyay, D. D. Kaña, R. P. Kennedy, A. J. Schiff

Brookhaven National Laboratory
Upton, NY 11973

R. Kenneally, NRC Project Manager

Prepared for
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
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ABSTRACT

Advanced Reactor Corporation (ARC) has developed a methodology for seismic qualification of equipment, cable trays and ducts in Advanced Light Water Reactor plants. A Panel (members of which acted as individuals) supported by the Office of Nuclear Regulatory Research of the Nuclear Regulatory Commission has evaluated this methodology. The review approach and observations are included in this report. In general, the Panel supports the ARC methodology with some exceptions and provides recommendations for further improvements.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

Advanced Reactor Corporation (ARC) has proposed a methodology for seismic qualification of equipment in Advanced Light Water Reactor (ALWR) plants by use of experience data. In addition, ARC has proposed a design-by-rule method for qualification of electrical cable trays and conduits, and heating, ventilation and air conditioning (HVAC) ducts. These qualification methodologies are evaluated in this report by an independent Panel (members of which acted as individuals) supported by the Office of Nuclear Regulatory Research of the Nuclear Regulatory Commission (NRC).

ARC Methodology

The requirements for seismic qualification are specified for nine classes of equipment (horizontal pumps, vertical pumps, motor-operated valves, air-operated valves, manual and check valves, temperature sensors, diesel generators, transformers, and batteries on racks). These equipment classes are divided into two groups depending on the potential for applying seismic experience data. Seven equipment classes are categorized as Group 1 and the other two as Group 2. Specifications of products in each of the nine equipment classes are provided based on experience data. Known vulnerabilities are avoided through procurement specifications and the need of additional analyses is identified.

Equipment classes may be qualified to either or both of two excitation levels: Level A and Level B. Level A with a 5% damped spectral acceleration of 1.2 g is the lower of the two levels and the same as the Reference Spectrum developed by the Senior Seismic Review and Advisory Panel (SSRAP). Unlike Level A, Level B varies depending on the specific equipment class.

The qualification method for cable trays, conduits and HVAC ducts is a simplified analytical technique and draws support from experience data.

Panel's Evaluation

In order to evaluate the ARC methodology, the Panel has developed a review approach by expanding on current practice as embodied in the NRC Regulatory Guide, Standard Review Plan and IEEE Std. 344. The fundamental objective is to ensure functionality of equipment. Emphasis is given on examining a large number of diverse products and screening out vulnerabilities through procurement specifications. Group 1 equipment classes should be selected such that structural integrity alone can demonstrate their functionality. Thus, structural analysis plays an important role in Group 1 equipment qualification. Caution needs to be exercised for the Group 2 equipment class selection such as to assure sufficient knowledge of malfunction mechanisms. The qualification (excitation) level may vary depending on equipment class definitions. For example, if a candidate equipment class is defined in strict conformance to equipment descriptions in an experience data set, the qualification level may be as high as the experience base excitation level. On the other hand, if the candidate equipment class is not defined in strict conformance to the equipment descriptions of the data set, the qualification level may need to be reduced. It is acknowledged that judgments may need to be used almost at every level of the qualification process while using experience data. Thus, an independent peer review of the qualification is an essential element of the process.

In general, the Panel observes that the ARC methodology conforms to its review approach. However, the Panel does not support the Level B qualification for the battery cells. For several classes of equipment, the documentation of equipment is poor and could be improved. Regarding the synergetic effect of aging and seismic qualification, the Panel recognizes this to be a complicated issue and has not done a detailed review. The ARC report provides only a short paragraph on this subject.

On qualification of trays and conduits, the Panel strongly supports the proposed methodology and judges that their seismic performance will be at least as good, and possibly better than current systems using existing designs that emphasize very stiff supports.

The ARC approach for HVAC is still in the conceptual state and will require further development before it can be implemented for design of ALWR plants. Nevertheless, the Panel fully supports the idea of design-by-rule for HVAC ducts.

The ground motion estimates of past earthquake events for which equipment performance data were used by ARC, have been independently verified by a consultant to the Panel and found to be reasonable.

In order to provide guidance for potential future qualification efforts, the Panel has also included an appendix which describes some fundamental concepts for seismic qualification of equipment by use of experience data.*

Conclusions

The Panel believes that the ARC methodology is a cost-effective approach for seismic qualification of equipment without compromising safety. The Panel encourages collection of additional data, specifically including experience on damage, and emphasizes the need for independent peer review especially to verify judgments used in the qualification process.

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*One Panel member, K. Bandyopadhyay, does not agree with these concepts.

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The authors wish to express great appreciation for the support and direction provided by the NRC Program Managers[1] Mr. Roger Kenneally, Dr. John O'Brien (retired) and Dr. Nilesh Chokshi. Interaction with other NRC staff[1], Drs. Pei-Ying Chen and Shou-Nien Hou, was beneficial for the program and is also very much appreciated. The technical contribution made by Dr. David Boore of the United States Geological Survey in estimating earthquake ground motions at experience data sites is gratefully acknowledged.

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Mr. Rush Horton, ABB
Mr. Mike DeEstrada, Nuclear Logistics (GNB)
Mr. Manahar Patel, Yuasa-Exide, Inc.
Mr. Graham Walker, C&D Charter Power System, Inc.

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[1] Participation of the NRC staff does not constitute NRC endorsement with regard to either the contents or the conclusions in this report or the referenced Advanced Reactor Corporation documents.

The ARC Review Panel consisted of the following members:

Mr. James Thomas, Duke
Mr. John Reynolds, Southern Nuclear Operating Company
Mr. Donald Moore, Southern Company Services
Mr. Neil P. Smith, Commonwealth Edison
Mr. Harv Henneman. Wisconsin Electric

Lastly, the authors wish to thank Mrs. Linda Hanlon for her dedication and secretarial assistance in preparing this report.

CHAPTER 1
INTRODUCTION

1.1 Background

For seismic design and qualification of equipment in Advanced Light Water Reactor (ALWR) plants, the industry (Advanced Reactor Corporation [ARC]) has proposed to use seismic experience data. In the past, the NRC accepted the use of experience data for verification of seismic adequacy of equipment in older operating plants (Reference 1.1). IEEE Std 344-1987 (Reference 1.2) allows the use of experience data for seismic qualification but does not provide enough guidance and specific acceptance criteria that are needed for implementation of the approach. In order to develop acceptance criteria for use of experience data for seismic qualification of ALWR equipment, and evaluate the industry approach, the NRC Office of Nuclear Regulatory Research has convened an independent Panel of outside experts[1] (who acted as individuals). Initially, the Panel developed a set of broad guidelines and acceptance criteria for use of experience data (Reference 1.3). The Panel held several meetings with the industry and evaluated their draft reports as the data analysis was performed and these documents were developed. Ultimately, the industry issued their final report (Reference 1.4) and the Panel reviewed it. The review findings and recommendations of the Panel are included in this report.

In addition, the industry developed simplified rules for design of distribution systems consisting of cable trays, conduits and ducts (References 1.5 and 1.6). The Panel reviewed these reports. The Panel's findings and recommendations are also included in this report.

1.2 ARC Methodology for Seismic Qualification of Equipment

The methodology used by ARC for seismic qualification of equipment in ALWR plants is primarily based on equipment characteristics, experience data and judgments. Performance of equipment in past earthquakes is a major source of the experience data. ARC has made use of earthquake experience data previously obtained by Electric Power Research Institute (EPRI, Reference 1.7) and collected additional data for the ALWR project. An important addition is the data from the 1994 Northridge earthquake. Testing of equipment performed in the past for seismic qualification and other purposes is another source of the experience data. ARC has made use of the results of an existing EPRI study for this purpose (Reference 1.8).

The ARC qualification for ALWR equipment consists of grouping of equipment classes,

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[1] The Panel members are Kamal K. Bandyopadhyay, Daniel D. Kana, Robert P. Kennedy and Anshel J. Schiff.

reviewing currently available experience data, establishing qualification excitation levels, defining product and installation specifications, and prescribing additional qualification requirements, such as structural and mounting analyses. These topics are briefly discussed in the following subsections.

1.2.1 Equipment Classes and Grouping

The ARC report (Reference 1.4) provides requirements for seismic qualification of the following classes of equipment:

1. Horizontal Pumps
2. Vertical Pumps
3. Motor-operated Valves
4. Air-operated Valves
5. Manual and Check Valves
6. Temperature Sensors
7. Diesel Generators
8. Transformers
9. Batteries on Racks

For seismic qualification purposes, these equipment classes have been divided into two groups. Items 1 through 7 belong to Group 1, and items 8 and 9 belong to Group 2. Group 1 equipment has been characterized in the ARC report as having "a mature design, with little design variability over time, and demonstrable inherent seismic ruggedness." Group 2 equipment has been defined as having "a mature design, with little design variability over time, and with well-known and well-understood structural response to seismic motions." Further, it is maintained in the ARC report that "Group 2 equipment may have ... potential seismic vulnerabilities, or malfunction mechanisms..." The ARC report mentions a third group of equipment which has more design variability and potential operability issues or a lack of well documented experience data. Seismic qualification of this group of equipment has not been addressed in the ARC report.

1.2.2 Excitation Level

In general, each equipment class has been qualified for up to two excitation levels expressed in terms of response acceleration spectra. Level A is the lower of the two excitation levels and is the same for all equipment classes. This level is characterized by the "Reference Spectrum" (Figure 1.1) developed by the Senior Seismic Review and Advisory Panel based on estimates of ground motion at several facilities that experienced severe earthquakes in the past (Reference 1.9). Level B is the higher level, and unlike Level A, Level B varies and depends on the equipment class. This level has been established by reviewing past shake table test data, requiring additional structural analysis and/or by use of judgments based on, for example,

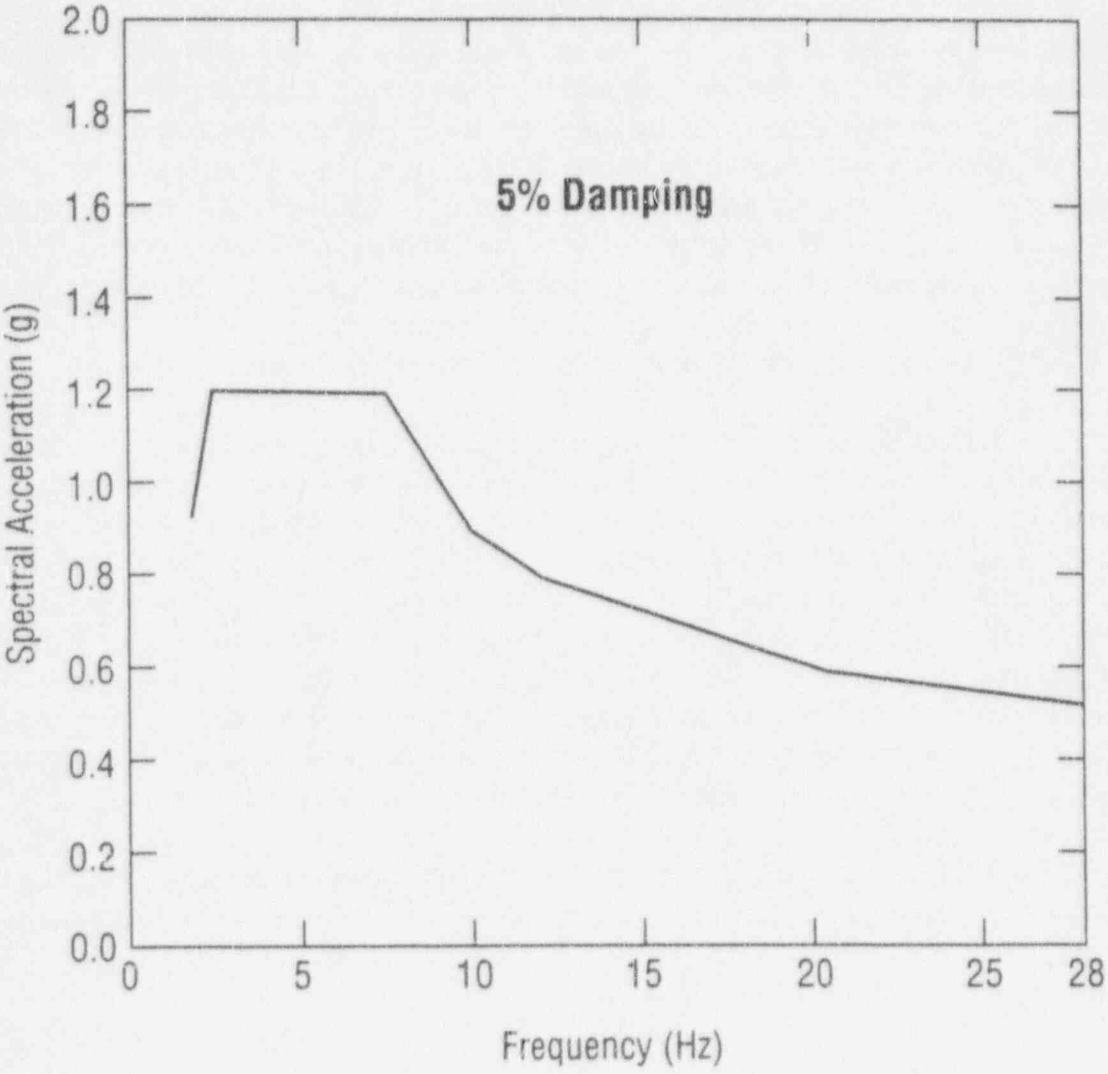

Figure 1.1 Reference Spectrum (Reference 1.9)

knowledge of equipment vulnerabilities, intrinsic strength and operating loads.

1.2.3 Qualification Requirements

The qualification requirements for each of the nine classes of equipment have been specified in the ARC report. Obviously, the requirements are more stringent for Level B excitation level compared to Level A. The requirements in the form of product specifications, installation procedures, mounting calculations and/or structural analyses have been derived from review of the experience data, discussions with manufacturers and testing engineers, and judgments. The primary objectives are to preclude any known or potential vulnerabilities in the product design and installations, and to restrict the products to the experience data characteristics. If a future equipment item for the ALWR satisfies the specified requirements, the particular item will be considered qualified for up to the pertinent excitation level (i.e., Level A or Level B).

1.3 ARC Methodology for Seismic Design of Raceway and Conduit System

Post-earthquake evaluations of raceway and conduit systems in industrial facilities have demonstrated that standard industrial practices have performed very well. Raceways and conduit have performed well under a wide variety of ground motions, of buildings in which systems are installed, and of raceway and conduit configurations. The key features of this good performance have been attributed to 1) supports that do not apply moments or prying action to support anchors, 2) substantial margin in the dead load design, and 3) an overall dynamic system response that exhibits high damping. To meet the needs for the nuclear industry, the following requirements have also been addressed: 1) adequate clearance between the suspended systems and nearby sensitive safe shutdown equipment, and 2) differential deflections that might be imposed when raceway or conduit systems are supported on independent support structures.

The Design-by-Rule method described in Reference 1.5 addresses these design objectives by imposing the following requirements and checks:

- Mandate the use of applicable codes and standards.
- Provide guidance for clearances to accommodate swinging of the suspended system.
- Make provisions for differential displacements between support structures.
- Limit the span length between supports.
- Limit the cable load that can be placed on the trays or conduit.
- Limit the allowable seismic excitation level for which the methodology can be applied.
- Identify installation practices that increase system vulnerabilities so that they can be avoided.
- Discuss acceptable types of supports.

- Specify support capacities.

1.4 ARC Methodology for Seismic Design of HVAC Ducts and Support Systems

ARC has presented a concept for seismic design of heating, ventilation and air conditioning (HVAC) ducts and their support systems (Reference 1.6). The idea is to define a set of simplified rules that can be used for design and installation of the ducts. Design principles for both safety-related and nonsafety-related ducts are included in the ARC report.

1.5 Report Organization

The findings of the Panel are included in the remainder of this report. Chapter 2 presents a general evaluation of the ARC report on equipment (Reference 1.4) including the relationship of the ARC methodology to the current criteria for seismic qualification of equipment. Specific evaluation comments for each of the aforementioned equipment classes are included in Chapter 3. Evaluation comments on electrical raceways and conduits (Reference 1.5) are presented in Chapter 4. Chapter 5 provides the comments on the HVAC ducts and support systems (Reference 1.6). Additional discussions on excitation and equipment similarity, and qualification level are presented in Appendix A and B, respectively. A consultant[2] to the Panel on seismology has performed independent estimates of ground motions for some of the data base sites. The results are included in Appendix C.

References

1.1 Generic letter 87-02, Supplement No. 1 transmitting Supplemental Safety Evaluation Report No. 2 (SSER#2) on SQUG Generic Implementation Procedure, Revision 2 as corrected on February 14, 1992 (GIP-2), Nuclear Regulatory Commission, May 22, 1992.

1.2 IEEE Standard 344-1987, "Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations".

1.3 "An Evaluation of the Industry Approach on the Seismic Qualification of Equipment in ALWR Plants," NRC Panel on Seismic Qualification of ALWR Equipment, May 1993.

1.4 "Advanced Light Water Reactor (ALWR) First-Of-A-Kind Engineering Project on Equipment Seismic Qualification," prepared by MPR Associates and EQE International for Advanced Reactor Corporation, February, 1996.

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[2] David Boore, USGS

1.5 "Advanced Light Water Reactor (ALWR) First-Of-A-Kind Engineering (FOAKE) Project on Design-by-Rule for Cable Tray and Conduit Systems," prepared by EQE International for Advanced Reactor Corporation, January, 1996.

1.6 "Advanced Light Water Reactor (ALWR) First-Of-A-Kind Engineering (FOAKE) Project on Design by Rule for HVAC Ducting and Supports," prepared by EQE International for Advanced Reactor Corporation, April, 1995.

1.7 EPRI Report NP-7149, "Summary of the Seismic Adequacy of Twenty Classes of Equipment Required for the Safe Shutdown of Nuclear Plants," prepared by EQE Engineering Consultants, March 1991.

1.8 EPRI Report NP-5223, Revision 1, "Generic Seismic Ruggedness of Power Plant Equipment," prepared by ANCO Engineers, August 1991.

1.9 Kennedy, R.P., et al., "Part I: Use of Seismic Experience and Test Data to Show Ruggedness of Equipment in Nuclear Power Plants, Part II: Review Procedure to Assess Seismic Ruggedness of Cantilever Bracket Cable Tray Supports," Sandia National Laboratory, Report No. SAND92-0140, June 1992.

CHAPTER 2
GENERAL EVALUATION OF EQUIPMENT SEISMIC QUALIFICATION

2.1 Introduction

In this Chapter, the equipment seismic qualification methodology and the implementation technique as proposed in the ARC document (Reference 2.1) are evaluated in general terms.[3] First, the ARC approach is compared with the current practice for seismic qualification and examined to verify whether and to what extent this approach conforms to the current criteria. The strengths and weaknesses of the ARC approach are also identified. Next, the implementation technique including the characteristics of the experience data is evaluated and the Panel's general observations are presented.

2.2 ARC Approach and Its Relationship to Current Practice and Criteria

Seismic qualification of equipment provides high confidence that it will perform the intended function for a given earthquake level. Currently, for nuclear power plants, this is achieved by following guidance of the NRC Regulatory Guide 1.100 (Reference 2.2), Standard Review Plan (Reference 2.3), IEEE Std 344-1987 (Reference 2.4) and a few other industry standards very specific for certain equipment (e.g., Reference 2.5). In order to meet the intent of the current criteria in using the experience data for seismic qualification, at the initiation of the ARC program, the Panel provided a set of broad recommendations (Reference 2.6).

All these documents allow seismic qualification by use of the similarity method which requires comparison of the candidate equipment items and excitation levels with similar information for equipment that has already successfully experienced a specific excitation level. In using the experience data, demonstration of both physical and excitation similarity can be addressed by defining a grouping technique that includes a graded approach commensurate with equipment characteristics and our knowledge (and lack thereof) about them. The essence of the criteria of the fore-cited documents is that a seismic qualification approach should be considered acceptable as long as it demonstrates functionality of the candidate equipment items. This implies the need for knowledge of potential vulnerabilities for malfunction in a vibratory environment. In the past two decades, extensive studies have been performed to understand the equipment characteristics and its performance in vibratory environments including past earthquakes, shake table testing and computer simulation (References 2.7 - 2.13). Some guidance in using experience

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[3] Similar evaluations of the raceway and ducts are provided in Chapters 4 and 5, respectively.

data for qualification has also been provided (Reference 2.14). These studies have identified robustness of certain equipment types and vulnerabilities of others by clearly examining and often citing the malfunction mechanisms. If the potential malfunction mechanisms are well understood, simplified techniques can be employed for seismic qualification. The grouping technique is based on our knowledge of the malfunction mechanisms (and a lack thereof). Thus, this technique is a means of demonstration of the similarity and geared toward the goal of seismic qualification i.e., equipment functionality as required by the acceptance criteria documents.

The three groups identified in the ARC document (Reference 2.1) and their abilities to demonstrate similarity, and thus meet the intent of the acceptance criteria are further discussed below. First, it is discussed how similarity can be demonstrated for each group in order to follow the current practice and satisfy the acceptance criteria, and then it is judged to what extent the ARC report has succeeded in meeting this goal. The Panel's approach is presented in the following sections.

2.2.1 Group 1 Equipment

The Group 1 equipment classes are inherently strong against seismic motion due to their normal design to satisfy operating and service requirements such as mechanical excitation and pressure boundary integrity, or their functions are insensitive to seismic motion. The following are the general characteristics of the Group 1 equipment classes, the relevant experience data, and the similarity demonstration and qualification procedures:

1. Functionality depends on structural integrity alone, i.e., functionality can be assured if structural integrity is demonstrated.

2. Design and experience data support inherent strength and resistance to earthquake. Some equipment types by design would not show any sensitivity to earthquake up to excitation levels of interest.

3. Malfunction mechanisms are well understood, or are not expected to occur at the anticipated excitation levels.

4. The fundamental frequency is high enough to allow static analysis.

5. Structural analysis should be performed to verify load transfer and avoid potential structural weakness to eliminate malfunction mechanisms.

6. For each equipment class, examine a large number of diverse products from various manufacturers and of different designs.

7. Preclude vulnerabilities through sound product, installation and maintenance specifications. These specifications should result from vast, accumulated experience.

8. Future variations that might be detrimental to seismic qualification should be excluded through product specifications.

9. The target qualification (excitation) level should be supported by a combination of experience data and structural analyses.

10. Judgments and independent expert peer review must play significant roles at every step.

Item numbers 1-8 and 10 are intended to demonstrate equipment physical similarity and item numbers 4, 9 and 10 are for demonstration of excitation similarity. Each equipment class should be thoroughly examined for the demonstration of both physical and excitation similarity. This similarity screening will produce a *subset* of each equipment class whose characteristics will be defined by explicit product specifications and excitation levels. For qualification, an ALWR equipment item will be compared to these specifications to demonstrate physical similarity. Multiple such subsets may be defined for each class for different excitation levels. Of course, the equipment class subset is expected to be narrower as the excitation level increases. This can be illustrated by considering extreme conditions. For example, if the excitation level is very low (e.g., 0.05g ZPA), an entire equipment class with all diversities may qualify; whereas, if the excitation level is extremely high (e.g., 10g ZPA), only a few specific products may qualify. Thus, subsetting depends on the qualification level and is defined by product and installation specifications.

2.2.2 Group 2 Equipment

Group 2 equipment classes do not satisfy the criteria for belonging to Group 1, but their malfunction mechanisms can be demonstrated from past experience or otherwise with a high degree of certainty. The general characteristics of Group 2 equipment, the relevant experience data, and the similarity demonstration and qualification procedures are as follows:

1. Perform detailed examination of equipment characteristics.

2. Equipment malfunction mechanisms should be well understood. Consult the experience data base, especially test data at high excitation levels to identify malfunctions.

3. Analyze the root causes of malfunctions.

4. Preclude all known and potential malfunctions by preparing strict specifications for product, installation and maintenance.

5. Describe the dynamic similarities related to functionality (or malfunction mechanisms) in the product specifications.

6. Avoid future variations, that may adversely affect seismic qualification, through product specifications.

7. Perform structural analysis to verify load transfer.

8. Maintain well-defined and well-documented seismic experience data. Only selected data from the overall body of seismic experience data can be considered. This will define a subset (the reference data) for each equipment class that will be used for future qualification.

9. The reference data must include a wide variation of specimens for each class (i.e., manufacturer, model number, size, etc.).

10. Target qualification (excitation) levels should be established from the reference data. High confidence must be assured in establishing the qualification level. The reference data should comprise a wide variation of input motion (e.g., over broad frequency band) applied to a wide variety of equipment within each class.

11. Judgments and independent expert peer review must play significant roles at all steps.

Item numbers 1-9 and 11 are intended to demonstrate equipment physical similarity and item numbers 8, 10 and 11 will support excitation similarity. Similar to Group 1 equipment, each class of Group 2 equipment will be thoroughly examined for demonstration of both physical and excitation similarity. This similarity screening will produce a subset of each equipment class whose characteristics will be defined by explicit product specifications and excitation levels. The reference data, as defined in Item Number 8, are required to substantiate the appropriateness of the qualification excitation levels. For qualification, an ALWR equipment item will be compared to these specifications for demonstration of physical similarity. Multiple subsets may be created for each equipment class for multiple excitation levels. As explained earlier, the equipment class subset is expected to be narrower as the excitation level increases. In summary, subsetting is a step toward qualification by similarity and it depends on the excitation level and is defined by product and installation specifications. These specifications for Group 2 equipment are more restrictive than those for Group 1 equipment.

2.2.3 Group 3 Equipment

Equipment classes that do not satisfy the criteria for Group 1 or 2 equipment become Group 3. Traditional shake table testing or more rigorous similarity analysis will be required for Group 3 equipment.

2.2.4 Excitation Level

In the previous subsections, the need for establishing an excitation level has been mentioned but the process for arriving at this level has not been presented. The purpose of this subsection is to consider several approaches to establish the qualification excitation level from a set of experience data that are obtained from previous tests and earthquake events. The use of these two sources of input motion in deriving the qualification excitation levels is discussed in the following paragraphs.

For testing experience data, the excitation level is controlled, usually well documented and mostly broad-banded with multifrequency inputs. Each of these input motions contains a definite amount of damage potential for a particular piece of equipment. The damage potential also depends on the equipment item, e.g., its natural frequencies, malfunction mechanisms, etc. Thus, the damage potential varies depending on the combination of the input motion and the equipment item exhibiting a particular malfunction, and is difficult to quantify, although this is the target parameter in comparing various input motions for qualification.

Typically, input motions are expressed in terms of acceleration response spectra and the damage potential may be represented by the ZPA, peak spectral acceleration, average spectral acceleration over a frequency range of interest (e.g., fundamental frequency band), ratio of the peak spectral acceleration to ZPA, etc. Even with well-defined experience response spectra, such as test response spectra a question remains how to draw the qualification response spectrum for a given number of experience response spectra. A lower envelope of the experience response spectrum set or a spectrum with an average of the spectral responses at each frequency may be considered as a potential candidate (more discussions on a composite spectrum are provided in Appendix A). But, each approach will provide a very different confidence level. Thus, there is no unique way to establish the qualification or excitation level. There are many other factors that complicate this matter further. For example, the resonant frequency corresponding to a given malfunction is mostly unknown and this frequency for each equipment of the same class can be significantly different. There could be multiple malfunction mechanisms which need to be considered in comparing the response spectra. The equipment subset that will be used for similarity comparison (i.e., the equipment set included in the experience data) should be representative of the diverse types of equipment within the same equipment class (i.e., size, shape, mass, material strength, manufacturing quality, etc.). Thus, there could be a substantial amount of diversity of damage potential within a given subset of any equipment class and, for equipment qualification, there is no simple tool to derive a unique qualification excitation level from a given set of test response spectra.

In the above discussions, it has been assumed that the excitation levels of the experience data are well-controlled and well-documented. This assumption is mostly true for testing experience data but definitely not true for earthquake experience data. There are two major sources of uncertainties in estimating the motion at the location of equipment in the earthquake experience data. Ground motion is typically recorded at a reasonably far distance (e.g., 1-2 km) from the site so that the ground motion estimate at the equipment site has a high uncertainty. The equipment item itself could experience a motion different from the ground motion at the site. The Panel believes that the motion that a particular piece of equipment has been subjected to could be as low as half, or as much as twice, the estimated motion. Because of the complexities discussed above, the development of a qualification level requires the exercise of considerable judgment.

The Panel does not believe that any definitive mathematical process can be prescribed for establishing the qualification level from a given set of experience excitation data. Instead, the Panel believes that if there has to be a method to integrate all these factors, it is through the use of expert judgments. A group having joint expertise in various aspects of equipment qualification and structural dynamics, as cited above, may attempt to draw a qualification excitation level. The Panel definitely recognizes the use and importance of many known parameters and calculation tools (e.g., ZPA, peak spectral acceleration, average spectral acceleration, root-mean-square of accelerations, ratio of any of these quantities, statistical treatment, etc.). But, the Panel considers that judgment is the primary means, and that other factors play an important but a supportive role.

An example that elaborates the judgment exercised for establishing the level A response spectra for Group 2 equipment is included in Appendix B. The ground motion estimates of past earthquake events for which equipment performance data were used by ARC have been independently verified by a consultant to the Panel and found to be reasonable.

2.2.5 Evaluation of ARC Methodology

The ARC Methodology (Reference 2.1) generally follows the approach as described in the above sections. ARC has selected two levels of qualification (Level A and Level B) and prescribed product specifications for each qualification level.

For Group 1 equipment qualified to Level A, the earthquake experience data primarily provide confirmation of the inherent strength of the equipment which has been incorporated into its design by the need to meet its service loads. On this basis, the Panel supports Level A qualification for the seven Group 1 equipment classes listed in Section 1.2.1 with further comments specified in Chapter 3.

For Group 1 equipment qualified to Level B, test data and knowledge gained from the analysis of equipment establish the level of the qualification. The Panel recognizes that in many cases there is very limited test data, but the service loads of the equipment type and limiting specifications address concerns about the potential vulnerabilities of the equipment class. The Panel supports Level B qualification for the seven Group 1 equipment classes but suggests that the basis for these qualification levels should be further strengthened with additional data.

For Group 2 equipment qualified to Level A, the earthquake experience and test data play a vital role in establishing the product specifications. The Panel recognizes that the ground motions at equipment items in the reference data and from other sites and in different earthquakes exhibit significant variation so that any particular ground motions could be below or above the component spectra that made up the Reference Spectrum (i.e., Level A). It is this variation, as well as the fact that an adequate number of a diverse collection of equipment has been subjected to these earthquakes, that provides the assurance of good equipment performance (see Appendix B for further discussion). So long as an adequate number of independent, diverse equipment data exist that bound the range of a particular class and represent well the diversity of the equipment class, the Panel concurs that the Level A Reference Spectrum can be established at the median level of the individual reference data base best-estimate response spectra. The Panel judges that for the transformers and batteries a population of 30 items is adequate for the given reference data. The Panel observes that the ARC reference data cover only a limited number of large transformers and suggests that additional data be collected for this equipment. Not withstanding this deficiency, the Panel supports Level A qualification for these two Group 2 equipment classes.

For Group 2 equipment qualification to Level B, the Panel has a concern that equipment subjected to qualification testing may have been different from its typical commercial grade counterpart. This concern complicates the use of test data for determining the qualification of industrial grade equipment. The Panel does not support Level B qualification for batteries as presented in the ARC report[4]. The Panel will support this level, however, if aged battery cells are tested as further elaborated in Chapter 3.

2.2.6 Summary

In the above sections, the Panel has attempted to show how the general principle of similarity as required by the current acceptance criteria can be applied when experience data are used. The Panel recognizes that a major difficulty in the generic use of experience data is how to apply a limited set of data to a larger group of equipment with possible diversity. For this concern, certain procedural steps have been described in the earlier sections. The Panel believes that detailed step by step procedures cannot at this time be adequately formulated and a broadly

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[4] In the ARC report, Level B qualification has not been proposed for transformers.

based expert review panel plays a vital role in the successful implementation of the process. For this reason, the Panel emphasizes the need for detailed examination of each equipment class including the pertinent experience data and has used the broad procedures of earlier sections in reviewing the equipment-specific qualification which is discussed in Chapter 3. Thus, the Panel's evaluation of the ARC report is based on its independent, detailed review of the subject matter.

The Panel would further like to note that the criteria documents prescribe the provisions in general or more mechanistic terms that are sometimes difficult to implement, subject to interpretation or may not effectively address the vulnerabilities (e. g., in demonstration of dynamic response of batteries, the cushion between battery cells and their restraining mechanisms are more important than the mass differences as would otherwise be required following the rules of dynamics). Such considerations are the essence of this approach, but unfortunately, cannot necessarily be assured through the prescriptive procedures alone provided earlier. Thus, judgments not only play a major role in demonstrating the physical and excitation similarity but also incorporate issues related to installation and maintenance. Because of this heavy reliance on judgments, it is essential that an extension of the generic use of experience data to additional equipment classes or higher excitation levels be reviewed by an independent expert group.

2.3 Overall Critique On Implementation

The Panel has reviewed the ARC report (Reference 2.1) following the similarity demonstration methodology discussed in the previous section. The detailed comments on it are presented in Chapter 3. The purpose of this section is to provide an overall critique on the report, including the overall qualification aspect and experience data.

2.3.1 Overall Qualification

The Panel believes that the ARC seismic qualification approach applied to the nine classes of equipment listed in Section 1.2.1 provides a high confidence that they will perform their intended function for the associated earthquake levels. Thus, the intent of seismic qualification has been satisfied. The Panel supports the approach to the classification of equipment and the establishment of two levels of qualifications contained in the report. It also supports, in general, the detailed equipment specifications for each equipment class and the associated seismic capacities. An exception is that the Panel does not support the Level B qualification for the battery cells. However, the Panel will support this level if aged battery cells are qualified to this level as further elaborated in Chapter 3. Other exceptions and comments are also included in Chapter 3.

2.3.2 Experience Data

It is the Panel's view that the use of earthquake experience data requires that earthquake experience data continue to be collected. The purpose of this is to provide additional data where present data are limited and to identify potential problems and possible future modification to equipment that reduces its earthquake resistance. Also, as test experience data become available, it should be added to the body of experience data.

The ARC report identifies a set of reference earthquakes and sites with significant ground motions. At these sites, facilities and specific equipment are identified and their seismic performance documented. The documentation of equipment and its seismic exposure provides a technical basis for determining the seismic performance of equipment in the different equipment classes.

Using observations from earthquakes, shake table tests, and results from the analysis of equipment, product, installation and maintenance specifications are developed and qualification excitation levels established. In case of Group 2 equipment, where earthquake experience data play an important role in substantiating good performance and in determining potential failure modes, a large diversity of equipment in each class must have experienced significant ground motions. Extensive data from other earthquakes, or other sites in the reference earthquakes, are not explicitly documented and they primarily serve to provide general support of the good performance of the equipment classes. These additional data also provide a basis for establishing equipment specifications to assure good performance.

The ARC report distinguishes earthquake data from earthquakes prior to 1985. In addition, selected sites from the list of post-1985 data have been included in Reference Data Sites. While the references to the various earthquakes are in different reports, there is no other significant distinction between the data associated with these sites, except that more recent earthquakes may contain newer equipment and more details about the equipment may have been gathered.

In summary, the Panel observes that although the report includes some experience data, the documentation is mixed and for several classes of equipment the documentation of experience data is poor and could be improved. Not withstanding this deficiency, the Panel has concluded that for the nine classes of equipment under consideration, the data are adequate to support the conclusions in the report. These conclusions are class specific, so that for other classes of equipment, a more robust collection of data may be necessary.

2.3.3 Presentation

In general, the Panel supports the presentation of the materials in the report including the general discussion on equipment performance. The Panel endorses a format which links the purpose of specific product, installation and maintenance specifications to the concerns that are being addressed or the potential malfunctions that are being excluded. This is especially important to demonstrate the similarity concept related to understanding of the malfunction mechanisms as elaborated in the earlier sections.

The Panel also observes that there is a lingering weakness in the development of the arguments that are presented in the report to support the concept of generic diversity. As a result, the presentation does not seem to elaborate on methods that follow from the philosophy of the current acceptance criteria, e.g., IEEE Std 344. The Panel has provided its own interpretation in the earlier sections. Furthermore, additional discussions on fundamental concepts for seismic qualification of equipment using experience data are included in Appendix A.[5]

2.3.4 Aging

The ARC report provides only a short paragraph on aging. The Panel recognizes that a significant portion of the equipment items that form the Reference Data set and much more other equipment that has performed well in significant earthquakes, was older equipment and limited aging has not apparently affected its performance in earthquakes. However, this information is not documented in the ARC report. The Panel notes that some aging issues have been addressed implicitly for Level A qualification, in that the earthquake experience data were for equipment that has been aged. However, only limited equipment was over 20 years old and almost none was over 40 years old. The Panel recognizes that the synergistic effects of aging and seismic qualification is a complicated issue and difficult to quantify. The Panel feels that normal aging will not have major impact on seismic performance of most equipment up to Level A, particularly when normal maintenance and refurbishment are taken into consideration. However, the Panel has not done detailed review of these issues.

2.3.5 References

The ARC report refers to several documents for acceptance criteria and experience data. The Panel's observations as presented in this report are only on the ARC document (i.e. Reference 2.1) and the Panel does not necessarily endorse any of the documents referenced in the ARC report.

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[5] One panel member questions the relevance of Appendix A. His view on Appendix A is included on Page A-16.

2.4 Conclusions

The Panel maintains that the approach for the use of experience data in equipment qualification should be to demonstrate similarity of the equipment characteristics and excitation levels. For diverse equipment types, the similarity demonstration requires broad representation of the equipment population that has been subjected to strong ground motions. Substantial expert judgments are required for reliability and success of this process. The Panel notes that a vital element of the use of this method has been a detailed examination of all candidate equipment classes by experts with broad experience in earthquake performance of equipment. This process has drawn on the experience of the Panel and has included a review of the performance of equipment in earthquakes, testing and seismic analysis, and discussions with manufacturers. This detailed review by a panel with this broad experience is needed to develop the product and installation and maintenance specifications and set the seismic qualification levels. Currently, the Panel's review is limited to the equipment classes and excitation levels included in the ARC document (Reference 2.1). The Panel feels that in the future, if new equipment classes are to be qualified by this methodology, a similar independent review be performed for the NRC. This independent review should be conducted by an independent panel with broad experience in seismic performance, testing and analysis of equipment.

References

2.1 "Advanced Light Water Reactor (ALWR) First-Of-A-Kind Engineering (FOAKE) Project on Equipment Seismic Qualification," prepared by MPR Associates and EQE International for Advanced Reactor Corporation, February, 1996.

2.2 U.S. NRC Regulatory Guide 1.100, "Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants," Revision 2, June 1988.

2.3 U.S. NRC Standard Review Plan, NUREG-800, Sections 3.9 and 3.10, 1981.

2.4 IEEE Standard 344-1987, "Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations".

2.5 IEEE Standard Seismic Testing of Relays, ANSI/IEEE C37.98-1987.

2.6 "An Evaluation of the Industry Approach on the Seismic Qualification of Equipment in ALWR Plants," NRC Panel on Seismic Qualification of ALWR Equipment, May 1993.

2.7 L.E. Cover, M.P. Bohn, R.D. Campbell and D.A. Wesley, "Handbook of Nuclear Power Plant Seismic Fragilities," NUREG/CR-3558, June 1985.

2.8 Holman, G.S., et al., "Component Fragility Research Program: Phase 1 Demonstration Tests," NUREG/CR-4900, Vols. 1 and 2, August 1987.

2.9 Kennedy, R.P., et al., "Part I: Use of Seismic Experience and Test Data to Show Ruggedness of Equipment in Nuclear Power Plants, Part II: Review Procedure to Assess Seismic Ruggedness of Cantilever Bracket Cable Tray Supports," Sandia National Laboratory, Report No. SAND92-0140, June 1992.

2.10 EPRI Report NP-5223, Revision 1. "Generic Seismic Ruggedness of Power Plant Equipment," prepared by ANCO Engineers, August 1991.

2.11 EPRI Report NP-7149, "Summary of the Seismic Adequacy of twenty Classes of Equipment Required for the Safe Shutdown of Nuclear Plants," prepared by EQE Engineering Consultants, March 1991.

2.12 Kaña, D.D., et al., "A Research Program for Seismic Qualification of Nuclear Plant Electrical and Mechanical Equipment," NUREG/CR-3892, August 1984.

2.13 Bandyopadhyay, K.K., et al., "Seismic Fragility of Nuclear Power Plant Components," NUREG/CR-4659, Vols. 1-4, June 1986-June 1991.

2.14 Kaña, D.D., and Pomerening, D.J., "Similarity Principles for Equipment Qualification by Experience," NUREG/CR-5012, July 1988.

CHAPTER 3
SPECIFIC EVALUATIONS OF EQUIPMENT SEISMIC QUALIFICATION

3.1 Introduction

The evaluations of the Panel for the equipment classes included in the ARC report (Reference 3.1) are presented in this chapter. For each equipment class, the Panel has provided a brief description that generally defines the class. This is followed by observations about the Level A and Level B seismic qualifications. Specific concerns or reservations, if any, of the Panel about the class are then expressed. Some of the parameters which limit the equipment class may be based on the fact that these are the limits for which there is adequate information in the experience data or that they represent a bound which meets the needs of the Advanced Light Water Reactor program. Thus, the establishment of bounds do not necessarily imply that equipment just beyond these bounds is seismically vulnerable.

3.2 Group 1 Equipment

3.2.1 Horizontal and Vertical Pumps

Section 4.2 of the ARC report (Reference 3.1) identifies the pumps and drivers included in the equipment class. They are horizontal and vertical pumps driven by electric motors. Pump/Driver product specifications establish the qualification for Level A as the Reference Spectrum (Figure 1.1 in Chapter 1), and the qualification for Level B at 2 g zero period acceleration (ZPA) for motor frame sizes greater than 449 and at 4 g ZPA for frame sizes equal to or less than 449.

The Panel observes that pump-motor assemblies have functionally simple components and their operational loads impose the need for strong components and assemblies that exceed seismic demands. Earthquake experience data of diverse pumps discussed and referenced in the ARC report support this observation. Based on inherent strengths of pumps and their drivers and the support of experience data, the Panel believes that this equipment is qualified to Level A as proposed in the ARC report.

For qualification to Level B, structural analyses of the pumps under seismic loads are required. The main concerns of the Panel are related to vertical pumps, and these are addressed by the specifications for Level B. Although experience data up to Level B do not exist because of limitation of earthquake data, the Panel does not find any potential malfunction concerns that have not been precluded through the product specifications. Therefore, the Panel judges that the qualification of Level B of 2 g/4 g ZPA as proposed in the ARC report to be reasonable.

In conclusion, the Panel finds that the pump-motor qualification criteria including installation and maintenance specifications presented in the ARC report meet the qualification approach discussed in Chapter 2 and hence supports these criteria.

3.2.2 Motor-Operated, Air-Operated, Manual and Check Valves

3.2.2.1 Motor-Operated Valves

Section 4.3.1 of the ARC report identifies motor-operated valves included in the equipment class. Motor-operators from specific manufacturers and model numbers are included in the equipment class. Motor-operated valve product specifications establish a qualification for Level A as the Reference Spectrum. Motor-operated valve product specifications of Level B include a more limited set of motor operators and establish qualification to a 6 g ZPA level, based on test data and analysis.

The Panel observes that motor operators have undergone testing and there is no record of damage from inertial loads, that has not been precluded by product specifications. The operational loads impose the need for strong components and assemblies. Earthquake experience data of selected motor operators as discussed and referenced in the ARC report supports this observation. Based on the inherent strengths of motor-operated valves and the support of experience data, the Panel believes that this equipment is qualified to Level A as proposed in the ARC report.

For qualification to Level B of 6 g ZPA, the acceptable models are further restricted to units that have been tested and additional requirements on system natural frequencies and analyses are imposed. Based on the required analyses, natural frequency requirements, and specifications to eliminate potential malfunction concerns, the Panel judges that the qualification of Level B of 6 g ZPA as proposed in the ARC report to be reasonable.

In conclusion, the Panel finds that the motor-operated valve qualification criteria including installation and maintenance specifications presented in the ARC report meet the qualification approach discussed in Chapter 2 and hence supports these criteria.

3.2.2.2 Air-Operated Valve

Section 4.3.2 of the ARC report identifies the air-operated valves included in the equipment class. They are diaphragm- or piston-type air-operated, on-off type valves. Air-operated valve product specifications establish a qualification for Level A as the Reference Spectrum. Air-operated valve product specifications establish Level B qualification of 4-1/2 g ZPA if performance is demonstrated by static analysis and 6 g ZPA if performance is demonstrated by static test.

The Panel observes that air-operated valves have functionally simple components and their operational loads impose the need for strong components and assemblies that exceed seismic demands. Earthquake experience data of diverse air-operated valves is extensive and referenced in the ARC report. This data supports the observation about the good performance of this equipment. Based on inherent strengths of air-operated valves and the support of earthquake experience data, the Panel believes that this equipment is qualified to Level A as proposed in the ARC report.

For qualification to Level B, the natural frequency of the valve assembly must be above 33 Hz. The main concern of the Panel related to air-operated valves is diaphragm damage. This concern is addressed by the specifications for Level B. Although limited experience data up to Level B is available, the Panel does not find any potential malfunction concerns that have not been precluded through the product specifications. Therefore, the Panel judges that the qualification of Level B of 4-1/2 g ZPA when supported by analysis and 6 g ZPA when supported by static tests as proposed in the ARC report to be reasonable.

In conclusion, the Panel finds that the air-operated qualification criteria and qualification levels including installation and maintenance specifications presented in the ARC report meet the qualification approach discussed in Chapter 2 and hence supports these criteria.

3.2.2.3 Manual and Check Valves

Section 4.3.3 of the ARC report identifies manual and check valves included in the equipment class. They are manually operated gate and globe valves or swing or titling-disc check valves. These valve product specifications establish Level B[6] qualification of 6 g ZPA. The Panel observes that the inherent strength incorporated in their design to meet operating loads of these valves qualifies them for Level B of 6 g ZPA.

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[6] No Level A qualification for manual and check valves has been proposed in the ARC report.

In conclusion, the Panel finds that the manual and check valve qualification criteria and qualification levels including installation and maintenance specifications presented in the ARC report meet the qualification approach discussed in Chapter 2 and hence supports these criteria.

3.2.3 Temperature Sensors

Section 4.4 of the ARC report identifies the temperature sensors included in the equipment class. They are thermocouples and resistance temperature detectors. Temperature sensor product specifications for qualification to Level A is the Reference Spectrum. Based on test data and the simplicity of the design the Level B capacity is 10 g ZPA.

The Panel recognizes that there is limited documentation of earthquake performance of temperature sensors; however, they are present in a wide range of facilities and no direct earthquake damage has been observed. The Panel judges that the inherent resistance and the earthquake experience data support the Level A capacity of the Reference Spectrum.

The Panel observes that the qualification to Level B is supported by a limited number of tests to a capacity of 10 g ZPA. However, the Panel judges that the simple physical form of these devices and the specifications that address potential vulnerabilities support the qualification of Level B to 10 g as proposed in the ARC report. Installation and maintenance specifications also address potential seismic vulnerabilities.

In conclusion, the Panel finds that the temperature sensor qualification criteria and qualification levels including installation and maintenance specifications presented in the ARC report meet the qualification approach discussed in Chapter 2 and hence supports these criteria.

3.2.4 Diesel Generating Units

Section 4.5 of the ARC report identifies diesel generating units included in the equipment class. They are units ranging is size from 50 KW to over 2000 KW. Diesel generating unit product specifications for qualification to Level A is the Reference Spectrum. Diesel generating unit product specifications for Level B is 1 g spectral acceleration (5% damping) in the range from 20 Hz to 33 Hz.

The Panel observes that a large number of small and moderate size diesel generating units have experienced many different earthquakes and have not been damaged. However, there have been many instances where diesel generator systems have not performed well after earthquakes.

secure supply of makeup water, that the fuel pump is connected to the emergency power supply, that the load on the generator is below the long-term capacity of the generator, and that all controls and systems are in their proper position after units are tested.

The test data for large diesel generating units are very limited. But the Panel feels that the operational loads impose the need for strong components and assemblies, and that these loads exceed seismic demands. Based on inherent strengths of diesel generating units and the support of earthquake experience data the Panel believes that this equipment is qualified to the Level A as proposed in the ARC report.

The Panel observes that the qualification to Level B is based on very limited test data, but judges the service loads impart substantial strength above the levels demonstrated by the earthquake experience data. Therefore, the Panel judges that the qualification of Level B of 1 g spectral acceleration (5% damping) in the interval from 20 Hz to 33 Hz as proposed in the ARC report to be reasonable.

The Panel observed an inconsistency in the product specifications 15, 16, and 17. Specifications 15 and 16 require an acceleration of 2g; whereas, specification 17 requires 1g (Reference 3.1, pages 4-65 and 4-66). This inconsistency was not present in the earlier ARC Report (dated April 1995) which required 2g for specification 17 as well as 15 and 16. This change was not discussed with the Panel. It is likely that the required acceleration level could be lower than 2g, but not as low as 1g. Without further information, the Panel notes that one way to eliminate this inconsistency is to use an acceleration level of 2g for all of the specifications 15, 16, and 17.

In conclusion, the Panel finds that except the inconsistency stated above the diesel generating unit qualification criteria and qualification levels including installation and maintenance specifications presented in the ARC report meet the qualification approach discussed in Chapter 2 and hence supports these criteria.

3.3 Group 2 Equipment

3.3.1 Ventilated and Non-Ventilated Dry-Type Transformers

Section 5.2 of the ARC report identifies the types of transformers included in the equipment class. They are ventilated and non-ventilated dry-type transformers operating at 13.8 KV or less and rated at 2500 KVA or less. Transformer product specifications for qualification to Level A allow use of the Reference Spectrum. Neither the qualification level nor the product specifications for Level B have been established at this time.

The Panel observes that there were a few transformer failures in the experience data, but the potential failure modes have been addressed by product specifications. Excluding these known failures, the earthquake experience data of diverse transformers are discussed and referenced in the ARC report and this data supports the good earthquake performance of transformers. However, the Panel notes that the reference data contains very few large transformers and it would be desirable to add large units to the reference data. The Panel believes that the potential failure modes at Level A inputs have been precluded through the use of equipment specifications. Based on a review of potential failure modes and the support of experience data the Panel believes that these transformers are qualified to Level A at the Reference Spectrum as proposed in the ARC report.

In conclusion, the Panel finds that the transformer qualification criteria and the qualification level including installation and maintenance specifications presented in the ARC report for Level A capacity meet the qualification approach discussed in Chapter 2 and hence supports these criteria. The Panel agrees with the conclusion in the ARC report that there is currently an insufficient basis to support experience-based seismic qualification of transformers at the Level B excitation. The Panel has not reviewed the Level B requirements.

3.3.2 Stationary Vented, Lead-Acid Batteries on Racks

Section 5.3 of the ARC report identifies batteries and battery racks included in the equipment class. Batteries must be manufactured by C&D Power Systems, Exide Corporation, or GNB Batteries, Inc. The product specifications for batteries on battery rack qualification to Level A allow use of the Reference Spectrum. The product specifications for the battery rack and for the cells for Level B is 3 g spectral acceleration (5% damping) in the range of 4 Hz to 20 Hz and 2 g ZPA.

For capacity Level A for batteries on racks the Panel has reviewed the earthquake experience reference data documenting the performance of batteries. The Panel has also had discussions with battery manufacturers. Battery life is limited to 10 year. The specifications address the concerns about the seismic vulnerability of batteries on rack. The Panel judges that degradation of the power capacity of cells after earthquakes, if any, should be acceptable for Level A. An important consideration in arriving at this judgment was the views expressed by the manufacturers that limiting the battery life to 10 years had a major impact on the ability of the cells to meet discharge requirements after an earthquake. The Panel judges that this equipment is qualified to Level A as proposed in the ARC report.

For qualification to Level B, the Panel observes that the specifications require a seismic analysis of the rack and thus qualify it to Level B. However, the Panel does have a concern about the use of any battery manufactured by the qualified manufacturers for this application.

Even for the 10-year life limitation, the Panel judges that the post-earthquake capacity of the battery cells that are not in the data base is an issue. The Panel is concerned about reliability of the cells in light of the low cost alternatives that are available for manufacturing the cells. Manufacturers indicated that the nuclear grade cells and the equivalent non-nuclear grade cells are similar, and other cells that would be used for nuclear applications are very similar. If that is true, it should be possible for the manufacturers to prepare a similarity analysis under IEEE Std 344 to qualify the cells. Alternatively, shake-table tests can be performed on candidate individual aged cells mounted on an excitation table to substantiate their ability to retain adequate electrical charge capacity after shaking.

Regarding installation and maintenance specifications, the Panel supports these provisions for batteries and racks for both Level A and Level B.

In conclusion, the Panel supports the battery on racks qualification criteria for Level A presented in the ARC report. The Panel supports the rack qualification criteria for Level B. The Panel does not accept the criteria for cells for Level B, but would recommend that aged batteries be qualified by test or similarity. If this recommendation were adopted the Panel would support Level B for batteries.

Reference

3.1 "Advanced Light Water Reactor (ALWR) First-Of-A-Kind Engineering Project on Equipment Seismic Qualification," prepared by MPR Associates and EQE International for Advanced Reactor Corporation, February, 1996.

CHAPTER 4
CABLE TRAYS AND CONDUITS

4.1 Introduction

The ARC methodology for cable trays and conduit is documented in Reference 4.1. The Panel's evaluations of this methodology and the criteria are presented in this chapter. These evaluations apply only to the ARC report (i.e., Reference 4.1), and the Panel does not necessarily endorse any of the documents referenced in the ARC report.

4.2 Relationship to Current Criteria

Current criteria for cables trays, conduits and ducts require that these systems satisfy standard structural analysis methods, i.e., dynamic analysis or equivalent static analysis.

The proposed approach is a major departure from typical practice used for cable trays and conduit in nuclear facilities. Present nuclear practice is to design very stiff systems and perform a linear system analysis to evaluate the dynamic response and resulting stresses. The proposed methodology is modeled after traditional non-nuclear practice with the use of very flexible systems. In general, cable tray and conduit systems are suspended. The proposed method for suspended systems establishes design criteria so that supports are flexible and that moments and prying action on anchorage is limited. The design by rule method establishes conservative loading criteria and eliminates the need for lateral load evaluation. For stiff supports and non-suspended cable trays and conduits, lateral loads must be evaluated and anchorage designed to accommodate gravity plus laterally induced loads. The design by rule method allows non-elastic deformation of clip angles, but assures acceptable low-cycle fatigue performance.

4.3 Critique

The Panel fully supports the ARC "design-by-rule" approach for cable trays and conduits, and encourages its use. Specifically, the Panel agrees that flexible suspended systems with substantial plastic capacity are very desirable.

The Panel notes that this approach requires that hard spots in the raceway systems be minimized. While the ARC report strongly discourages the use of hard spots, it is recognized that if restraints are needed to limit the motion of the cable tray because of potential interaction with a nearby safe-shutdown equipment item, a stiff support may have to be added. If it is an isolated support, it may draw very large tributary loads and apply large local loads for the raceway. To limit these loads additional stiff supports could be added, but this is counter to the general design philosophy. Several approaches to this problem were explored, and one example of how to treat such a hard spot is given in the ARC report. However, the Panel recommends that more detailed guidance be developed to deal with these special cases. In the meantime, designers should give special attention to avoiding such hard spots and provide justification for their design on a case-by-case basis.

Finally, it is the view of the Panel that a demonstration of these guidelines by a traditional plant design organization would be very desirable during their initial implementation. The objective of this exercise is to verify that the design philosophy and design practice contained in the report have been clearly explained and can be properly implemented.

4.4 Summary

In summary, the Panel strongly supports the proposed methodology and judges that the seismic performance of cable trays and conduits using this methodology will be at least as good, and possibly better than current systems using existing designs that emphasize very stiff supports.

Reference

4.1 "Advanced Light Water Reactor (ALWR) First-Of-A-Kind Engineering (FOAKE) Project on Design by Rule for Cable Tray and Conduit Systems," prepared by EQE International for Advanced Reactor Corporation, January, 1996.

CHAPTER 5
HVAC DUCTS AND SUPPORT SYSTEMS

The ARC approach for seismic design of heating, ventilation and air conditioning (HVAC) ducts and their supports is presented in Reference 5.1. (The Panel's evaluations presented in this chapter apply only to the ARC report, i.e., Reference 5.1, and the Panel does not necessarily endorse any of the documents referenced in the ARC report.) The design philosophy proposes a two-tier approach: one for non-safety related and another for safety related ducts. For non-safety related systems, ducts will conform to national construction standards (without explicit seismic requirements) and the supports will include light weight structural systems similar to the cable tray supports. Vulnerabilities learned from past experience will be factored in the design. This design is supposed to assure structural integrity and not necessarily the leak tightness. On the other hand, the safety ducts will be designed with stiff supports to ensure leak tightness.

Currently, the ARC approach is still in the conceptual state and will require further development and review of technical details before it can be implemented for design in ALWR plants. Therefore, at this point the Panel provides the following comments only on the general design concept and does not address the details expecting that they will be developed in the future.

1. The Panel fully supports the idea of "design-by-rule" for HVAC ducts. This requires simplified design procedures with minor computational needs. The Panel observed that, in the past, significant efforts were expended for nuclear power plants to analyze and design HVAC ducts. The lessons learned from past practice and experience, if incorporated in the new design rules, will significantly reduce cost without sacrificing confidence in performance. Therefore, the Panel not only endorses a new design approach but also encourages it.

2. The two-tier approach - one for non-safety related and another for safety related ducts -is an acceptable approach. However, further work and improvements are necessary to show that the ducts remain leak tight.

3. Typically, ducts include several control features such as dampers and air handlers. Such accessory equipment should be considered and included in the scope of the HVAC ducts. As a minimum, their influence (e.g., response interaction, loading, etc.) should be included in the duct design.

4. Displacements may need to be controlled, especially, for leak tight ducts. Special considerations will be required at "hard spots" (e.g., tees, elbows, longitudinal bracings).

5. Structural integrity of special duct runs may need to be addressed on a case-by-case basis (e.g., a cantilever duct with diffusers mounted on it).

6. Attention needs to be given to local buckling, corner lengths for available equivalent cross sections, allowable stresses, etc. Caution may need to be exercised in applying limited test data to draw broad conclusions.

Reference

5.1 "Advanced Light Water Reactor (ALWR) First-Of-A-Kind Engineering (ARC) Project on Design Concepts for HVAC Ducting and Supports," prepared by EQE International for Advanced Reactor Corporation, April, 1995.

APPENDIX A
FUNDAMENTAL CONCEPTS FOR SEISMIC QUALIFICATION OF EQUIPMENT BY USE OF EXPERIENCE DATA

One Panel member does not agree with this Appendix. His comments are included on Page A-16. Other Panel members' response is included on Page A-17.

A.1 Introduction

This appendix will briefly review the historical development for use of experience data for seismic qualification and will formulate a conceptual framework for the application of IEEE Std 344 for the similarity approach to equipment qualification. It will deal with issues of excitation and equipment similarity. It should be noted that the application of the methodology will sometimes require deviations, possibly large deviations, from the conceptual framework established here, and therefore independent peer review must accompany the process throughout. Some of the detail about the origins of this methodology has already been described in the ARC report [1]. Therefore, herein we will concentrate primarily on a further elaboration of how the methodology is related to these origins, and on capabilities and limitations that are not so evident from the ARC report.

Guidelines for seismic qualification of equipment have always fallen under the purview of IEEE Std 344 [2], which typically emphasizes methods based on analyses, laboratory tests, or a combination thereof. However, the 1975 version of this standard does recognize the use of comparative data for "closely similar" equipment. Generally, this has been interpreted to mean nearly identical equipment, with some size or design variations. On the other hand, in 1975 it was recognized that many already operating nuclear plants had never been reviewed by these guidelines. In fact, the guidelines were published after the plants were docketed. As a result, USI A-46 [3] was declared, and a new methodology was sought which would allow evaluation of the equipment capabilities without interference with plant operation, and at the same time reduce ever-increasing costs. It was from this origin that methodology for use of generic data from both actual earthquake and laboratory test experiences was developed. After several years, these efforts culminated in the guidelines set forth in the Generic Implementation Procedures (GIP) [4]. Although the approach has been deemed acceptable by the NRC for "seismic verification" of equipment adequacy for certain designated operating plants, it has not been approved for "seismic qualification" for equipment in new plants.

During the developmental period for the GIP [4], a parallel effort was conducted to update the 1975 version of IEEE Std 344 [2b]. There was included a logical attempt to incorporate the use of experience methodology into the revision. However, because of the relative infancy of this methodology at the time, it was decided to include only a philosophical approach, which was based on a generalization of the "closely similar" method that was recognized in the 1975 version of the standard. Thus, the 1987 version [2c] was published, with qualification by experience based on similarity principles set forth in Section 9.0 of the document. However, the approach was still very developmental, and therefore was approved only for use on a case-by-case basis [5]. Subsequently, further research on details for similarity approaches was conducted [6], and these and other results were combined into ASME Standard QME-1-1994 [7], which includes experience data qualification only for mechanical pumps and valves.

This appendix was compiled by the panel to help clarify certain fundamental concepts that form the basis for future emerging methodology developments. In so doing, it should be recognized that mention of the above references is included exclusively for historical recognition, and does not necessarily imply endorsement by the panel, or approval by the NRC.

A.2 Basis for Use of Experience Data

IEEE Std 344-1987 [2c] permits seismic qualification of equipment by either direct methods or by similarity. Direct methods of qualification of equipment deal with test or analyses of equipment classes in which the individual items are essentially identical in dynamic properties and the excitation to a given item is well established. On the other hand, for qualification by similarity, both equipment properties and excitation are allowed to expand into a prescribed variation within a given class of similar equipment. The details of how the physical and excitation similarity are prescribed and how the class of equipment is defined form the essence of the qualification by similarity approach. One approach for the application of IEEE Std 344-1987 to experience data qualification of equipment by similarity has been developed by Kaña and Pomerening [6], and summarized in Attachment A to Appendix QR-A of Ref. [7]. Herein this approach will be called "qualification by close similarity."

The general approach to qualification by close similarity using experience data as outlined in IEEE Std 344-1987(2c) is based on the same fundamental dynamic principles that are required for qualification by test or analysis. However, when applying the experience approach to qualify a candidate equipment item, one seeks to show that a certain capability has already been demonstrated in a group of similar equipment, and therefore it need not be demonstrated by direct test or analysis that the same capability exists in the candidate equipment. The standard clearly states that similarity of the excitation and similarity of the equipment physical dynamic properties (that influence its potential malfunction) must be given careful consideration in order to demonstrate qualification by close similarity. This consideration must be based on the same fundamental dynamic principles one would deal with when attempting to perform qualification by direct methods.

Other than for the approach herein called "qualification by close similarity," the IEEE Std 344-1987 standard gives very little detailed guidance on qualification by similarity. However, it is the judgment of this panel that other approaches to qualification by similarity also can satisfy the IEEE Std 344-1987 Standard. Whereas qualification by close similarity relies on an explicit comparison of physical and excitation similarity, extended methods can rely more on an implicit comparison of physical and excitation similarity, and generally depend upon having a greater diversity of available experience data. The degree of extension which might be permitted will depend upon such things as:

1. the diversity of the class being qualified
2. the diversity of the available experience data
3. the qualification excitation level
4. the degree of knowledge of the experience data physical characteristics and excitation levels

Similarity qualification methods which rely to some extent on an implicit comparison of physical and excitation similarity herein will be called "qualification by extended similarity."

In the remainder of this appendix, first some fundamental aspects of demonstrating physical and excitation similarity will be discussed. Next, some general aspects of qualification by similarity will be presented and followed by some details of how qualification by close similarity might be satisfied. Finally, one approach for qualification by extended similarity will be discussed. In this approach, the physical and excitation similarity requirements will be addressed implicitly by the introduction of generic diversity concepts. This approach can be used to qualify a generic class of equipment that satisfies certain physical specifications. It relies on having available a large and diverse experience data base of successful performance of equipment within the class when subjected to a diverse set of broad-frequency excitation levels. It also requires having a detailed knowledge of the minimum physical specification requirements needed to provide high confidence that a malfunction will not occur at the qualification excitation level.

A.2.1 Excitation Similarity

Qualification typically requires that an equipment item be demonstrated, or otherwise shown, to possess a capacity for excitation motion that exceeds an anticipated demand for excitation motion. For seismic qualification, this process is usually done in terms of a response spectrum description. For qualification by test, close similarity of excitation is assured by the simple requirement that "the test (i.e., minimum capacity) response spectrum closely envelope the required (i.e., demand) response spectrum throughout the frequency range." However, with the use of experience data for similarity qualification, it is necessary to compare the effects of relatively different spectra and, furthermore, to combine them into a composite spectrum by some rationale. Inherently the approach includes the assumption that there is a damage equivalence between the motion implied by the composite spectrum and that implied by each of the different constituent spectra. For such an approach, definition of an additional set of parameters for describing the implied motions can be more useful than the response spectra alone.

Figure A.1 lists several parameters that also describe the motion implied by a corresponding response spectrum, and taken together, are an equivalent means of specifying the motion. Thus, these criteria also form a basis for demonstrating similarity of the implied motion. Note that similarity of ZPA is an obvious item. Indication of frequency bandwidth by amplification frequency range is somewhat qualitative, but can be determined more accurately if necessary by a power spectral density (which is required now for use of a single motion time history in certain qualifications). The peak amplification factor $S_a^*(f)/ZPA$ represents the peak spectral acceleration/ZPA ratio, which is a measure of the amplification capacity of the excitation. Finally, the consideration of multiple axis effects is obvious. Later it will be shown how combinations of these criteria can be applied to provide specific guidance for development of a composite spectrum.

A.2.2 Physical Similarity

Qualification by similarity requires that physically similar equipment be identified. As was previously mentioned, IEEE Std. 344 defines physical similarity to include a consideration of malfunction mechanism and dynamic response properties that can influence the malfunction. The basis for this concept is shown in Figure A.2, while possible properties for its determination are shown in Figure A.3. Note that in general for similarity qualification, malfunction mechanisms and their location should always be considered, but fundamental mode frequency range and mode amplification-factor need be considered only if they have a potentially direct influence on the malfunction mechanism.

Parameters	Response Spectrum Characteristic
Peak Excitation Value	ZPA
Frequency Bandwidth	Amplification Frequency Range
Peak Amplification Factor	$S_a^*(f)/ZPA$
Multiple Axes	Multiple Axes Effects Included

Figure A.1. Excitation Similarity Parameters for Response Spectrum

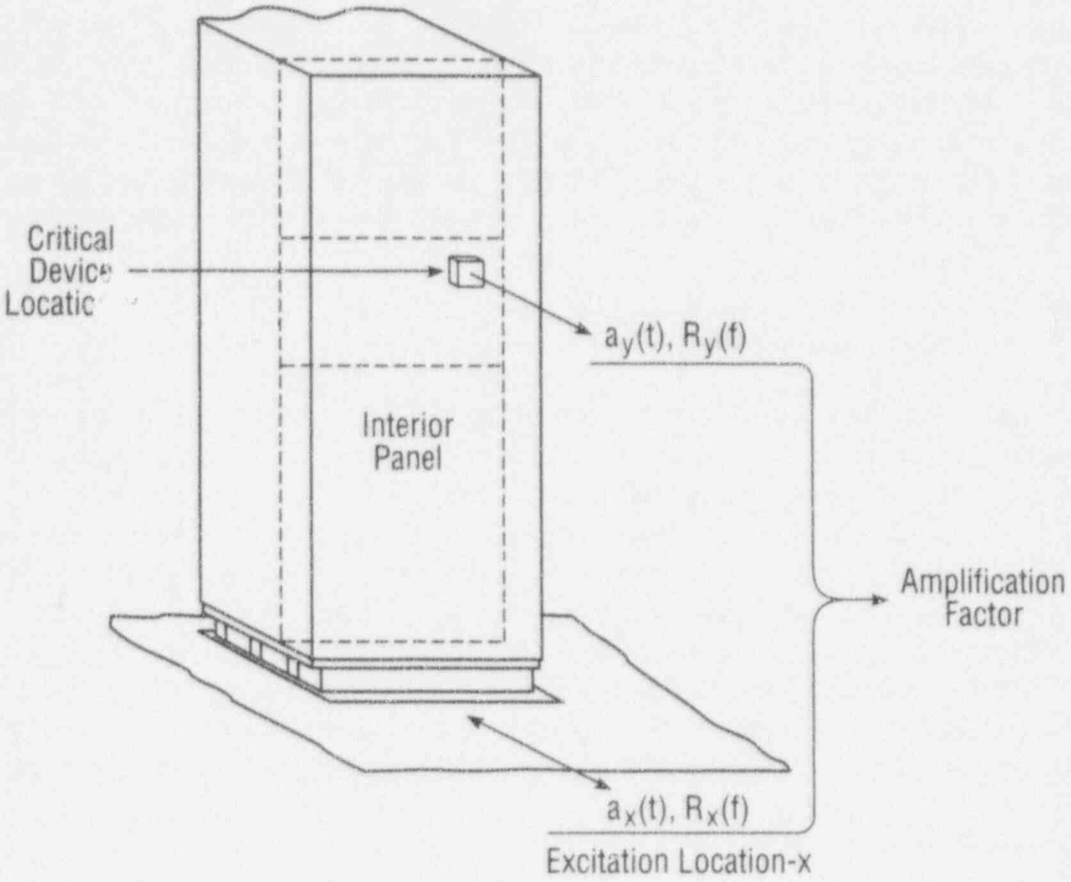


Figure A.2. Basis for Physical Simiiarity-Malfunction Mechanism and Dynamic Properties

Primary Malfunction and Location	-	Primary Basis for Equipment Classification
Fundamental Mode Frequency Range, Δf_n	-	Mode that Influences Malfunction
Fundamental Mode Amplification Factor	-	Mode Participation at Malfunction Location

Figure A.3. Physical Similarity Properties

Furthermore, similarity of dynamic properties requires at least that there be established a frequency range within which the fundamental response mode (mode which most influences the malfunction mechanism) occurs, and the degree of excitation amplification that occurs at the location of the malfunction. As indicated in Figure A.3, information about the fundamental mode amplification factor is what is of direct concern. However, exact information on this property may not be available for some data. Therefore, at least an estimate should be established. Typically, this can be done by comparing equipment dimensions, stiffness, and mass properties, etc.

A.2.3 Correspondence of Similarity

The above requirements deal with excitation and physical similarity individually. However, there is an additional requirement that should be imposed when they are used in combination. That is, for equipment and its associated experience response spectra that are used to form a designated qualification class experience base, the established fundamental frequency range for each item of equipment should be compared with the composite spectrum. Within the fundamental frequency range for any constituent equipment item, the composite spectrum should be no greater than the corresponding constituent response spectrum for that item. Where large amounts of experience data are available, a mean composite spectrum may be considered, as will be described in Section A.4.2. Furthermore, if the fundamental frequency range is above the amplified region of the excitation spectrum, this requirement is automatically satisfied.

A.3 Qualification By Similarity

For qualification by similarity, both equipment properties and excitation are allowed to expand into prescribed variations within a given class of similar equipment. The details of how the physical and excitation similarity are prescribed and how the class of equipment is specified form the differences of the two approaches previously defined. Generally, for either approach an experience base is formed from available experience data for a defined set of equipment whose class definition is based on the physical similarity properties identified in Figures A.2 and A.3. If the stated properties are compared explicitly, the approach is referred to as a "qualification by close similarity." As such, it can be applied with a relatively few independent data samples. However, if the comparison of properties is performed only implicitly, then the approach is referred to as a "qualification by extended similarity." For this case, more independent samples will be required. Furthermore, to satisfy excitation similarity, a composite spectrum is developed from various constituent spectra that are available from the experience base equipment. The details will also vary for each approach. Nevertheless, once the experience base has been formed, the general approach for qualification of a candidate item is as summarized in Figure A.4 for both approaches. However, the details of how 1) malfunctions, 2) fundamental frequency range, and 3) mode participation range are identified and accounted for are very different in each case.

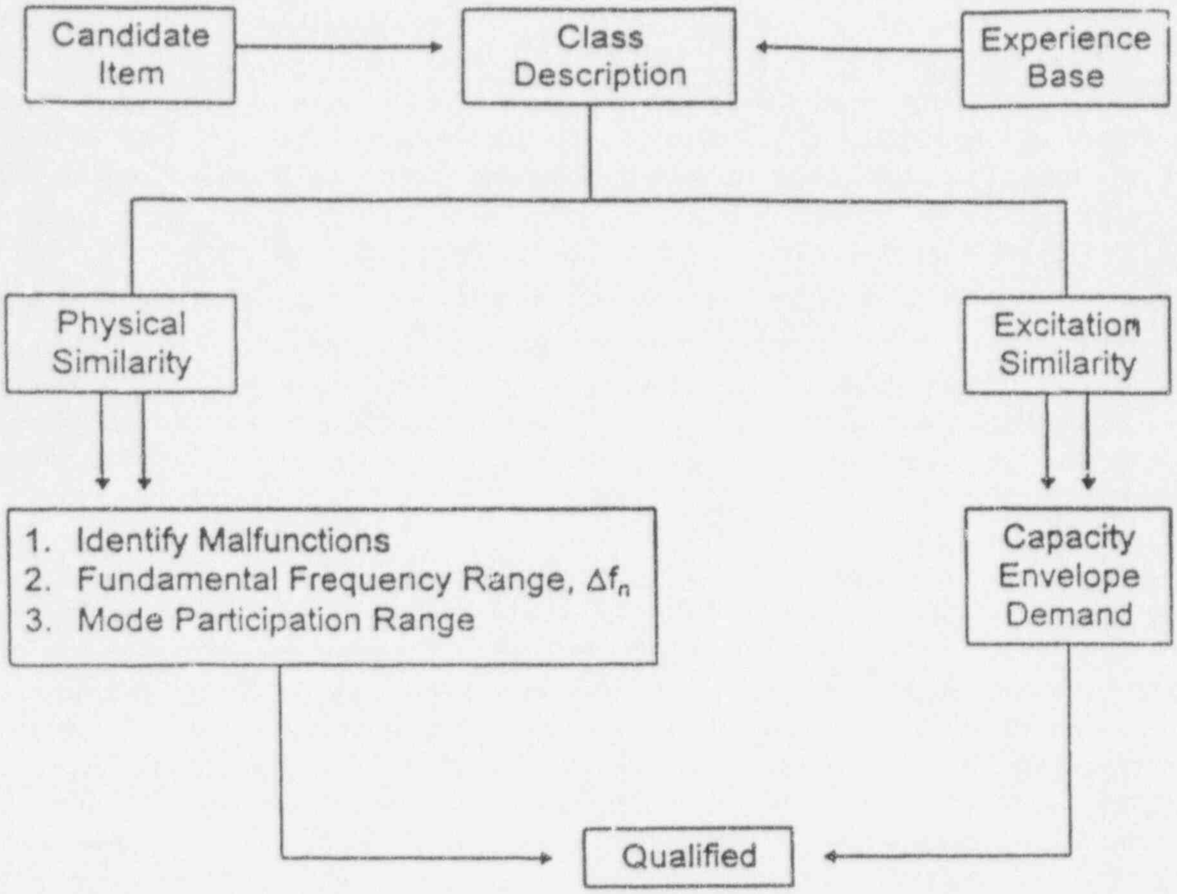


Figure A.4. General Considerations for Qualification of Candidate Item

A.4 Qualification by Close Similarity

A.4.1 General

Qualification by close similarity is defined as an experience data approach which is most applicable to equipment having relatively small variations in its physical characteristics and small uncertainties associated with its excitation data. With this understanding, the approach directly follows the guidance outlined in IEEE Std. 344-1987 [2c]. The standard clearly states that similarity of excitation and similarity of equipment physical dynamic properties (that influence its potential malfunction) must be given careful consideration. Therefore, comparisons are based on explicit descriptions of these properties, and explicit interpretation of the same fundamental dynamic principles one would deal with when attempting to perform a qualification by traditional test or analysis methods. Some further details of this approach will now be described. Although this approach may be considered for future applications, it has not been applied to any plant case to date.

A.4.2 <u>Development of Experience Base</u>

An experience base can be developed for a defined class of equipment whose physical similarity properties can be sufficiently justified. A general outline of one suggested procedure is indicated in Figure A.5. Typically, malfunction mechanisms should be identified and any dynamic properties which influence them must be considered. As previously indicated, any characteristics that influence the properties listed in Figure A.3 should be recorded and compared, unless it can be justified that the malfunction behavior is independent of the dynamic properties. In particular, a fundamental frequency bandwidth Δf_n, within which all the equipment falls, and a range of amplification factors are established for the entire class. Any supporting test or analysis data should be documented. Then, a composite capacity spectrum should be developed from the constituent spectra available for the experience base equipment. For this, the parameters of Figure A.1 may be employed. Finally, correspondence of similarity should be shown, as previously described.

Figure A.6 shows conceptually how a composite spectrum $S_{a3}(f)$ may be developed from two other constituent spectra. The composite spectrum is usually composed of several <u>different</u> constituent spectra that represent severe levels available from existing qualification data. Usually successful qualification data are most directly employed, although data that resulted in a failure may also be included if noted appropriately. The final composite is drawn primarily by some rational procedure based on a combination of the constituent spectra. In order to emphasize the degree of judgment that must be used for this process, we show a mean, conservative, and most conservative example of the final form that $S_{a3}(f)$ may take, depending on the fidelity of the constituent spectra data. To satisfy IEEE Std. 344, this procedure should be fully documented and traceable. This means that the general steps followed and the constituent spectra utilized must be clearly listed to allow possible future audit. The degree of detail should recognize that different persons may be involved with future study of the results. Furthermore, there are certain additional requirements that may be imposed on the procedure. These requirements may be based on the similarity parameters listed in Figure A.1 and an indication of the inherent uncertainties in the results. To satisfy the peak amplification factor criterion, the composite spectrum cannot imply a greater energy content in the excitation capacity motion than was present in the most severe constituent spectrum. The simplest way to satisfy this similarity requirement approximately is that the area of the amplified region of the composite spectrum should not exceed the largest amplified area present in the most severe constituent spectrum. This is <u>approximately</u> equivalent to saying that the maximum RMS level of excitation that has been experienced should not be exceeded by that represented by the composite spectrum (note that a common level of damping must also be inherent in all spectra). Furthermore, it should be specified that all of the constituent spectra be reasonably broadbanded. This would prevent the use of multiple sinewave and other very narrow band spectra as constituents unless special considerations are observed. Finally, a critical bandwidth Δf_c can be identified that is enveloped by all the constituent

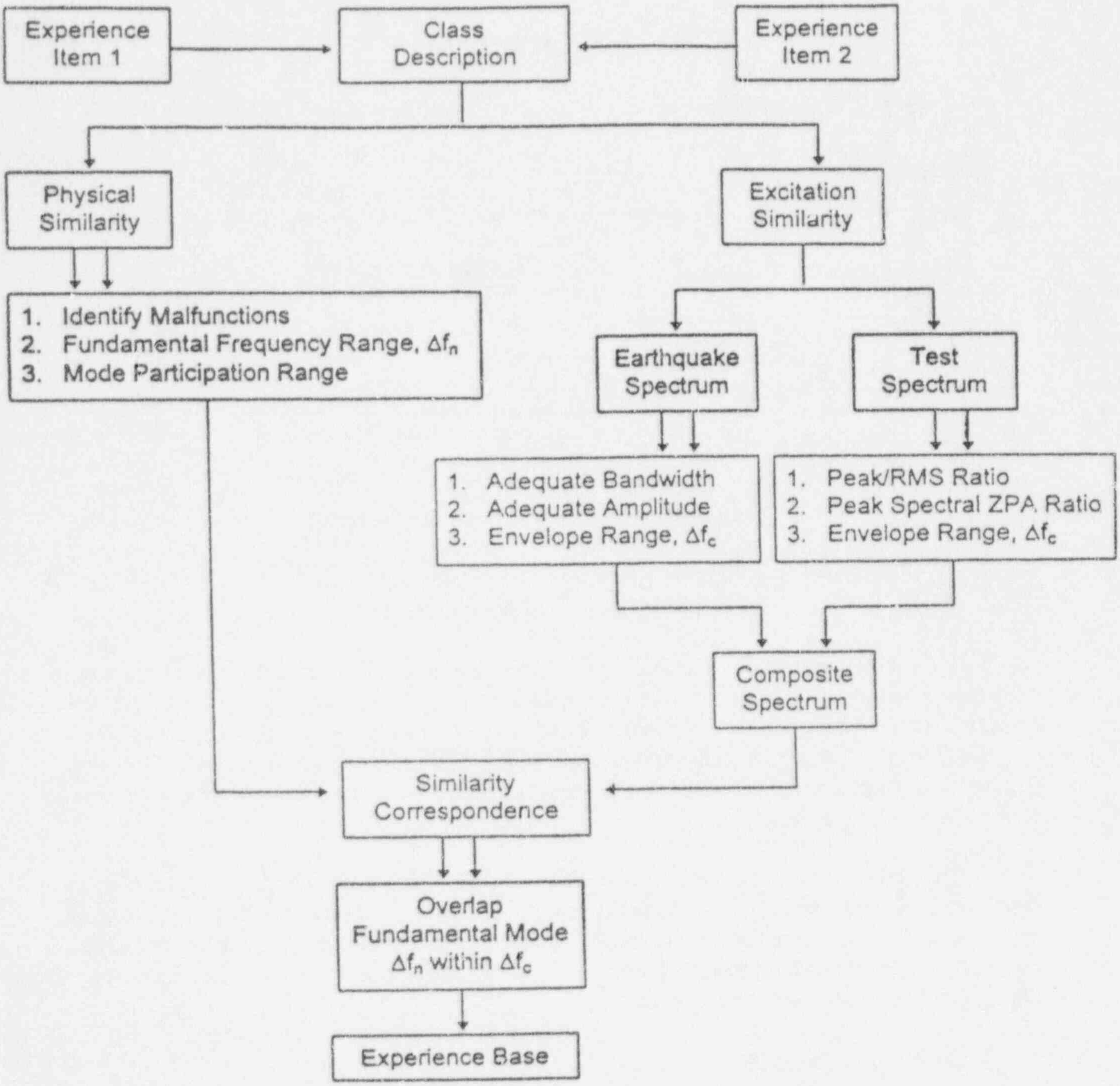


Figure A.5. General Considerations for Development of Experience Base

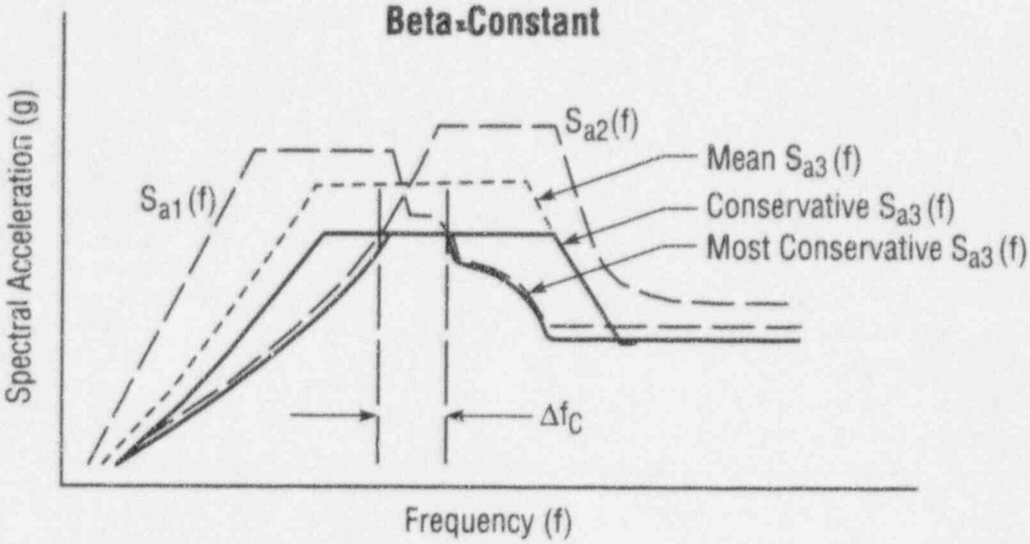


Figure A.6. Derivation of Composite Spectrum

Basis for Excitation Similarity - Equivalent Composite Severity for Physically Similar Equipment

spectra, if the most conservatism is desired. As indicated in Figure A.6, this is a bandwidth for which the composite is enveloped by all, or at least most of, the constituent spectra. Then for the most conservative justification for similarity correspondence, it should be shown that Δf_n falls within or above Δf_c for the entire equipment experience base; otherwise, further justification must be given. Typically, this includes the use of either a "conservative" spectrum or a mean composite spectrum, as are also shown in Figure A.6.

The above description includes only three of several approaches that can be justified for developing the final composite spectrum, depending on the exact nature of the data. Furthermore, for cases where largely varied data are available, significant judgment must be envoked in the process. Finally, no single approach is necessarily more valid than another. The final choice must be based on the aggregate of information that is available.

A.4.3 Qualification of Candidate Items

With the establishment of an equipment class and its associated composite spectrum, one can now consider the close similarity qualification of a candidate item of equipment. This is done explicitly according to the summary of Figure A.5. It must first be established as belonging to the class. This is done as appropriate, by comparing the primary malfunction, fundamental frequency, and fundamental mode participation as with experience base equipment. Then, one must show that its fundamental mode falls within or above the critical bandwidth Δf_c for the class, or otherwise show that sufficient data are available that tend to satisfy this requirement. Upon proper documentation of all results, a qualification according to IEEE Std. 344 (1987) has then been accomplished for any excitation demand spectrum that falls below the composite capacity spectrum.

It should again be emphasized that this qualification by "close similarity" approach is based on the traditional concept of small variability of equipment in the class that is being qualified and on the availability of significant knowledge about the equipment (such as dynamic properties associated with failure modes, modal participation factors, etc.).

A.5 Qualification by Extended Similarity

The previously described procedures represent a close similarity qualification approach in which the IEEE Std. 344 (1987) [2c] requirements for physical and excitation similarity are explicitly addressed. As was previously mentioned, it has not yet been applied to any plant case. In contrast, the ARC procedures [1] represents an example of an approach which addresses physical and excitation similarity requirements only implicitly by the introduction of generic diversity concepts. With these concepts the intent is to emphasize the need to know more about equipment functional properties, and to de-emphasize the need to know more about structural dynamic properties. Therefore, the ARC methodology falls under the concept of extended similarity as previously introduced. Hereafter, we will concentrate on a description of some extensions to the IEEE Std. 344 (1987) methodology that help establish a direct relationship to the ARC methodology, including certain inherent assumptions that the panel believes have been employed.

A.5.1 Close Similarity Versus Generic Diversity

The IEEE Std. 344 close similarity arguments described above were originally conceived as "variations" on essentially identical properties of physical equipment characteristics and well defined excitation characteristics. As such, the smaller the degree of the variations, the more readily one could justify the qualification approach. This, in general, requires quite detailed information about the physical properties of the equipment and the excitation, but it can be obtained from only a small number of equipment samples, since the variations are small. Therefore, as the physical characteristics become more diverse and less precisely defined, a larger number of equipment samples must be subjected to the demand spectrum to assure that all potential failures have been addressed. A process that considers the variations of physical characteristics and excitation characteristics is necessary to arrive at a corresponding sample size. Theoretically, by choosing a proper combination of values for each of the indicated variations, a given degree of confidence in the results can be established. In other words, an equivalent degree of confidence can also be achieved if the variations on physical characteristics and excitation characteristics are allowed to expand (i.e., become more diverse), providing that the sample size is also correspondingly expanded.

A most important issue, then, becomes how this can be done in a justifiable manner, when the properties of the inherently defined variability process remain unknown.

Generic diversity is a concept that satisfies physical similarity and excitation similarity by collecting for each equipment class an experience base of a large number of equipment samples that have successfully experienced a variety of earthquake or test excitation conditions. In particular, an equipment class can be formed of constituent items whose functionality is similar, but whose dynamic properties (i.e., fundamental frequency and mode participation) are not explicitly identified, but are judged to range over the bounds of the equipment class. Furthermore, the corresponding experience data excitations must be sufficiently broad in frequency content so that all potential malfunctions are exercised.

A.5.2 Variable Physical and Excitation Properties

It is important to discuss further the implications of the generic diversity concepts in terms of the stated IEEE Std 344 requirements for both physical similarity and excitation similarity. Wider deviations of dynamic physical characteristics for a class of equipment with a common type of operational function are used. Although the malfunction mechanisms may be known, the stiffness, mass variation, distribution of fundamental natural frequency, and mode participation factors that may influence the malfunction mechanisms are all unknown. These characteristics may be summarized by stating alternately that the random distribution of the fragility data statistically represents the fragility distribution of the class. Furthermore, each item of equipment in the experience base for this class has experienced some excitation that, when combined with all items in the experience base, forms a composite with bandwidths distributed over some (unknown) bandwidth Δf_c. The IEEE Std. 344 requirements for concurrence of similarity is then satisfied by arguing that with a sufficient number of samples in the experience base, there is a high confidence of a low probability of failure. These arguments apply primarily to ARC methodology Group 2 classes of equipment. They are not so relevant to Group 1 classes of equipment, since the inherent strength of equipment in this group precludes the necessity of more detailed evaluation.

There are some additional implications in the consideration of a set of excitations that are used to form the composite capacity spectrum from earthquake experience data. For the composite spectrum to properly represent the constituent spectra, it should be formed as a frequency-by-frequency mean of all the constituent spectra. It can then be said that at any frequency half the data base equipment experienced more, and half experienced less excitation, than the composite. As a result, rather than explicitly identifying the bandwidth Δf_c as in Figure A.6, the process has assumed that constituent spectra exceed the composite spectra over the entire frequency band, as is shown in the example spectrum in Figure A.7. Therefore, the exact fundamental frequency of the equipment is immaterial within the entire frequency band.

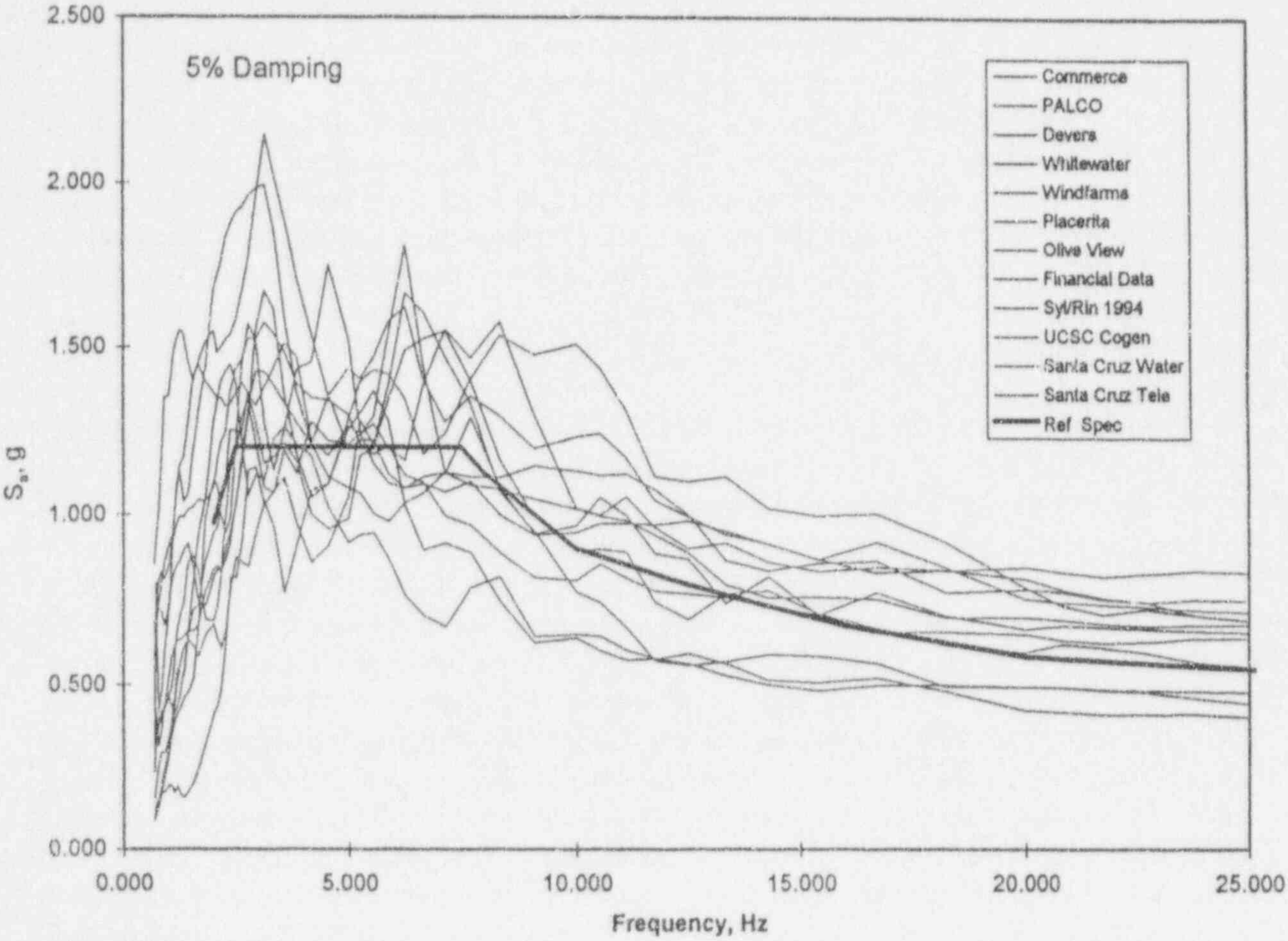


Figure A.7 Average Reference Site Spectra (Adapted from Ref. [1])

A.5.3 Variability Justification and Judgment

The above described generic diversity approach has been employed in the ARC methodology program on the basis of a "large" amount of success data for each equipment class. Only limited statistical analysis has been performed to support the results. Instead, judgment is used in the sample numbers required for some classes, depending on what forms of composite excitation levels can be developed.

For the ARC methodology, a primarily judgment-based approach (i.e., without use of numerical statistics) is used for Group 1 equipment, but for Group 2 equipment, a more strict requirement is placed on statistical analysis. The actual number of independent samples required was calculated by assuming that a homogeneous, log-normal distribution can be used to describe the random process. For this, based on experience, variabilities are assigned to the equipment physical properties (i.e., variation in probability of failure as input demand is increased) and the excitation properties (i.e., probability of exceeding any specified excitation spectrum for any frequency). In effect, the frequency bandwidth Δf_c becomes the entire region of the composite capacity spectrum.

A.5.4 Equipment Class Definition

To this point herein, equipment class definition has been discussed as if based primarily on operational functionality. This is exclusively true for the close similarity qualification approach. However, this is not the only criterion that is used for class definition in the ARC methodology. A set of rules are developed that exclude from each class certain types of otherwise operationally similar equipment. Generally, the rules are based on equipment functional characteristics and on physical properties that by experience are expected to cause concerns. Statistically, this means they are not within the same set as the true similar equipment. In the ARC methodology, these rules are termed "product specifications." The nature of the rules is such that they enhance the probability of success of the experience data qualification process. Thus, it is the use of a relatively large number of data samples, plus the use of exclusion rules, that forms the basis for the generic diversity concept. Finally, it should then be noted that the complete exclusion rules are applied exclusively to the qualification of a candidate equipment item only. That is, unlike for the close similarity approach, certain items that form constituents of the extended similarity experience base may not satisfy all the exclusion rules. They must, however, have successfully experienced a given designated excitation level, and there must be no failures at the designated excitation level for equipment items that do satisfy the exclusion rules. Thus, for the ARC methodology, the properties of 1) malfunctions, 2) fundamental frequency range, and 3) mode participation range listed under physical similarity in Figure A.4 are never established explicitly, but are established only implicitly by means of the generic diversity and exclusion rule arguments.

A.6 References

1. Advanced Light Water Reactor (ALWR) First-of-a-Kind Engineering Project on Equipment Seismic Qualification," Advanced Reactor Corporation Report, February 1996.

2. IEEE Standard 344, "Recommended Practices for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations," (a) 1971, (b) 1975, (c) 1987.

3. "Seismic Qualification of Equipment in Operating Nuclear Plants Unresolved Safety Issue A-46," NUREG-1030, U.S. Nuclear Regulatory Commission.

4. "Generic Implementation Procedure (GIP) for Seismic Verification of Nuclear Plant Equipment," Seismic Qualification Utilities Group Report, Rev. 2, Corrected February 14, 1992.

5. U.S. NRC Regulatory Guide 1.100, "Seismic Qualification of Electric and Mechanical Equipment for Nuclear Power Plants," Revision 2, June 1988.

6. Kana, D. D., and Pomerening, D. J., "Similarity Principles for Equipment Qualification by Experience," NUREG/CR-5012, U.S. Nuclear Regulatory Commission, July 1988.

7. "Qualification of Active Mechanical Equipment Used in Nuclear Power Plants," ASME QME-1-1994.

A NOTE ON APPENDIX A

Kamal K. Bandyopadhyay

I do not agree with the concepts promulgated in Appendix A. My principal concern stems from partitioning of the similarity principle that ultimately led to the so-called "indirect similarity" or "extended similarity." My view is that the similarity principle should be kept intact and not be redefined or "diluted" to accommodate the use of experience data.

It should be noted that the panel members unanimously accepted the equipment seismic qualification results presented in the ARC report and further clarified in this Panel report by use of their individual experience and judgments and not necessarily the concept presented in Appendix A. In fact, Appendix A was prepared after the Panel had accepted the equipment-specific qualification results.

A set of guidelines for qualification by the use of experience data are described in Chapter 2 of this report. These guidelines emphasize the need for equipment-specific considerations and data, and allow graded applications commensurate with equipment characteristics and the users' knowledge about them. It is my view that these guidelines represent a more practical basis for preparation, evaluation and acceptance of the experience-based equipment qualification.

A NOTE ON THE COMMENT OF KAMAL K. BANDYOPADHYAY ON APPENDIX A

Dan Kaña, Robert Kennedy and Anshel Schiff

The purpose of this note is to explain the intent in developing Appendix A. Appendix A was finalized and incorporated into the Panel Report after the body of the report was completed. There was a concern about how experience data would be used in the future. It was felt that it would be useful to identify several fundamental concepts that should be considered in the review of the similarity of equipment in arriving at the judgment that the equipment meets the intent of IEEE 344 for the qualification of equipment. It was generally agreed that there were differences in the degree of similarity (or conversely diversity) as it was used in IEEE 344. However, in the traditional and long standing approach to the use of similarity for qualification, very little variation was allowed between the new item of equipment that was being compared to a previously qualified item. In contrast, in the use of experience data for seismic qualification by ARC, the degree of diversity was clearly expanded. Appendix A has attempted to identify and name differences in similarity as an aid to discussing and thinking about similarity. The definitions and names developed in Appendix A are not unique and others may choose different formulations to meet their needs. It is the view of the above-named authors (D. Kaña, R. Kennedy and A. Schiff) that Appendix A does provide a useful discussion of physical and excitation similarity and does identify and clarify issues that should be considered in assessing the similarity of equipment for qualification.

It should be emphasized that Appendix A is not meant to provide a cook book approach to qualification. Qualification is highly dependent on informed engineering judgment that is supported by a documented body of equipment that has survived significant ground motions with their function unimpaired. In some cases, additional support is provided by analyses of the equipment.

APPENDIX B
COMMENTS ON LEVEL A REFERENCE SPECTRUM FOR GROUP 2 EQUIPMENT

Specific reference equipment earthquake experience data has been documented in Appendix A of Reference B.1 for Group 2 equipment located at specified reference data base-sites. A best-estimate of the horizontal ground motion response spectrum has been provided for each of these reference data base-sites. Based on a review of these data base-site best-estimate response spectra by David Boore (see Appendix C), the Panel concurs that these Appendix A of Reference B.1 response spectra can be considered to be best-estimates of the horizontal ground motion response spectra at the data base-sites. Next, the Level A Reference Spectrum has been established to be at roughly the median level of all of these reference data base-site best-estimate response spectra. Appendix D of Reference B.1 demonstrates that the median of all of these reference data base-site best-estimate response spectra closely corresponds to the Level A Reference Spectrum.

The Panel wishes to note that any specific piece of reference equipment may have seen an input either substantially greater than or substantially less than that represented by the corresponding reference data base-site best-estimate response spectrum. First, the best-estimate response spectrum is only an estimate of the response spectrum for the site in general. Some of these estimates have considerable uncertainty. Second, many of the sites are large with equipment located at different locations on the site. The Panel is aware that response spectra can differ substantially between locations only a short distance apart. Therefore, even if the best-estimate response spectrum was measured at a specific location on the site, the free-field ground response spectrum at the equipment location could be substantially different. In addition, much of the equipment was located within buildings which are likely to have modified the input felt by the equipment. This building induced modification of the input motion is likely to have increased the input motion for equipment located above grade and to have reduced the input motion for equipment located below grade. The conclusion is that there is considerable uncertainty as to the level of motion any piece of equipment felt.

Additionally, as shown in Figure B.1, there is considerable variability between the best-estimate response spectra at the various reference data base-sites. Because of:

1. the variability of the best-estimate response spectra between reference data sites, and
2. the uncertainty of the response spectrum at any equipment location relative to the best-estimate for that site,

the Panel judges that some of the reference equipment felt input motion as much as twice the

Level A Reference Spectrum, while roughly 50% of the reference equipment felt input motions in excess of the Level A Reference Spectrum. Despite these instances of input motion substantially in excess of the Level A Reference Spectrum no failure occurred. Thus, so long as sufficient reference data exist with adequate equipment diversity to represent the range of the particular equipment class, this variability and uncertainty of the input motion with no reported failures helps to provide a high-confidence of a low-probability of failure for the reference data equipment at the Level A Reference Spectrum. So long as an adequate number of independent items of reference equipment data exist that bound the range of a particular equipment class and represent the diversity of the equipment class, the Panel concurs that the Level A Reference Spectrum can be established at the median level of the individual reference data-base best-estimate response spectra.

Reference

B.1 "Advanced Light Water Reactor (ALWR) First-Of-A-Kind Engineering Project on Equipment Seismic Qualification," prepared by MPR Associates and EQE International for Advanced Reactor Corporation, February, 1996.

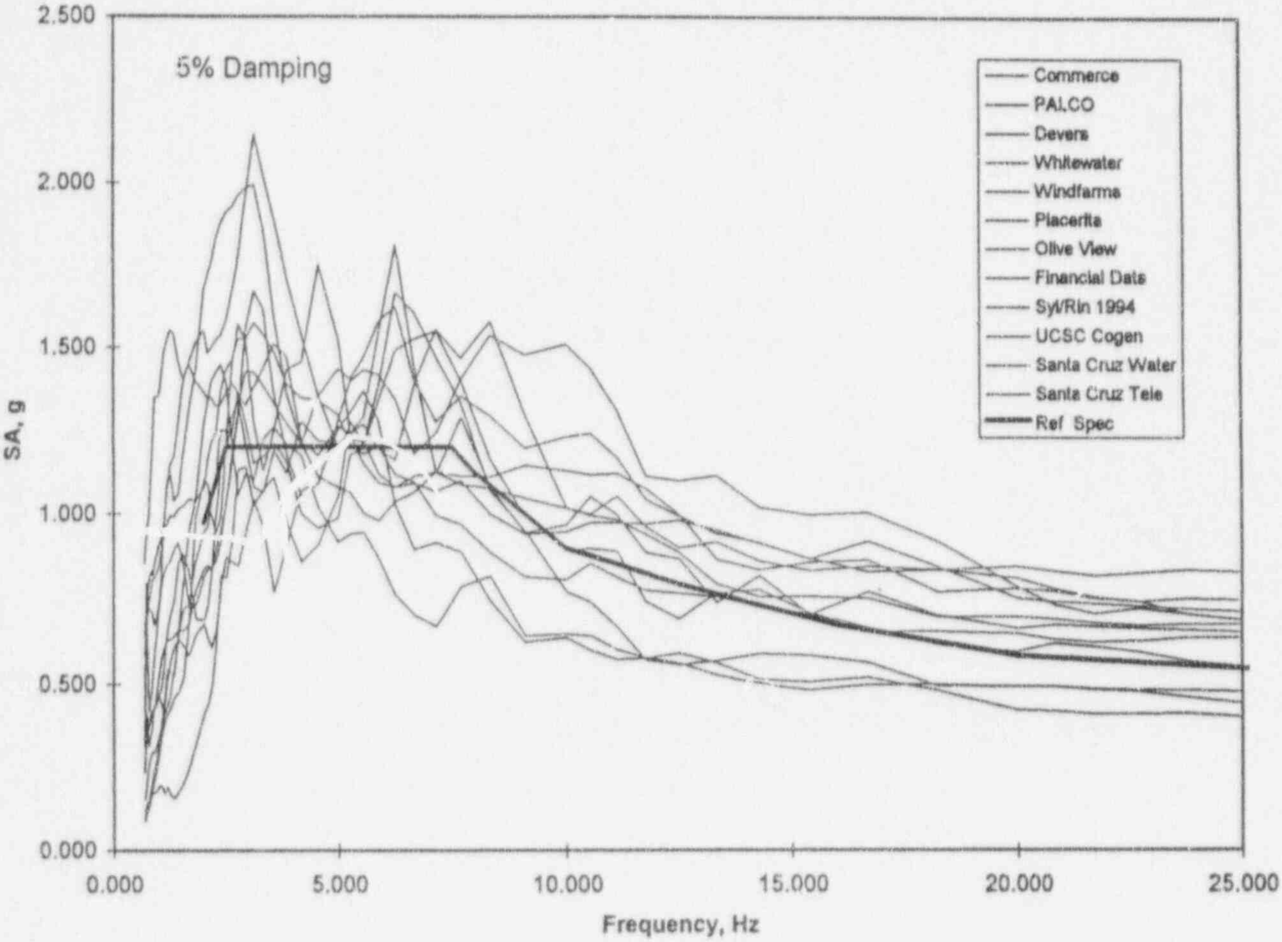


Figure B.1 Average Reference Site Spectra (Adapted from Reference B.1)

APPENDIX C
ESTIMATES OF AVERAGE SPECTRAL AMPLITUDES AT FOAKE SITES

David M. Boore
U.S. Geological Survey
Menlo Park, CA 94025
(415)-329-5616

Introduction

In my role as consultant to the panel of experts evaluating the equipment qualification work for the NRC, I was asked to estimate ground motions at selected FOAKE sites. This report presents my estimates and the method used to arrive at the estimates. After a brief description of the method, I present the results with a short description of particular considerations for each site, if needed. For clarity of presentation, tables giving the details of the estimates are gathered together in an appendix. Another appendix contains plots of the acceleration response spectra for each station used in the estimation process, with the average level from 3 to 8 Hz (the measure of ground motion used in the report) given by horizontal lines.

Method

The method for estimating the mean ground motion from a particular earthquake at a specified site required finding nearby strong motion recordings, computing the ground motion measure of interest, and correcting these recordings for differences in site geology and for differences in the distance from the sites to the earthquake. In addition, uncertainty bounds are computed that account for the distance between the reference site and the recording site.

In somewhat more detail, these steps are as follow:

1. Search strong-motion database for all recordings within a radius of 10 km.
2. Determine the distance from the reference site to each strong-motion station identified in step 1.
3. Pick one or several recordings from this set, depending on proximity to the reference site and similarity of site geology.
4. Compute the response spectra for each site, in most cases using uncorrected

acceleration data with a least-square fitted straight line removed (no instrument correction or high- and low-cut filtering was done).

5. For each horizontal component, compute the average acceleration response spectra (S_a) between 3 and 8 Hz, according to

$$S_a = \frac{1}{5} \int_3^8 (2\pi f)^2 \, S_d \, df,$$

where S_d is the relative displacement of a 5 percent damped oscillator with natural frequency f. Find the arithmetic average of S_a for each horizontal component. Plots of all spectra used are given in Appendix C.1.

6. Determine the shortest distance from each strong-motion recording station and the reference site to the surface projection of the rupture surface (the boundaries of the rupture surface were extracted from published studies of each earthquake, using my judgment as to the best estimate of the rupture surface).

7. Assign a shear-wave velocity to each station and to the reference site. This is the time-averaged velocity over the first 30 m of depth, computed as 30 m divided by the travel time from the surface to 30 m. In some cases velocities from a nearby borehole were available, but in most cases the velocities were estimated from boreholes in geologic materials similar to those under the site; Tom Fumal, who has had years of experience in making these assessments, helped me in assigning the velocities.

8. For each recording to be used in the estimation, correct for differences in site response and distance to the earthquake by multiplying average spectral acceleration by the correction factor

$$\mathrm{psv}(m, d_{ref}, \upsilon_{ref}) / \mathrm{psv}(m, d_{sta}, \upsilon_{sta}),$$

where psv is the response spectrum predicted from the regression equations of Boore, Joyner, and Fumal (1993 and 1994), and d_{ref}, d_{sta} and υ_{sta} are the earthquake-to-site distances and average sub-site shear velocity for the reference and recording site, respectively (I have included in Appendix C.3 a listing of the Fortran program used in the analysis).

9. Compute the geometric mean of the corrected estimates (i.e., average the logs of the corrected estimates and raise 10 to this average of the logs).

10. Approximate the plus and minus one sigma uncertainty ranges by multiplying and dividing the averaged corrected spectral estimate by the factor

$$10^{0.182} \sqrt{1 + \frac{1}{N}} (1 - \exp - \sqrt{0.6\Delta}) .$$

The basis for this equation is given in the next section.

Uncertainty in Estimates

Analysis of scatter about regression curves yields the uncertainty in the prediction of any one value of ground motion. The analyses that I have been associated with have regressed on the common log of the ground motion, and all of my discussion here will refer to logs to the base 10. We found from our regression work that the within-earthquake $\sigma_{\log pga}$ was 0.188 and 0.182 for the larger and random horizontal peak acceleration, respectively, for earthquakes with magnitudes between 6.0 and 6.9. (I am assuming that the uncertainty of the 3-to-8 Hz averaged spectral acceleration will be similar to that for the peak acceleration.) In the application in this report, nearby records provide an estimate of the actual mean motion at the reference site, but because there is a spatial variation in ground motion, the reference site motion will be uncertain even if the true value of the mean of the motions within a small region surrounding the site has been determined. Clearly, this additional uncertainty reduces to zero if the recording site is at the exact location of the reference site. On the other hand, for a great enough separation distance, the spatial correlation reduces to zero and the additional uncertainty reaches that for an individual observation. This discussion suggests the following equation for the variance of the estimated motion at the reference site (because ground motions are well-approximated by a lognormal distribution, the standard deviations in the following discussion are those of the log of the ground motion; uncertainty ranges for the ground motion are given by respectively multiplying and dividing the ground motion by 10 raised to a power equal to the standard deviation):

$$\sigma_{ref}^2 = \sigma_{sta}^2 (1 + \frac{1}{N}) F(\Delta)^2,$$

where σ_{sta} is the standard deviation of an individual observation (e.g., 0.182 for the random horizontal component of peak acceleration), and N is the number of recordings used in the average (the term in N accounts for the uncertainty in the estimate of the mean motion). $F(\Delta)$ is a function that accounts for the spatial correlation of the motion, where Δ is the average separation between recording station and reference site; F takes on values of 0.0 and 1.0 for $\Delta = 0$ and $\Delta = \infty$, respectively.

I estimated F(Δ) by studying larger peak horizontal accelerations from the 1994 Northridge mainshock (the most complete data set available to me), supplemented by studies of spatial variability in small arrays (Abrahamson and Sykora, 1993), the SMART 1 array in Taiwan (Abrahamson, written commun, 1995), and local regions in the 1971 San Fernando earthquake (McCann and Boore, 1983). The analysis for the Northridge data followed these steps:

1. Compute Δ for all pairs of stations, keeping only those for which the separation was less than 10 km (over 600 pairs).

2. For each pair, compute the difference of the larger peak horizontal acceleration after correcting for differences in distance from the station to the earthquake (the distance attenuation used for this correction was derived in the course of the analysis as corrections to the average attenuation of Boore, Joyner, and Fumal, 1993).

3. Divide the range of Δ into bins such that 15 station pairs are within each bin. This was done so that a reasonable estimate of the variance of the residuals could be obtained for each bin.

4. Compute the standard deviation of the residuals within each Δ bin.

5. Plot the standard deviations against the median distance for each bin, and fit a function to this plot, guided also by the Abrahamson and Boore and McCann studies. The results are shown in Figure C.1. This procedure yielded the following equation for F(Δ):

$$F = (1 - \exp - \sqrt{0.6\Delta})$$

Listings of the computer programs used in the analysis are included in Appendix C.3.

I am aware that a whole computational structure ("kriging") has been built up to deal with spatial estimation problems (e.g., Journel, 1989). I did not have time to learn about this structure, so I devised a simplified procedure that should give reasonable results (I have presented the uncertainty ranges to only one decimal place to emphasize the imprecision of the estimates).

Results

The results are summarized in Table C.1; details are given in tables gathered together in Appendix C.2. The detailed tables contain all the information used in the processing. In addition to the corrected values summarized in Table C.1, the Appendix tables give values uncorrected for distance and site differences. Although not annotated, the entries in the tables should be self explanatory.

There were many recordings for the Whittier Narrows earthquake, including a large number from the USC array. I have these data, but I have not yet entered them into my database. In view of the proximity of the Commerce Refuse reference site to the Bulk Mail facility (0.8 km) and the limited time available to me, I did not do a search for nearby stations that recorded the Whittier Narrows earthquake; I simply used the recording at the Bulk Mail facility. According to Ed Etheridge (personal communication, 1995) and the notes in the station files in the strong motion lab at the U.S.G.S., the Bulk Mail site is located within a very large warehouse with a slab foundation of considerable horizontal extent. It is very likely that the motions at the recording instrument were reduced by the slab, particularly for the higher frequencies of interest to the FOAKE study. This will mean that the motions estimated from that record will be conservative for purposes of FOAKE.

Note that for the Northridge earthquake two estimates are given for the Placerita cogen reference site and three for the Sylmar Converter Station reference site. For Placerita the nearest site is at Newhall ($\Delta = 3.5$ km), but there were a number of additional sites at $\Delta \approx 7.5$ km. The Newhall site is not so close that it is obvious that it alone should be used in the estimate. Note that the two estimates of the median motions are well within the uncertainty ranges.

For the Sylmar Converter Station, the VG1-6 (Valve Group 1-6) record was obtained in the basement of the terminal building containing the equipment of interest. I assume that the reference site coincides with that building. Logically, the VG1-6 record should be used solely for the estimate of the motions of equipment in that structure. On the other hand, the VG1-6 spectrum is quite different from the nearby free-field recording near Valve Group 7 (VG7FF). I wonder whether the VG1-6 record is contaminated by building response and embedment depth effects. (The differences could, of course, also be due to variations in local geology or to the soil failure that was observed in the vicinity). I was instructed by the Panel to estimate free-field motions, which I have attempted to do. Modifications of the motion due to structural effects are the responsibility of others more qualified than I to do so. I do not have the expertise to evaluate the possible modifications of the VG1-6 record due to embedment and structure. If the modifications are small, then I would recommend using estimate 1 for equipment in the terminal building (and I note that during our meeting on March 29, 1995, the Panel instructed me to use only the VG1-6 record). In view of possible structural effects at VG1-6, for the Sylmar Converter Station reference site I think it might be most appropriate to use my second estimate, which combines the VG1-6 and VG7FF. For completeness, Table 1 also contains an estimate from VG7FF alone.

I am assuming that most of the equipment at the Sylmar Converter Station is in the terminal building, but I do recall that we walked through Valve Group 7. If there is equipment in that structure, it should be considered a separate reference site. For completeness, I include in the summary table and in Appendix C.2 estimates for the Valve Group 7 building, using the average of the free field and floor spectra.

References

Abrahamson, N. and D. Sykora (1993). Variation of ground motions across individual sites, *Fourth DOE Natural Phenomena Hazards Mitigation Conference*, 1993.

Boore, D. M., W. B. Joyner, and T. E. Fumal (1993). Estimation of response spectra and peak accelerations from western North American earthquakes: An interim report, *U. S. Geol. Surv. Open-File Rept. 93-509*, 72 pp.

Boore, D. M., W. B. Joyner, and T. E. Fumal (1994). Estimation of response spectra and peak accelerations from western North American earthquakes: An interim report, Part 2 *U. S. Geol. Surv. Open-File Rept. 94-127*, 40 pp.

Journel, A. G. (1989). Fundamentals of geostatistics in five lessons, *American Geophysical Union Short Course in Geology: Volume 8*, 40 pp.

McCann, Jr., M. W. and D. M. Boore (1983). Variability in ground motions: root mean square acceleration and peak acceleration for the 1971 San Fernando, California, earthquake, *Bull. Seism. Soc. Am.* **73**, 615-632.

Table C.1
Summary of Results - SA Averaged from 3 to 8 Hz, in g.

Site	FOAKE	Boore		Comments
Altwind, NPS86	1.39	1.23	(0.8, 1.8)	
Buckwind, NPS86	1.39	1.37	(1.0, 1.9)	
Devers, NPS86	1.33	1.48	(1.1, 2.1)	
Garnet Sub, NPS86	1.39	1.16	(0.8, 1.7)	
Renwind, NPS86	1.39	1.28	(0.8, 2.0)	
Sanwind, NPS86	1.39	1.47	(1.0, 2.2)	
Terrawind, NPS86	1.39	1.35	(0.9, 1.9)	
Venwind, NPS86	1.39	1.53	(1.0, 2.3)	
Whitewater, NPS86	1.39	1.45	(0.9, 2.2)	
Commerce Refuse, W87	1.03	1.11	(0.8, 1.5)	
SC Telephone, LP89	1.30	1.10	(0.7, 1.7)	
SC Water, LP89	1.26	1.18	(0.8, 1.8)	
Soquel Water, LP89	1.30	1.47	(1.0, 2.1)	
UCSC cogen, LP89	1.23	1.30	(1.2, 1.4)	
Centerville, P92	0.90	1.00	(0.9, 1.1)	
PALCO cogen, P92	0.93	0.93	(0.6, 1.4)	
Financial Center, NR94	1.22	1.52	(1.0, 2.3)	
Olive View cogen, NR94	1.20	1.18	(1.0, 1.4)	
Placerita cogen, NR94: est. 1	1.33	1.26	(0.8, 2.0)	Using closest station
Placerita cogen, NR94: est. 2	1.33	1.10	(0.7, 1.6)	Using 4 stations
Rinaldi, NR94	1.20	1.33	(1.1, 1.6)	
Sylmar CS, NR94: est. 1	1.20	0.62	(0.6, 0.6)	Using VG1-6
Sylmar CS, NR94: est. 2	1.20	0.82	(0.7, 0.9)	Using VG1-6 & VG7 FF
Sylmar CS, NR94: est. 3	1.20	1.09	(0.9, 1.3)	Using VG7 FF
Sylmar CS, VG7, NR94	1.20	1.05	(1.0, 1.1)	Using VG7 FF & Bldg

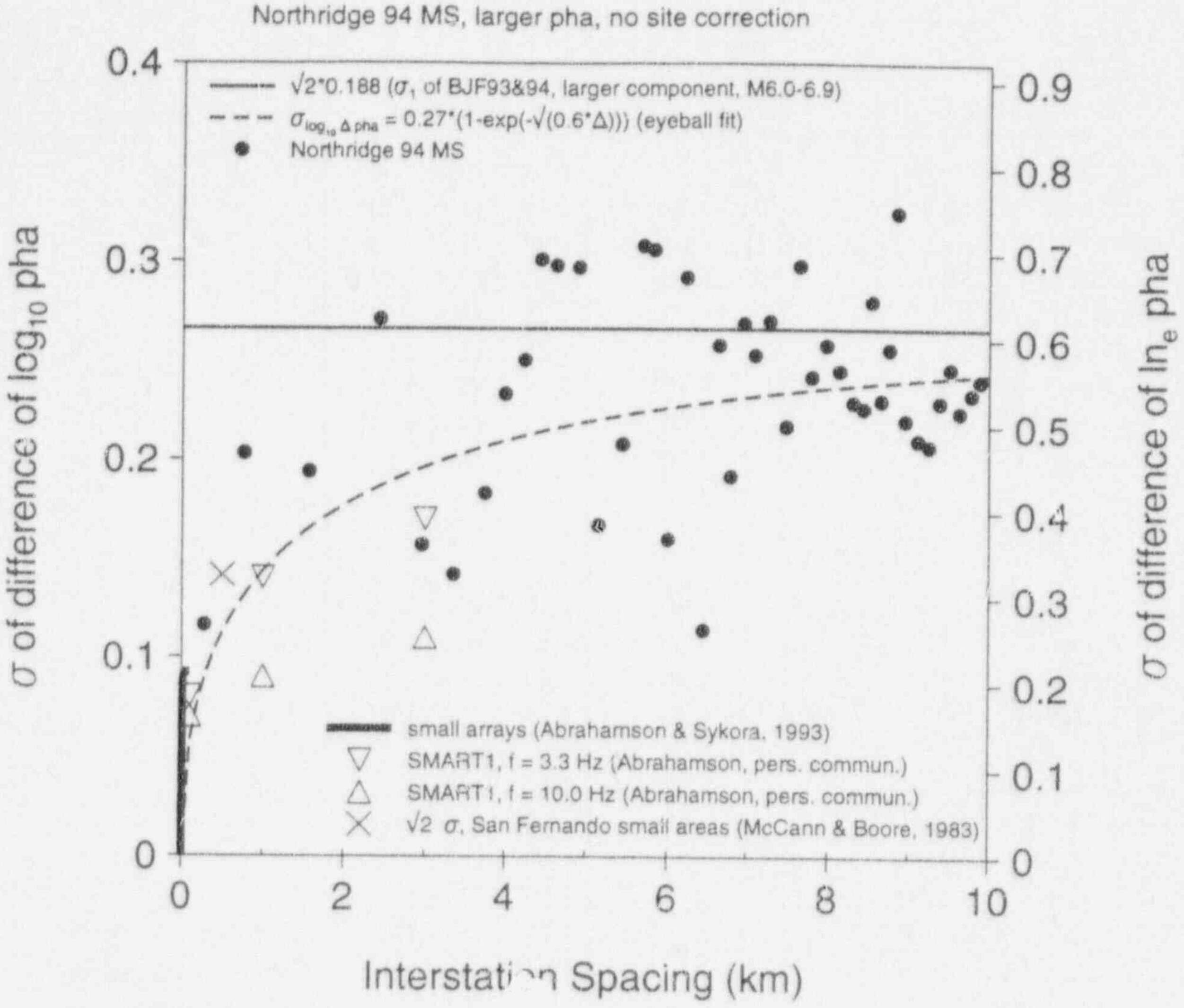
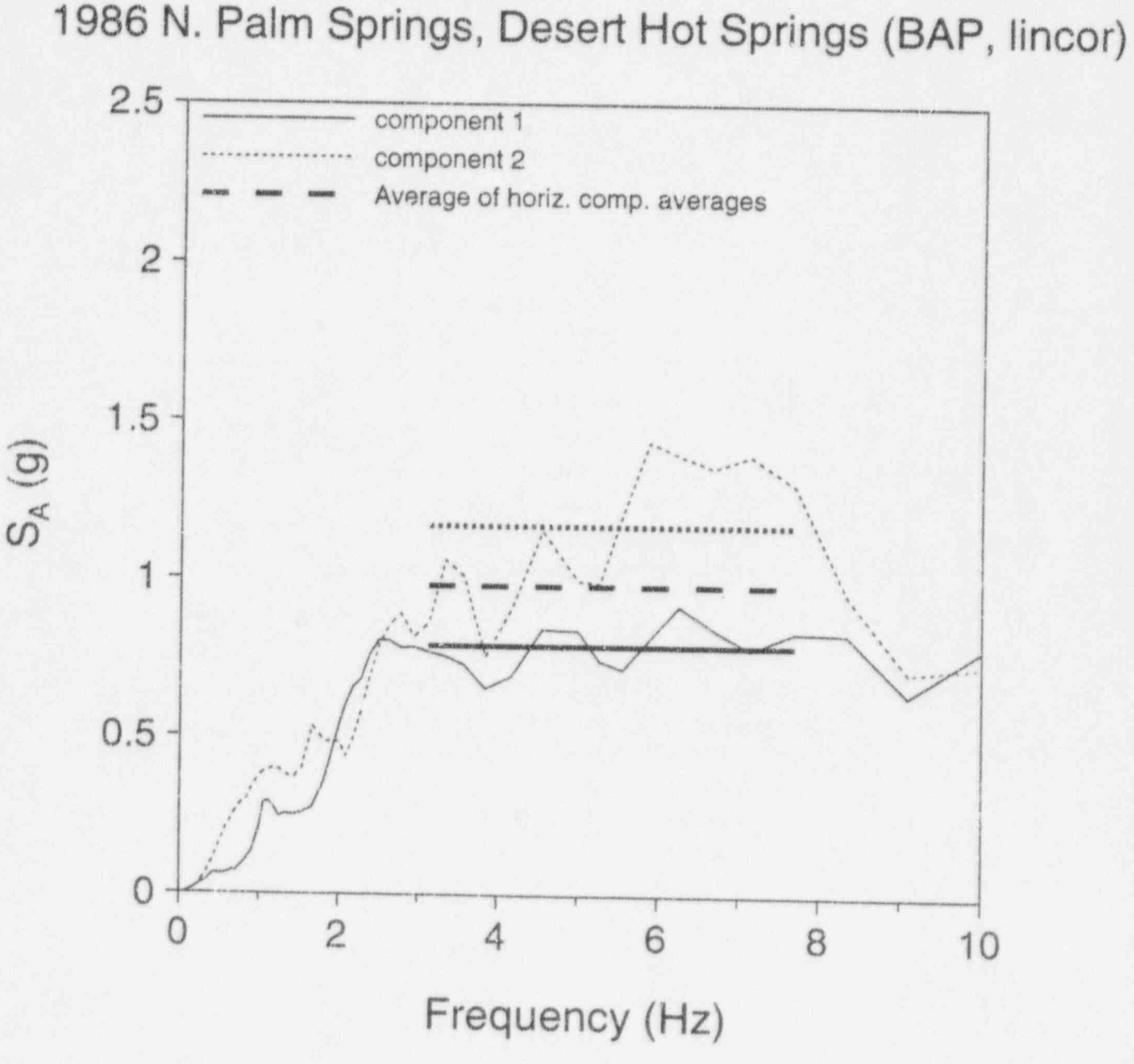


Figure C.1 - Standard deviation of difference of log of the larger peak horizontal acceleration as a function of interstation spacing. This provides the function F(Δ) referred to in the text. As an example of use, assume that a recording of 0.6 g was obtained 2 km from a reference site, and that the parameter of interest is larger peak horizontal acceleration (I assume that F(Δ) is independent of whether larger or random motions are being estimated--- those differences are accounted for in the leading term; see the equation in the text). If both the recording and reference sites are on the same geology and are both at the same distances from the earthquake, then the best estimate of the motion at the reference site is 0.6 g, with an uncertainty range given by $0.6/10^{0.18} = 0.4$ and $0.6 \times 10^{0.18} = 0.9$; I would report this as 0.6 (0.4, 0.9). (The factor 0.18 came from the value of the dashed curve at an interstation spacing of 2 km.)

APPENDIX C.1

FIGURES OF RESPONSE SPECTRA



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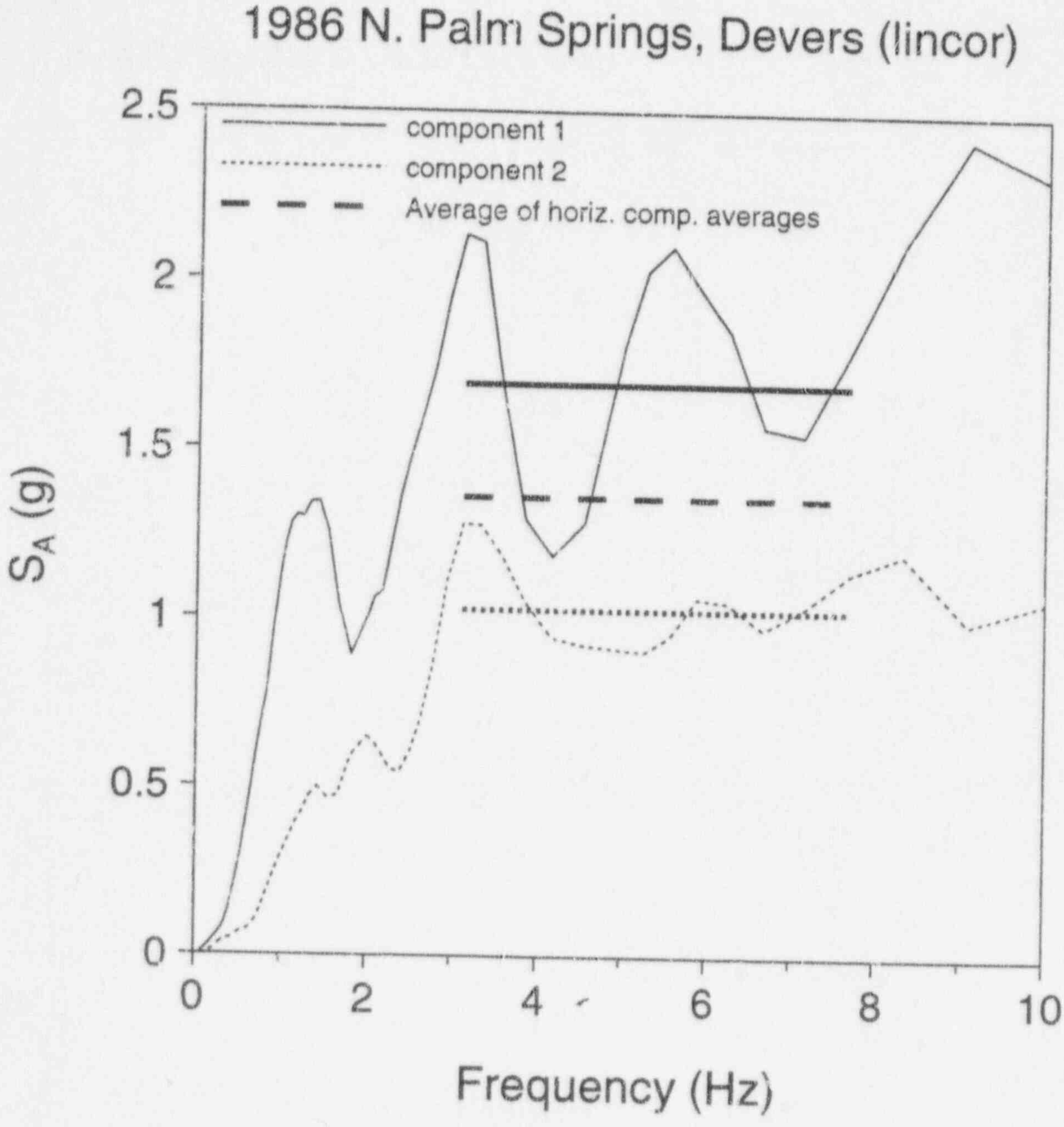

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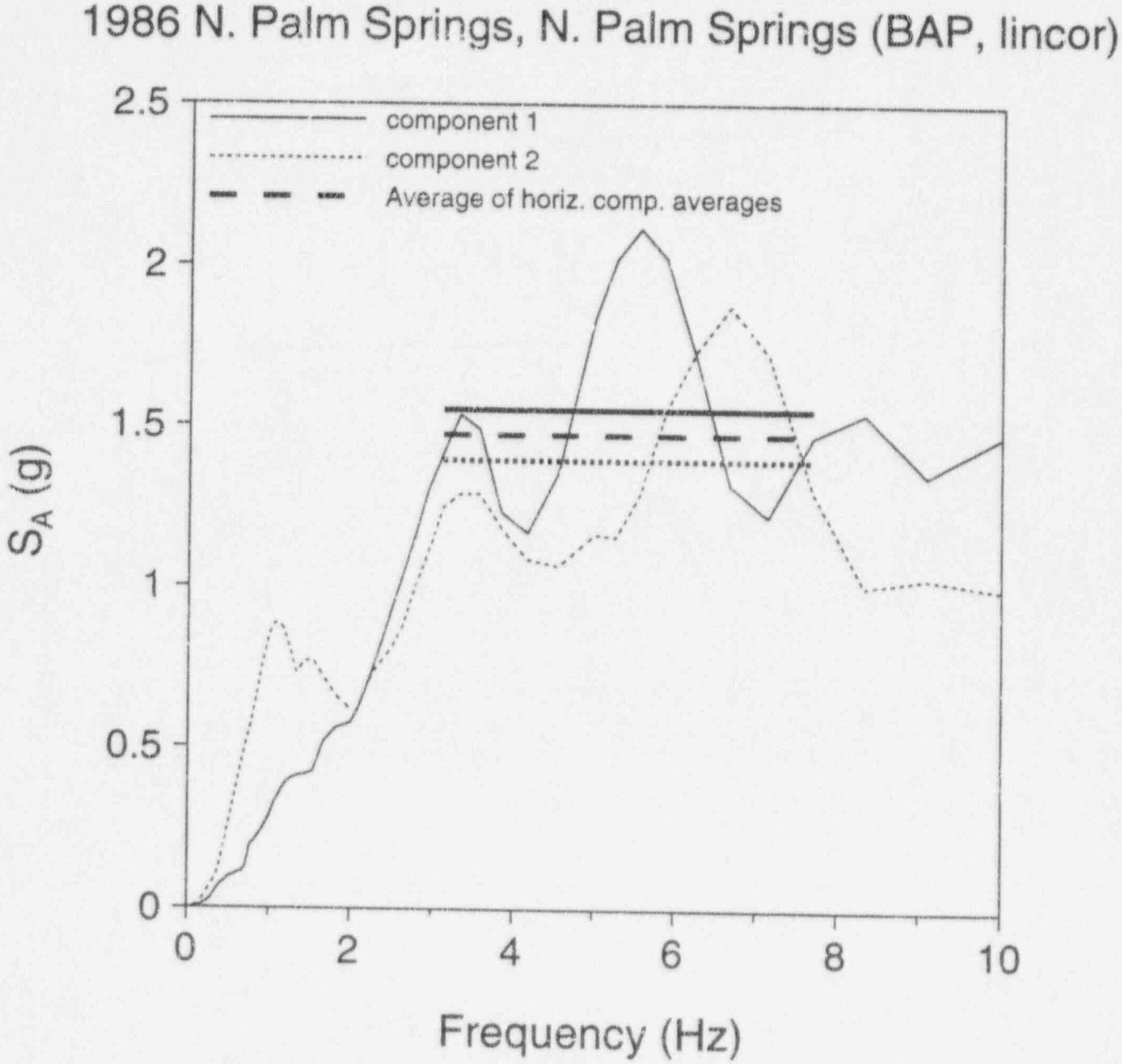
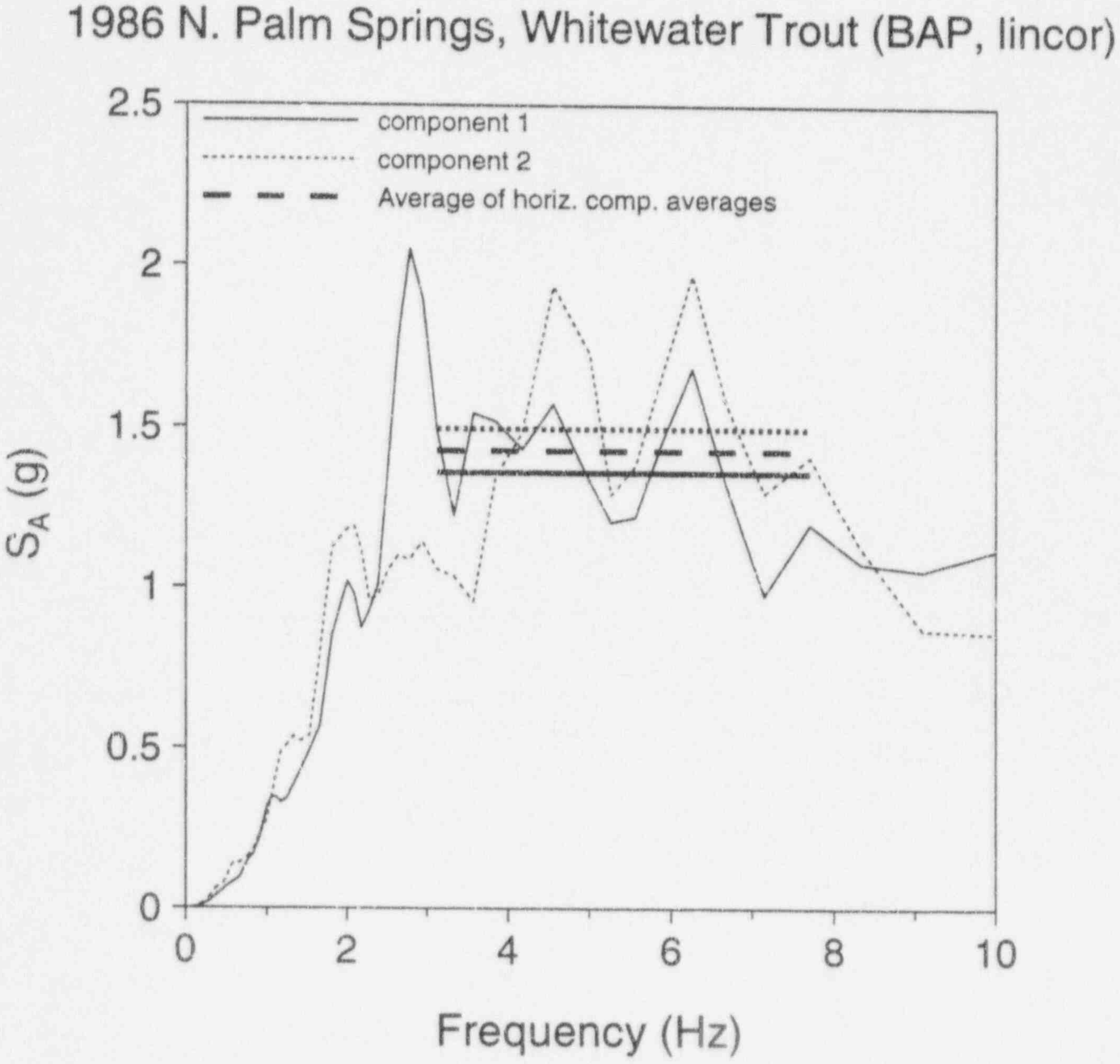


1986 N. Palm Springs, N. Palm Springs (BAP, lincor)

Apr 11, 1995 1:34:05 pm nps_bap.gra



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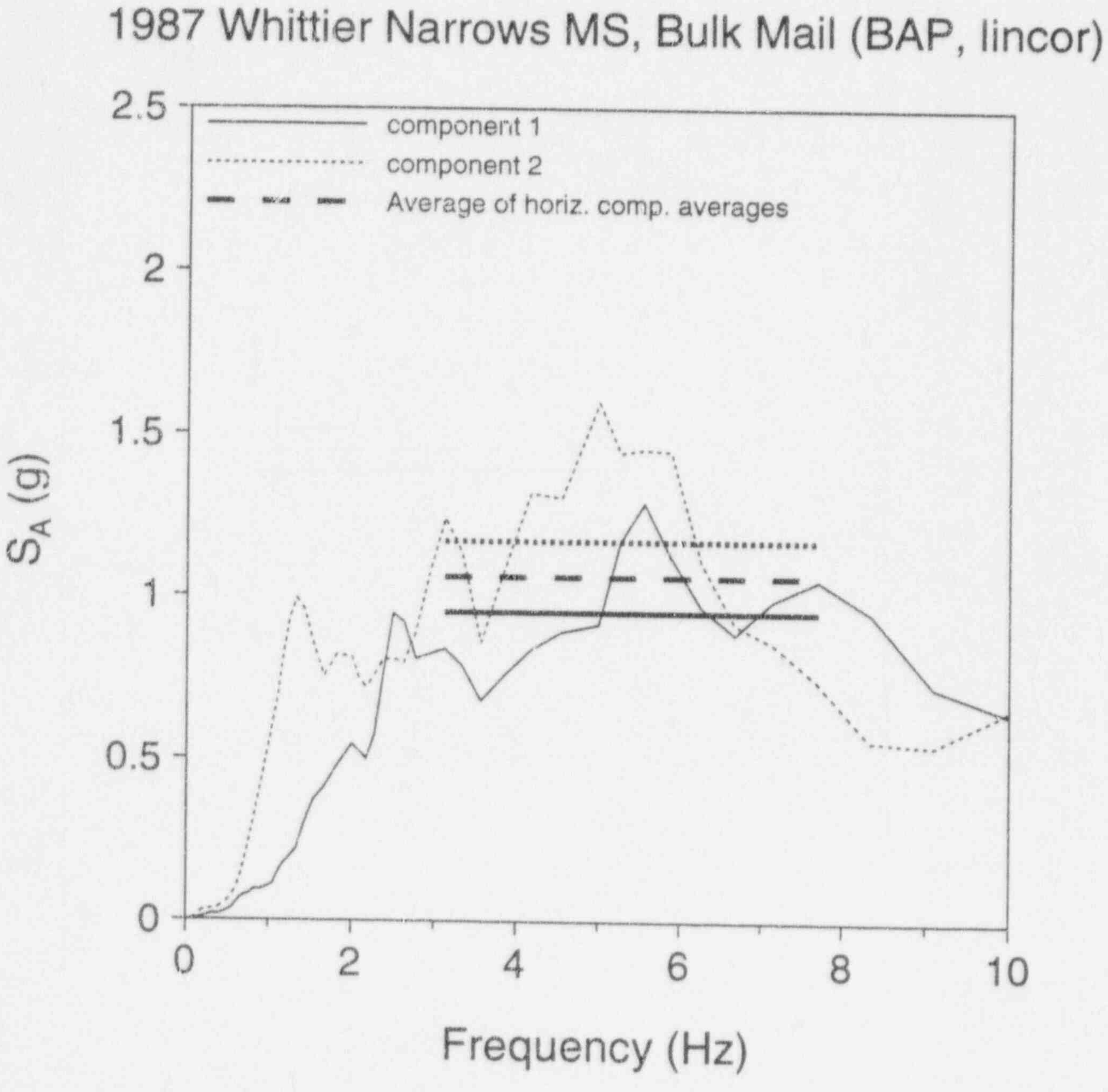
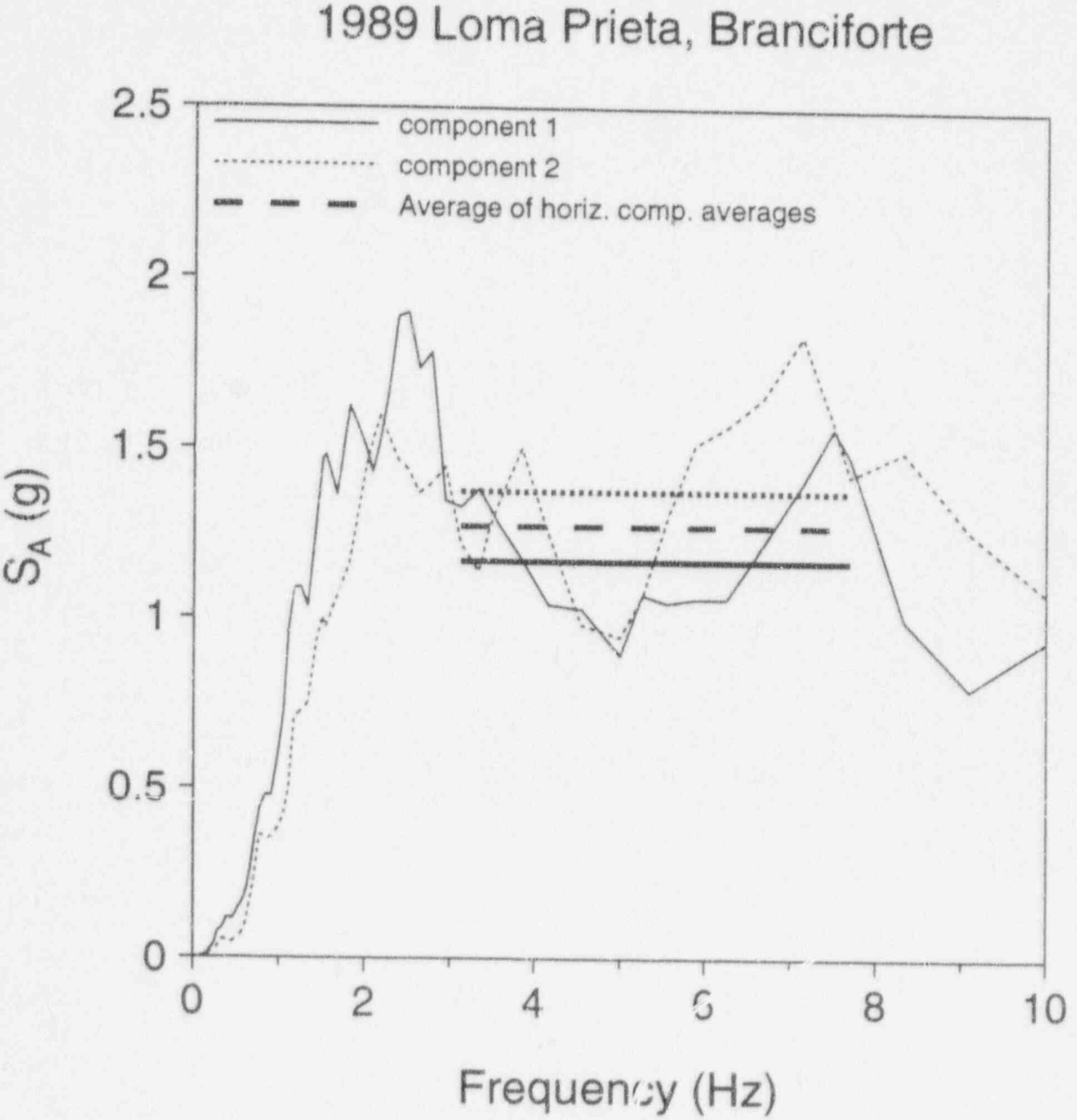
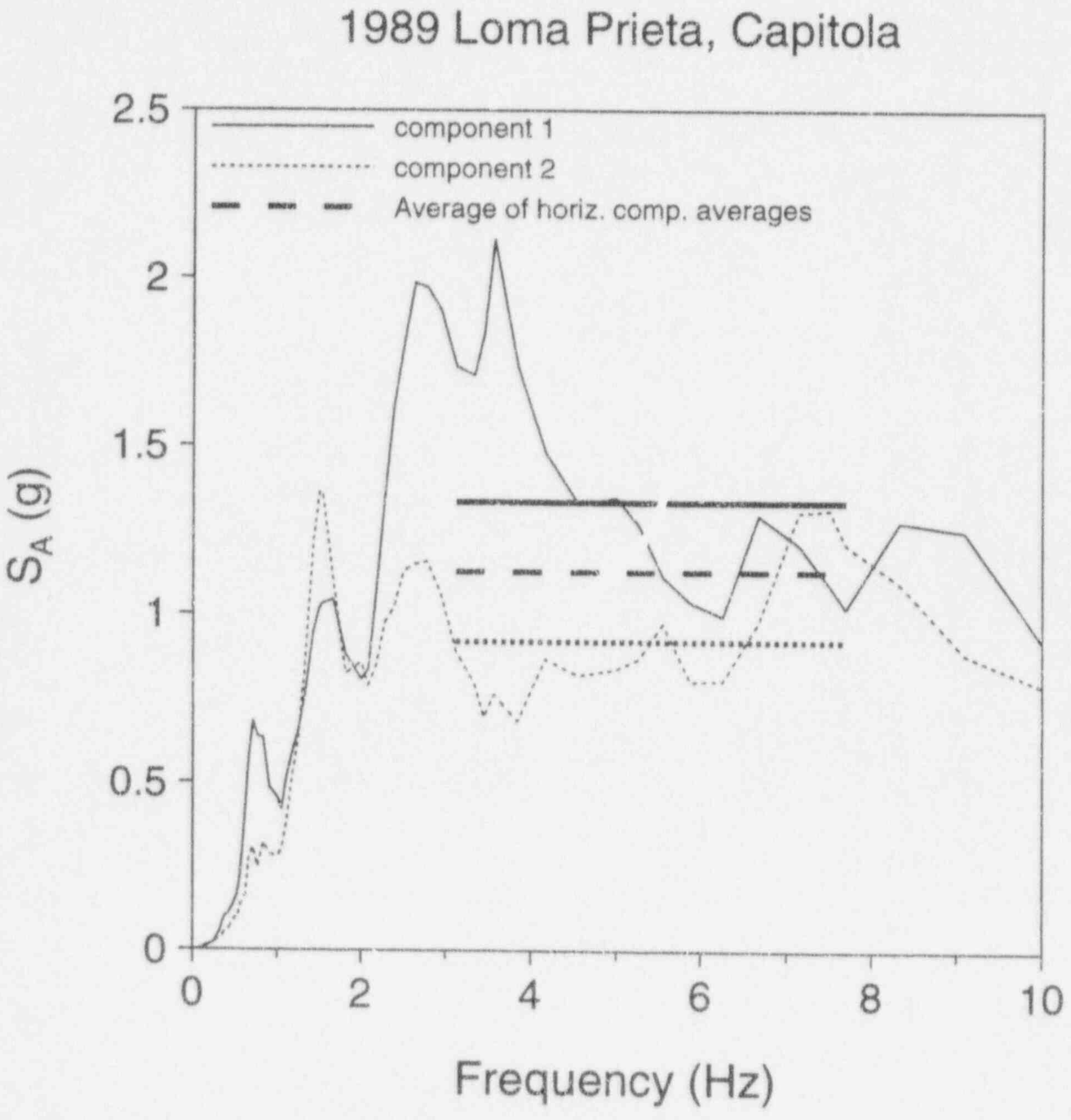


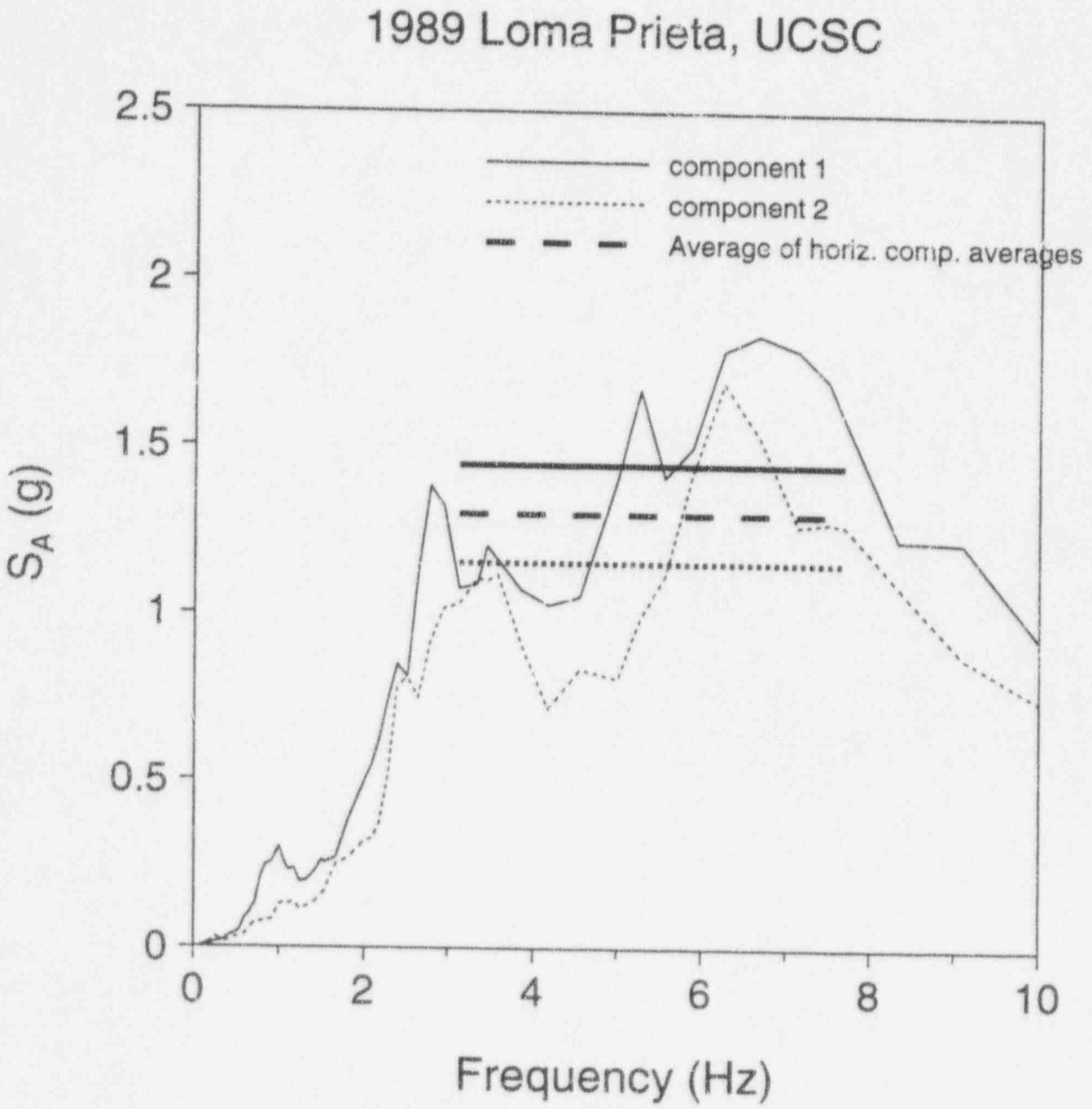
Apr 11, 1995 3:14:22 pm bulk_bap.gra



Apr 11, 1995 3:37:38 pm bran.gra



Apr 11, 1995 3:37:51 pm capitola.gra



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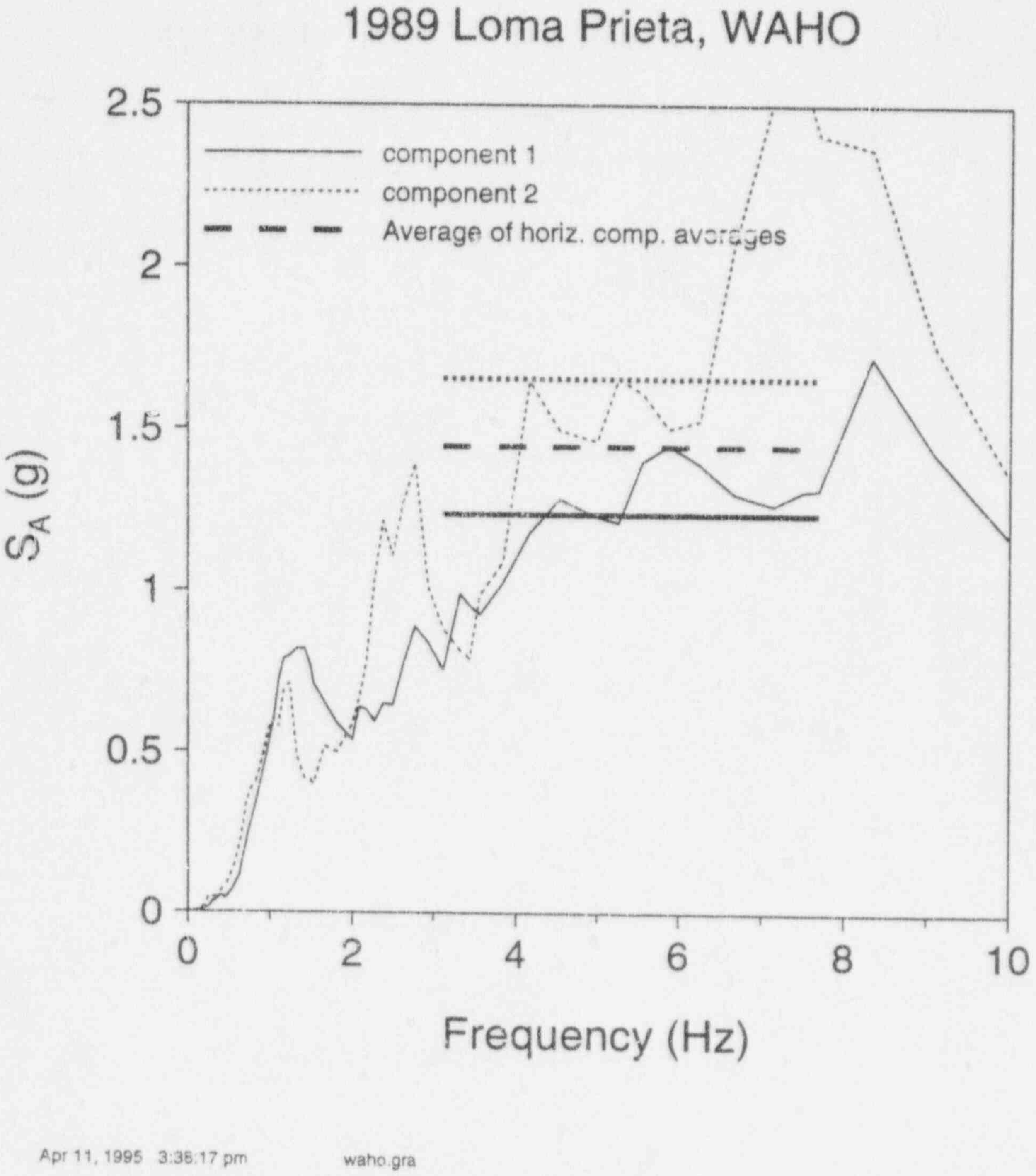

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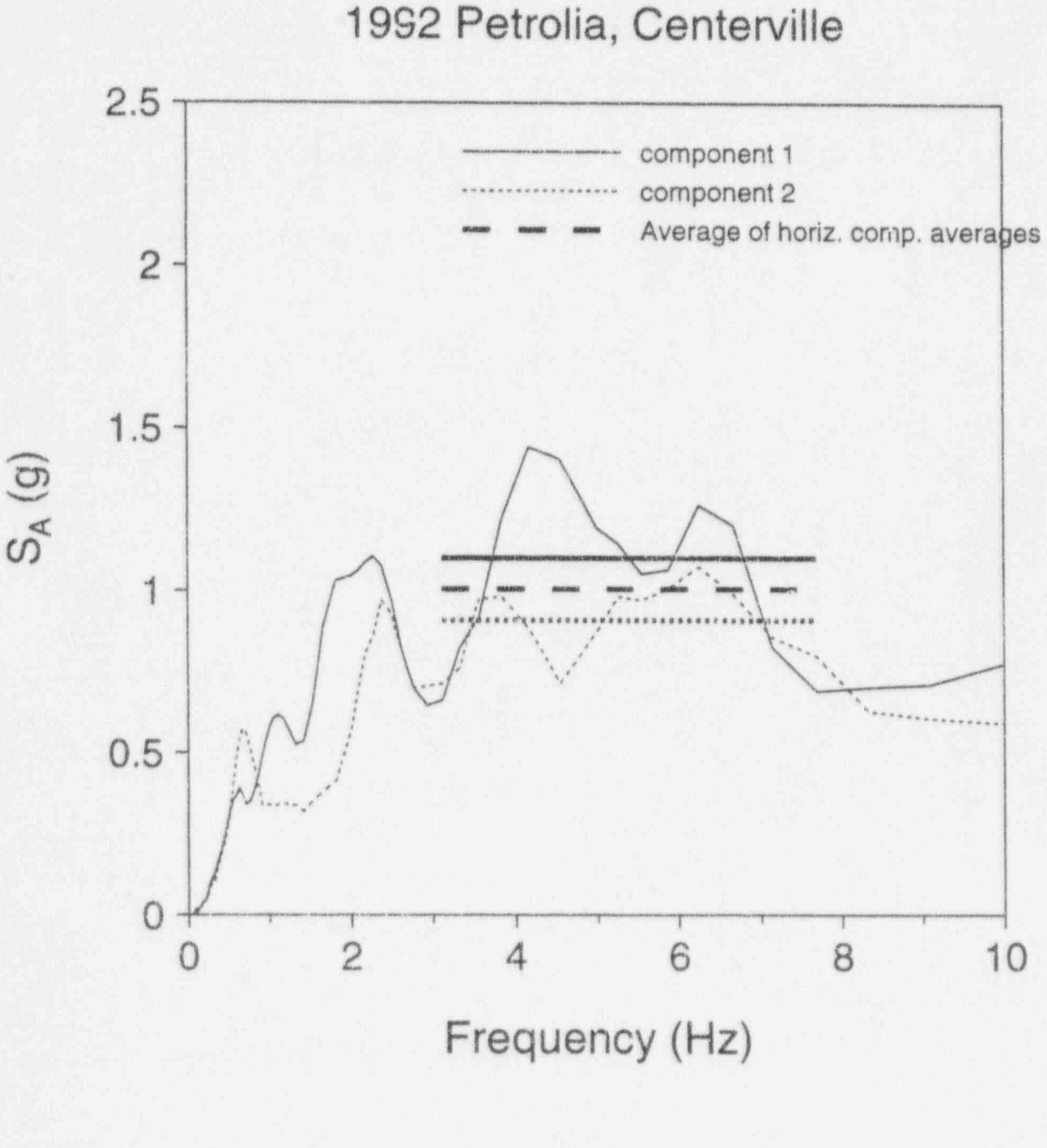

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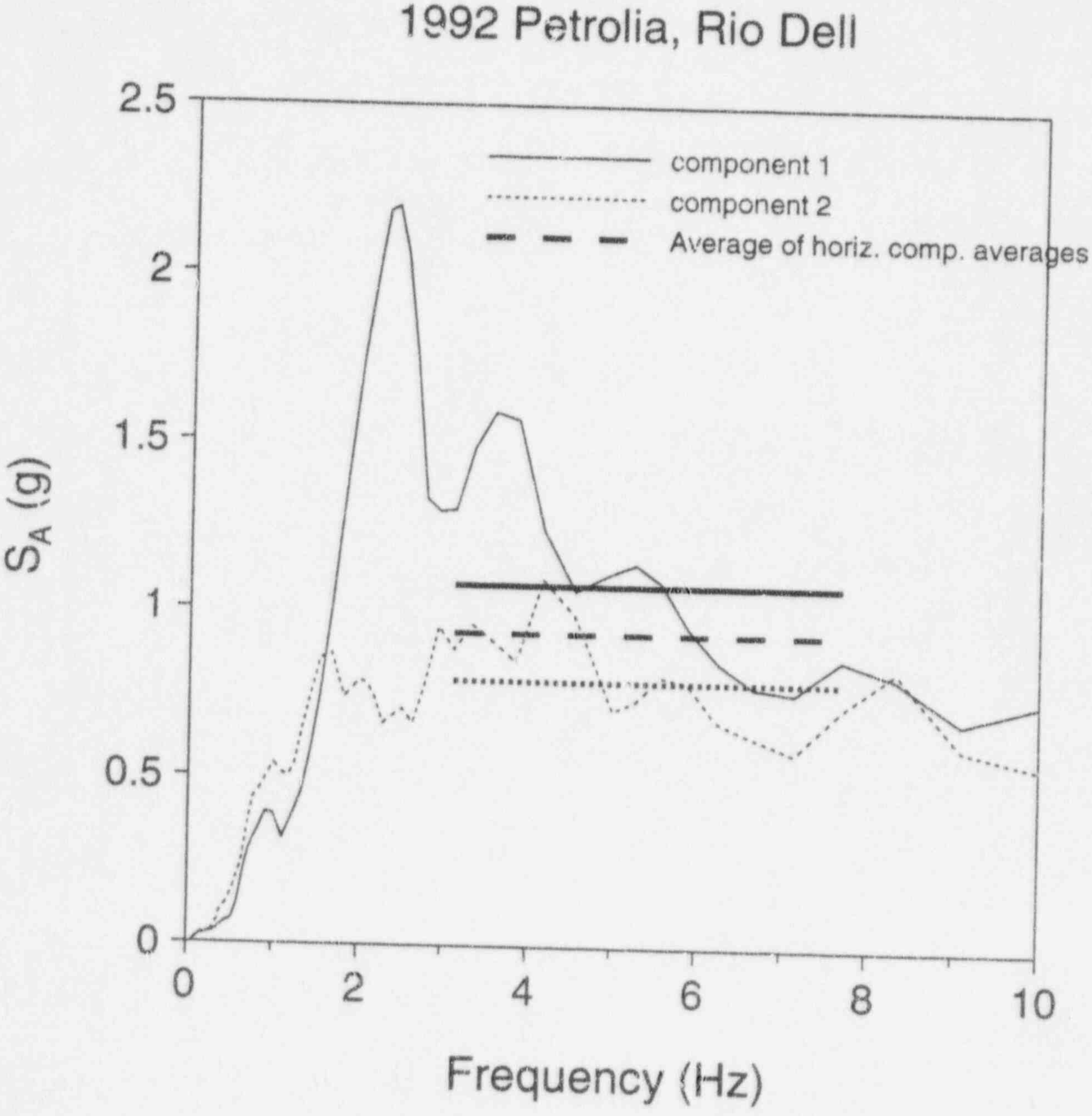

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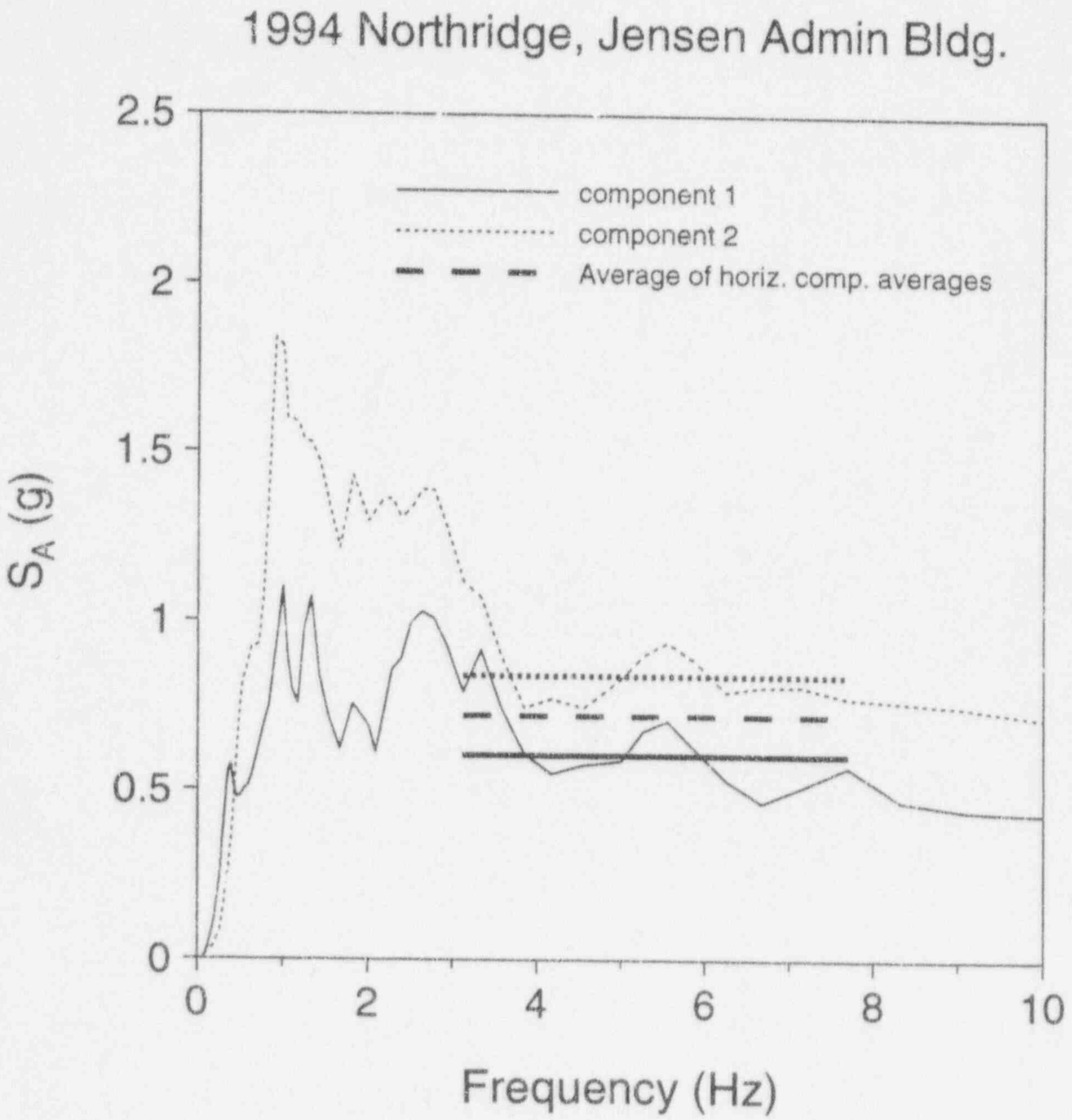

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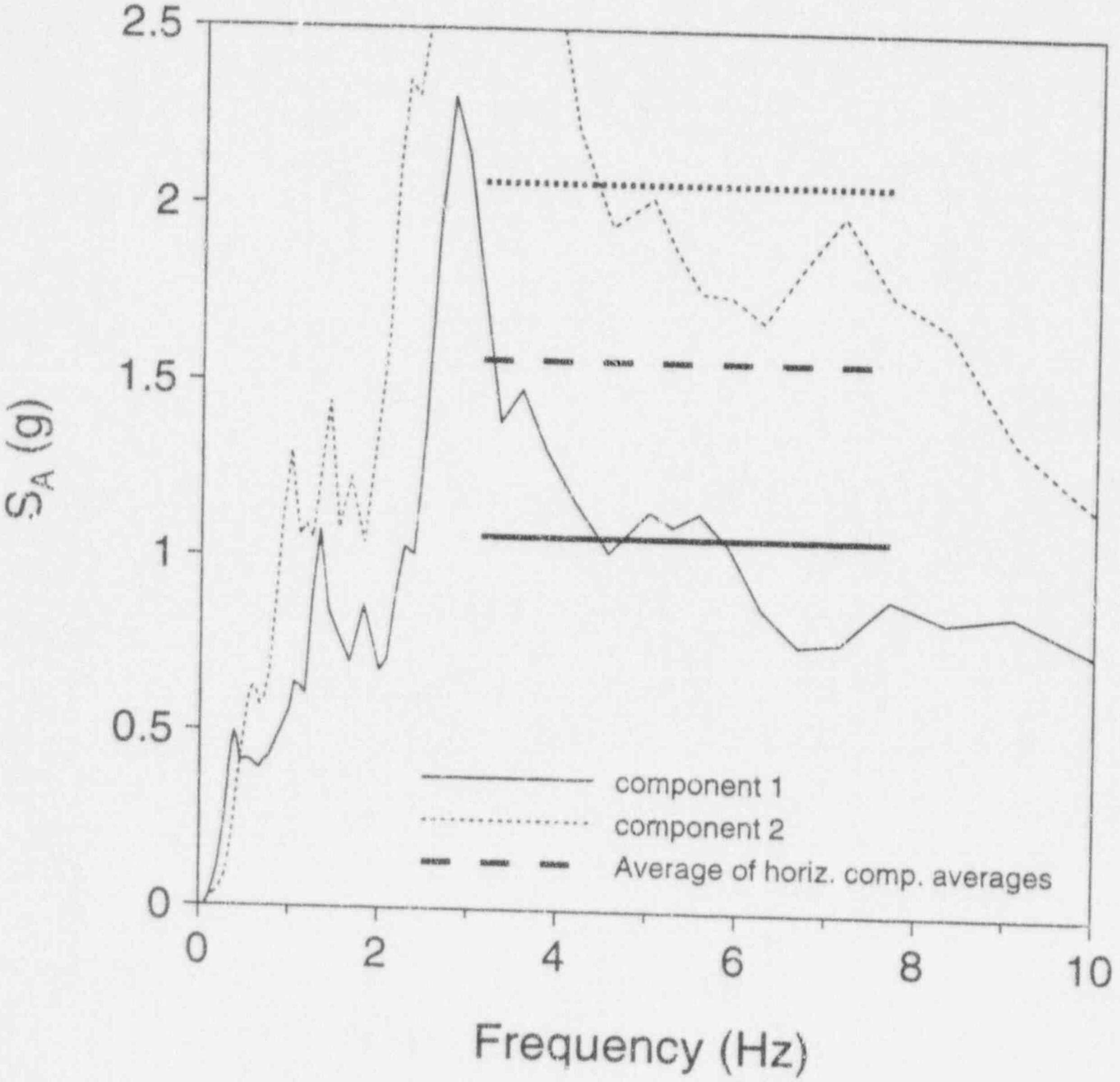

1994 Northridge, Jensen Generator Bldg.

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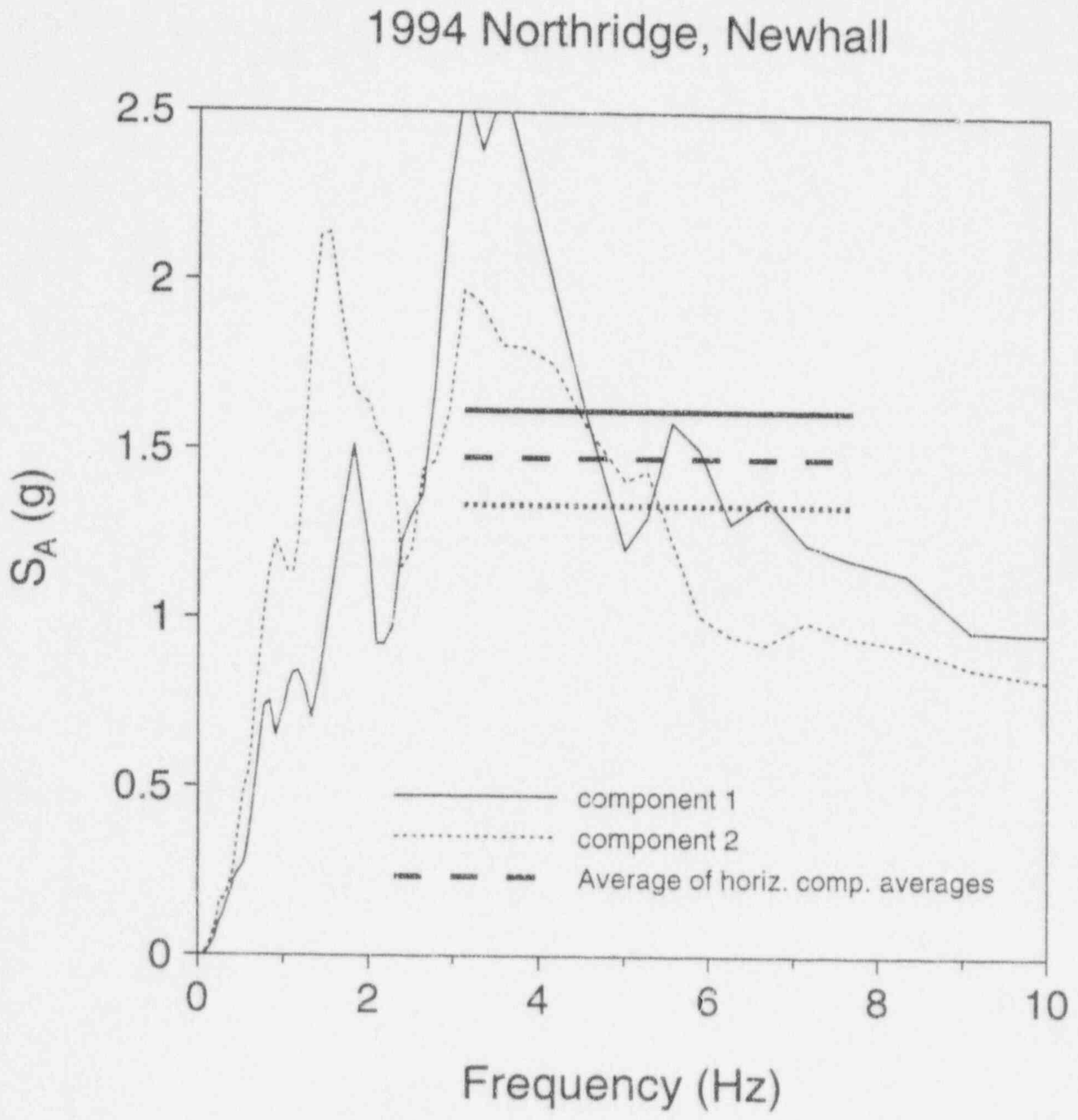

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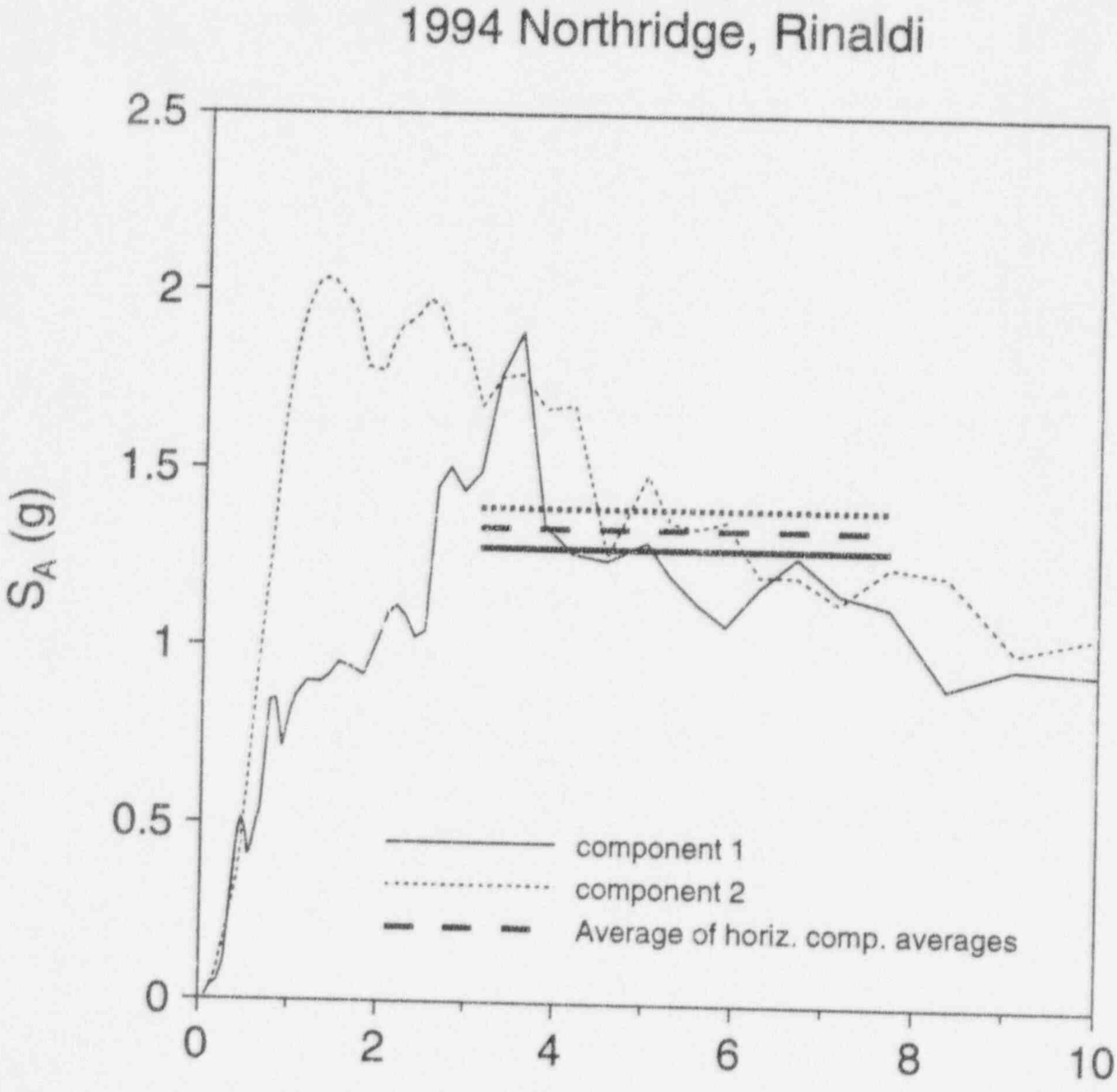

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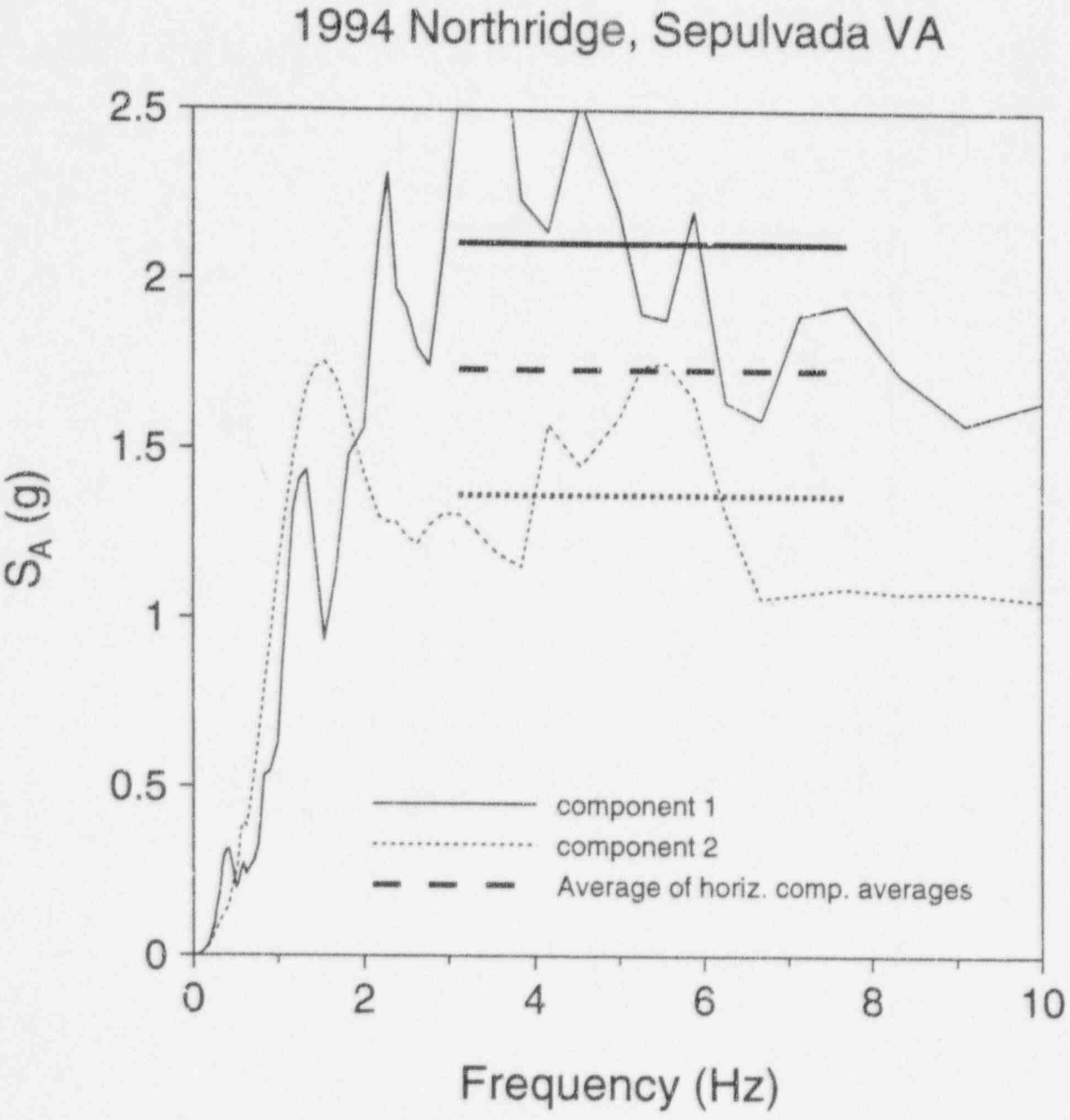

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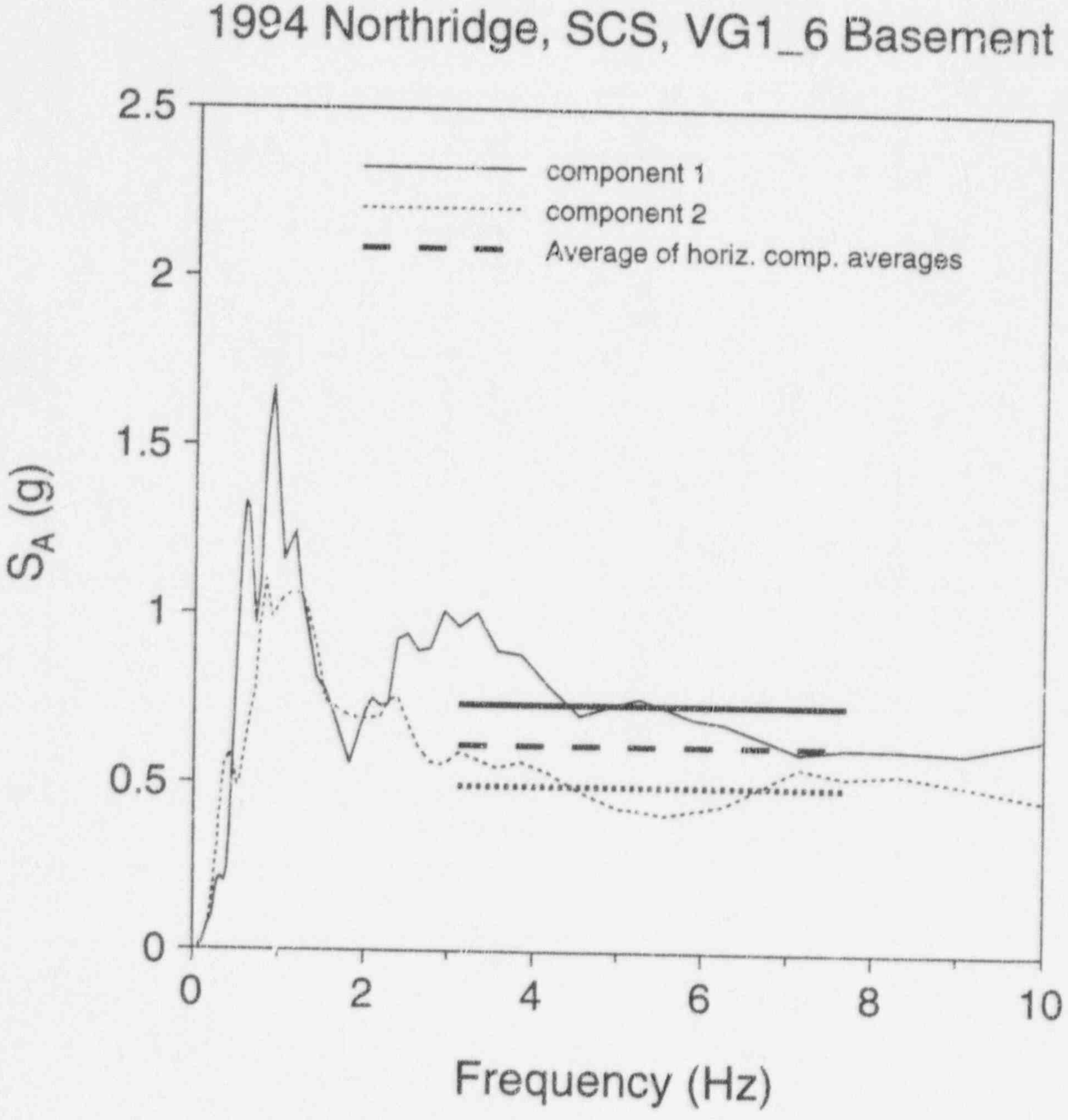

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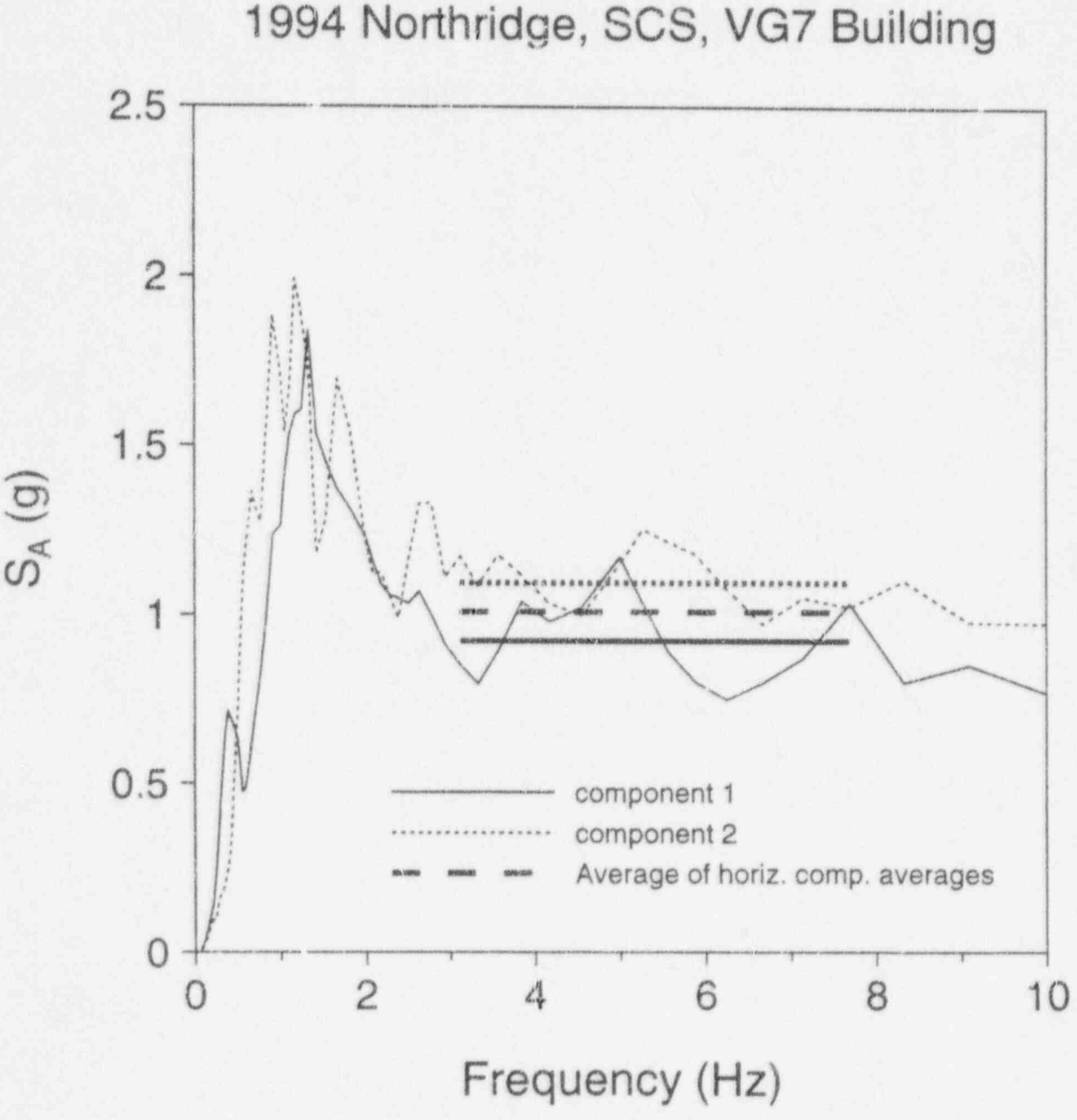

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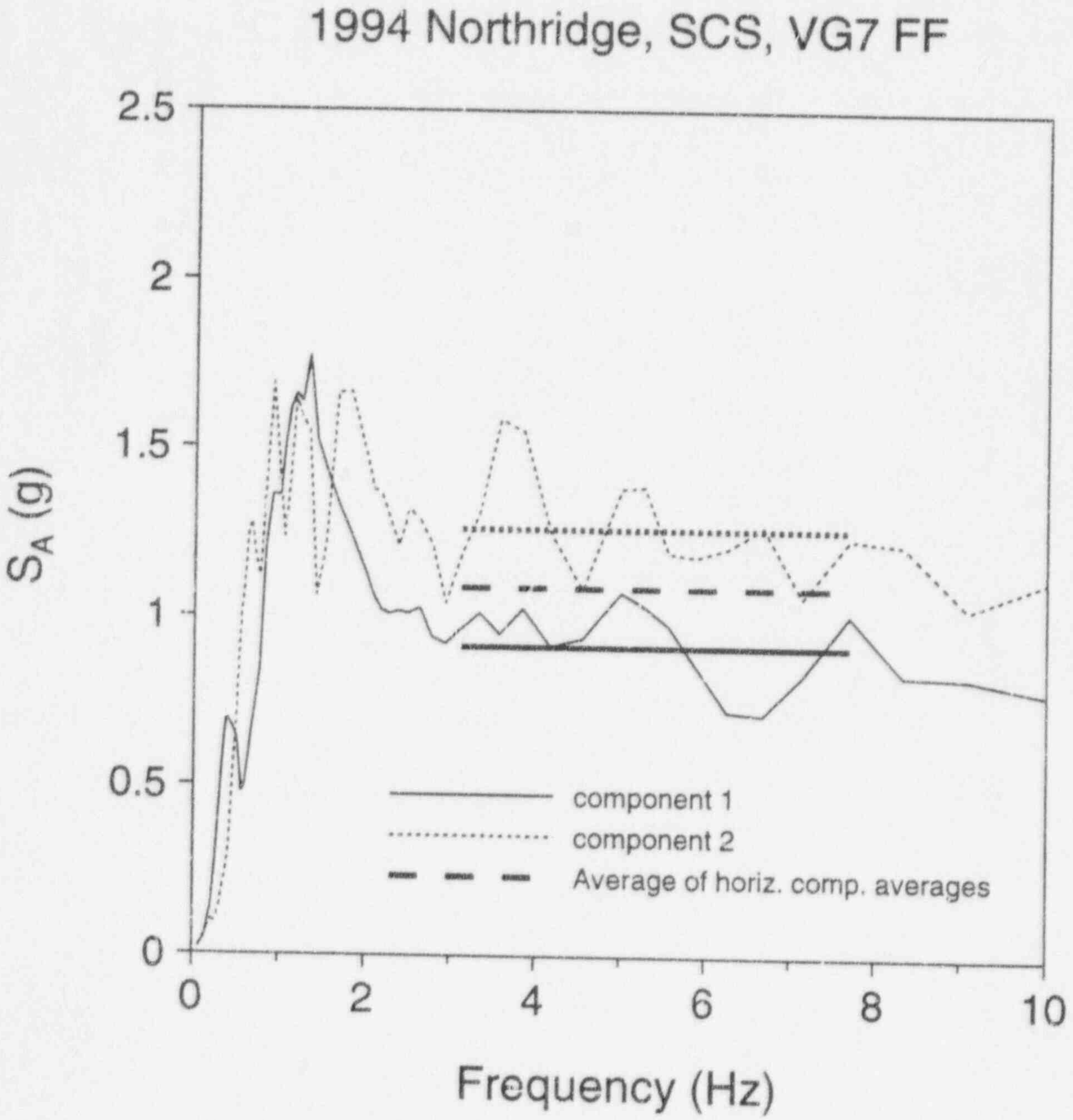

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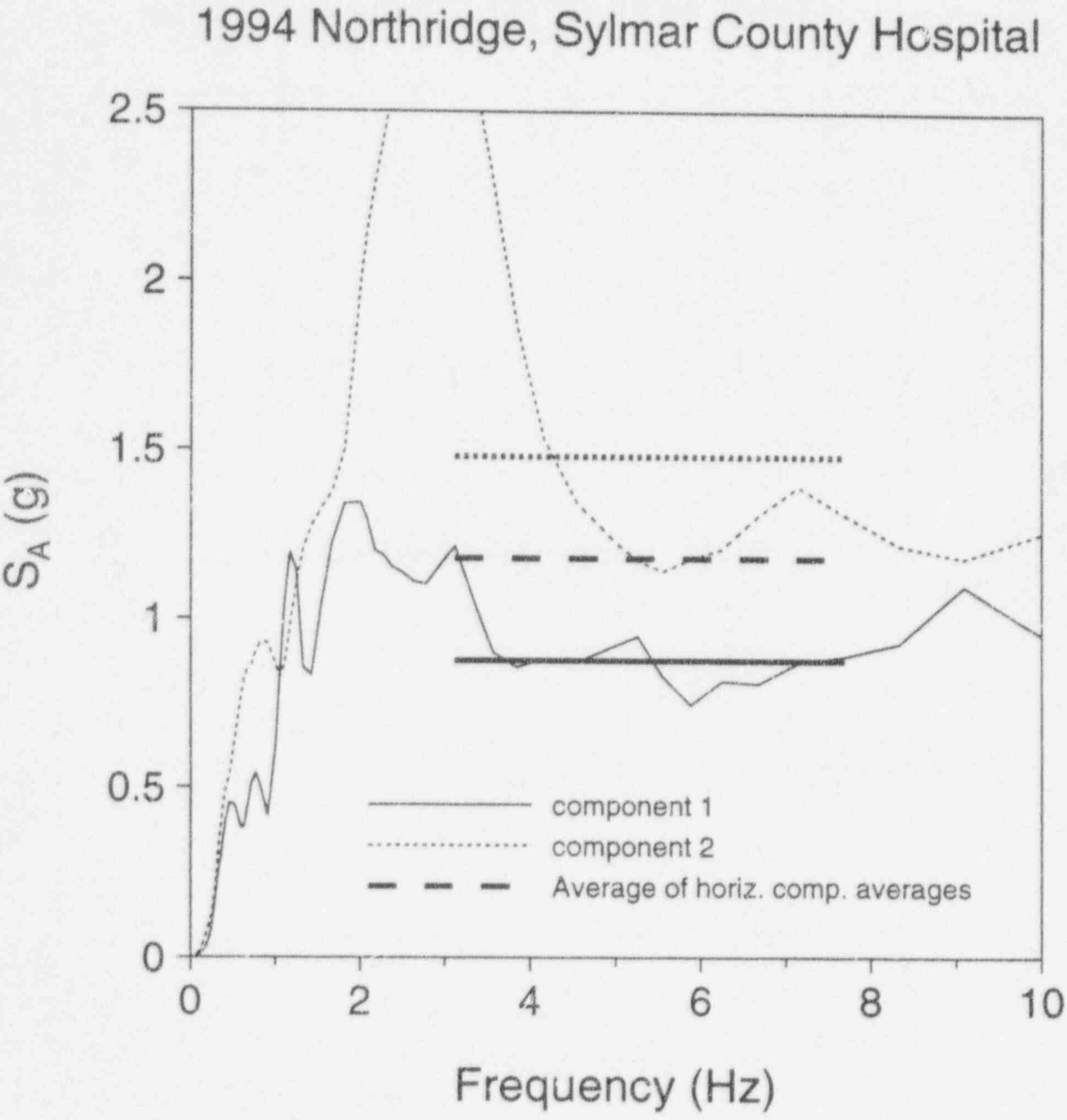

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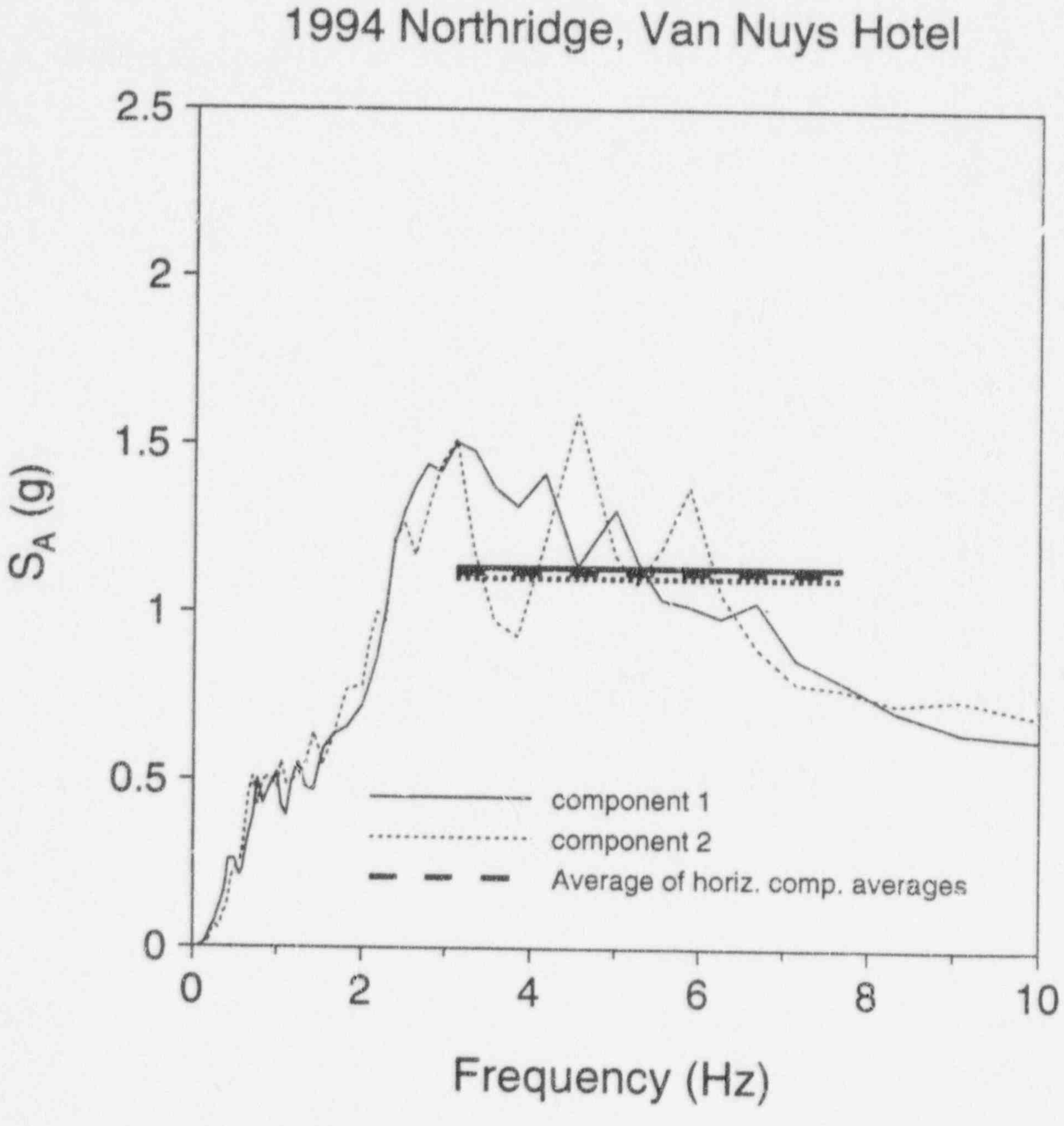


Apr 11, 1995 5:48:44 pm vnuys.grc

APPENDIX C.2

TABLES OF RESULTS

```
Summary of processing, file altwind.in

Contents of input file:

   |Nsta |DRef20 |AvgVel |Summaryfile
    2      6.2    520.0  altwind.sum

   |RS_Source |FileComp1     |FileComp2     |DSta20 |DSta2Ref |AvgVel |File&Plots
   bap         devers_a.rs2 devers_c.rs2 3.11     03.35     0520.0  junk.col
   bap         npalms_a.rs2 npalms_c.rs2 4.71     02.94     0520.0  junk.col

Results of Processing:

  For each station:

      FileComp1     FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   devers_a.rs2 devers_c.rs2  1.693  1.025  1.359         1.403   .848  1.125
   npalms_a.rs2 npalms_c.rs2  1.550  1.392  1.471         1.408  1.264  1.336

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
      3.14      .17    1.47   1.41( 1.0, 2.1)   1.23(  .8, 1.8)

ALTWIND.SUM  4-11-95  1:59p                                              Page 1 of 1
```

```
Summary of processing, file buckwind.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    2      4.5    520.0  buckwind.sum

   |RS_Source |FileComp1     |FileComp2     |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         devers_a.rs2 devers_c.rs2 5.11    01.43      0520.0  junk.col
   bap         npalms_a.rs2 npalms_c.rs2 4.71    02.99      0520.0  junk.col

Results of Processing:

  For each station:

     FileComp1    FileComp2    SA1    SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   devers_a.rs2 devers_c.rs2  1.693  1.025  1.359       1.566   .948  1.257
   npalms_a.rs2 npalms_c.rs2  1.550  1.392  1.471       1.572  1.411  1.492

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
      2.21      .15    1.42   1.41( 1.0, 2.0)   1.37( 1.0, 1.9)
```

BUCKWIND.SUM 4-11-95 1:59p

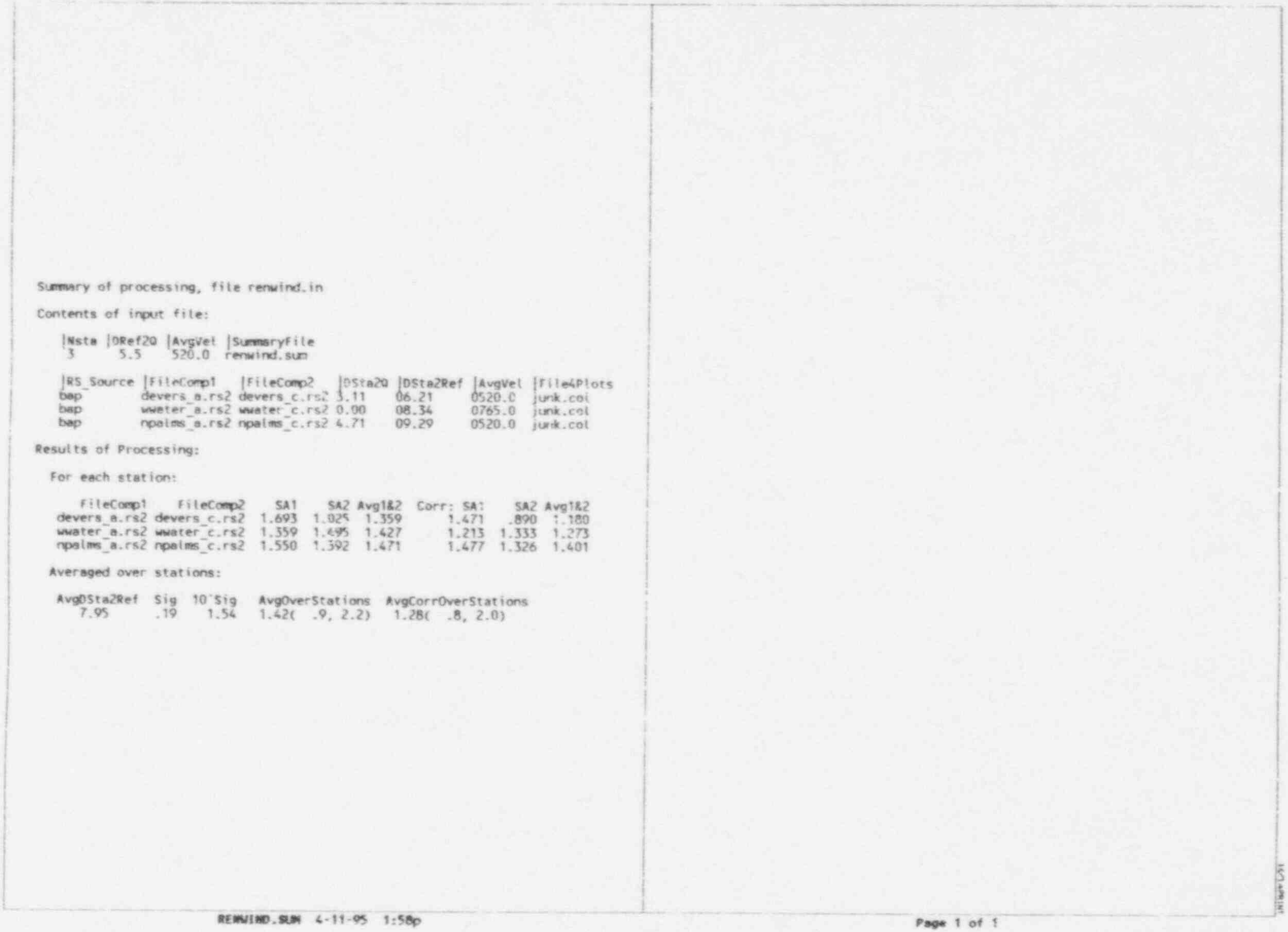
Page 1 of 1

```
Summary of processing, file devers.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    2      3.1    520.0  devers.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         devers_a.rs2 devers_c.rs2 3.11     00.00     0520.0  junk.col
   bap         npalms_a.rs2 npalms_c.rs2 4.71     03.55     0520.0  junk.col

Results of Processing:

  For each station:

     FileComp1    FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   devers_a.rs2 devers_c.rs2  1.693  1.025  1.359        1.693  1.025  1.359
   npalms_a.rs2 npalms_c.rs2  1.550  1.392  1.471        1.698  1.524  1.611

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
      1.77      .14    1.39   1.41( 1.0, 2.0)   1.48( 1.1, 2.1)

DEVERS.SUM  4-11-95  1:59p                                    Page 1 of 1
```

```
Summary of processing, file garnet.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    2      7.0    520.0  garnet.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         devers_a.rs2 devers_c.rs2 3.11    04.77     0520.0  junk.col
   bap         npalms_a.rs2 npalms_c.rs2 4.71    02.51     0520.0  junk.col

Results of Processing:

  For each station:

     FileComp1    FileComp2    SA1    SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   devers_a.rs2 devers_c.rs2  1.693  1.025  1.359        1.331   .805  1.068
   npalms_a.rs2 npalms_c.rs2  1.550  1.392  1.471        1.337  1.200  1.269

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
     3.64       .17    1.49   1.41( 1.0, 2.1)   1.16(  .8, 1.7)
```

GARNET.SUM 4-11-95 1:59p

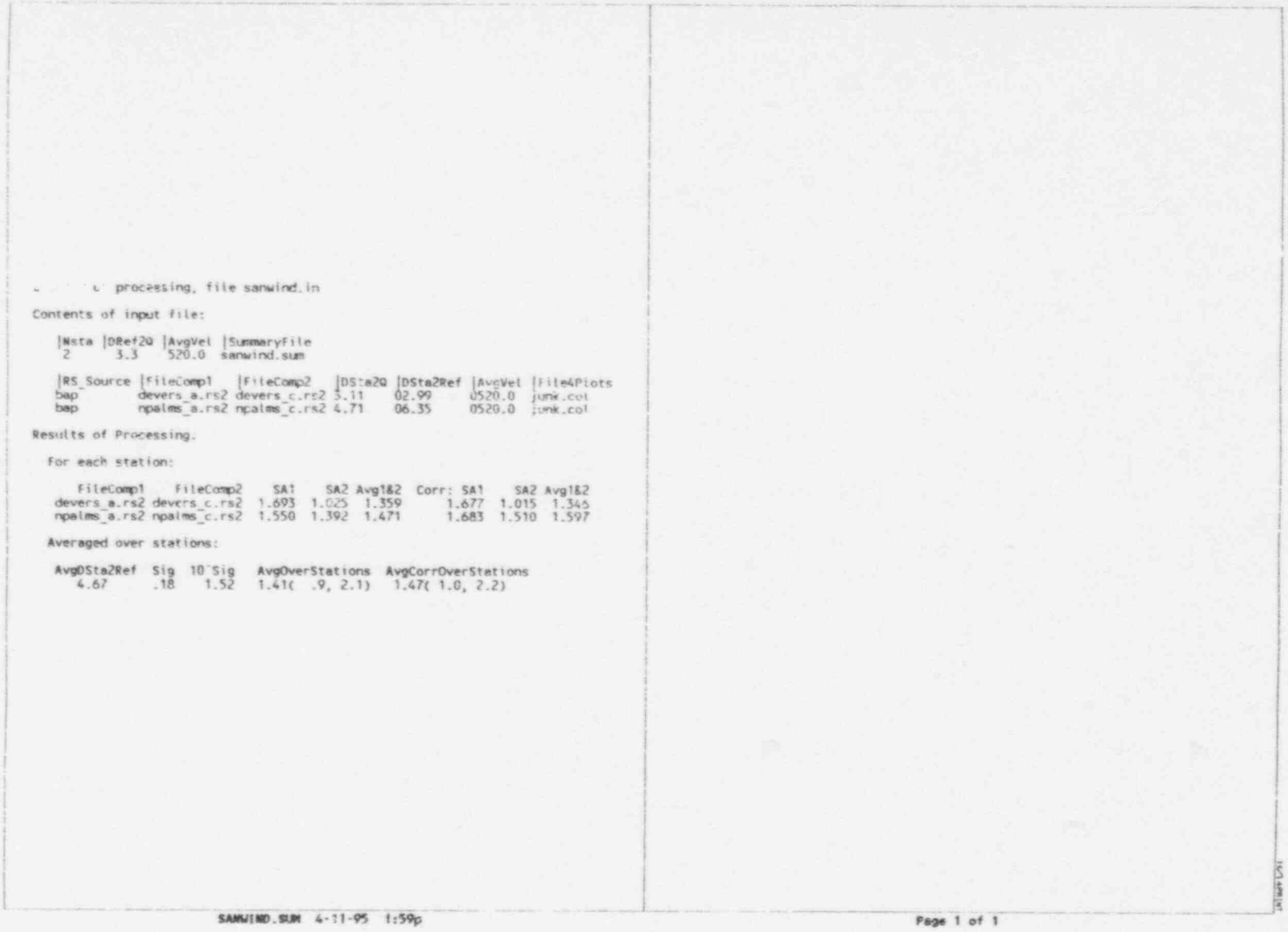
Page 1 of 1



```
Summary of processing, file renwind.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    3     5.5    520.0  renwind.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         devers_a.rs2 devers_c.rs2 3.11    06.21     0520.0  junk.col
   bap         wwater_a.rs2 wwater_c.rs2 0.00    08.34     0765.0  junk.col
   bap         npalms_a.rs2 npalms_c.rs2 4.71    09.29     0520.0  junk.col

Results of Processing:

  For each station:

     FileComp1     FileComp2     SA1    SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   devers_a.rs2 devers_c.rs2  1.693  1.025  1.359        1.471   .890  1.180
   wwater_a.rs2 wwater_c.rs2  1.359  1.495  1.427        1.213  1.333  1.273
   npalms_a.rs2 npalms_c.rs2  1.550  1.392  1.471        1.477  1.326  1.401

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
      7.95      .19    1.54   1.42( .9, 2.2)    1.28( .8, 2.0)
```

RENWIND.SUM 4-11-95 1:58p

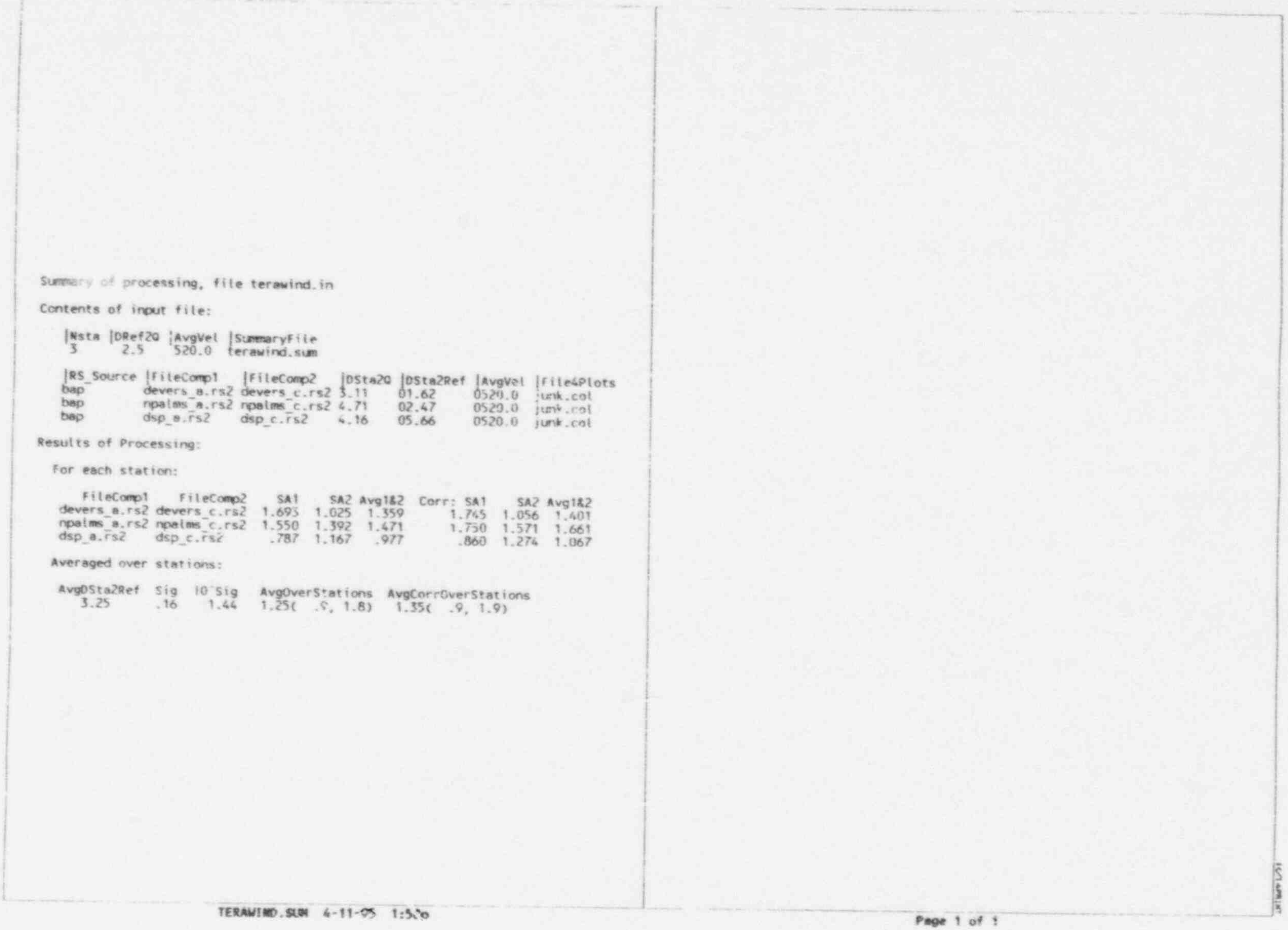
Page 1 of 1



```
[illegible] processing, file sanwind.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    2      3.3    520.0  sanwind.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         devers_a.rs2 devers_c.rs2 3.11     02.99     0520.0  junk.col
   bap         npalms_a.rs2 npalms_c.rs2 4.71     06.35     0520.0  junk.col

Results of Processing.

  For each station:

     FileComp1     FileComp2     SA1    SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   devers_a.rs2 devers_c.rs2  1.693  1.025  1.359       1.677  1.015  1.345
   npalms_a.rs2 npalms_c.rs2  1.550  1.392  1.471       1.683  1.510  1.597

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig  AvgOverStations  AvgCorrOverStations
      4.67      .18    1.52  1.41(  .9, 2.1)   1.47( 1.0, 2.2)
```

SAMWIND.SUM 4-11-95 1:59p

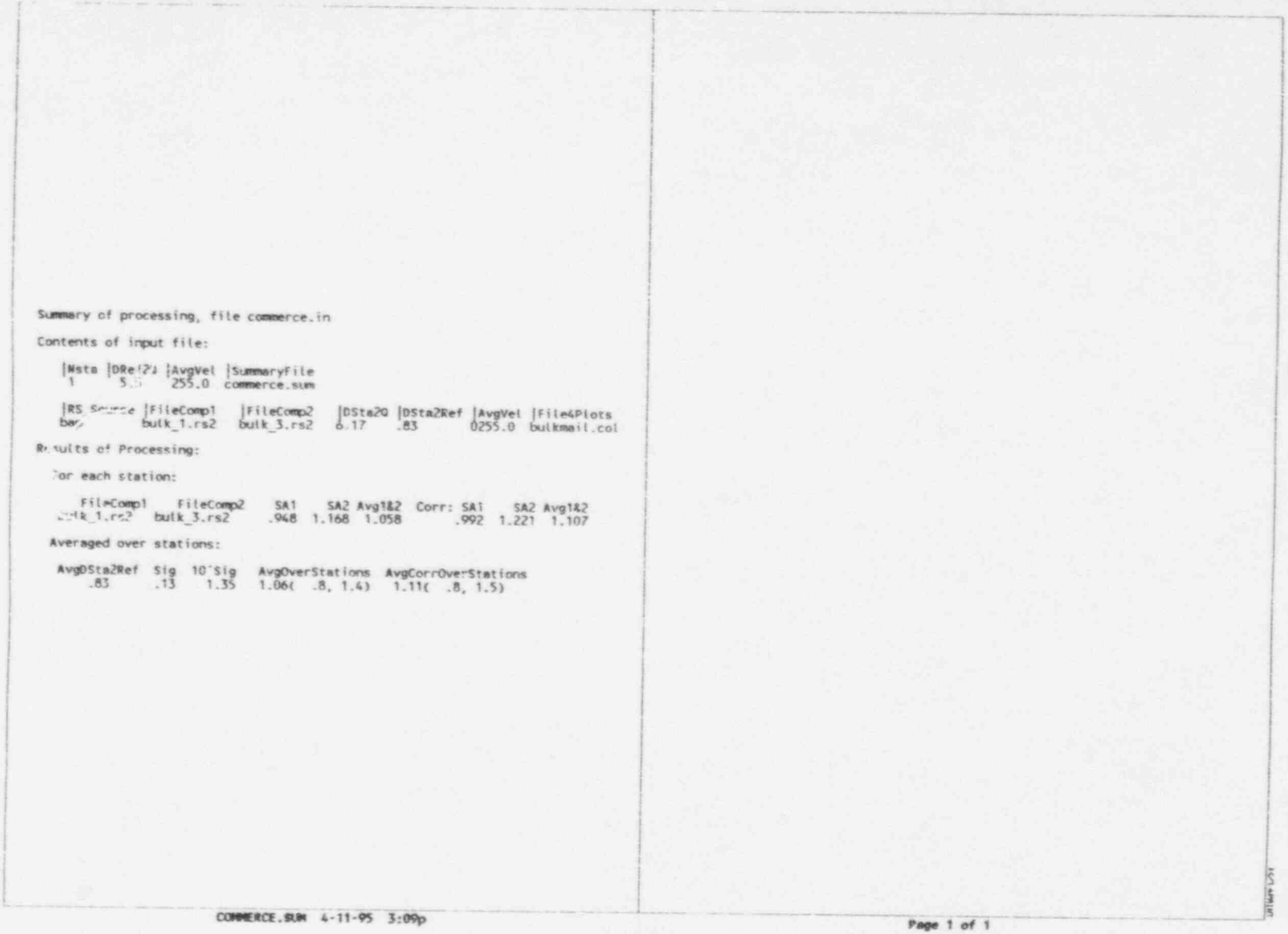
Page 1 of 1



```
Summary of processing, file terawind.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    3      2.5    520.0  terawind.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         devers_a.rs2 devers_c.rs2 3.11    01.62      0520.0  junk.col
   bap         npalms_a.rs2 npalms_c.rs2 4.71    02.47      0520.0  junk.col
   bap         dsp_a.rs2    dsp_c.rs2    4.16    05.66      0520.0  junk.col
Results of Processing:

  For each station:

     FileComp1    FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   devers_a.rs2 devers_c.rs2  1.693   1.025  1.359        1.745  1.056  1.401
   npalms_a.rs2 npalms_c.rs2  1.550   1.392  1.471        1.750  1.571  1.661
   dsp_a.rs2    dsp_c.rs2      .787   1.167   .977         .860  1.274  1.067

  Averaged over stations:

   AvgDSta2Ref   Sig   10^Sig   AvgOverStations   AvgCorrOverStations
      3.25       .16    1.44    1.25(  .9, 1.8)    1.35(  .9, 1.9)

TERAWIND.SUM  4-11-95  1:50p                                        Page 1 of 1
```

```
Summary of processing, file venwind.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    3      2.3    520.0  venwind.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2G |DSta2Ref |AvgVel |File4Plots
    bap        devers_a.rs2 devers_c.rs2 3.11    03.47     0520.0  junk.col
    bap        wwater_a.rs2 wwater_c.rs2 0.00    06.58     0765.0  junk.col
    bap        npalms_a.rs2 npalms_c.rs2 4.71    06.92     0520.0  junk.col

Results of Processing:

  For each station:

     FileComp1    FileComp2    SA1    SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   devers_a.rs2 devers_c.rs2  1.693  1.025  1.359       1.760  1.066  1.413
   wwater_a.rs2 wwater_c.rs2  1.359  1.495  1.427       1.452  1.593  1.523
   npalms_a.rs2 npalms_c.rs2  1.550  1.392  1.471       1.766  1.585  1.675

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig  AvgOverStations  AvgCorrOverStations
     5.66       .18   1.50   1.42(  .9, 2.1)   1.53( 1.0, 2.3)

                    VENWIND.SUM  4-11-95  1:58p                                        Page 1 of 1
```

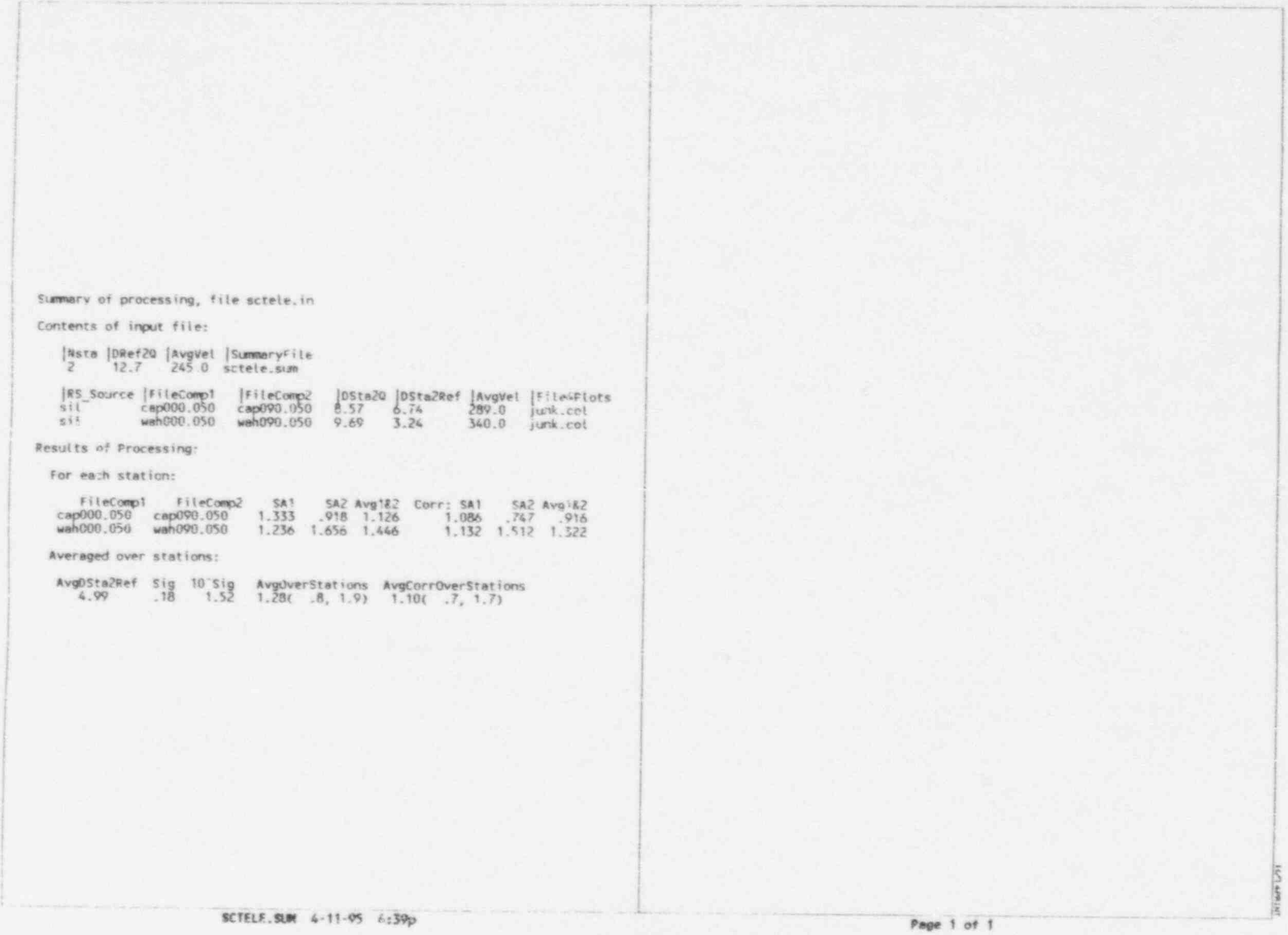
```
Summery of processing, file wwhydro.in

Contents of input file:

  |Nste |DRef2Q |AvgVel |SummaryFile
   2      2.6    520.0  wwhydro.sum

  |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap        devers_a.rs2 devers_c.rs2 3.11     05.75      0520.0  junk.col
   bap        wwater_a.rs2 wwater_c.rs2 0.00     05.38      0765.0  junk.col

Results of Processing:

 For each station:

    FileComp1    FileComp2    SA1    SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
  devers_a.rs2 devers_c.rs2 1.693 1.025  1.359        1.737 1.052  1.395
  wwater_a.rs2 wwater_c.rs2 1.359 1.495  1.427        1.433 1.573  1.503

 Averaged over stations:

  AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
     5.57      .19    1.54   1.39(  .9, 2.1)   1.45(  .9, 2.2)

WWHYDRO.SUM  4-11-95  1:59p                                   Page 1 of 1
```



```
Summary of processing, file commerce.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    1      5.5    255.0  commerce.sum

   |RS Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bay         bulk_1.rs2   bulk_3.rs2   6.17    .83       0255.0  bulkmail.col

Results of Processing:

  For each station:

     FileComp1     FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   bulk_1.rs2   bulk_3.rs2      .948  1.168  1.058         .992  1.221  1.107

  Averaged over stations:

   AvgDSta2Ref   Sig   10^Sig   AvgOverStations  AvgCorrOverStations
       .83       .13    1.35    1.06(  .8, 1.4)   1.11(  .8, 1.5)
```

COMMERCE.SUM 4-11-95 3:09p

Page 1 of 1



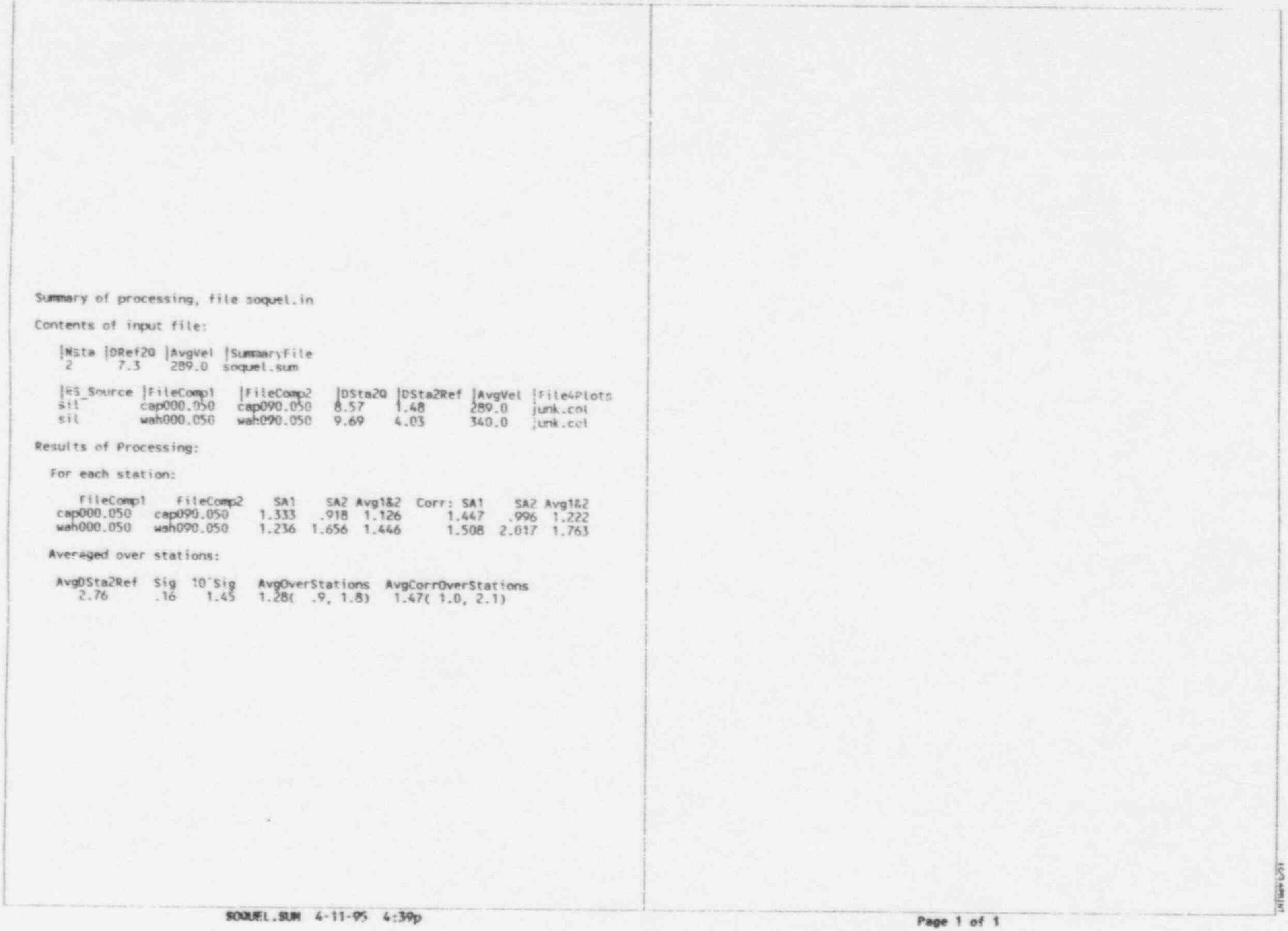
```
Summary of processing, file sctele.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    2     12.7    245.0  sctele.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
    sil        cap000.050   cap090.050   8.57    6.74      289.0   junk.col
    sil        wah000.050   wah090.050   9.69    3.24      340.0   junk.col

Results of Processing:

  For each station:

     FileComp1     FileComp2      SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   cap000.050   cap090.050     1.333    .918  1.126       1.086    .747   .916
   wah000.050   wah090.050     1.236   1.656  1.446       1.132   1.512  1.322

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
      4.99      .18    1.52   1.28(  .8, 1.9)   1.10(  .7, 1.7)
```

SCTELE.SUM 4-11-95 6:39p

Page 1 of 1

```
Summary of processing, file scwater.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    2     11.0    340.0  scwater.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   sil        lob000.050    lob090.050    12.53   2.51      612.0   junk.col
   sil        brn000.050    brn090.050    4.32    6.64      340.0   junk.col

Results of Processing:

  For each station:

     FileComp1     FileComp2     SA1    SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   lob000.050   lob090.050     1.443  1.151  1.297        1.865  1.489  1.677
   brn000.050   brn090.050     1.168  1.373  1.271         .760   .894   .827

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
     4.57       .18    1.51   1.28(  .8, 1.9)   1.18(  .8, 1.8)
```

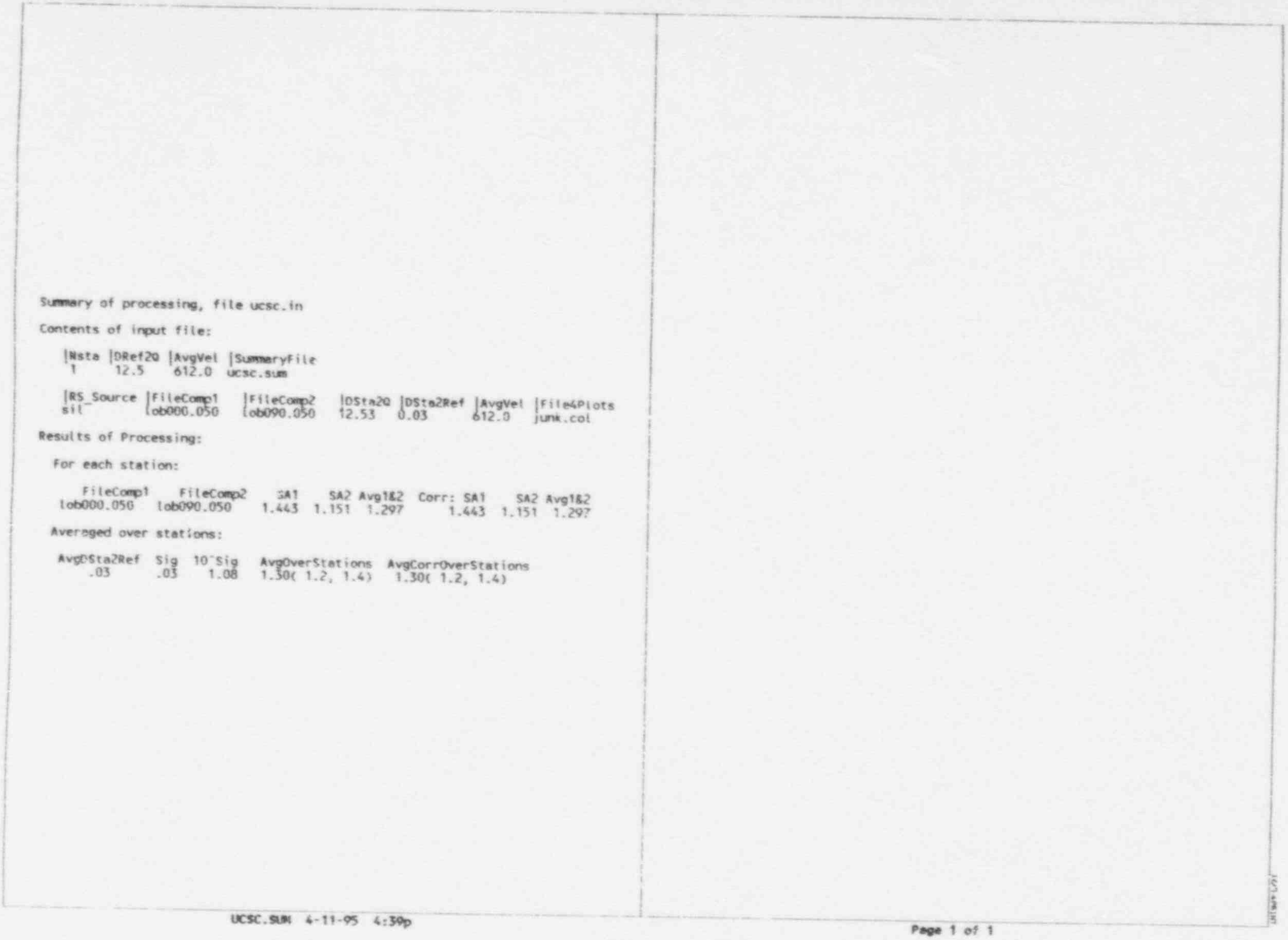
```
SCWATER.SUM  4-11-95  4:39p                                    Page 1 of 1
```



```
Summary of processing, file soquel.in

Contents of input file:

   |NSta |DRef2Q |AvgVel |SummaryFile
    2      7.3    289.0  soquel.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   sil         cap000.050   cap090.050    8.57    1.48      289.0   junk.col
   sil         wah000.050   wah090.050    9.69    4.03      340.0   junk.col

Results of Processing:

  For each station:

     FileComp1     FileComp2     SA1     SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   cap000.050   cap090.050     1.333   .918  1.126       1.447   .996  1.222
   wah000.050   wah090.050     1.236  1.656  1.446       1.508  2.017  1.763

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
      2.76      .16    1.45   1.28(  .9, 1.8)   1.47( 1.0, 2.1)
```

SOQUEL.SUM 4-11-95 4:39p

Page 1 of 1

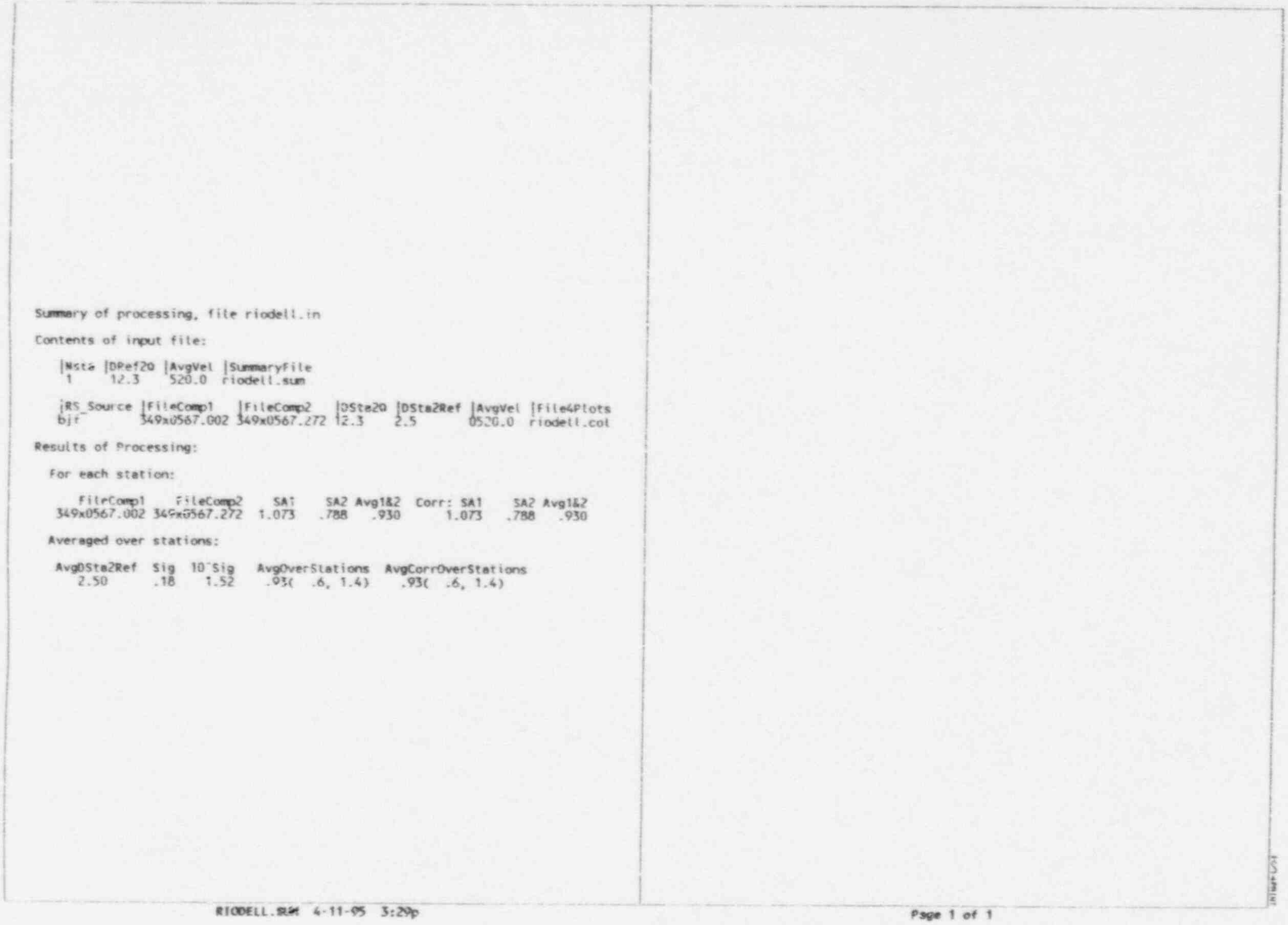


```
Summary of processing, file ucsc.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    1      12.5   612.0  ucsc.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   sil         lob000.050    lob090.050    12.53   0.03      612.0   junk.col
Results of Processing:

  For each station:

     FileComp1    FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   lob000.050   lob090.050    1.443  1.151  1.297         1.443  1.151  1.297
  Averaged over stations:

   AvgDSta2Ref   Sig  10^Sig   AvgOverStations  AvgCorrOverStations
       .03       .03    1.08   1.30( 1.2, 1.4)   1.30( 1.2, 1.4)
```

UCSC.SUN 4-11-95 4:30p

Page 1 of 1

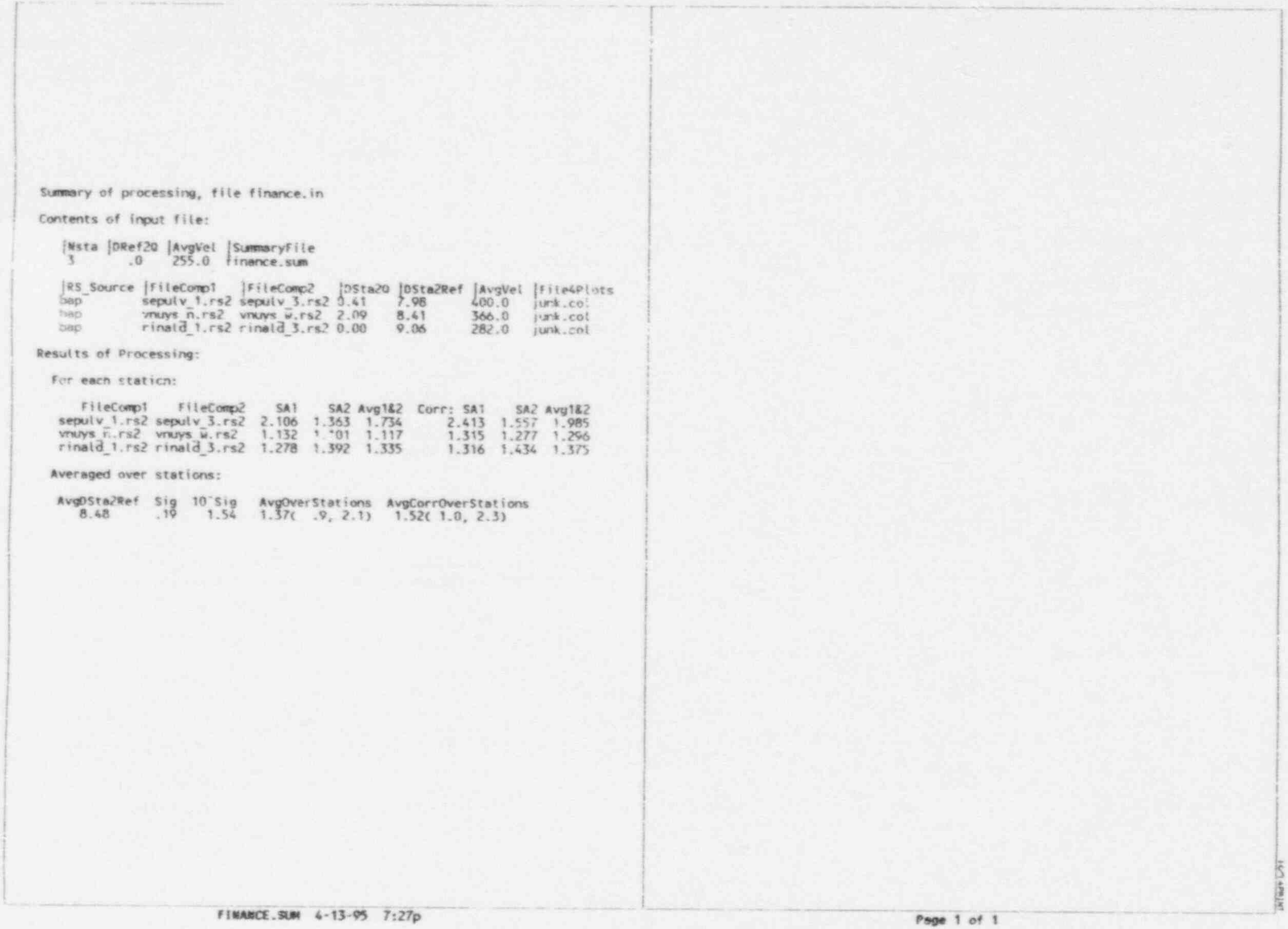
```
Summary of processing, file centerv.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    1      9.8    520.0  centerv.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         centrv_a.rs2 centrv_c.rs2 9.8     0.1        0520.0  centerv.col

Results of Processing:

  For each station:

     FileComp1     FileComp2    SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   centrv_a.rs2 centrv_c.rs2  1.101    .908  1.005        1.101   .908  1.005

  Averaged over stations:

   AvgDSta2Ref  Sig  10*Sig   AvgOverStations  AvgCorrOverStations
       .10      .06    1.14   1.00(  .9, 1.1)   1.00(  .9, 1.1)

CENTERV.SUM  6-11-95  3:29p                                Page 1 of 1
```



```
Summary of processing, file riodell.in

Contents of input file:

   |Nsta |DRef20 |AvgVel |SummaryFile
    1     12.3    520.0  riodell.sum

   |RS_Source |FileComp1    |FileComp2    |DSta20 |DSta2Ref |AvgVel |File4Plots
   bjf         349x0567.002 349x0567.272 12.3    2.5        0520.0  riodell.col

Results of Processing:

  For each station:

      FileComp1    FileComp2      SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   349x0567.002 349x0567.272  1.073    .788   .930       1.073    .788   .930

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
      2.50      .18   1.52     .93(  .6, 1.4)     .93(  .6, 1.4)
```

RIODELL.SUM 4-11-95 3:29p

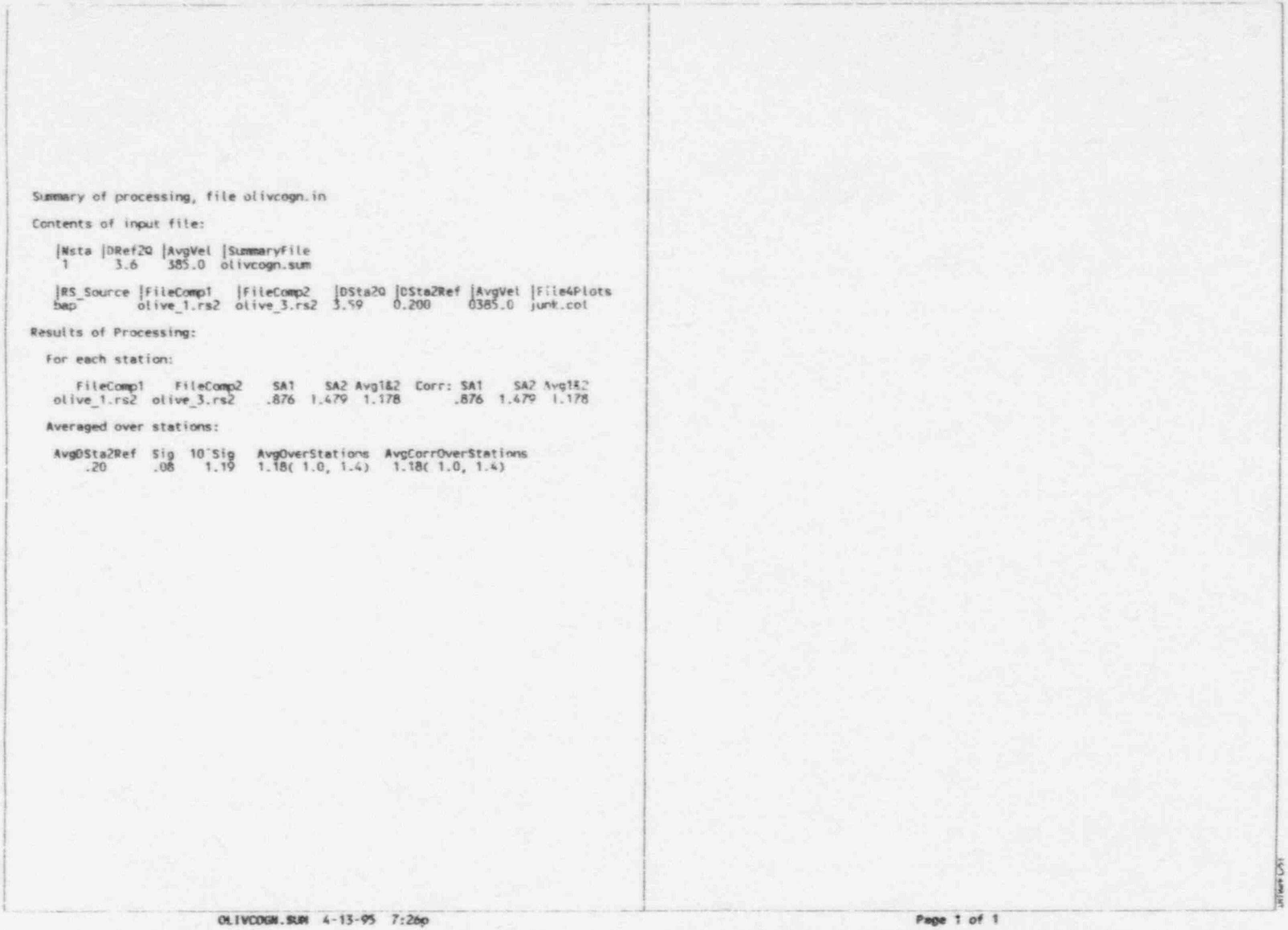
Page 1 of 1



```
Summary of processing, file finance.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    3       .0    255.0  finance.sum

   |RS_Source |FileComp1     |FileComp2     |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         sepulv_1.rs2 sepulv_3.rs2 0.41    7.98       400.0   junk.col
   bap         vnuys_n.rs2  vnuys_w.rs2  2.09    8.41       366.0   junk.col
   bap         rinald_1.rs2 rinald_3.rs2 0.00    9.06       282.0   junk.col

Results of Processing:

  For each station:

      FileComp1     FileComp2     SA1     SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   sepulv_1.rs2 sepulv_3.rs2  2.106  1.363  1.734       2.413  1.557  1.985
   vnuys_n.rs2  vnuys_w.rs2   1.132  1.101  1.117       1.315  1.277  1.296
   rinald_1.rs2 rinald_3.rs2  1.278  1.392  1.335       1.316  1.434  1.375

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
      8.48      .19   1.54    1.37(  .9, 2.1)   1.52( 1.0, 2.3)
```

FINANCE.SUM 4-13-95 7:27p

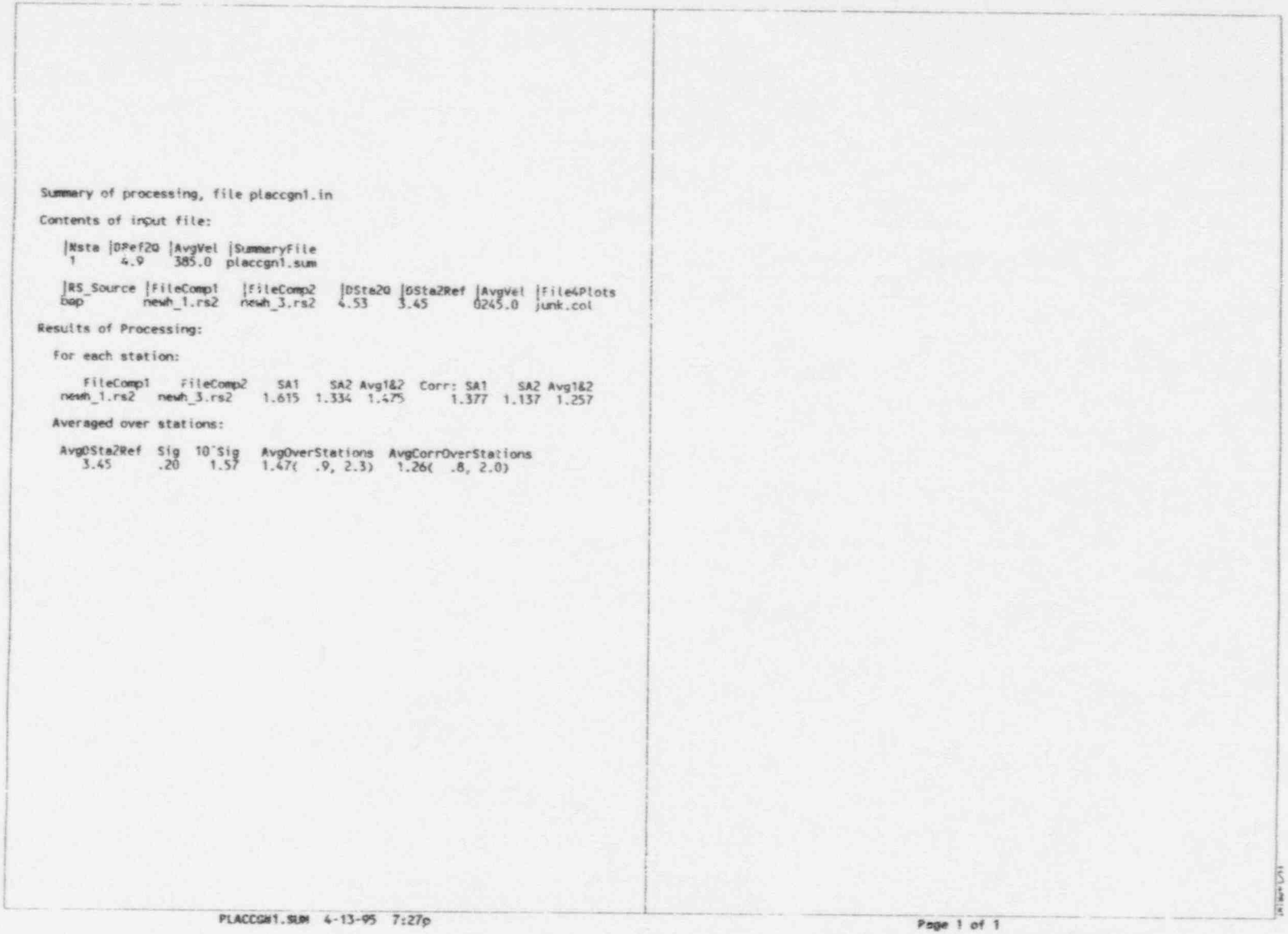
Page 1 of 1



```
Summary of processing, file olivcogn.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    1      3.6    385.0  olivcogn.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         olive_1.rs2  olive_3.rs2  3.59     0.200     0385.0  junk.col

Results of Processing:

  For each station:

     FileComp1    FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   olive_1.rs2  olive_3.rs2    .876  1.479  1.178         .876  1.479  1.178

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
       .20      .08    1.19   1.18( 1.0, 1.4)    1.18( 1.0, 1.4)
```

OLIVCOGN.SUM 4-13-95 7:26p

Page 1 of 1

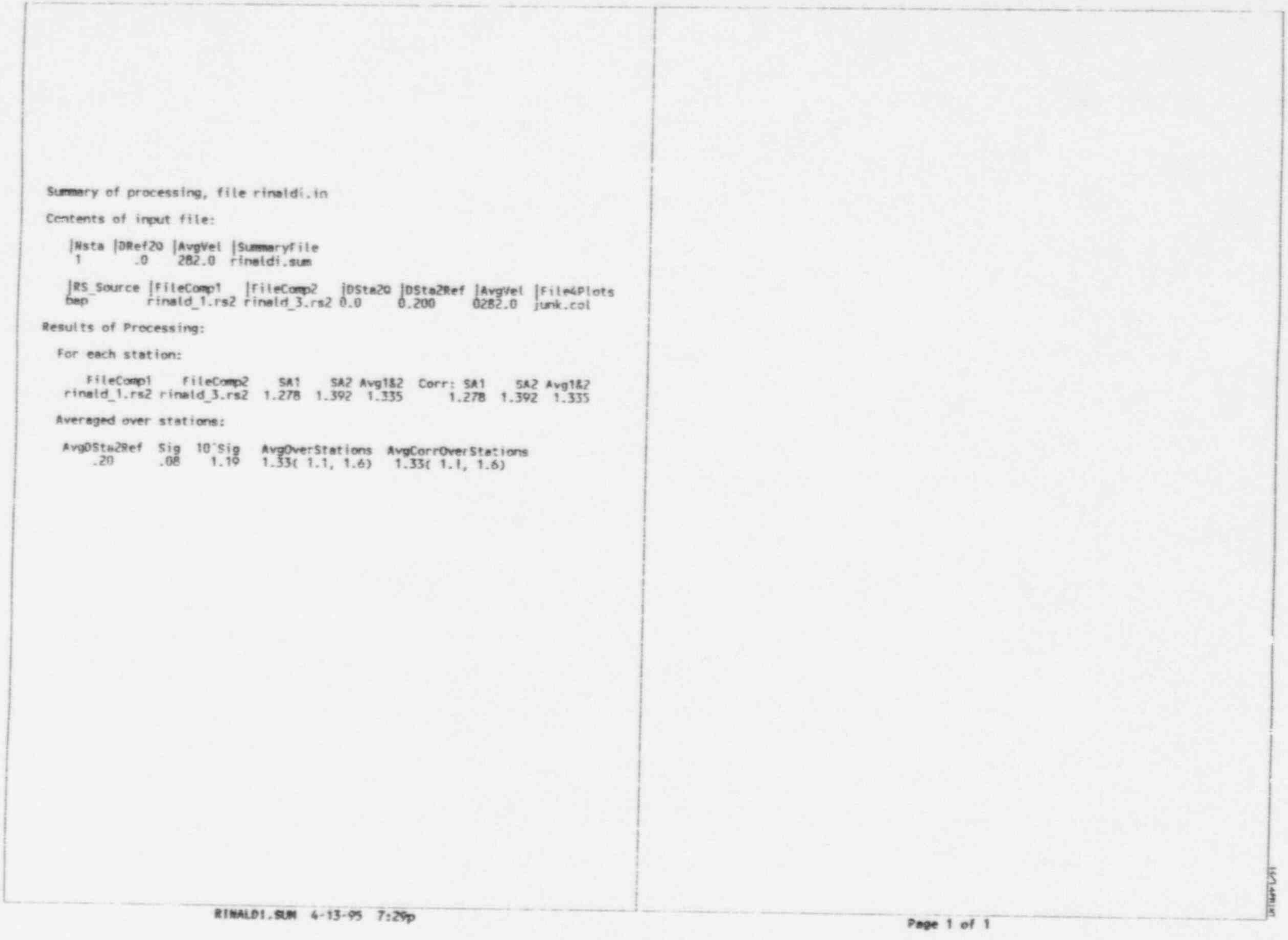


```
Summary of processing, file placcgn1.in

Contents of input file:

   |Nsta |DRef20 |AvgVel |SummeryFile
    1      4.9    385.0  placcgn1.sum

   |RS_Source |FileComp1    |FileComp2    |DSta20 |DSta2Ref |AvgVel  |File4Plots
   bap         newh_1.rs2   newh_3.rs2    4.53    3.45        0245.0  junk.col

Results of Processing:

  For each station:

      FileComp1     FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   newh_1.rs2   newh_3.rs2     1.615  1.334  1.475         1.377  1.137  1.257

  Averaged over stations:

   AvgDSta2Ref   Sig   10^Sig    AvgOverStations   AvgCorrOverStations
      3.45       .20     1.57    1.47(  .9, 2.3)    1.26(  .8, 2.0)
```

PLACCGN1.SUM 4-13-95 7:27p

Page 1 of 1

```
Summary of processing, file placcgn2.in

Contents of input file:

   |Nsta |DRef2Q |AvgVel |SummaryFile
    4      4.9    385.0  placcgn2.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
    bap        newh_1.rs2    newh_3.rs2    4.53    3.45       0245.0  junk.col
    bap        jengena.rs2   jengenc.rs2   0.00    7.42       0385.0  junk.col
    bap        vg7ff_1.rs2   vg7ff_3.rs2   0.00    7.59       0282.0  junk.col
    bap        olive_1.rs2   olive_3.rs2   3.59    7.76       0385.0  junk.col

Results of Processing:

  For each station:

     FileComp1     FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   newh_1.rs2    newh_3.rs2    1.615   1.334  1.475      1.377   1.137  1.257
   jengena.rs2   jengenc.rs2   1.061   2.067  1.564       .876   1.706  1.291
   vg7ff_1.rs2   vg7ff_3.rs2    .911   1.260  1.086       .688    .952   .820
   olive_1.rs2   olive_3.rs2    .876   1.479  1.178       .811   1.367  1.089

  Averaged over stations:

   AvgDSta2Ref   Sig  10^Sig   AvgOverStations   AvgCorrOverStations
      6.55       .18    1.50   1.31(  .9, 2.0)    1.10(  .7, 1.6)

              PLACCGN2.SUM  4-14-95  12:51p                                  Page 1 of 1
```



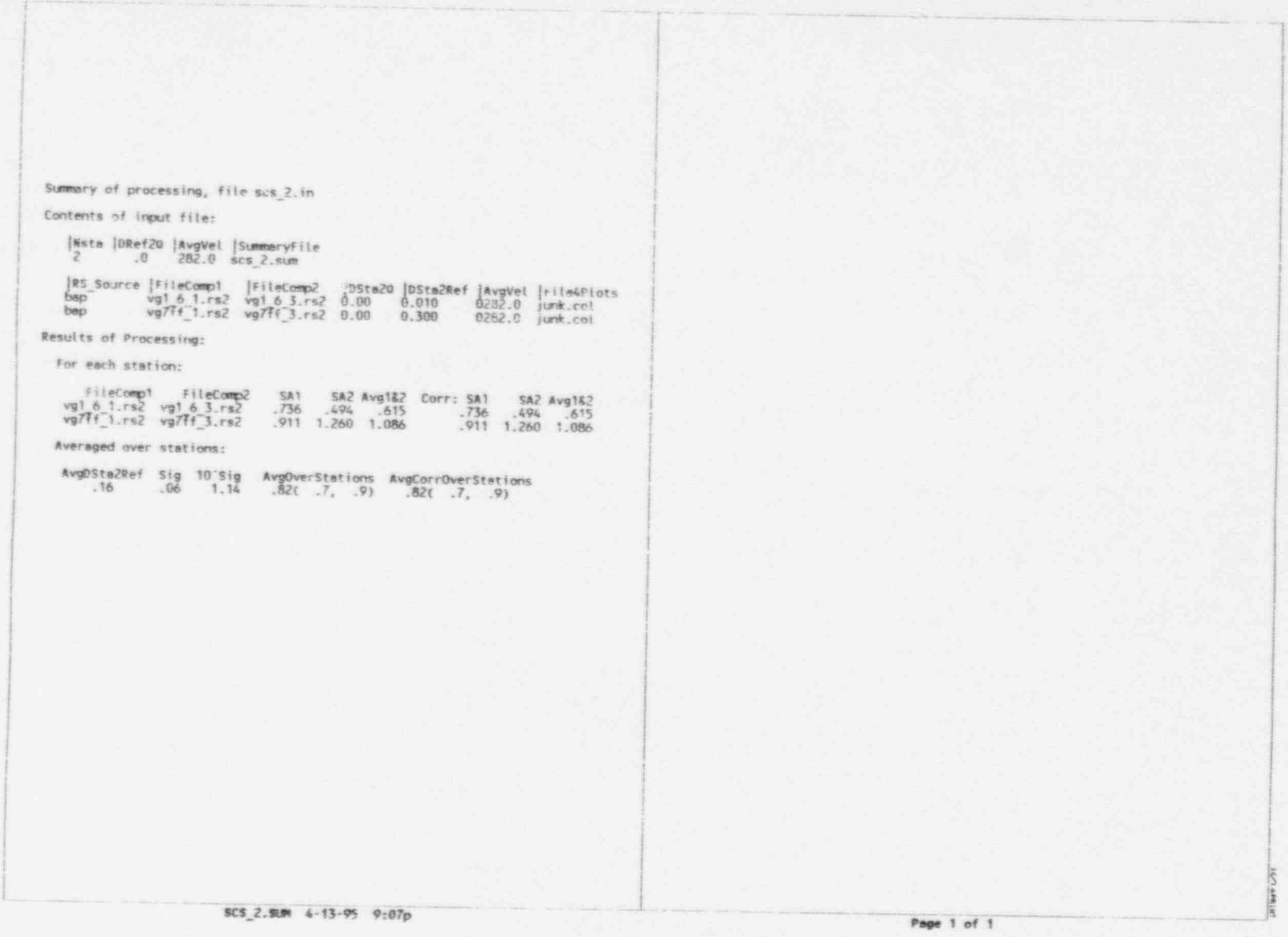
```
Summary of processing, file rinaldi.in

Contents of input file:

   |Nsta |DRef2O |AvgVel |SummaryFile
    1       .0    282.0  rinaldi.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2O |DSta2Ref |AvgVel |File4Plots
   bep         rinald_1.rs2 rinald_3.rs2 0.0      0.200     0282.0  junk.col
Results of Processing:

  For each station:

      FileComp1    FileComp2    SA1    SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   rinald_1.rs2 rinald_3.rs2  1.278  1.392  1.335        1.278  1.392  1.335

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
       .20      .08    1.19   1.33( 1.1, 1.6)   1.33( 1.1, 1.6)
```

RINALDI.SUM 4-13-95 7:29p

Page 1 of 1

```
Summary of processing, file scs_1.in

Contents of input file:

   |Nsta |DRef2O |AvgVel |SummaryFile
    1       .0    282.0  scs_1.sum

   |RS_Source |FileComp1   |FileComp2   |DSta2O |DSta2Ref |AvgVel |File4Plots
   bap         vg1_6_1.rs2  vg1_6_3.rs2  0.00    0.010     0282.0  junk.col

Results of Processing:

  For each station:

     FileComp1    FileComp2    SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   vg1_6_1.rs2  vg1_6_3.rs2   .736    .494   .615          .736   .494   .615

  Averaged over stations:

   AvgDSta2Ref   Sig   10^Sig    AvgOverStations   AvgCorrOverStations
      .01        .02    1.05      .62(  .6,  .6)     .62(  .6,  .6)
```

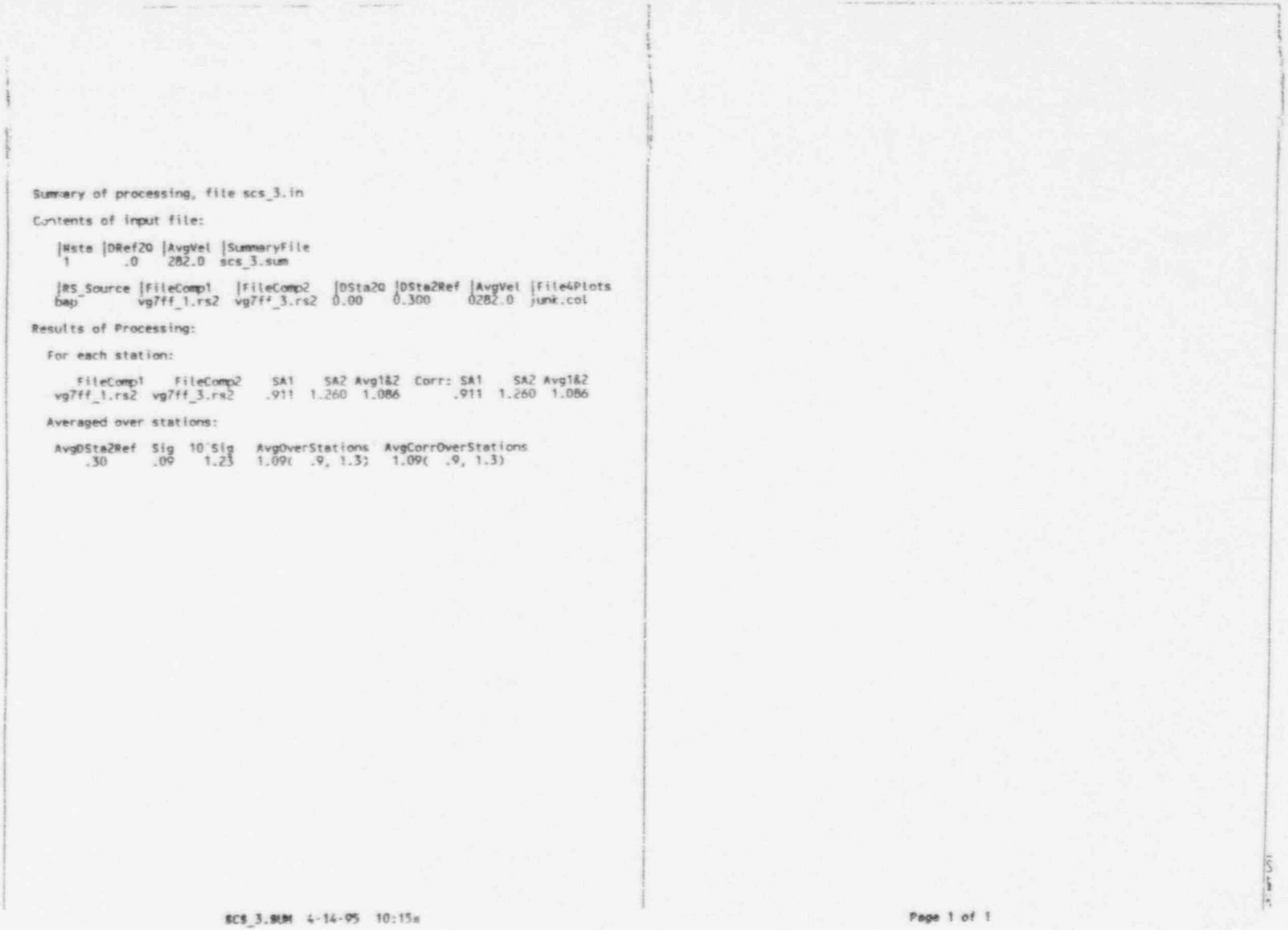
```
SCS_1.SUM  4-13-95  7:31p                                   Page 1 of 1
```



```
Summary of processing, file scs_2.in

Contents of input file:

   |Nsta |DRef20 |AvgVel |SummaryFile
    2        .0    282.0  scs_2.sum

   |RS_Source |FileComp1    |FileComp2    |DSta20 |DSta2Ref |AvgVel |File4Plots
   bap         vg1_6_1.rs2  vg1_6_3.rs2  0.00    0.010     0282.0  junk.col
   bap         vg7Tf_1.rs2  vg7Tf_3.rs2  0.00    0.300     0262.0  junk.col

Results of Processing:

  For each station:

      FileComp1    FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   vg1_6_1.rs2  vg1_6_3.rs2     .736    .494   .615        .736    .494   .615
   vg7Tf_1.rs2  vg7Tf_3.rs2     .911   1.260  1.086        .911   1.260  1.086

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
       .16      .06    1.14    .82( .7,  .9)     .82( .7,  .9)
```

SCS_2.SUM 4-13-95 9:07p

Page 1 of 1



```
Summary of processing, file scs_3.in

Contents of input file:

   |Nsta |DRef2O |AvgVel |SummaryFile
    1       .0    282.0  scs_3.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2O |DSta2Ref |AvgVel |File4Plots
   bap         vg7ff_1.rs2  vg7ff_3.rs2  0.00    0.300     0282.0  junk.col

Results of Processing:

  For each station:

      FileComp1    FileComp2     SA1     SA2 Avg1&2  Corr: SA1     SA2 Avg1&2
   vg7ff_1.rs2  vg7ff_3.rs2     .911  1.260  1.086         .911  1.260  1.086

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
       .30      .09    1.23   1.09(  .9, 1.3)   1.09(  .9, 1.3)
```

SCS_3.SUM 4-14-95 10:15a

Page 1 of 1

```
Summary of processing, file scs_vg7.ir

Contents of input file:

   |Nsta |DRef2C |AvgVel |SummaryFile
    2        .0    282.0  scs_vg7.sum

   |RS_Source |FileComp1    |FileComp2    |DSta2Q |DSta2Ref |AvgVel |File4Plots
   bap         vg7ff_1.rs2  vg7ff_3.rs2  0.00    0.030     0282.0  junk.col
   bap         vg7bld_1.rs2 vg7bld_3.rs2 0.00    0.008     0282.0  junk.col

Results of Processing:

  For each station:

     FileComp1     FileComp2     SA1    SA2 Avg1&2  Corr: SA1    SA2 Avg1&2
   vg7ff_1.rs2  vg7ff_3.rs2    .911  1.260  1.086        .911  1.260  1.086
   vg7bld_1.rs2 vg7bld_3.rs2   .922  1.094  1.008        .922  1.094  1.008

  Averaged over stations:

   AvgDSta2Ref  Sig  10^Sig   AvgOverStations  AvgCorrOverStations
       .02      .02    1.05   1.05( 1.0, 1.1)   1.05( 1.0, 1.1)

SCS_VG7.SUM  4-14-95  10:37a                                        Page 1 of 1
```

APPENDIX C.3

LISTINGS OF PROGRAMS

```
      Program GetDist

* Gets interstation distances.  Use as a preprocessor for
* CorrelPA.

* Note: Uses input file made by Paradox, report in RECS_IN, sorted by distance.
* Note that the report file must be cleaned up, making sure that the
* data start on line 11, eliminating page breaks, deleting the
* very last line (some distance below the
* last actual entry), and putting "stop" after the last entry (starting
* in column 2)

* Dates:
*  03/20/95 - Written by Dave Boore

      real lat(300), long(300)
      real temp_delta, delta(3000), delta_max
      integer indx(3000), ndelta. max_ndelta,
     :  temp_ista_1, temp_ista_2, ista_1(3000), ista_2(3000)
      character buffer*150

      delta_max = 15.0
      max_ndelta = 1500

* Read in data:

      nu_in = 10

      open(unit= nu_in, file = 'nr94pga.prn', recl = 150,
     :     status = 'unknown')

      do i = 1, 10
        read(nu_in, *)
      end do

      nsta = 0

 100  continue
      buffer = ' '
      read(nu_in, '(a)') buffer

      if (buffer(2:5) .eq. 'stop') goto 1000
      nsta = nsta + 1
      read(buffer(93:98), '(f6.3)') lat(nsta)
      read(buffer(100:106), '(f7.3)') long(nsta)
      goto 100

1000  continue
      close(unit=nu_in)

*<<<<<<<<<<<<<<<<<<<<<<<<<<<<<<< START COMPUTATION OF DISTANCES >>>>>>>>>>>>>>>>

      ndelta = 0
      do i = 1, nsta-1
        do j = i+1, nsta
          call distaz(+1.0, lat(i), long(i), lat(j), long(j),
     :         rdeg, temp_delta, az, baz)
          temp_ista_1 = i
          temp_ista_2 = j
          if (temp_delta .le. delta_max) then
            ndelta = ndelta + 1

            if (ndelta .gt. max_ndelta) then
              ndelta = max_ndelta
              go to 9999
            end if
```

GETDIST.FOR 3-20-95 9:39p

```
            delta(ndelta) = temp_delta
            ista_1(ndelta) = temp_ista_1
            ista_2(ndelta) = temp_ista_2

          end if
        end do
      end do

 9999 continue

* Now sort and write the information:

      call indexx( ndelta, delta, indx)

      nu_out = 30
      open(unit = nu_out, file = 'delta.out', status='unknown')

      write(nu_out, '(a,f6.1)') ' Max delta = ', delta_max
      write(nu_out, '(a)') ' ista_1 ista_2  delta'

      do i = 1, ndelta
        write(nu_out, '(4x,i3,4x,i3,1x,f6.2)')
     :          ista_1(indx(i)), ista_2(indx(i)), delta(indx(i))
      end do

      close(unit=nu_out)

      stop
      end


      subroutine distaz( wlongsign, alat, along, blat, blong,
     * rdeg, rkm, az, baz)
c
c compute distances, azimuths using formulas from
c Bruce Julian.
c
c latest modification: 1/27/84
c
      pi = 4.0 * atan( 1. )
      dtor = pi/ 180.
c
c convert from degrees to radians and correct sign of
c longitude so that east longitude is positive.
c
      alatr = dtor * alat
      alongr = -dtor * along * wlongsign
      blatr = dtor * blat
      blongr = -dtor * blong * wlongsign
c
c compute geocentric latitudes.
c
      alatr = atan( 0.993305 * tan( alatr ) )
      blatr = atan( 0.993305 * tan( blatr ) )
c
c compute latitude dependent quantities
c
      ca = cos( alatr )
      cb = cos( blatr )
      sa = sin( alatr )
      sb = sin( blatr )
c
c now compute other quantities
c
      a = cb * sin( blongr - alongr )
```

Page 1 of 2

```
      b = ca * sb - sa * cb * cos( blongr - alongr )
      cd = ca * cb * cos( blongr - alongr ) + sa * sb
      sd = sqrt( a*a + b*b )
c
c compute distances
c
      rdeg = atan2( sd, cd )/ dtor
      rkm = 111.19 * rdeg
c
c compute azimuth (from a to b) and make it positive.
c
      az = atan2( a, b )/ dtor
      if ( az .lt. 0.0 ) az = az + 360.0
c
c compute back azimuth (from b to a) and make it positive.
c
      a = ca * sin( alongr - blongr )
      b = cb * sa - sb * ca * cos( alongr - blongr )
      baz = atan2( a, b)/ dtor
      if ( baz .lt. 0.0 ) baz = baz + 360.0
c
      return
      end


      SUBROUTINE indexx(n,arr,indx)
      INTEGER n,indx(n),M,NSTACK
      REAL arr(n)
      PARAMETER (M=7,NSTACK=50)
      INTEGER i,indxt,ir,itemp,j,jstack,k,l,istack(NSTACK)
      REAL a
      do 11 j=1,n
        indx(j)=j
11    continue
      jstack=0
      l=1
      ir=n
1     if(ir-l.lt.M)then
        do 13 j=l+1,ir
          indxt=indx(j)
          a=arr(indxt)
          do 12 i=j-1,1,-1
            if(arr(indx(i)).le.a)goto 2
            indx(i+1)=indx(i)
12        continue
          i=0
2         indx(i+1)=indxt
13      continue
        if(jstack.eq.0)return
        ir=istack(jstack)
        l=istack(jstack-1)
        jstack=jstack-2
      else
        k=(l+ir)/2
        itemp=indx(k)
        indx(k)=indx(l+1)
        indx(l+1)=itemp
        if(arr(indx(l+1)).gt.arr(indx(ir)))then
          itemp=indx(l+1)
          indx(l+1)=indx(ir)
          indx(ir)=itemp
        endif
        if(arr(indx(l)).gt.arr(indx(ir)))then
          itemp=indx(l)
          indx(l)=indx(ir)
          indx(ir)=itemp
        endif
        if(arr(indx(l+1)).gt.arr(indx(l)))then
          itemp=indx(l+1)
          indx(l+1)=indx(l)
          indx(l)=itemp
        endif
        i=l+1
        j=ir
        indxt=indx(l)
        a=arr(indxt)
3       continue
          i=i+1
        if(arr(indx(i)).lt.a)goto 3
4       continue
          j=j-1
        if(arr(indx(j)).gt.a)goto 4
        if(j.lt.i)goto 5
        itemp=indx(i)
        indx(i)=indx(j)
        indx(j)=itemp
        goto 3
5       indx(l)=indx(j)
        indx(j)=indxt
        jstack=jstack+2
        if(jstack.gt.NSTACK)pause 'NSTACK too small in indexx'
        if(ir-i+1.ge.j-l)then
          istack(jstack)=ir
          istack(jstack-1)=i
          ir=j-1
        else
          istack(jstack)=j-1
          istack(jstack-1)=l
          l=i
        endif
      endif
      goto 1
      END
C  (C) Copr. 1986-92 Numerical Recipes Software $!6)$-"11j.
```

```
      Program CorrelPA

*  Computes correletion of peak accelerations as a function of distance

* Note: Uses input file made by Paradox, report in RECS_IN, sorted by distance.
* Note that the report file must be cleaned up, making sure that the
* data start on line 11, deleting the very last line (some distance below the
* last actual entry), and putting "stop" after the last entry (starting
* in column 2)

* Dates:
*  03/18/95 - Written by Dave Boore

      real mag(300), dist(300), pgah1(300), lat(300), long(300)
      real resid(300), d_bin(100), ave_bin(100)
      real bjf93(300), resid_old(300)
      integer ibin(300), num_not_empty_bins, bin_num_not_empty(100),
     :  istart_not_empty_bin(100), istop_not_empty_bin(100)
      character buffer*150, stem_name*8, f_out*12

      real temp_delta, delta(1000), delta_max
      integer indx(1000), ndelta, max_ndelta,
     :  temp_ista_1, temp_ista_2, ista_1(1000), ista_2(1000)

      real diff_old(1000), diff_new(1000)

* !!!!!!!!!! SET SOME PARAMETERS !!!!!!!!!!!!!!!!

      max_ndelta = 1000
      nu_in = 10
      nu_atn = 20
      nu_ald = 30
      nu_std = 40
      nu_als = 50

      d_min = 0.1
      d_max = 300

*<<<<<<<<<<<<<<<<< OBTAIN DATA AND PARAMETERS >>>>>>>>>>>>>>>>

      write(*, '(a\)') ' Enter stem name for files: '
      stem_name = ' '
      read(*, '(a8)') stem_name

*      write(*, '(a\)') ' Enter d_min: '
*      read(*, '(f5.0)') d_min

*      write(*, '(a\)') ' Enter d_max: '
*      read(*, '(f5.0)') d_max

*      write(*, '(a\)') ' Enter n_bin: '
*      read(*, '(i3)') n_bin

      write(*, '(a\)') ' Enter num_pnts_per_dist_bin: '
      read(*, '(i2)') num_pnts_per_dist_bin

      write(*, '(a\)') ' Enter delta_max: '
      read(*, '(f5.0)') delta_max

      write(*, '(a\)') ' Enter num_diff_per_dlta_bin: '
      read(*, '(i2)') num_diff_per_dlta_bin

      write(*, '(a\)') ' Enter num_diff_2_print: '
      read(*, '(i4)') num_diff_2_print

* Read in data:
```

CORRELPA.FOR 3-21-95 5:40p

```
      open(unit= nu_in, file = 'nr94pga.prn', recl = 150,
     :    status = 'unknown')

      do i = 1, 10
        read(nu_in, *)
      end do

      nsta = 0

 100  continue
      buffer = ' '
      read(nu_in, '(a)') buffer

      if (buffer(2:5) .eq. 'stop') goto 1000
      nsta = nsta + 1
      read(buffer(15:18), '(f4.2)') mag(nsta)
      read(buffer(20:24), '(f5.1)') dist(nsta)
      read(buffer(32:35), '(f4.2)') pgah1(nsta)
      read(buffer(93:98), '(f6.3)') lat(nsta)
      read(buffer(100:106), '(f7.3)') long(nsta)
      goto 100

 1000 continue

      close(unit=nu_in)

*<<<<<<<<<<<<<<<<< ATTENUATION ANALYSIS >>>>>>>>>>>>>>>>

* Debug
      i = 1
      write(*, '(a,i4,f5.2,f6.1,f5.2,f7.3,f8.3)')
     :  ' i=', i, mag(i), dist(i), pgah1(i), lat(i), long(i)
      i = nsta
      write(*, '(a,i4,f5.2,f6.1,f5.2,f7.3,f8.3)')
     :  ' i=', i, mag(i), dist(i), pgah1(i), lat(i), long(i)
* Debug

* Compute residuals, relative to BJF93:

      do i = 1, nsta
        r = sqrt(dist(i)**2 + (5.48)**2)
        bjf93(i) = -0.038+0.216*(mag(i)-6.0)-0.777*alog10(r)+0.254
        resid(i) = alog10(pgah1(i)) - bjf93(i)
      end do

* Data are already sorted by distance (this was done by the Paradox report),
* so now find the bins:

* Skip over this old coding:

      goto 9119

 6116 continue


* Define bins (this was originally inside bin_data.  Put
* it outside to increase flexibility):
      dlogd = (alog10(d_max/d_min))/n_bin
      do i = 1, n_bin
       d_bin(i) = d_min * 10.0**((i-1)*dlogd)
      enddo

* Reset all distances less than d_min to slightly more than d_min:
      do i = 1, nsta
        if (dist(i) .le. d_min) dist(i) = 1.001* d_min
```

Page 1 of 5

```
      end do

      call bin_data(d_bin, n_bin,
     :   dist, nsta, ibin,
     :   num_not_empty_bins, bin_num_not_empty,
     :   istart_not_empty_bin, istop_not_empty_bin)

* Debug
      open(unit=30, file='temp.out', status='unknown')
      do i = 1, nsta
        write(30, '(a,i4,f5.2, f6.1,i4,f6.1,f6.1)')
     :    ' ista, resid, dist, ibin, d_bin_low, d_bin_high =',
     :     i, resid(i), dist(i),
     :     ibin(i), d_bin(ibin(i)), d_bin(ibin(i))*10.0**dlogd
      end do
* Debug

* Now compute the mean residual in each bin:
* (requires that resid be sorted by distance)

      do i = 1, num_not_empty_bins
        call momntdmb(resid,
     :     istart_not_empty_bin(i), istop_not_empty_bin(i),
     :     ave_bin(bin_num_not_empty(i)), adev, sdev, var, skew, curt)


* Debug
         istart = istart_not_empty_bin(i)
         istop =  istop_not_empty_bin(i)
         write(30, '(2a, i3,i4,i4,i4,i4,f6.1,f5.2)')
     :     ' n,bn_#_nt_mpty,#_in_bn,istrt,istp,',
     :     'avdst,resid = ',
     :     i, bin_num_not_empty(i),
     :     istop - istart + 1, istart, istop,
     :     d_bin(bin_num_not_empty(i))*10.0**(dlogd/2.0),
     :     ave_bin(bin_num_not_empty(i))
* Debug

      end do

* Find the new residual for each station by subtracting the average found above
* for each bin:

      do i = 1, nsta
        resid_old(i) = resid(i)
        resid(i) = resid_old(i) - ave_bin(ibin(i))

        write(30, '(a,i4, i4,3f6.2)')
     :     ' nsta, ibin, resid_old, ave_bin, resid_new= ',
     :       i, ibin(i), resid_old, ave_bin(ibin(i)), resid(i)

      end do

9119  continue

      f_out = ' '
      f_out = stem_name//'.atn'

      open(unit=nu_atn, file = f_out, status='unknown')
      write(nu_atn, 721)
721   format(t2,'ibin', t7,'istrt', t13,'istp', t18,'d_strt',
     :        t25,'d_stp', t31,'avdst', t38,'resid')

      f_out = ' '
      f_out = stem_name//'.ald'
      open(unit=nu_ald, file = f_out, status='unknown')
```

```
      write(nu_ald, 722)
722   format( t2,'ista', t7,'ibin', t13,'dist',
     :        t18,'res_old', t26,'res_new',
     :        t34,'bjf+ave_bin',
     :        t46,'ave_bin', t54,'bjf93')

      number_dist_bins = nsta/num_pnts_per_dist_bin

      istrt = -num_pnts_per_dist_bin + 1
      do i = 1, number_dist_bins
        istrt = istrt + num_pnts_per_dist_bin
        istp = istrt + num_pnts_per_dist_bin - 1
        call momntdmb(resid, istrt, istp, ave_bin(i),
     :     adev, sdev, var, skew, curt)
        write(nu_atn, '(t3,i3, t9,i3, t14,i3, t19,f5.1,
     :        t25,f5.1, t31,f5.1, t37,f6.3)')
     :        i, istrt, istp, dist(istrt), dist(istp),
     :        sqrt(dist(istrt)*dist(istp)), ave_bin(i)

        do j = istrt, istp
           resid_old(j) = resid(j)
           resid(j) = resid_old(j) - ave_bin(i)
           write(nu_ald, '(t3,i3, t8,i3, t12,f5.1,
     :            t20,f5.2, t28,f5.2, t40,f5.2,
     :            t48,f5.2, t54,f5.2)')
     :        j, i, dist(j), resid_old(j), resid(j),
     :       bjf93(j) + ave_bin(i), ave_bin(i), bjf93(j)
        end do

      end do

      close(unit=nu_ald)
      close(unit=nu_atn)

*<<<<<<<<<<<<<<<<<< INTERSTATION ANALYSIS >>>>>>>>>>>>>>>>

      ndelta = 0
      do i = 1, nstr-1
        do j = i+1, nsta
          call distaz(+1.0, lat(i), long(i), lat(j), long(j),
     :         rdeg, temp_delta, az, baz)
          temp_ista_1 = i
          temp_ista_2 = j
          if (temp_delta .le. delta_max) then
            ndelta = ndelta + 1

            if (ndelta .gt. max_ndelta) then
              ndelta = max_ndelta
              go to 9999
            end if

            delta(ndelta) = temp_delta
            ista_1(ndelta) = temp_ista_1
            ista_2(ndelta) = temp_ista_2

          end if
        end do
      end do

9999  continue

      write(*, '(a, i5)') ' ndelta = ', ndelta

* Now sort and fill difference array:

      call indexx( ndelta, delta, indx)
```

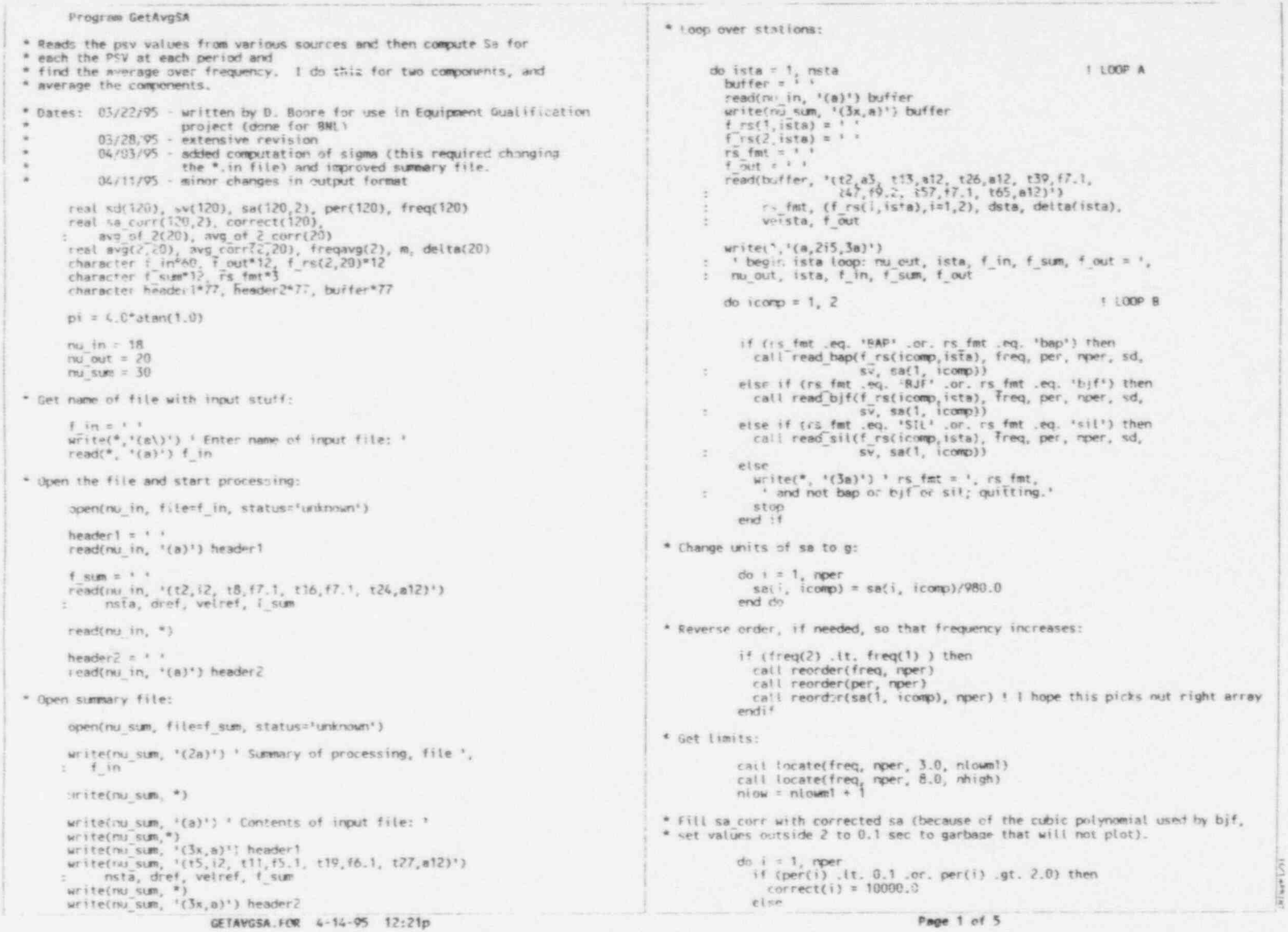
```
      do i = 1, ndelta
        resid1 = resid(ista_1(indx(i)))
        resid2 = resid(ista_2(indx(i)))
        diff_new(i) = resid2 - resid1
        resid1 = resid_old(ista_1(indx(i)))
        resid2 = resid_old(ista_2(indx(i)))
        diff_old(i) = resid2 - resid1
      end do

* Write the first num_diff_2_print values:

      f_out = ' '
      f_out = stem_name//'.als'

      open(unit=nu_als, file = f_out, status='unknown')
      write(nu_als, 723)
723   format(t2,'indx1', t8,'indx2', t14,'delta',
     :       t20,'resid1', t27,'resid2',
     :       t34,'diff_new', t43,'diff_old')

      imax = ndelta
      if (imax .gt. num_diff_2_print) imax = num_diff_2_print

      do i = 1, imax
        resid1 = resid(ista_1(indx(i)))
        resid2 = resid(ista_2(indx(i)))
        write(nu_als, '(t3,i4, t10,i4, t14,f5.2, t21,f5.2,
     :                 t28,f5.2, t37,f5.2, t46,f5.2)')
     :         ista_1(indx(i)), ista_2(indx(i)), delta(indx(i)),
     :         resid1, resid2, diff_new(i), diff_old(i)
      end do

      close(unit=nu_als)

* Now set up bins for interstation spacing and compute sdev:

      f_out = ' '
      f_out = stem_name//'.std'

      open(unit=nu_std, file = f_out, status='unknown')
      write(nu_std, 724)
724   format(t2,'i_dlta_bin', t13,'istrt', t19,'istp',
     :       t24,'avg_dst', t32,'avg_new', t40,'std_new',
     :       t48,'avg_old', t56,'std_old')

      number_delta_bins = ndelta/num_diff_per_dlta_bin

      istrt = -num_diff_per_dlta_bin + 1
      do i = 1, number_delta_bins
        istrt = istrt + num_diff_per_dlta_bin
        istp = istrt + num_diff_per_dlta_bin - 1
        call momntdmb(diff_new, istrt, istp, ave_new,
     :                adev, sdev_new, var, skew, curt)
        call momntdmb(diff_old, istrt, istp, ave_old,
     :                adev, sdev_old, var, skew, curt)

        avgdist = 0.5*(delta(indx(istrt))+delta(indx(istp)))
        write(nu_std, '(t8,i3, t14,i4, t19,i4, t26,f5.2,
     :                  t34,f5.2, t41,f6.3, t50,f5.2, t57,f6.3)')
     :     i, istrt, istp, avgdist,
     :     ave_new, sdev_new, ave_old, sdev_old

      end do

      stop
```

```
      end

      subroutine bin_data(d_bin, n_bin,
     :   dist, nsta, ibin,
     :   num_not_empty_bins, bin_num_not_empty,
     :   istart_not_empty_bin, istop_not_empty_bin)

       real d_bin(*), dist(*)
       integer ibin(*)
       integer num_not_empty_bins, bin_num_not_empty(*),
     :   istart_not_empty_bin(*), istop_not_empty_bin(*)

* assign distances to bins:

      do i = 1, nsta
        call locate(d_bin, n_bin, dist(i), ibin(i))
      end do


* Find indices at start and stop of each bin:

      num_not_empty_bins = 1
      istart_not_empty_bin(1) = 1
      istop_not_empty_bin(1) = 1
      bin_num_not_empty(1) = ibin(1)

      do i = 1, nsta-1
        if (ibin(i+1) .eq. ibin(i)) then
          istop_not_empty_bin(num_not_empty_bins) = i+1
        else
          num_not_empty_bins = num_not_empty_bins + 1
          bin_num_not_empty(num_not_empty_bins) = ibin(i+1)
          istart_not_empty_bin(num_not_empty_bins) = i+1
          istop_not_empty_bin(num_not_empty_bins) = i+1
        end if
      end do

      return
      end



      subroutine distaz( wlongsign, alat, along, blat, blong,
     * rdeg, rkm, az, baz)
c
c compute distances, azimuths using formulas from
c Bruce Julian.
c
c latest modification: 1/27/84
c
      pi = 4.0 * atan( 1. )
      dtor = pi/ 180.
c
c convert from degrees to radians and correct sign of
c longitude so that east longitude is positive.
c
      alatr = dtor * alat
      alongr = -dtor * along * wlongsign
      blatr = dtor * blat
      blongr = -dtor * blong * wlongsign
c
c compute geocentric latitudes.
c
      alatr = atan( 0.993305 * tan( alatr ) )
      blatr = atan( 0.993305 * tan( blatr ) )
c
```

```
c compute latitude dependent quantities
c
      ca = cos( alatr )
      cb = cos( blatr )
      sa = sin( alatr )
      sb = sin( blatr )
c
c now compute other quantities
c
      a = cb * sin( blongr - alongr )
      b = ca * sb - sa * cb * cos( blongr - alongr )
      cd = ca * cb * cos( blongr - alongr ) + sa * sb
      sd = sqrt( a*a + b*b )
c
c compute distances
c
      rdeg = atan2( sd, cd )/ dtor
      rkm = 111.19 * rdeg
c
c compute azimuth (from a to b) and make it positive.
c
      az = atan2( a, b )/ dtor
      if ( az .lt. 0.0 ) az = az + 360.0
c
c compute back azimuth (from b to a) and make it positive.
c
      a = ca * sin( alongr - blongr )
      b = cb * sa - sb * ca * cos( alongr - blongr )
      baz = atan2( a, b)/ dtor
      if ( baz .lt. 0.0 ) baz = baz + 360.0
c
      return
      end



      SUBROUTINE locate(xx,n,x,j)
      INTEGER j,n
      REAL x,xx(n)
      INTEGER jl,jm,ju
      jl=0
      ju=n+1
10    if(ju-jl.gt.1)then
        jm=(ju+jl)/2
        if((xx(n).gt.xx(1)).eqv.(x.gt.xx(jm)))then
          jl=jm
        else
          ju=jm
        endif
      goto 10
      endif
      j=jl
      return
      END
C  (C) Copr. 1986-92 Numerical Recipes Software $16)$-"11j.

      SUBROUTINE indexx(n,arr,indx)
      INTEGER n,indx(n),M,NSTACK
      REAL arr(n)
      PARAMETER (M=7,NSTACK=50)
      INTEGER i,indxt,ir,itemp,j,jstack,k,l,istack(NSTACK)
      REAL a
      do 11 j=1,n
        indx(j)=j
11    continue
      jstack=0
```

```
      l=1
      ir=n
1     if(ir-l.lt.M)then
        do 13 j=l+1,ir
          indxt=indx(j)
          a=arr(indxt)
          do 12 i=j-1,1,-1
            if(arr(indx(i)).le.a)goto 2
            indx(i+1)=indx(i)
12        continue
          i=0
2         indx(i+1)=indxt
13      continue
        if(jstack.eq.0)return
        ir=istack(jstack)
        l=istack(jstack-1)
        jstack=jstack-2
      else
        k=(l+ir)/2
        itemp=indx(k)
        indx(k)=indx(l+1)
        indx(l+1)=itemp
        if(arr(indx(l+1)).gt.arr(indx(ir)))then
          itemp=indx(l+1)
          indx(l+1)=indx(ir)
          indx(ir)=itemp
        endif
        if(arr(indx(l)).gt.arr(indx(ir)))then
          itemp=indx(l)
          indx(l)=indx(ir)
          indx(ir)=itemp
        endif
        if(arr(indx(l+1)).gt.arr(indx(l)))then
          itemp=indx(l+1)
          indx(l+1)=indx(l)
          indx(l)=itemp
        endif
        i=l+1
        j=ir
        indxt=indx(l)
        a=arr(indxt)
3       continue
          i=i+1
        if(arr(indx(i)).lt.a)goto 3
4       continue
          j=j-1
        if(arr(indx(j)).gt.a)goto 4
        if(j.[illegible].i)goto 5
        itemp=indx(i)
        indx(i)=indx(j)
        indx(j)=itemp
        goto 3
5       indx(l)=indx(j)
        indx(j)=indxt
        jstack=jstack+2
        if(jstack.gt.NSTACK)pause 'NSTACK too small in indexx'
        if(ir-i+1.ge.j-l)then
          istack(jstack)=ir
          istack(jstack-1)=i
          ir=j-1
        else
          istack(jstack)=j-1
          istack(jstack-1)=l
          l=i
        endif
      endif
```

```
      goto 1
      END
C  (C) Copr. 1986-92 Numerical Recipes Software $16)$-"11j.

      SUBROUTINE momntdmb(data,nstart,nstop,ave,adev,
     :                    sdev,var,skew,curt)

* Modified by Dave Boore on 03/18/95 so that it will
* compute the moment for array entries from nstart to nstop

      INTEGER n, nstart, nstop
      REAL adev,ave,curt,sdev,skew,var,data(*)
      INTEGER j
      REAL p,s,ep
*      if(n.le.1)pause 'n must be at least 2 in moment'
      s=0.
      do 11 j=nstart,nstop
        s=s+data(j)
11    continue
      n = nstop - nstart + 1
      ave=s/n
      adev=0.
      var=0.
      skew=0.
      curt=0.
      ep=0.
      do 12 j=nstart,nstop
        s=data(j)-ave
        ep=ep+s
        adev=adev+abs(s)
        p=s*s
        var=var+p
        p=p*s
        skew=skew+p
        p=p*s
        curt=curt+p
12    continue
      adev=adev/n
      if ( n .eq. 1) then
        var = 0.0
        sdev = 0.0
      else
        var=(var-ep**2/n)/(n-1)
        sdev=sqrt(var)
      end if
      if(var.ne.0.)then
        skew=skew/(n*sdev**3)
        curt=curt/(n*var**2)-3.
      else
*         pause 'no skew or kurtosis when zero variance in moment'
        skew = 0.0
        curt = 0.0
      endif
      return
      END
C  (C) Copr. 1986-92 Numerical Recipes Software $16)$-"11j.
```



```
      Program GetAvgSA

* Reads the psv values from various sources and then compute Sa for
* each the PSV at each period and
* find the average over frequency.  I do this for two components, and
* average the components.

* Dates:  03/22/95 - written by D. Boore for use in Equipment Qualification
*                    project (done for BNL)
*         03/28/95 - extensive revision
*         04/03/95 - added computation of sigma (this required changing
*                    the *.in file) and improved summary file.
*         04/11/95 - minor changes in output format

      real sd(120), sv(120), sa(120,2), per(120), freq(120)
      real sa_corr(120,2), correct(120),
     :    avg_of_2(20), avg_of_2_corr(20)
      real avg(2,20), avg_corr(2,20), freqavg(2), m, delta(20)
      character f_in*60, f_out*12, f_rs(2,20)*12
      character f_sum*12, rs_fmt*3
      character header1*77, header2*77, buffer*77

      pi = 4.0*atan(1.0)

      nu_in = 18
      nu_out = 20
      nu_sum = 30

* Get name of file with input stuff:

      f_in = ' '
      write(*,'(a\)') ' Enter name of input file: '
      read(*, '(a)') f_in

* Open the file and start processing:

      open(nu_in, file=f_in, status='unknown')

      header1 = ' '
      read(nu_in, '(a)') header1

      f_sum = ' '
      read(nu_in, '(t2,i2, t8,f7.1, t16,f7.1, t24,a12)')
     :     nsta, dref, velref, f_sum

      read(nu_in, *)

      header2 = ' '
      read(nu_in, '(a)') header2

* Open summary file:

      open(nu_sum, file=f_sum, status='unknown')

      write(nu_sum, '(2a)') ' Summary of processing, file ',
     :   f_in

      write(nu_sum, *)

      write(nu_sum, '(a)') ' Contents of input file: '
      write(nu_sum,*)
      write(nu_sum, '(3x,a)') header1
      write(nu_sum, '(t5,i2, t11,f5.1, t19,f6.1, t27,a12)')
     :     nsta, dref, velref, f_sum
      write(nu_sum, *)
      write(nu_sum, '(3x,a)') header2
```

GETAVGSA.FOR 4-14-95 12:21p

```
* Loop over stations:


      do ista = 1, nsta                                  ! LOOP A
        buffer = ' '
        read(nu_in, '(a)') buffer
        write(nu_sum, '(3x,a)') buffer
        f_rs(1,ista) = ' '
        f_rs(2,ista) = ' '
        rs_fmt = ' '
        f_out = ' '
        read(buffer, '(t2,a3, t13,a12, t26,a12, t39,f7.1,
     :                 t47,f9.2, t57,f7.1, t65,a12)')
     :       rs_fmt, (f_rs(i,ista),i=1,2), dsta, delta(ista),
     :       velsta, f_out

        write(*,'(a,2i5,3a)')
     :   ' begin ista loop: nu_out, ista, f_in, f_sum, f_out = ',
     :  nu_out, ista, f_in, f_sum, f_out

        do icomp = 1, 2                                   ! LOOP B


          if (rs_fmt .eq. 'BAP' .or. rs_fmt .eq. 'bap') then
            call read_bap(f_rs(icomp,ista), freq, per, nper, sd,
     :                    sv, sa(1, icomp))
          else if (rs_fmt .eq. 'BJF' .or. rs_fmt .eq. 'bjf') then
            call read_bjf(f_rs(icomp,ista), freq, per, nper, sd,
     :                    sv, sa(1, icomp))
          else if (rs_fmt .eq. 'SIL' .or. rs_fmt .eq. 'sil') then
            call read_sil(f_rs(icomp,ista), freq, per, nper, sd,
     :                    sv, sa(1, icomp))
          else
            write(*, '(3a)') ' rs_fmt = ', rs_fmt,
     :       ' and not bap or bjf or sil; quitting.'
            stop
          end if

* Change units of sa to g:

          do i = 1, nper
            sa(i, icomp) = sa(i, icomp)/980.0
          end do

* Reverse order, if needed, so that frequency increases:

          if (freq(2) .lt. freq(1) ) then
            call reorder(freq, nper)
            call reorder(per, nper)
            call reorder(sa(1, icomp), nper) ! I hope this picks out right array
          endif

* Get limits:

          call locate(freq, nper, 3.0, nlowm1)
          call locate(freq, nper, 8.0, nhigh)
          nlow = nlowm1 + 1

* Fill sa_corr with corrected sa (because of the cubic polynomial used by bjf,
* set values outside 2 to 0.1 sec to garbage that will not plot).

          do i = 1, nper
            if (per(i) .lt. 0.1 .or. per(i) .gt. 2.0) then
              correct(i) = 10000.0
            else
```

Page 1 of 5

```
            m = 6.0  ! can be anything, since the correction is for same quake
            correct(i) = 10.0**(psvper_f(per(i), m, dref, velref)
     :                         - psvper_f(per(i), m, dsta, velsta))
          end if
        end do

        do i = 1, nper
          sa_corr(i, icomp) = correct(i)* sa(i, icomp)
        end do

* Now compute the averages:

       call find_avg(freq, sa(1, icomp), nlow, nhigh,
     :               avg(icomp, ista))
       call find_avg(freq, sa_corr(1, icomp), nlow, nhigh,
     :               avg_corr(icomp, ista))
       freqavg(1) = freq(nlow)
       freqavg(2) = freq(nhigh)

* Then loop back for another component

      end do                                      ! LOOP B (over components)

* Then compute average of the average and write out a column
* file that has freq, per, sa1, sa2, freq, avg1, avg2, avgavg
* that I can use in copiot.

      avg_of_2(ista) = 0.5 * (avg(1, ista) + avg(2, ista))
      avg_of_2_corr(ista) =
     :          0.5 * (avg_corr(1, ista) + avg_corr(2, ista))

      write(*, '(a, i5, 1p2e10.3)')
     :   ' ista, avg_corr1, avg_corr2 = ',
     :     ista, avg_corr(1,ista), avg_corr(2, ista)

      write(*, '(a, i5, 1p2e10.3)')
     :   ' ista, avg_of_2, avg_of_2_corr = ',
     :   ista, avg_of_2(ista), avg_of_2_corr(ista)

      open(unit=nu_out, file=f_out, recl=155, status='unknown')

      write(nu_out, 999)
999     format(t4,'freq', t12,'per', t24,'sa1', t35,'sa2',
     :         t43,'sa1_corr', t55,'sa2_corr',
     :         t64,'freqavg', t72,'peravg',
     :         t84,'avg1', t95,'avg2', t103,'avgavg',
     :         t112,'avg1corr', t123,'avg2corr', t132,'avgavgcorr')

       do i = 1,2
         peravg = 1.0/freqavg(i)
         write(nu_out, '(t2,f6.3, t9,f6.3, t16,e11.4,
     :           t27,e11.4, t40,e11.4, t52,e11.4,
     :           t65,f6.3, t72,f6.3,1x,
     :           t78,e10.3, t89,e10.3, t99,e10.3,
     :           t110,e10.3, t121,e10.3, t132,e10.3)')
     :   freq(i), per(i), (sa(i,j), j=1,2), (sa_corr(i,j), j=1,2),
     :   freqavg(i), peravg, (avg(j, ista), j=1,2), avg_of_2(ista),
     :   (avg_corr(j, ista), j=1,2), avg_of_2_corr(ista)
       end do

       do i = 3, nper
         write(nu_out, '(t2,f6.3, t9,f6.3, t16,e11.4,
     :           t27,e11.4, t40,e11.4, t52,e11.4,
     :           t64,f6.3, t71,f6.3,
     :           t77,e11.4, t88,e11.4, t99,e11.4,
     :           3(1x,e11.4))')
```

```
     :    freq(i), per(i), (sa(i,j), j=1,2), (sa_corr(i,j), j=1,2)
        end do

        write(*,'(a,i5,3a)')
     :        ' end ista loop:ista, f_in, f_sum, f_out = ',
     :         ista, f_in, f_sum, f_out

        write(*, '(a,3i5)')
     :         ' nu_in, nu_sum, nu_out = ',
     :          nu_in, nu_sum, nu_out


        close(unit=nu_out)

        end do                                    ! LOOP A (over stations)

* Write out SA for each station and component

        write(nu_sum,*)
        write(nu_sum, '(a)') ' Results of Processing:'
        write(nu_sum,*)
        write(nu_sum, '(a)') '   For each station:'
        write(nu_sum,*)
        write(nu_sum, 9669)
9669    format(7x,'FileComp1', 4x,'FileComp2',
     :     4x,'SA1', 4x,'SA2', 1x,'Avg1&2',
     :     2x, 'Corr: SA1', 4x,'SA2', 1x,'Avg1&2' )
        do i = 1, nsta
          write(nu_sum, '(4x,a,1x,a,
     :      1x,f6.3,1x,f6.3,1x,f6.3,
     :      5x,f6.3,1x,f6.3,1x,f6.3)')
     :      f_rs(1,i), f_rs(2,i),
     :      (avg(j,i),j=1,2), avg_of_2(i),
     :      (avg_corr(j,i),j=1,2), avg_of_2_corr(i)
        end do

* Compute geometric average of corrected averages
* over stations and print out various averages

        cumdelta = 0.0
        cum = 0.0
        cumcorr = 0.0
        do i = 1, nsta
          cumdelta = cumdelta + delta(i)
          cum = cum + alog10(avg_of_2(i))
          cumcorr = cumcorr + alog10(avg_of_2_corr(i))
        end do
        avg_delta_over_sta = cumdelta/nsta
        cum = cum / nsta
        avg_over_sta = 10.0**cum
        cumcorr = cumcorr / nsta
        avg_corr_over_sta = 10.0**cumcorr

        call inter_interstation_sigma(
     :     avg_delta_over_sta, nsta, sigma)

        write(nu_sum,*)
        write(nu_sum, '(a)') '   Averaged over stations:'
        write(nu_sum,*)
        write(nu_sum, 309)
309     format(3x,' AvgDSta2Ref  Sig  10 Sig',
     :      '   AvgOverStations  AvgCorrOverStations')

      ten2sig = 10.0**sigma
      write(nu_sum, 948) avg_delta_over_sta,
     : sigma, ten2sig,
```

```
     : avg_over_sta,
     : avg_over_sta/ten2sig, avg_over_sta*ten2sig,
     : avg_corr_over_sta,
     : avg_corr_over_sta/ten2sig, avg_corr_over_sta*ten2sig

948   format(6x, f5.2,
     :        5x, f4.2, 4x, f4.2,
     :        2x, f5.2,
     :        '(', f4.1, ',', f4.1, ')',
     :        2x, f5.2,
     :        '(', f4.1, ',', f4.1, ')' )

        close(unit=nu_in)
        close(unit=nu_sum)

        stop
        end

      subroutine inter_interstation_sigma(delta, nsta, sigma)
        sig_1 = 0.1817       !  BJF, random comp, M 6.0-6.9
        sigma = sig_1 * sqrt(1.0+1.0/nsta) *
     :          (1.0 - exp(-sqrt(0.6*delta)))

        return
        end

      subroutine reorder(a, n)
        real a(*)
        do i = 1, n/2
          dum = a(n+1-i)
          a(n+1-i) = a(i)
          a(i) = dum
        end do
        return
      end

      subroutine find_avg(x, y, nlow, nhigh, avg)
        real x(*), y(*)
        area = 0.0
        do i = nlow, nhigh-1
          area = area + 0.5*(y(i)+y(i+1))*(x(i+1)-x(i))
        end do
        avg = area/(x(nhigh)-x(nlow))
        return
      end

      SUBROUTINE locate(xx,n,x,j)
      INTEGER j,n
      REAL x,xx(n)
      INTEGER jl,jm,ju
      jl=0
      ju=n+1
10    if(ju-jl.gt.1)then
        jm=(ju+jl)/2
        if((xx(n).gt.xx(1)).eqv.(x.gt.xx(jm)))then
          jl=jm
        else
          ju=jm
        endif
      goto 10
      endif
      j=jl
      return
      END
C  (C) Copr. 1986-92 Numerical Recipes Software $!6)$-"11j.
```

```
      subroutine read_bap(fil_name, freq, per, nper, sd, sv, sa)

* Read response spectra file made by BAP.

* NOTE: This version assumes that the spectra were computed for
* only one damping

* Also note that the array of values is inverted in order so that
* frequency increases.

* Dates: 03/27/95 - Written by D. Boore
*        03/29/95 - allow for comment lines

      real freq(*), per(*), sd(*), sv(*), sa(*), rhead(50)
      integer ihead(48)
      character fil_name*(*)

      open(unit=10, file=fil_name, status='unknown')

      call skip(10, 11)
      read(10, '(8i10)') (ihead(i), i=1,48)
      read(10, '(5e15.7)') (rhead(i), i=1,50)
      nskip = ihead(16)
      call skip(10, nskip)
      call skip(10, 1)

      read(10, '(3i5)') ndamp, nper, iflag
      read(10, '(5e10.5)') damp

      read(10, '(7e11.4)') (per(i), i=1, nper)

      read(10, *)

      read(10, '(7e11.4)') (sd(i), i=1, nper)

      close(unit=10)

      pi = 4.0*atan(1.0)

      do i = 1, nper
        freq(i) = 1.0/per(i)
        sv(i) = 2.0*pi*freq(i)*sd(i)
        sa(i) = 2.0*pi*freq(i)*sv(i)
      end do

      return
      end


      subroutine read_bjf(fil_name, freq, per, nper, sd, sv, sa)

* Read response spectra file in format used in BJF93 study.

* NOTE: This version assumes that the spectra were computed for
* only one damping

* Dates: 03/27/95 - Written by D. Boore

      real freq(*), per(*), sd(*), sv(*), sa(*)
      character fil_name*(*)


* Read the periods:

      open(unit=12,file='\psv\progs\csmip.per')
```

```
      read(12, '(8f10.3)') (per(i), i=1, 91)
      close(12)

      nper = 91

      open(unit=10, file=fil_name, status='unknown')

* Skip 32 lines:

        do i = 1, 32
          read(10, *)
        end do

* Read the psv values:

        read(10, '(7e11.4)') (sv(i), i = 1, 91)

      close(unit=10)

      pi = 4.0*atan(1,0)

      do i = 1, nper
        freq(i) = 1.0/per(i)
        sd(i) = sv(i)/(2.0*pi*freq(i))
        sa(i) = 2.0*pi*freq(i)*sv(i)
      end do

      return
      end

      subroutine read_sil(fil_name, freq, per, nper, sd, sv, sa)

* Read response spectra file made by Walt Silva.

* NOTE: This version assumes that the spectra were computed for
* only one damping

* Dates: 03/27/95 - Written by D. Boore

      real freq(*), per(*), sd(*), sv(*), sa(*)
      character fil_name*(*)

      open(unit=10, file=fil_name, status='unknown')

      do i = 1, 3
        read(10, *)
      end do

      read(10, '(t3,i3)') nper

      do i = 1, nper
        read(10, '(3x, 8(3x, e12.7))') freq(i), sd(i)
      end do

      close(unit=10)

      pi = 4.0*atan(1.0)

      do i = 1, nper
        per(i) = 1.0/freq(i)
        sv(i) = 2.0*pi*freq(i)*sd(i)
        sa(i) = 2.0*pi*freq(i)*sv(i)
      end do

      return
      end
```

GETAVGSA.FOR 4-14-95 12:21p

```
      function psvper_f(t, m, d, v)

* Returns BJF93, 94 value for random value, 5 % damping

*      t = period
*      m = moment magnitude
*      d = distance
*      v = average shear-wave velocity

* This routine uses the cubic polynomial results for the regression
* coefficients, from Table 8 in BJF94.

* Dates:
*         03/28/95 - Written by D. Boore

      real b1_c(4), b2_c(4), b3_c(4), h_c(4), b5_c(4), bv_c(4),
     :     logva_c(4), sig1_c(4), sig2_c(4), sig4_c(4)
      real b1, b2, b3, h, b5, bv,
     :     logva, sig1, sig2, sig4
      real m, d

      data b1_c    /  1.65301,  1.87615,  -3.17713,  1.37157/
      data b2_c    /  0.32667, -0.22536,   0.64842, -0.29982/
      data b3_c    / -0.09803, -0.06168,   0.35352, -0.20739/
      data h_c     /  6.26923, 10.59215, -32.48153, 18.51690/
      data b5_c    / -0.93430, -0.09835,   0.52386, -0.28909/
      data bv_c    / -0.21172,  0.06619,  -1.35085,  0.79809/
      data logva_c/  3.04586,  1.69975,  -2.97445,  1.37668/
      data sig1_c /  0.19117, -0.05830,   0.13415, -0.05913/
      data sig2_c /  0.00266,  0.05649,   0.07367, -0.03324/
      data sig4_c /  0.08263,  0.11264,  -0.09145,  0.04751/

* Evaluate coefficients:

      call get_coeff(b1, b1_c, t)
      call get_coeff(b2, b2_c, t)
      call get_coeff(b3, b3_c, t)
      call get_coeff(h, h_c, t)
      call get_coeff(b5, b5_c, t)
      call get_coeff(bv, bv_c, t)
      call get_coeff(logva, logva_c, t)
      call get_coeff(sig1, sig1_c, t)
      call get_coeff(sig2, sig2_c, t)
      call get_coeff(sig4, sig4_c, t)

* Check for sig less than 0... this is possible because of the smoothing.
      if (sig1 .lt. 0.0) sig1 = 0.0
      if (sig2 .lt. 0.0) sig2 = 0.0
      if (sig4 .lt. 0.0) sig4 = 0.0

      sigc = sig4
      sige = sig2

      sigr = sqrt(sig1**2+ sigc**2)
      sloga = sqrt(sigr**2+sige**2)

      r = sqrt(d**2.0+ h**2.0)

      b4 = 0.0   ! in BJF93

      psvper_f = b1 + b2*(m-6.0)+b3*(m-6.0)**2.0
     :             + b4*r + b5*alog10(r)
     :             + bv*(alog10(v)-logva)

      return
```

Page 4 of 5

```
end

subroutine get_coeff(b, b_c, t)

  real b_c(*), logtnrm

  logtnrm = alog10(t/0.1)

  b = 0.0
  do i = 1, 4
    b = b + b_c(i)*(logtnrm)**(i-1)
  end do

  return
end

subroutine SKIP(lunit, nlines)
  if (nlines .eq. 0) return
  do i = 1, nlines
     read(lunit, *)
  end do
  return
end
```

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10. SUPPLEMENTARY NOTES

R. Kenneally, NRC Project Manager

11. ABSTRACT *(200 words or less)*

Advanced Reactor Corporation (ARC) has developed a methodology for seismic qualification of equipment, cable trays, and ducts in Advanced Light Water Reactor plants. A Panel (members of which acted as individuals) supported by the Office of Nuclear Regulatory Research of the Nuclear Regulatory Commission has evaluated this methodology. The review approach and observations are included in this report. In general, the Panel supports the ARC methodology with some exceptions and provides recommendations for further improvements.

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