APPENDIX A

UNRESOLVED SAFETY ISSUE (USI) A-46

AND

GENERIC LETTER (GL) 87-02

FLORIDA POWER & LIGHT COMPANY
DECEMBER 1989

APPENDIX A

INDEX

TECHNICAL AND ECONOMIC BASIS FOR THE EXCLUSION OF RELAYS FROM THE FPL PLANT SPECIFIC SEISMIC ADEQUACY IMPLEMENTATION PROCEDURE TO RESOLVE UNRESOLVED SAFETY ISSUE A-46 AND GENERIC LETTER(GL) 87-02

GL 87-02 is concerned that older plants (predating IEEE 344-75) may not be able to achieve/maintain the hot shutdown condition in the event of a Safe Shutdown Earthquake (SSE).

GL 87-02 states that "Direct application of current seismic criteria to older plants could require extensive, and probably impractical modification of these facilities." GL 87-02 proposes a solution whereby older plants would be reviewed against new seismic criteria specifically chosen for A-46 resolution, and acknowledges that these new seismic criteria are different than any previously licensed seismic criteria or any currently licensed seismic criteria.

The essence of this new seismic approach is that instead of using (10 CFR 50 App. B) test and /or analysis programs it uses a new program developed by an industry group which includes new generic ground response spectra; similarity comparisons with (non-nuclear) earthquake experience databases; and the judgement of qualified/experienced engineers. Due to the reviews proposed by GL 87-02 using this new program and due to there being no evidence to show that older plants do not presently have "adequate protection" in the context of the Backfit Rule (10 CFR 50.109), GL 87-02 acknowledges that the proposed resolution constitutes a backfit.

Included in the new program are seismic criteria which have never been required of any licensed nuclear plants, including those nuclear plants exempted from GL 87-02 by virtue of being IEEE 344-75 plants, such as St. Lucie Unit 2. One of these seismic criteria is the requirement that relays (including contactors and switches) be functional/free from chatter for a period of 30 seconds of strong shaking.

The purpose of this paper is to address this subject as it applies to FPL's plants from seismological, operational, risk assessment, licensing and economic perspectives and to show that it is entirely appropriate that relays be excluded from FPL's final plant specific implementation procedure.

SUMMARY OF CONCLUSIONS

(1) Strong shaking of any duration is not credible at FPL's plants.

(2) St. Lucie Unit 2 was totally exempted from A-46 (via GL 87-03) because it is licensed to current criteria (IEEE 344-75/RG 1.100 Rev.1). Neither the IEEE nor RG document require relay chatter during strong shaking to be addressed.

(3) Future plants will be licensed to IEEE 344-87/RG 1.100 Rev.2. The IEEE and RG documents only require relay chatter during the first 15 seconds of strong shaking to be addressed, which is 15 seconds less than the requirements in GL 87-02 for older plants.

(4) All seismic PRAs done to date using NRC approved methodologies (with the possible exception of Limerick's), did not assign relay chatter, any risk contribution to core melt. The PRA's considered relay chatter to not be an equipment failure but rather to be an event, which if it occurred at all, would be recoverable by operator action.

(5) NUREG 1211, the Regulatory Analysis for A-46, written by the NRC for GL 87-02, did not assign relay chatter any risk contribution to core melt.

(6) NUREG/CR 4710 (St Lucie) and NUREG/CR 4762 (Turkey Point), the A-45 (Decay Heat Removal) analyses written by Sandia under contract to the NRC, examined the risk contributors to core melt from earthquake accelerations up to and including 4XSSE. Sandia did not assign relay chatter any risk contribution to core melt, at either the St. Lucie plant or the Turkey Point plant.

(7) NRC approved criteria for the purpose of evaluating relays under the A-46 program do not exist.

(8) Required expenditures by FPL to address relays under the A-46 program would not be prudent.

DISCUSSION

(1) Florida Seismicity

State of the art seismic hazard studies have recently been completed by the Electric Power Research Institute (EPRI) for a utility owners group, and by Lawrence Livermore National Laboratories (LLNL) for the NRC. Neither the EPRI nor the NRC studies placed any seismic sources in Florida. Further, the University of Florida, a United States Geological Survey Station, presented a paper in December 1988 (Appendix A, Tab A-2) at the EPRI Seismic Symposium in Orlando, which concluded that the Florida land mass attached to North America during the Paleozoic era and that it is lithologically and tectonically distinct from and more stable than the (seismically active) Appalachian area which was the original margin of North America. In summary, Florida is legally, but not seismically, a part of the Eastern United States.

(2) Time Duration of Strong Shaking

Strong shaking durations depend upon magnitude and source-to-site distance, with lesser dependencies on wave frequency and amplitude threshold. In 1973, Professor Bruce Bolt presented the definitive paper on the subject (Appendix A, Tab A-3) at the World Conference on Earthquake Engineering in Rome. The paper was, and still is, the only NRC approved reference document on the subject in NUREG-0800 (Standard Review Plan) Section 2.5.2 (Vibratory Ground Motion).

In accordance with Professor Bolt's paper, to have any duration of strong shaking at any of FPL's plants would require a Magnitude 5.5 earthquake within approximately 45 miles; a Magnitude 6.5 earthquake within approximately 75 miles; a Magnitude 7.5 earthquake within approximately 100 miles . None of these events can be considered as credible, considering Florida's seismicity.

As another example to illustrate the application of Professor Bolt's paper, the effects of the January 1986 Leroy, Ohio earthquake on the Perry plant are worth reviewing. The earthquake was centered approximately 10 miles from the plant and had a Magnitude of 5.0. The recorded duration of strong shaking was less than 1 second which is compatible with Professor Bolt's paper. In addition, although 39 safety related systems made up of several thousand components and devices were in operation or standby during the earthquake, all systems functioned normally. The only relays which malfunctioned were the generator protection relays which tripped due to not having voltage applied because the plant was in the startup mode. Had they had voltage applied they most likely would not have tripped (EPRI NP-6389).

(3) Operator Action

GL 87-02 states that "credit can be taken for timely operator action to reset relays in case change of state occurs during an SSE". This is the position taken by seismic PRAs to date and it is the position taken by FPL in responding to A-46.

(4) Relay Evaluation Efforts

At the present time, the NRC's contractor, Brookhaven National Laboratories has taken the position that evaluation of relays to the new seismic criteria (GERS) is difficult and may not be possible on a generic basis.

The Steering Group for the industry group developing the new seismic approach has proposed a solution whereby the evaluation of relays would be accomplished by having a group of engineers experienced in both relays and seismic testing make similarity comparisons to previously qualified relays and then reach a judgement as to qualification by a consensus methodology (Seismic Qualification Utility Group Meeting Minutes of October 26 and 27, 1989).

This methodology may be appropriate for higher seismic risk utilities and may receive NRC approval for use. In the meantime, there is no NRC approved methodology for the purpose of evaluating relays under the A-46 program. The alternative is to replace the relays with IEEE 344-75/RG 1.100 Rev.1 relays but this would require extensive modification to FPL's facilities, which has been recognized as impractical by GL 87-02 as stated earlier.

(5) Economic Considerations

Recently, the industry group developing the new approach was taken over by EPRI and EPRI's proposed charter limits the availability of the new seismic approach (including relay evaluation criteria) to paid members for a period of ten years. The charter further requires new members to pay an initiation fee equal to the sum of all payments made by original members. Since FPL has never been a member of the industry group, it would cost FPL hundreds of thousands of dollars in initiation fees to get the (proposed) relay evaluation criteria at this time.

Even if the relay evaluation criteria had NRC approval at this time, in order to use them FPL would have to prepare a list of essential relays required for hot shutdown. At each of FPL's three plants this would involve screening approximately 1000 to 2000 relays, 500 to 1000 circuit breakers/contactors, and 1000 switches, at an estimated cost of $200,000 to $400,000 per plant.

The alternative to joining the EPRI industry group would be to replace existing relays with IEEE 344-75/RG 1.100 Rev.1 relays which also would cost hundreds of thousands of dollars and as stated earlier, would not provide qualification for strong shaking and would be impractical as recognized by GL 87-02.

In previously docketed correspondence (L-88-333/August 4, 1988) FPL made the point that the (potential) benefit of resolving A-46, calculated by using site specific data together with the NRC's methodology in the Regulatory Analysis for A-46 (NUREG-1211) was $15,000 for the St Lucie plant and $8,000 for the Turkey Point plant. The (actual) implementation program being offered by FPL at this time already has a cost in excess of this (potential) benefit and further voluntary expenditures in the hundreds of thousands of dollars to additionally address relays under the A-46 program would not be prudent.

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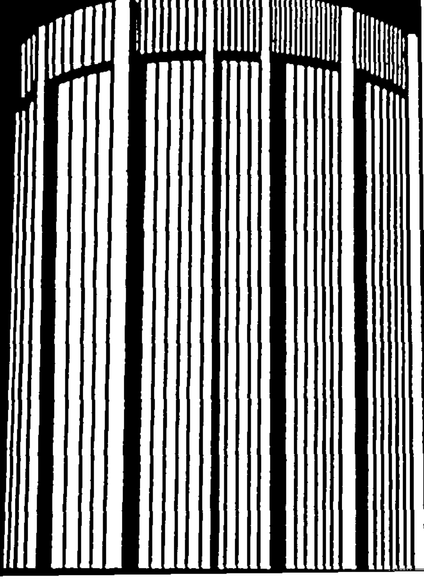

Current Issues Related to Nuclear Power Plant Structures, Equipment and Piping

Background

In December 1986, the 1st Symposium on Current Issues Related to Nuclear Power Plant Structures, Equipment and Piping was held at North Carolina State University (NCSU). The symposium was sponsored by NCSU and cosponsored by the U.S. Nuclear Regulatory Commission (USNRC) and the Electric Power Research Institute (EPRI). In the two years since the first symposium, very significant advances have been made in understanding and resolving concerns particularly with respect to seismic issues. Industry and the NRC have completed development of probabilistic seismic hazard methodologies, procedures for equipment qualification and seismic margins evaluation procedures. It is timely to review these and other advances in resolving nuclear plant related issues.

A symposium proceedings will be published and distributed at the symposium. It is anticipated that selected papers from the proceedings may be published in a special issue of *Nuclear Engineering and Design.*

Purpose of the Second Symposium

The purpose of this 2nd Symposium is to address a broad range of nuclear plant issues with emphasis on resolution of seismic issues in low seismicity regions.

Who Should Attend

This symposium is directed to structural, geotechnical, mechanical and plant operation engineers, engineering managers, licensing engineers and managers working in the area of nuclear power plants with electrical utilities, and to regulatory personnel. Equipment manufacturers and suppliers, architect-engineers and other consulting firms and research organizations will also benefit.

Technical Information

For further information on the technical content of the program, contact:

Ajaya K. Gupta, Professor of Civil Engineering, *North Carolina State University*
Raleigh, NC 27695-7908 • (919) 737-7207

SUMMARY OF SYMPOSIUM EVENTS

Time	Tuesday, Dec. 6	Wednesday, Dec. 7	Thursday, Dec. 8	Friday, Dec. 9
7:00 am		Continental Breakfast/ Registration		
7:30 am			Continental Breakfast	Continental Breakfast
8:00 am		Session I	Session V	Session IX
		Break	Break	Break
Between 10-10:25 am		Session II	Session VI	Session X
12 NOON		LUNCH	LUNCH	LUNCH
1:30 pm		Session III	Session VII	Session XI
		Break	Break	Break
Between 3-3:25 pm		Session IV	Session VIII	Session XII
6:00 pm	Reception/ Early Registration		Reception	Symposium adjourns
7:30 pm			Dinner	

Second Symposium on

CURRENT ISSUES RELATED TO NUCLEAR POWER PLANT STRUCTURES, EQUIPMENT AND PIPING

With Emphasis on
Resolution of Seismic Issues in Low Seismicity Regions

Wednesday, December 7, 1988

7:00 am
Registration and Continental Breakfast

SESSION I: SEISMIC HAZARD-1

Chairmen:
C. Allin Cornell
Stanford University
Stanford, CA

Walter W. Hays
U.S. Geological Survey
Reston, VA

8:00-8:30 am
Probabilistic Assessment of the Seismic Hazard for Eastern United States Nuclear Power Plants
Don L. Bernreuter, Jean B. Savy and Richard W. Mensing
Lawrence Livermore National Laboratory
Livermore, CA

8:30-9:00 am
Probabilistic Seismic Hazard Assessment: EPRI Methodology
Gabriel R. Toro and Robin K. McGuire
Risk Engineering Incorporated
Golden, CO

J. Carl Stepp
Electric Power Research Institute
Palo Alto, CA

9:00-9:30 am
Probabilistic Seismic Hazard Assessment—Trends in USGS Approach
David M. Perkins
U.S. Geological Survey
Golden, CO

9:30-9:50 am
Probabilistic Seismic Hazard Assessment—A Utility Perspective
John P. Jacobson and Thomas F. O'Hara
Yankee Atomic Electric Company
Framingham, MA

9:50-10:10 am
Probabilistic Seismic Hazard Results for Sites in a Region of Low Seismicity
Samir G. Khoury and Umesh Chandra
EBASCO Services Incorporated
Greensboro, NC

10:10 am—Break

SESSION II: SEISMIC HAZARD-2

Chairmen:
Walter W. Hays
U.S. Geological Survey
Reston, VA

C. Allin Cornell
Stanford University
Stanford, CA

10:25-10:50 am
Probabilistic Seismic Hazard—Lessons Learned, A Regulator's Perspective
Leon Reiter
U.S. Nuclear Regulatory Commission
Washington, D.C.

10:50-11:15 am
A Decision Framework Using Seismic Hazard Results to Address Issues of Nuclear Power Plant Seismic Safety
Robert T. Sewell, Robin K. McGuire and Gabriel R. Toro
Risk Engineering Incorporated
Golden, CO

J. Carl Stepp
Electric Power Research Institute
Palo Alto, CA

11:15-11:40 am
Lower Bound Earthquake Magnitude for Probabilistic Seismic Hazard Evaluation
Martin W. McCann, Jr. and John W. Reed
Jack R. Benjamin & Associates, Incorporated
Mountain View, CA

11:40-12:00
History of Seismological Activity in Florida
Douglas L. Smith and Anthony F. Randazzo
Geohazards, Incorporated
Gainesville, FL

12:00 pm—Luncheon
Luncheon Speaker—Commissioner Thomas M. Roberts,
Nuclear Regulatory Commission

SESSION III: SEISMIC PROBABILISTIC RISK ASSESSMENT AND MARGIN STUDIES–1

Chairmen:

Daniel J. Guzy
U.S. Nuclear Regulatory Commission
Washington, D.C.

Robert P. Kassawara
Electric Power Research Institute
Palo Alto, CA

1:30-1:50 pm

Recent PRA Applications

Mayasandra K. Ravindra
EQE Engineering, Incorporated
Cosa Mesa, CA

Michael P. Bohn
Sandia National Laboratories
Albuquerque, NM

David L. Moore
EI International Incorporated
Kent, WA

Robert C. Murray
Lawrence Livermore National Laboratory
Livermore, CA

1:50-2:10 pm

On Some Aspects of Seismic Fragility Evaluation for Diablo Canyon Seismic PRA

Robert P. Kennedy
RPK Structural Mechanics Consulting
Yorba Linda, CA

Bimal E. Sarkar
Bechtel Power Corporation
San Francisco, CA

Lloyd S. Cluff
Pacific Gas and Electric Company
San Francisco, CA

2:10-2:30 pm

Validation Studies of Seismic PRAs

Bruce Ellingwood
Johns Hopkins University
Baltimore, MD

2:30-2:50 pm

Component Fragility Study—Lessons Learned

Kamal K. Bandyopadhyay, Charles H. Hofmayer, Mumtaz K. Kassir, and Susan E. Pepper
Brookhaven National Laboratory

2:50-3:10 pm

Seismic Margin Assessment of Hatch Nuclear Power Plant

Donald P. Moore and Keith Wooten
Southern Company Services, Incorporated
Birmingham, AL

Robert P. Kassawara
Electric Power Research Institute
Palo Alto, CA

3:10-3:25 pm—Break

SESSION IV: SEISMIC PROBABILISTIC RISK ASSESSMENT AND MARGIN STUDIES–2

Chairmen:

Robert P. Kassawara
Electric Power Research Institute
Palo Alto, CA

Daniel J. Guzy
U.S. Nuclear Regulatory Commission
Washington, D.C.

3:25-3:50 pm

Recent Extensions to the Seismic Margin Review Methodology

Robert J. Budnitz
Future Resources Associates, Incorporated
Berkeley, CA

Peter G. Prassinos
Lawrence Livermore National Laboratory
Livermore, CA

Mayasandra K. Ravindra
EQE Engineering, Incorporated
Costa Mesa, CA

3:50-4:15 pm

Use of Boundary Spectra to Demonstrate Seismic Margin at Low Seismicity Sites

John D. Stevenson
Stevenson and Associates
Cleveland, OH

4:15-4:40 pm

Seismic Evaluation of Large Flat-Bottomed Tanks

Robert P. Kennedy
RPK Structural Mechanics Consulting
Yorba Linda, CA

Robert P. Kassawara
Electric Power Research Institute
Palo Alto, CA

4:40-5:05 pm

Earthquake Experience Data Relevant to Nuclear Plant Vertical Storage Tanks

Philip S. Hashimoto
EQE Engineering, Incorporated
Costa Mesa, CA

H. T. Tang
Electric Power Research Institute
Palo Alto, CA

Lu Woon Tiong
EQE Engineering Incorporated
Costa Mesa, CA

5:05-5:30 pm

Comparison Studies of HCLPF Capacities Determined by CDFM and Fragility Analysis Methods

Robert C. Murray
Lawrence Livermore National Laboratory
Livermore, CA

Robert P. Kennedy
RPK Structural Mechanics Consulting
Yorba Linda, CA

Thursday, December 8, 1988

SESSION V: UNRESOLVED SEISMIC ISSUES, A46 AND RELATED TOPICS–1

Chairmen:

Newton R. Anderson
U.S. Nuclear Regulatory Commission
Washington, D.C.

Neil P. Smith
Commonwealth Edison Company
Chicago, IL

8:00-8:20 am

The SQUG Program for Resolution of USI A46—Status and Implementation Plans

William R. Schmidt
MPR Associates, Incorporated
Washington, D.C.

Neil P. Smith
Commonwealth Edison Company
Chicago, IL

Robert P. Kassawara
Electric Power Research Institute
Palo Alto, CA

Peter I. Yanev
EQE Engineering, Incorporated
San Francisco, CA

8:20-8:40 am

Seismic Qualification of Equipment in Operating Plants: Overview and Regulatory Implications

Newton R. Anderson, T. Y. Chang, and Ledyard B. (Tad) Marsh
U.S. Nuclear Regulatory Commission
Washington, D.C.

8:40-9:05 am

Overview of SQUG Generic Implementation Procedure (GIP)

Richard G. Starck II
MPR Associates, Incorporated
Washington, D.C.

G. Gary Thomas
Stevenson and Associates
Cleveland, OH

9:05-9:25 am

Zion SQUG Pilot Walkdown and Resolution of Outliers

Pawan K. Agrawal, Adolf Walser, and Steve R. Bertheau
Sargent and Lundy
Chicago, IL

Neil P. Smith
Commonwealth Edison
Chicago, IL

9:25-9:45 am

An Update of Nine Mile Point SQUG Activities

Frances H. Feng and Robert F. Oleck
Niagara Mohawk Power Company
Syracuse, NY

9:45 am—Break

SESSION VI: UNRESOLVED SEISMIC ISSUES, A46 AND RELATED TOPICS–2

Chairmen:

Neil P. Smith
Commonwealth Edison Company
Chicago, IL

Newton R. Anderson
U.S. Nuclear Regulatory Commission
Washington, D.C.

10:00-10:20 am

SQUG Cable Tray and Conduit Evaluation Procedure

Paul D. Smith, Steve J. Eder and Jean-Paul Conoscente
EQE Engineering, Incorporated
San Francisco, CA

10:20-10:40 am

Guidelines for Estimation of Cabinet Dynamic Amplification

K. L. Merz and Paul Ibanez
ANCO Engineers, Incorporated
Culver City, CA

10:40-11:00 am

Seismic Demand Evaluation Based on Actual Earthquake Records

Dilip P. Jhaveri and R. M. Czarnecki
URS Consultants/John A. Blume and Associates
San Francisco, CA

Robert P. Kassawara and Avtar Singh
Electric Power Research Institute
Palo Alto, CA

11:00-11:20 am

An Experience Based Procedure for Estimating Seismic Demand

Miguel A. Manrique, Alejandro Asfura and Gole Mukhim
Impell Corporation
Walnut Creek, CA

11:20-11:40 am

Use of Experience Data for Replacement and New Equipment

Harry W. Johnson
EQE Engineering, Incorporated
Melville, NY

Greg S. Hardy
EQE Engineering, Incorporated
Costa Mesa, CA

Paul D. Baughman
EQE Engineering, Incorporated
Stratham, NH

Nancy G. Horstman
EQE Engineering, Incorporated
San Francisco, CA

11:40-12:00

Testing to Determine Relay Seismic Ruggedness

K. L. Merz
ANCO Engineers, Incorporated
Culver City, CA

Jess Betlack
MPR Associates, Incorporated
Washington, D.C.

M. P. Wade
ANCO Engineers, Incorporated
Culver City, CA

12:00 pm—Luncheon
Luncheon Speaker—Byron Lee, *President, NUMARC*

SESSION VII: SIMPLIFIED SEISMIC ANALYSIS METHODS AND APPLICATIONS TO LOW SEISMICITY SITES–1

Chairmen:

John D. Stevenson
Stevenson and Associates
Cleveland, OH

Peter I. Yanev
EQE Engineering, Incorporated
San Francisco, CA

1:30-1:50 pm

Simplified Seismic Analysis Methods in the Federal Republic of Germany

Maximilian Hintergraeber
Siemens AG UB KWU
Erlangen, Federal Republic of Germany

Guenther Joachim Schauer
Technischer Uberwachungsverein
Stuttgart, Federal Republic of Germany

1:50-2:10 pm

Use of Simplified Seismic Analysis Methods in Belgium for Seismic Evaluation of Existing Plants

Luc H. Geraets
TRACTEBEL
Brussels, Belgium

2:10-2:30 pm

Simplified Seismic Analysis Methods in France

Jacques Betbeder-Matibet and Pierre B. Labbe
Electricite de France
Villeurbanne, France

2:30-2:50 pm

Methods and Requirements for Seismic Design in United Kingdom

Roy Kunar
BEQE Limited
St. Helens, United Kingdom

Charles Smith
National Nuclear Corporation
Knutsford, Cheshire, United Kingdom

2:50-3:10 pm

Simplified Seismic Analysis Methods in Japan

Makota Watabe
Tokyo Metropolitan University
Tokyo, Japan

3:10-3:25 pm—Break

SESSION VIII: SIMPLIFIED SEISMIC ANALYSIS METHODS AND APPLICATIONS TO LOW SEISMICITY SITES–2

Chairmen:

Peter I. Yanev
EQE Engineering, Incorporated
San Francisco, CA

John D. Stevenson
Stevenson and Associates
Cleveland, OH

3:25-3:40 pm

Simplified Seismic Analysis Methods Proposed by the International Atomic Energy Agency

C. Gordon Duff
Atomic Energy of Canada, Ltd.
Mississauga, Ontario

3:40-3:55 pm

Simplified Seismic Analysis Methods Used by AECL for the Seismic Qualification of CANDU Nuclear Power Plants

C. Gordon Duff
Atomic Energy of Canada, Ltd.
Mississauga, Ontario

3:55-4:15 pm

Load Coefficient Methods

John D. Stevenson
Stevenson and Associates
Cleveland, OH

Thursday, December 8, 1988 *(continued)*

4:15-4:35 pm

Consistent Natural Phenomena Design and Evaluation Guidelines for U.S. Department of Energy Facilities

Robert C. Murray
Lawrence Livermore National Laboratory
Livermore, CA

Stephen A. Short
Impell Corporation
Mission Viejo, CA

4:35-5:30 pm

Panel Discussion

Participants: All the speakers on the topic and Goutam Bagchi and Daniel J. Guzy
U.S. Nuclear Regulatory Commission
Washington, D.C.

Friday, December 9, 1988

SESSION IX: CONSTRUCTION AND OPERATION ISSUES

Chairmen:

Warren Bilanin
Electric Power Research Institute
Palo Alto, CA

S. B. Hager
Duke Power Company
Charlotte, NC

8:00-8:25 am

Visual Welding Inspection and Related Code Issues

Randall L. Kurtz
Sargent and Lundy
Chicago, IL

8:25-8:50 am

Configuration Management and Load Monitoring Procedures for Nuclear Plant Structures

Shih-Lung Chu and Anthony T. Skaczylo
Sargent and Lundy
Chicago, IL

8:50-9:15 am

Computer Aided Maintenance of Operating Nuclear Stations

Harry E. Vanpelt and Kenneth L. Ashe
Duke Power Company
Charlotte, NC

9:15-9:40 am

Design Basis Reconstitution and Configuration Management of Nuclear Power Plants Structures, Equipment and Piping for Seismic Application

Raul R. Smith
Paul R. Smith, P.E. and Associates
Boston, MA

Wayne J. Merritt
Engineering Planning and Management Incorporated
Framingham, MA

9:40-10:05 am

The Utilization of Commercial Grade Items in Nuclear Safety-Related Applications

Warren J. Bilanin
Electric Power Research Institute
Palo Alto, CA

Tom J. Mulford
Nuclear Construction Issues Group
Palo Alto, CA

10:05 am—Break

SESSION X: PIPING ISSUES–1

Chairmen:

Asadour H. Hadjian
Bechtel Western Power Corporation
Los Angeles, CA

Gerald C. Slagis
Walnut Creek, CA

10:20-10:45 am

Improved Load Definitions for Incremental Hinge Based Nonlinear Piping Analysis Methods

Ken Jaquay
Rockwell International
Canoga Park, CA

H. T. Tang
Electric Power Research Institute
Palo Alto, CA

10:45-11:10 am

Dynamic Testing of A Large Scale Piping System with Alternate Pipe Supports

Avtar Singh
Electric Power Research Institute
Palo Alto, CA

11:10-11:35 am

PVRC Damping and Application Benefits

Jerry L. Bitner
JLB Engineering, Incorporated
Bethel Park, PA

11:35-12:00 am

Piping System Damping Evaluation

Asadour H. Hadjian
Bechtel Western Power Corporation
Los Angeles, CA

H. T. Tang
Electric Power Research Institute
Palo Alto, CA

12:00 pm—Luncheon

SESSION XI: PIPING ISSUES–2

Chairmen:

Gerald C. Slagis
Walnut Creek, CA

Asadour H. Hadjian
Bechtel Western Power Corporation
Los Angeles, CA

1:30-1:55 pm

Systems Interaction and II/I Issues

Steven P. Harris
EQE Engineering, Incorporated
San Francisco, CA

Robert D. Campbell
EQE Engineering, Incorporated
Costa Mesa, CA

1:55-2:20 pm

Piping Dynamic Reliability and Code Rule Change Recommendations

Sam W. Taggart, Jr. and Y. K. Tang
Electric Power Research Institute
Palo Alto, CA

Daniel J. Guzy
U.S. Nuclear Regulatory Commission
Washington, D.C.

Sam Ranganath
General Electric
San Jose, CA

2:20-2:45 pm

Seismic Evaluation of Piping Using Experience Data

Paul D. Baughman
EQE Engineering, Incorporated
Stratham, NH

Mani L. Aggarwal
Ontario Hydra
Toronto, Ontario, Canada

Robert D. Campbell
EQE Engineering, Incorporated
Costa Mesa, CA

Steven P. Harris
EQE Engineering, Incorporated
San Francisco, CA

2:45 pm—Break

SESSION XII: INTEGRATION OF SEISMIC ISSUES

Chairmen:

Goutam Bagchi
U.S. Nuclear Regulatory Commission
Washington, D.C.

Ruble A. Thomas
Southern Company Services
Birmingham, AL

3:00-3:30 pm

Industry Perspective on Resolution of Seismic Issues

Roger Huston
Nuclear Management and Resources Council
Washington, D.C.

J. Carl Stepp
Electric Power Research Institute
Palo Alto, CA

James S. Whitcraft
Nuclear Management and Resources Council
Washington, D.C.

3:30-4:00 pm

Regulatory Perspective of Seismic Issues

Lawrence C. Shao and Robert L. Rothman
U.S. Nuclear Regulatory Commission
Washington, D.C.

4:00-4:30 pm

A Criterion for Determining Exceedance of the Operating Basis Earthquake

John W. Reed
Jack R. Benjamin and Associates
Mountain View, CA

Robert P. Kassawara
Electric Power Research Institute
Palo Alto, CA

4:30-5:00 pm

Lotung Large-Scale Seismic Experiment and Soil-Structure Interaction Method Validation

H. T. Tang, Y. K. Tang and J. Carl Stepp
Electric Power Research Institute
Palo Alto, CA

5:00-5:30 pm

Proposed Modifications of NRC's Standard Review Plan for Seismic Analysis

Goutam Bagchi, David Jeng and Hans Ashar
U.S. Nuclear Regulatory Commission
Washington, D.C.

ABOUT THE KEYNOTE SPEAKERS

Luncheon, Wednesday, December 7, 1988

Thomas Morgan Roberts is a member of the Nuclear Regulatory Commission. Before assuming his position with the NRC for a second term on July 12, 1985, Commissioner Roberts was Chief Executive Officer and President of Southern Boiler and Tank Works, Inc., of Memphis, Tennessee. Sixteen years with the company provided daily experience in nuclear-component production as well as with codes, standards, and regulations. Mr. Roberts has also been an underwriting member of Lloyd's of London and a director of Boyle Investment Company.

After graduating from Georgia Institute of Technology with a B.S. in Industrial Engineering in 1959, Mr. Roberts was commissioned an ensign in the United States Navy, where he served as engineering officer for three years aboard a destroyer.

Mr. Roberts has served as a member of the Employee Benefits Committee of the National Association of Manufacturers, and was formerly President of the Memphis Symphony and Vice President of the Washington Opera.

THOMAS M. ROBERTS

Luncheon, Thursday, December 8, 1988

Byron Lee, Jr. is President and Chief Executive Officer of the Nuclear Management and Resources Council (NUMARC) in Washington, D.C. NUMARC is a new nuclear industry organization whose basic objectives are to draw upon the nuclear power industry's operational and technical knowledge to further enhance excellence and to provide one industry position and line of communication to the Nuclear Regulatory Commission on issues of generic safety and regulatory policy issues.

Before assuming his position with NUMARC in June 1987, Mr. Lee was with Commonwealth Edison for 34 years, where he became Vice President in 1973, Executive Vice President in 1980, and Director of the Board in 1985. Mr. Lee was awarded the James N. Landis Medal from the American Society of Mechanical Engineers in 1983.

A graduate of Purdue University, Mr. Lee received his M.A. degree in Business Administration from the University of Chicago. He was honored by Purdue as a "Distinguished Engineering Alumnus" in 1970.

BYRON LEE

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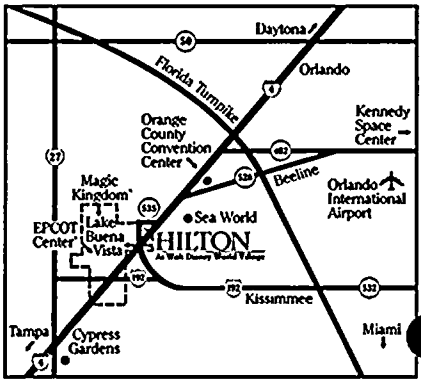

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PROBABILISTIC SEISMIC HAZARD RESULTS FOR SITES IN A REGION OF LOW SEISMICITY

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ABSTRACT

The methodology for seismic hazard evaluation developed by the Electric Power Research Institute (EPRI) was applied to two nuclear power plant sites, St. Lucie and Turkey Point, located in the Florida Peninsula, a region of low-seismicity. The seismic source zones and the seismicity parameters established by each of six technical evaluation contractors (TEC) for the Eastern U.S., and the seismic source zones and seismicity parameters determined by Ebasco Services Incorporated for the Northern Caribbean were used in the computations. The seismic hazard values thus calculated for each of these models were then aggregated in accordance with the EPRI recommended procedure to generate the final hazard curves.

The results of these evaluations indicate that the hazard is very low for the two sites. The 50th percentile annual probability of exceeding 0.10g is 1.27E-5 for St. Lucie and 1.05E-5 for the Turkey Point site. These values are significantly lower than 2.5E-4 used as input in the "Shutdown Decay Heat Removal Analysis" computations for the two plants (1, 2). Also, median hazards computed for the St. Lucie and Turkey Point sites fall well below the hazard computed at the SSE for various nuclear power plant sites in the eastern United States: 1.0E-3 to 4.0E-5, EPRI; and 2.0E-3 to 7.0E-5, LLNL (3).

The Seismic Safety Margins Research Program (SSMRP) was established to develop models that predict the probability of core damage and radioactivity release in nuclear power plants from seismic initiating events. The results of seismic analyses for several plants in the eastern United States indicate that the dominant contribution to core damage is likely to occur from earthquakes causing peak ground acceleration at the site in the range of 0.2 to 0.4g, and generally greater than 0.3g. The 50th percentile annual probability of exceeding 0.3g at St. Lucie is 1.32E-6 and at Turkey Point is 7.70E-7. The mean core damage frequencies at the two plant sites, computed by using these probabilities, are well below 1.0E-5 per reactor year, an estimate consistent with the U.S. Nuclear Regulatory Commission safety objective.

INTRODUCTION

Deterministic methods of seismic risk evaluation are suitable in tectonically active areas, for example, where seismogenic structures can be identified and fault length-magnitude relations applied. In areas of low seismicity, the use of deterministic methods do not lead to satisfactory results and some understanding of the frequency of occurrence of earthquakes for various levels of magnitude is essential. Since the deterministic procedure ignores the frequency of occurrence of earthquakes, probabilistic methods complement the hazard estimates in an important manner. Probabilistic methods also provide an interesting and, usually robust, comparison about the relative level of seismic hazard among different sites.

As a result of the unresolved questions regarding the cause and source of seismicity in the region of the United States east of 105 W longitude (Eastern U.S.), the U.S. Nuclear Regulatory Commission (NRC) has been actively pursuing the use of probabilistic methods, as alternatives to the deterministic approach used in the past, for re-evaluation of the seismic design of nuclear facilities in the eastern United States. This re-evaluation takes into account the uncertainties in source geometry, seismicity parameters and ground motion for the large earthquakes that occur in the Eastern U.S. As part of the NRC-funded investigations, the Lawrence Livermore National Laboratory (LLNL) (4) conducted probabilistic seismic hazard evaluations for ten "sample sites". A parallel probabilistic seismic hazard study, based on an intensive data collection and evaluation effort, was implemented by the Electric Power Research Institute (EPRI) (5, 6, 7, 8, 9, 10, 11, 12, 13, 14) with the assistance of six Technical Evaluation Contractors (TEC). Both the NRC funded LLNL studies, and the EPRI investigations, funded by a group of nuclear power plant owners in the Eastern U.S., utilize comprehensive seismic and tectonic data bases and recent advances in the probabilistic methodologies for the evaluation of seismic hazard for sites located in the Eastern U.S.

In this study we apply the methodology developed by the EPRI to estimate seismic hazard at two nuclear power plant sites located in the Florida Peninsula, a region of low seismicity.

METHODOLOGY

The general theory of probabilistic seismic hazard analysis was developed by Cornell (15, 16, 17) and Cornell and Merz (18). A FORTRAN Computer program for seismic risk analysis based on this theory was published by McGuire (19) as the USGS Open-File Report 76-67.

The details of the EPRI methodology are presented by McGuire and Stepp in these proceedings. Briefly, the software package, EQHAZARD, developed by the EPRI (6, 7) differs from McGuire (19) in that it allows for the incorporation of multiple hypotheses and associated probabilities for the ground motion model, maximum magnitude for each source zone, and seismicity parameters for each source zone. With multiple hypotheses, the number of possible source combinations becomes very large. The software package is so designed as to minimize computation time, form various possible combinations, and extract constant percentile hazard curves at specified percentile levels. The procedure allows for expressions of uncertainty in input to hazard computations, and analysis of sensitivity of various source and attenuation parameters to the hazard. The procedure also allows for the spatial variation of the rate of seismicity within a source zone.

The input parameters (source geometries, maximum magnitudes, seismicity parameters, and associated probabilities) for seismic hazard computation were developed independently by six technical evaluation contractors (TEC) (5, 6, 7, 8, 9, 10). These parameters along with

appropriate ground motion models (attenuation relations) form the basis for the seismic hazard computation using the EPRI methodology.

INPUT DATA

The methodology developed by the EPRI for the computation of seismic hazard was applied to two nuclear power plant sites located in the Florida Peninsula (Figure 1).

The three different attenuation relations discussed in the EPRI Applications Manual (8, Section 6) were used, with equal weights, in the hazard calculations. These are: i) semi-theoretical model of Nuttli (20), which utilizes a theoretical scaling model and low magnitude earthquake recordings from the Central United States, ii) an empirical method that uses ground motion data from the central and eastern United States, and data from California (21), and iii) a random vibration method which utilizes source scaling model, a random-process representation of acceleration, and a simplified representation of propagation effects (21).

For the computation of hazard at the two sites, the source containing the sites, the source or source combinations adjacent to the one containing the sites, Charleston area sources, and New Madrid sources were considered appropriate. Also it was noted that some of the Caribbean sources of high seismicity were closer to the sites than the Charleston or New Madrid sources. This was especially true for the Turkey Point site. Consequently, we investigated the tectonics of the Northern Caribbean region in order to delineate seismic source zones and develop associated seismicity parameters for that region (22). These data were then used to evaluate the hazard at the sites from earthquakes in the Northern Caribbean.

The maximum magnitude distribution and seismicity parameter distribution (referred to as smoothing options in the EPRI reports) for each source zone for each of the six Technical Evaluation Contractors were taken from the report prepared by that contractor. For each source zone a focal depth of 10 km for the occurrence of earthquakes was assumed. The lower bound magnitude of integration was taken to be 5. It was thus assumed that earthquakes of magnitude smaller than 5 will not have any damaging effect on the plant structure or components.

HAZARD COMPUTATION

Using the EPRI software package, seismic hazards were computed for the St. Lucie and Turkey Point sites using the seismic source zones and seismicity parameters established by each of the six EPRI Technical Evaluation Contractors (TEC), and the seismic source zones and seismicity parameters identified by Ebasco Services Incorporated for the Northern Caribbean. The location and extent of the seismic source zones that were evaluated in this study are shown on Figures 2 through 8. The source zones that contributed more than 1.0E-10 to the seismic hazard at each of the two plant sites have also been listed on these figures. The TEC source zone names, labels, and the EPRI Data Base Manager code numbers are given in Table 1. Two of the Northern Caribbean sources, Cayman Trough and Jamaica-Western Hispaniola, contributed to the seismic hazard at Turkey Point, but none contributed to the hazard at St. Lucie. Also contributions of New Madrid area sources to the seismic hazard at both plant sites for each of the six TECs were negligible. The scenarios and weights for the source zones that contributed to seismic hazard are given in Table 2. The seismic hazard values that were calculated from each TEC model were then aggregated in accordance with the EPRI recommended procedure to generate the final hazard curves.

RESULTS

Seismic hazard results for the St. Lucie and Turkey Point sites, computed in terms of annual probability of exceedance for different values of peak ground acceleration, are shown on Figures 9 and 10, respectively. The results are presented as constant percentile hazard curves. The 15th, 50th, and 85th percentile curves represent the equally weighted aggregated results of all six TECs. The 50th percentile hazard curve of each TEC prior to aggregation is also shown on Figures 9 and 10.

It is observed that the hazard curves of St. Lucie for Bechtel, Rondout Associates and Weston Geophysical are very close to each other, and to the aggregated 50th percentile hazard curve for all TECs. The hazard curve for Dames and Moore is also close, although it shows a somewhat smaller annual probability of exceedance. At the two extremes are the hazard curves derived from the input data for Law Engineering (lowest hazard) and Woodward Clyde Consultants (highest hazard).

The hazard curves of Turkey Point for Bechtel, Rondout Associates, Weston Geophysical and Woodward Clyde Consultants teams are very close to each other, and to the aggregated 50th percentile hazard curve for all TECs. The hazard curve for Dames and Moore team is also close, although it shows a somewhat smaller hazard. The hazard curve derived from the input data for Law Engineering team yields the lowest hazard result.

As shown on Figure 9, the peak ground acceleration (PGA) seismic hazard calculated for the St. Lucie site is very low. The annual probability of exceeding 0.10g is 1.27E-5. The seismic hazard calculated for the Turkey Point site, Figure 10, is even lower. The annual probability of exceeding 0.10g is 1.05E-5.

Finally, it should be noted that the application of the EPRI methodology to evaluate seismic hazard at the St. Lucie and Turkey Point sites provides a conservative estimate. Generalized assumptions that may be valid for most of the eastern United States were also applied by some of the Technical Evaluation Contractors to Florida Peninsula by default. For example, one of the TEC teams, Woodward Clyde Consultants, specified the use of the following maximum magnitudes (and associated probabilities) for background sources along the entire East Coast: 5.8 (0.33), 6.2 (0.34), and 6.6 (0.33). Although these values may be appropriate for other regions along the East Coast, they do constitute over-estimates of seismic conditions in Florida Peninsula. The sites are located in a region of very low seismicity. Figure 1 shows a map of maximum Modified Mercalli (MM) intensity experienced at sites in Florida from historical earthquakes, 1780-1980 (23). Lane (24) stated that of the earthquakes felt in Florida, only six could be considered to have had epicenters in Florida. It is possible that the shaking in some of these earlier events were caused by distant earthquakes outside Florida. Shaking and rumblings associated with some other natural (such as collapse of a sink hole) or man-made phenomena (such as explosion caused by mining or construction activity, or during military exercises) may be mistaken for earthquakes. The seismic origin of a shock felt in 1930 in Everglades, La Belle, and Ft. Myers, has been questioned and blasting is suspected. Similarly, generalized assumptions made by other TECs can also be questioned for conservative estimates of seismicity in Florida. This is especially important because most of the contribution to the St. Lucie and Turkey Point sites, in the case of each of the TEC source zones, is derived from the background source containing the sites.

Of the three ground motion models considered, the random vibration model yields lowest hazard results. This is illustrated on Figures 11 and 12, showing sensitivity of results to different attenuation relations by plotting 50th percentile hazard curves. The random

vibration model for ground motion prediction appears to be gaining greater acceptance in the scientific community. For example, Savy (25) noted that a large weight, in the LLNL study, is now assigned to the class of "random vibration" models (RV-models). If this model is considered more representative of conditions in eastern North America, then the hazard computed using all three attenuations (Nuttli, 1984; Empirical Model; and random vibration model) should be considered a conservative estimate.

DISCUSSIONS

The seismic events of interest in the evaluation of external hazards to nuclear power plants are those that are accompanied by ground motions of sufficiently large amplitudes and duration to initiate accident scenarios that would result in the release of radioactive material from a damaged reactor core. Therefore, it is important to develop evaluation criteria to discriminate between significant and inconsequential levels of seismic risk.

The guidance provided by the NRC in their Safety Goal Policy Statement requires a licensee to "provide reasonable assurance, giving consideration to the uncertainties involved, that a core-damage accident will not occur at a U.S. nuclear power plant". Based on an evaluation of the total population of nuclear power plants operating in the U.S. it was suggested that this objective can be met if individual plants have mean core damage frequencies in the range of about 1.0E-5 or less per reactor year (3). This numerical estimate was presented as a trial value which was used to estimate whether or not the risk from seismically initiated accidents is an important contributor to the overall risk at six nuclear power plant test sites.

The Seismic Safety Margins Research Program (SSMRP) studies indicate that the dominant earthquake generated peak ground acceleration range for seismic core damage is between 0.2-0.4g. The Probabilistic Risk Assessment (PRA) studies sponsored by the utilities, and performed between 1981 and 1985, show that the dominant acceleration level that lead to seismic core damage is generally greater than 0.3g. The studies of Decay Heat Removal Requirements at nuclear power plants (TAP A-45, 26) conclude that the dominant contribution to core damage is from accelerations in the range of 0.2-0.4g

The seismic risk assessment performed under Task Action Plan A-45, to evaluate the Decay Heat Removal Requirements of six nuclear power plants, adopted the value of 2.5E-4 as the annual probability of exceeding 0.10g at St. Lucie and 0.06g at Turkey Point nuclear power plant sites (1, 2). The slopes of the probabilistic seismic hazard curves at higher acceleration levels for the two plant sites were derived from hazard curves developed by LLNL for Vogtle, Georgia and River Bend, Louisiana sites. The curve coordinates for St. Lucie and Turkey Point were obtained by shifting the curves of Vogtle and River Bend sites vertically downward so that the values at 0.10g for St. Lucie and 0.06g for Turkey Point were fixed at 2.5E-4 per year. From these curves, the probability of having an earthquake at St. Lucie with a peak ground acceleration of 0.30g was estimated at 1.9E-5; while the probability of an earthquake at Turkey Point with a peak ground acceleration of 0.30g was estimated at 5.2E-6 (nominal) and 8.0E-6 (corrected for local site conditions). Based on these assumptions, the TAP A-45 studies concluded that the seismic core damage frequency (point estimate) per year was 1.3E-5 for St. Lucie and 1.0E-5 for Turkey Point, matching closely the target value of 1.0E-5 per reactor year suggested in the report NUREG/CR-5042 (3) for meeting the NRC safety objective.

However, the site specific annual probabilities of exceeding 0.10g at St. Lucie and Turkey Point are significantly lower than 2.5E-4. The probability of exceeding 0.10g is 1.27E-5 for St. Lucie and 1.05E-5 for Turkey Point, while the probability that the peak ground accelerations

will exceed 0.3g is 1.32E-6 for St. Lucie and 7.70E-7 (nominal) for Turkey Point. Using these values, that are an order of magnitude lower than those used in the TAP A-45 studies, to compute a mean seismic core damage frequency for the two plants will result in values that are well below the target value of 1.0E-5 suggested by NUREG/CR-5042 (3) as a lower bound estimate, below which seismic hazard should be of little concern.

CONCLUSION

Both the St. Lucie and Turkey Point sites are located in a region which is considered seismically benign (1, 2). In fact, both sites are located in the lowest U.S. seismic risk zone, one of no damage (27). In confirmation, the probabilistic seismic hazard results for the two plant sites are also very low. It would be appropriate that sites that have such low seismic hazard be classed Below Regulatory Concern (BRC).

ACKNOWLEDGMENTS

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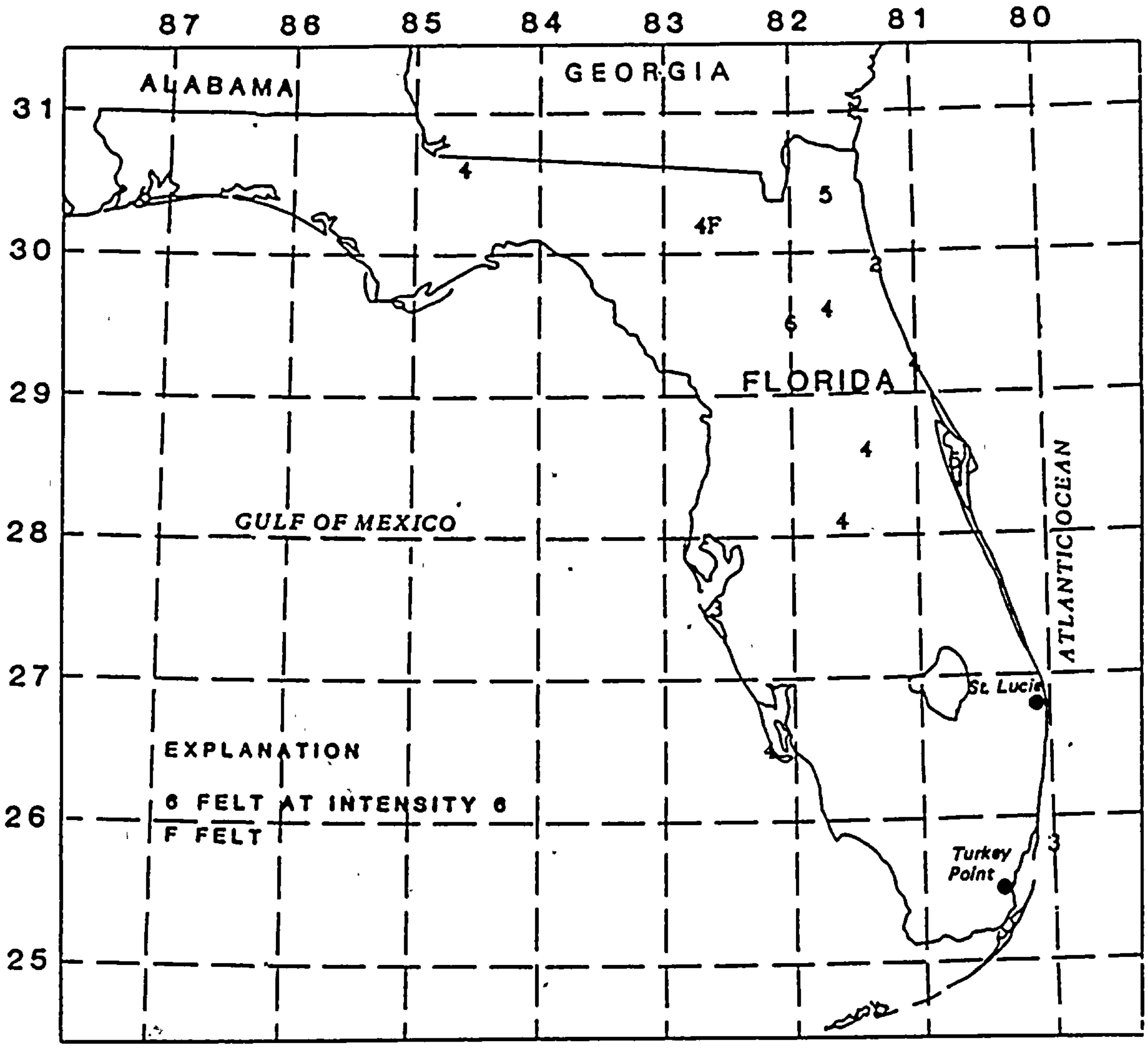
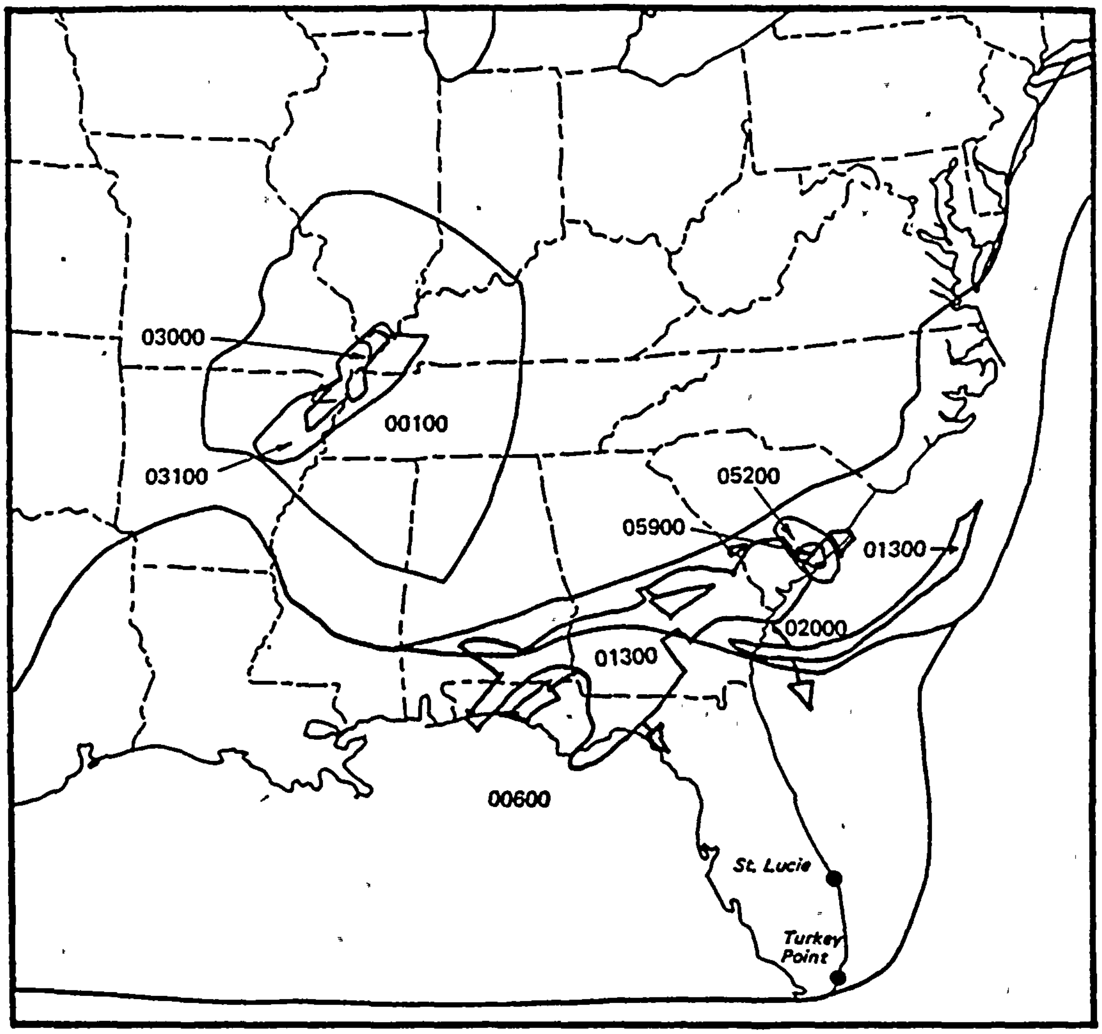
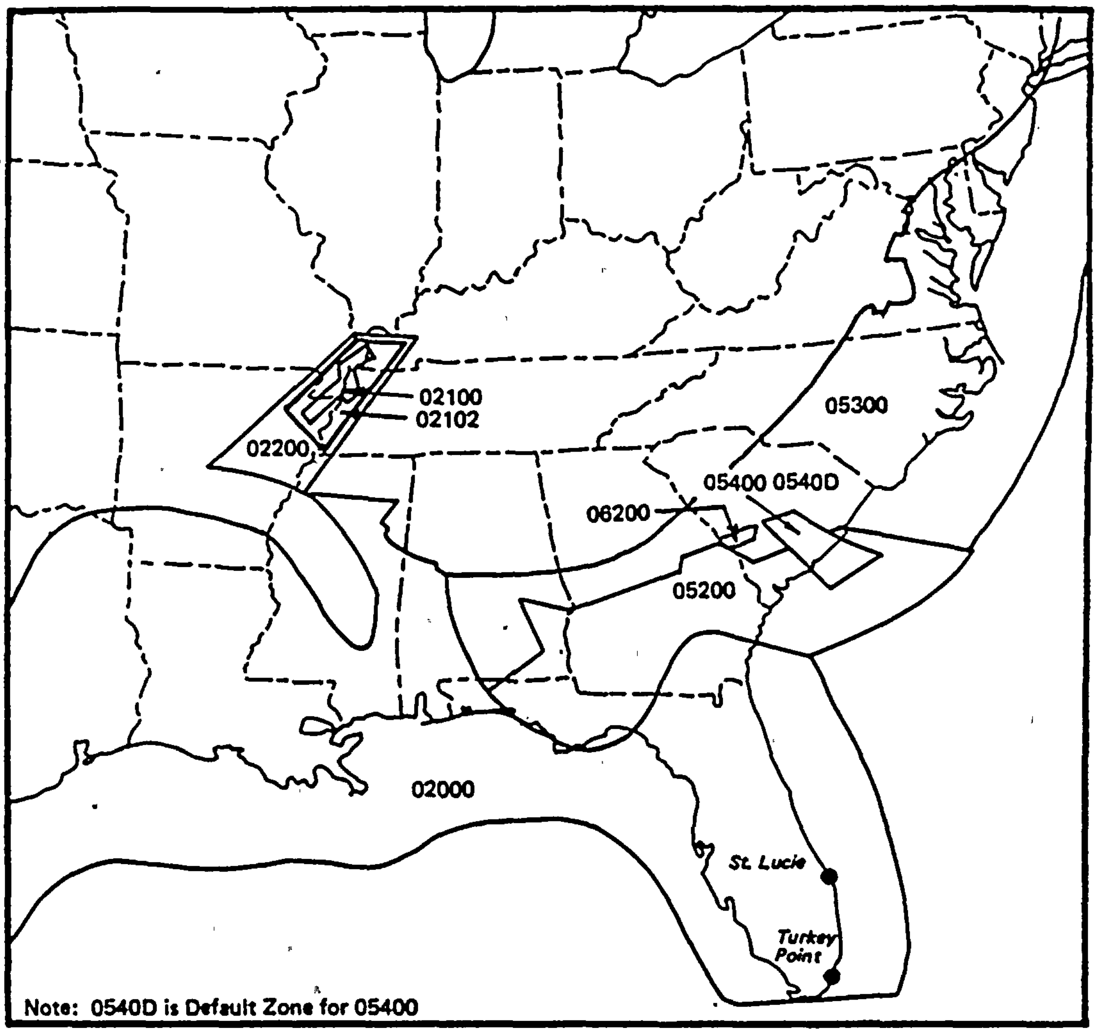


Figure 1.[illegible] Location of St. Lucie and Turkey Point nuclear power plant sites. The map also shows maximum Modified Mercalli (MM) intensity experienced at sites in Florida from historical earthquakes, 1780-1980. Intensities are given in arabic numerals. After, Reagor and Stover (23).



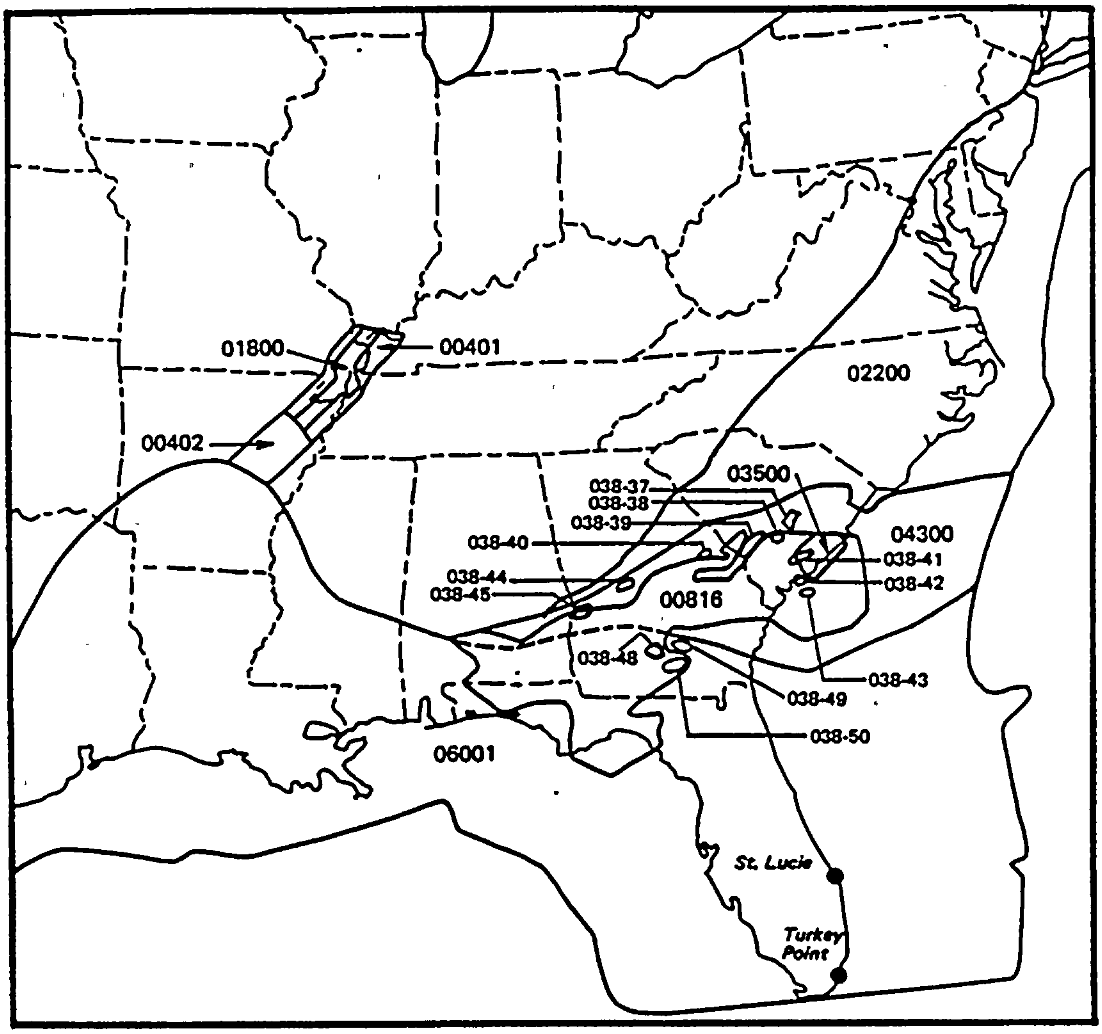
Source Zone Number	Name	Source Zone Contributing to Hazard: St. Lucie	Turkey Point
01300	Mesozoic Basins	01300	
03000	New Madrid		
03100	Reelfoot Rift		
05200	Charleston Area	05200	
05900	Charleston Faults		
00100	New Madrid Background		
00600	Site Background	00600	00600
02000	Adjacent Background	02000	02000

Figure 2. Seismic source zones derived from the tectonic interpretations by Bechtel Group, Inc., and used in the hazard computation for the St. Lucie and Turkey Point sites



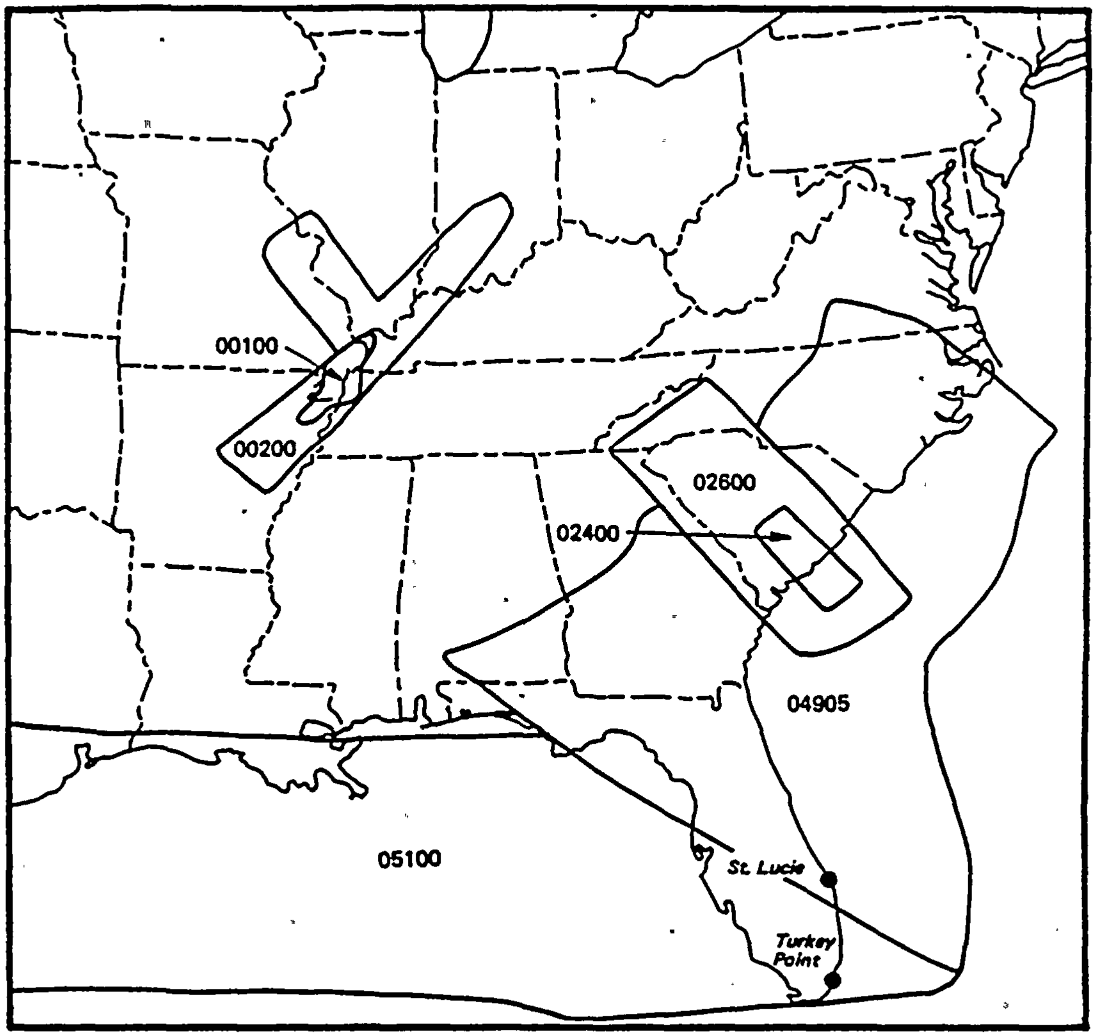
Source Zone		Source Zone Contributing to Hazard	
Number	Name	St. Lucie	Turkey Point
02000	Southern Coastal Margin	02000	02000
02100	New Madrid		
02200	Reelfoot Rift		
05200	Charleston Rift	05200	
05300	Southern Appalachian Default	05300	
05400	Charleston Seismic Zone	05400	
0540D	Charleston Default Zone	0540D	
06200	Dunbarton Triassic Basin		

Figure 3. Seismic source zones derived from the tectonic interpretations by Dames & Moore, and used in the hazard computation for the St. Lucie and Turkey Point sites



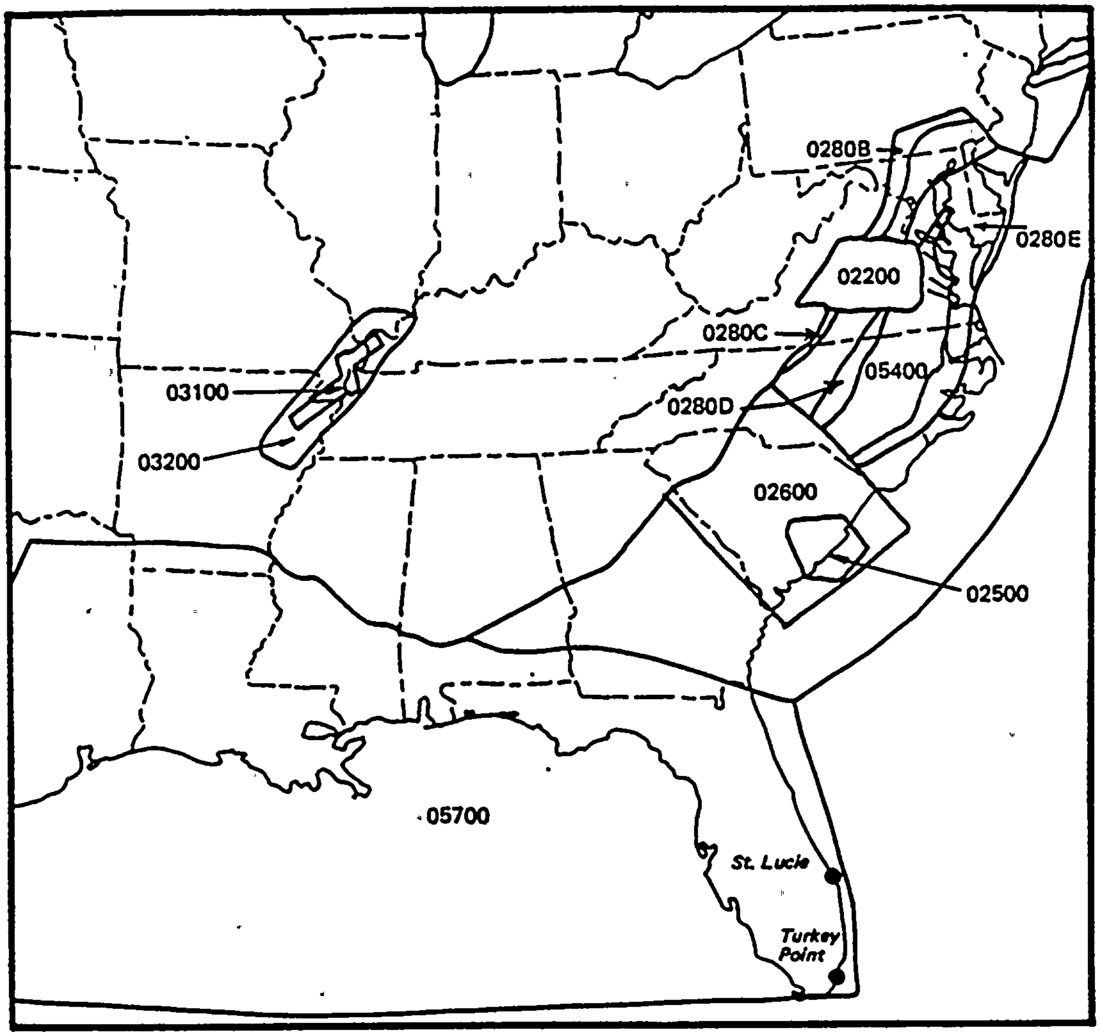
Source Zone Number	Name	Source Zone Contributing to Hazard: St. Lucie	Turkey Point
00401	Reelfoot Rift (A)		
00402	Reelfoot Rift (B)		
00816	Mesozoic Basins	00816	00816
01800	Reelfoot Rift Faults		
02200	Reactivated Eastern Seaboard	02200	02200
03500	Charleston		
04300	Brunswick	04300	04300
06001	Southern Coastal Block	06001	06001
03837 to 03845	Mafic Plutons		
03848 to 03850	Mafic Plutons		

Figure 4. Seismic source zones derived from the tectonic interpretations by Law Engineering Testing Company, and used in the hazard computation for the St. Lucie and Turkey Point sites



Source Zone		Source Zone Contributing to Hazard	
Number	Name	St. Lucie	Turkey Point
00100	New Madrid		
00200	New Madrid Rift		
02400	Charleston	02400	
02600	South Carolina	02600	
04905	Appalachian Basement Background	04905	04905
05100	Gulf Coast to Bahamas Background	05100	05100

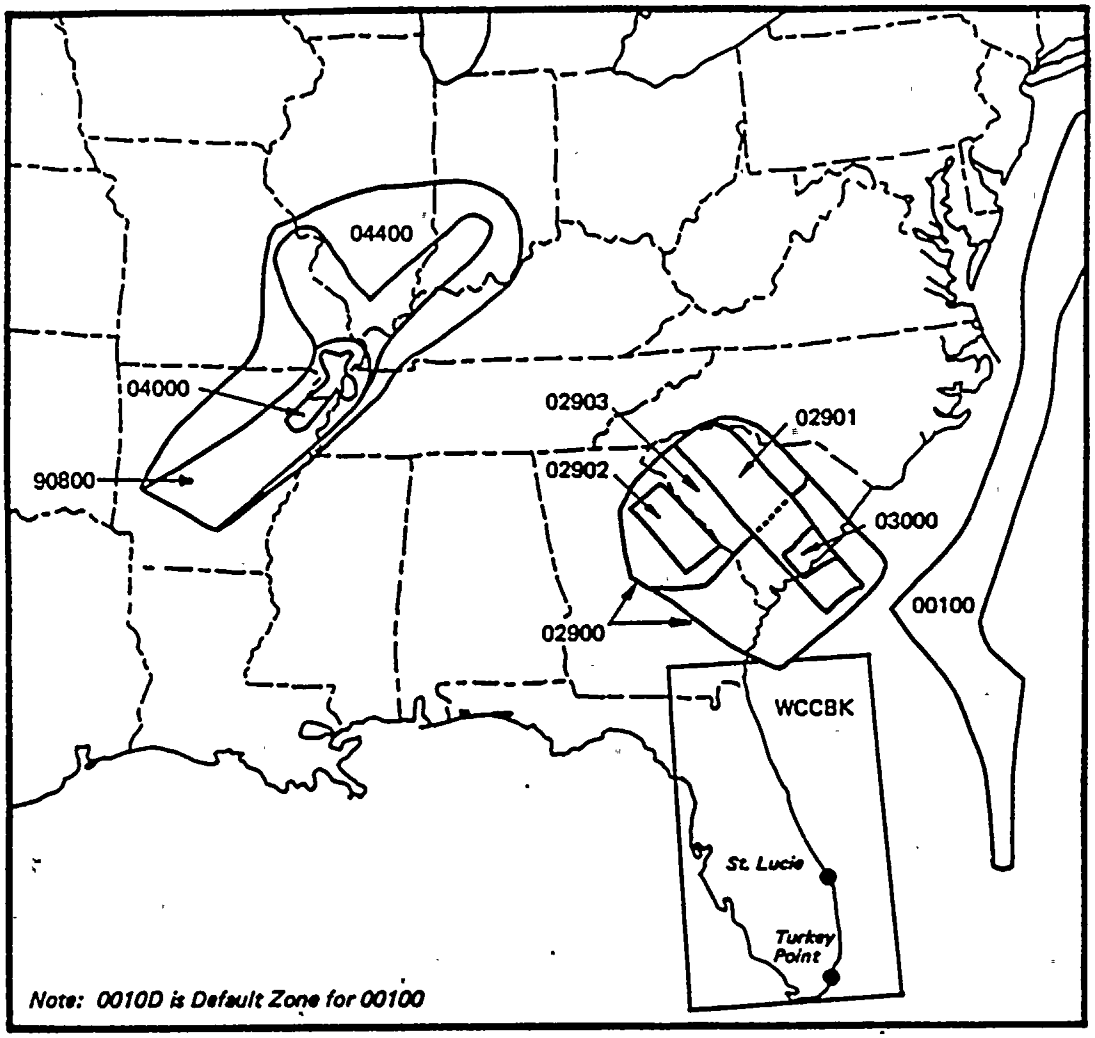
Figure 5. Seismic source zones derived from the tectonic interpretations by Rondout Associates, Incorporated, and used in the hazard computation for the St. Lucie and Turkey Point sites



Source Zone		Source Zone Contributing to Hazard	
Number	Name	St. Lucie	Turkey Point
02500	Charleston	02500	
02600	South Carolina	02600	
03100	New Madrid		
03200	Reelfoot Rift		
05400	Southern Coastal Plain	05400	
05700	Gulf Coast Background	05700	05700
91100*	Combination 11		
92000* to 92400*	Combinations 920 to 924	92000 to 92400	
92700*	Combination 927	92700	
92800*	Combination 928	92800	

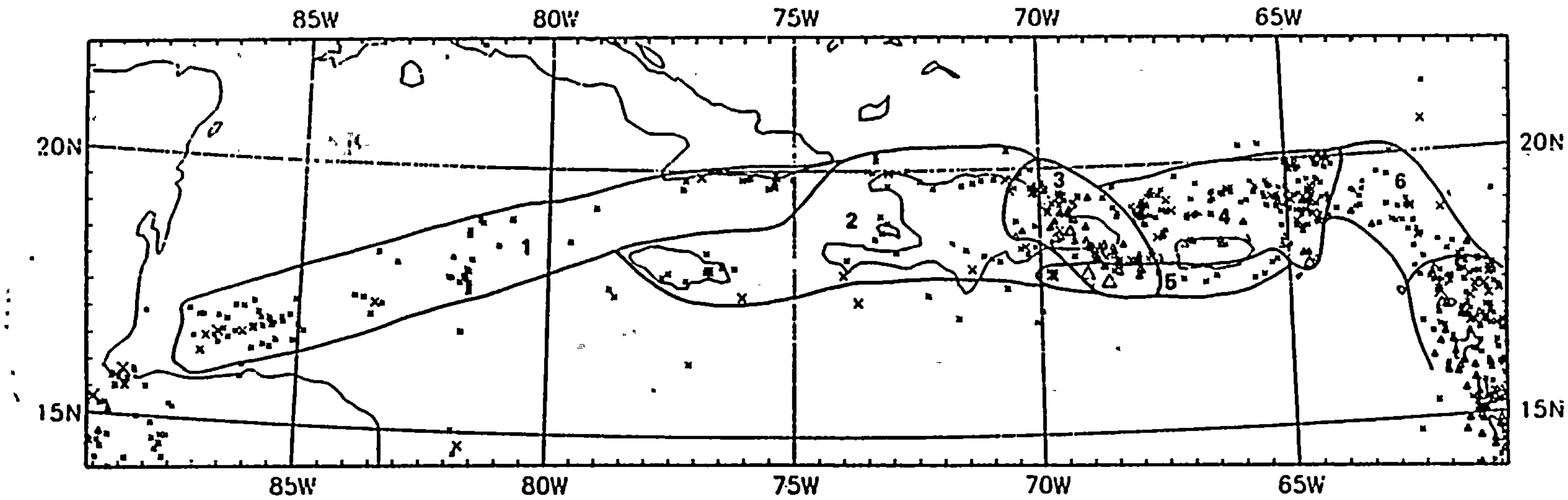
*Geometry of Combination Sources Given in Table 1.

Figure 6. Seismic source zones derived from the tectonic interpretations by Weston Geophysical Corporation, and used in the hazard computation for the St. Lucie and Turkey Point sites



Source Zone Number	Name	Source Zone Contributing to Hazard: St. Lucie	Turkey Point
00100	Continental Shelf Edge		
02900	South Carolina, Option 1	02900	
02901	South Carolina, Option 2	02901	
02902	South Carolina, Option 2	02902	
02903	South Carolina, Option 3	02903	
03000	Charleston NOTA		
04000	Central Reelfoot Rift		
90800	Reelfoot Rift		
04400	New Madrid Loading Zone		
WCCBK	Background	WCCBK	WCCBK

Figure 7. Seismic source zones derived from the tectonic interpretations by Woodward Clyde Consultants, and used in the hazard computation for the St. Lucie and Turkey Point sites



Source Zone		Source Zone Contributing to Hazard	
Number	Name	St. Lucie	Turkey Point
1 CB001	Cayman Trough		1.
2 CB002	Jamaica–Western Hispaniola	None	2
3 CB003	Eastern Hispaniola		
4 CB004	Puerto Rico Trench		
5 CB005	Muertos Trench		
6 CB006	Greater Antilles– Lesser Antilles Transition		

Figure 8. Seismic source zones in the northern Caribbean developed by Ebasco Services Incorporated from tectonic interpretations, and used in the hazard computation for the St. Lucie and Turkey Point sites

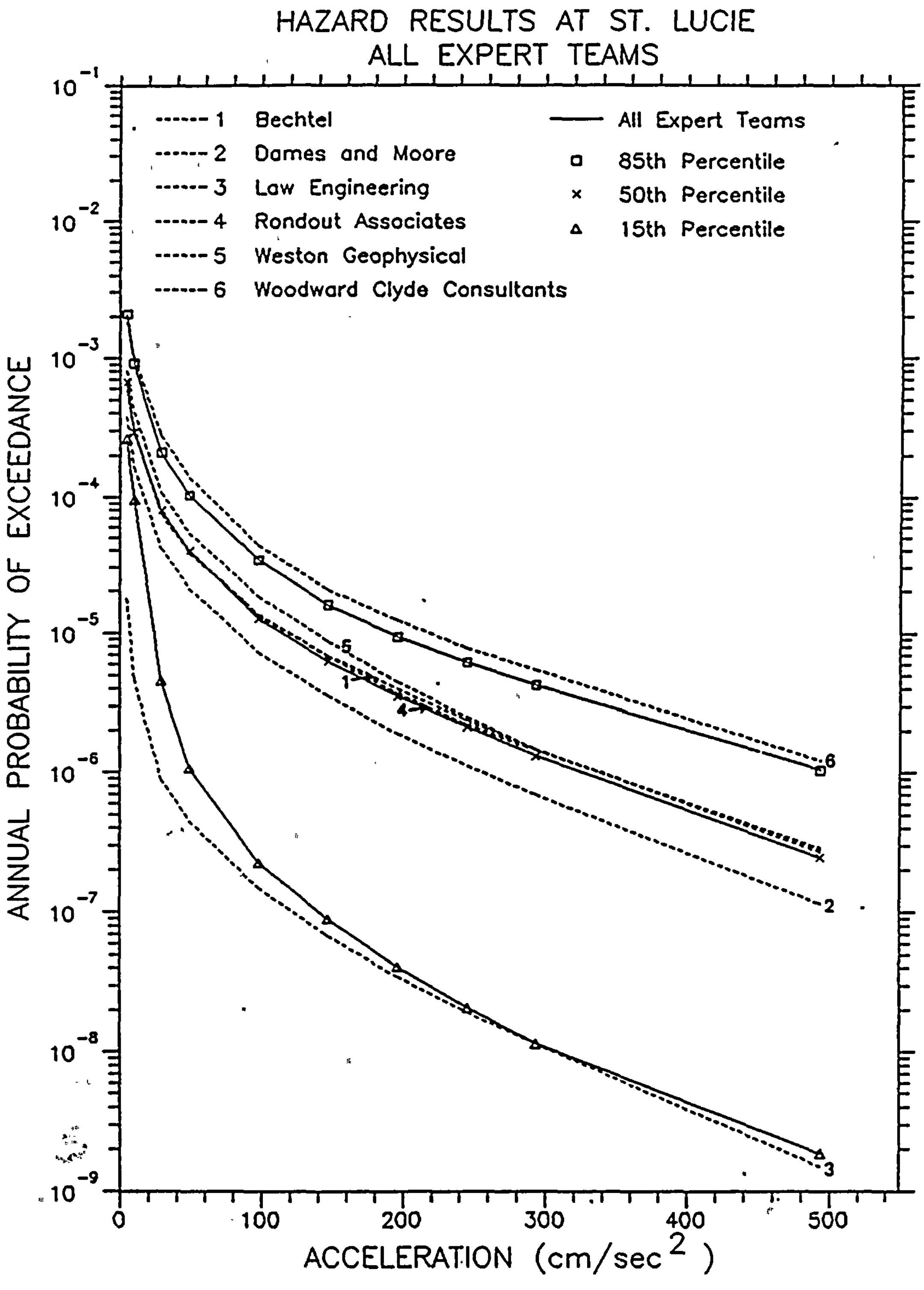


Figure 9. Hazard results at St. Lucie showing 50th percentile hazard curves (dashed lines) for each Technical Evaluation Contractor, and 15th, 50th and 85th percentile hazard curves (solid lines) when equally weighted hazard results for all Technical Evaluation Contractors were aggregated.

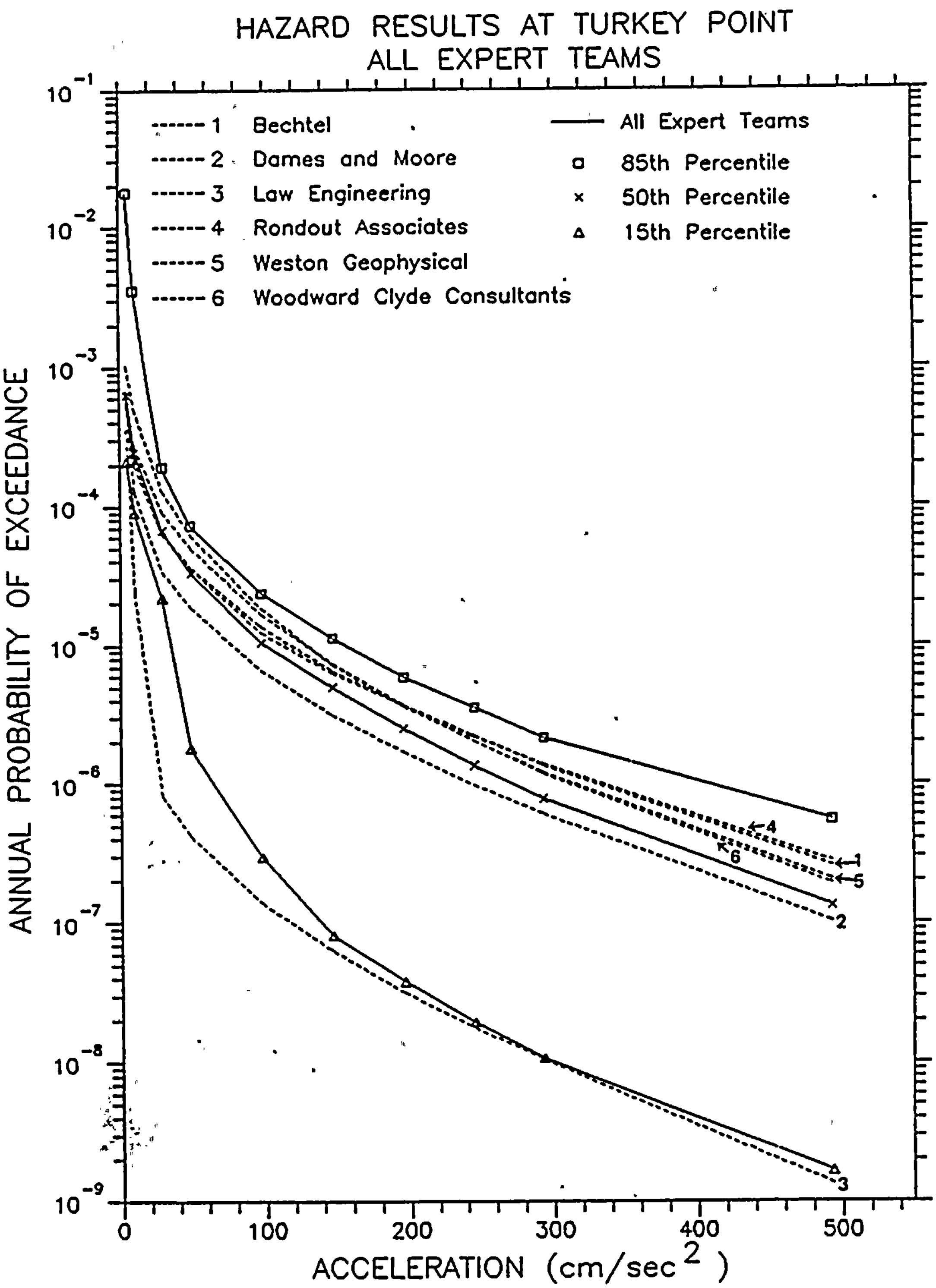


Figure 10. Hazard results at Turkey Point showing 50th percentile hazard curves (dashed lines) for each Technical Evaluation Contractor, and 15th, 50th and 85th percentile hazard curves (solid lines) when equally weighted hazard results for all Technical Evaluation Contractors were aggregated.

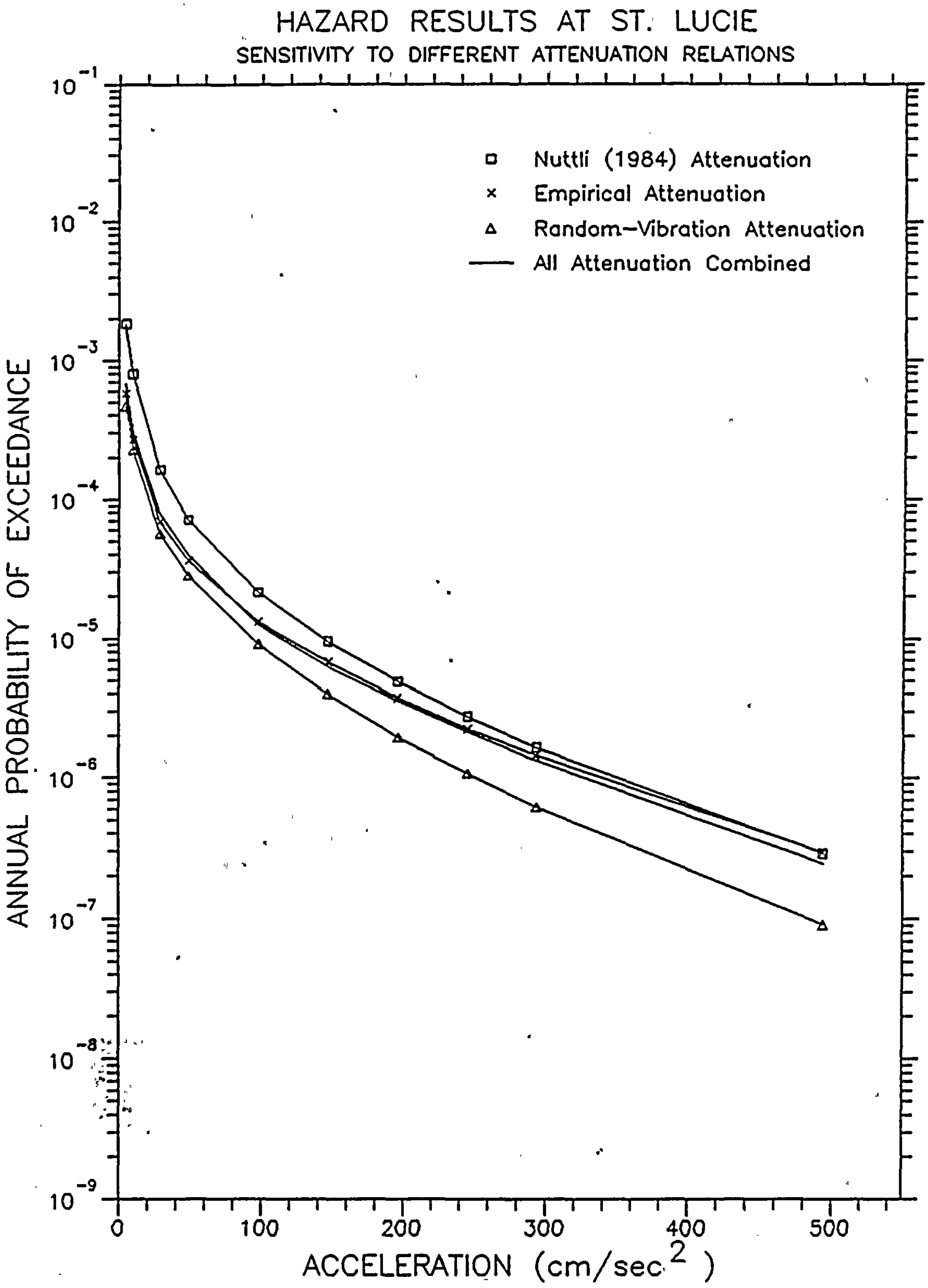


Figure 11. Sensitivity of hazard results (50th percentile) at St. Lucie for different attenuation relations

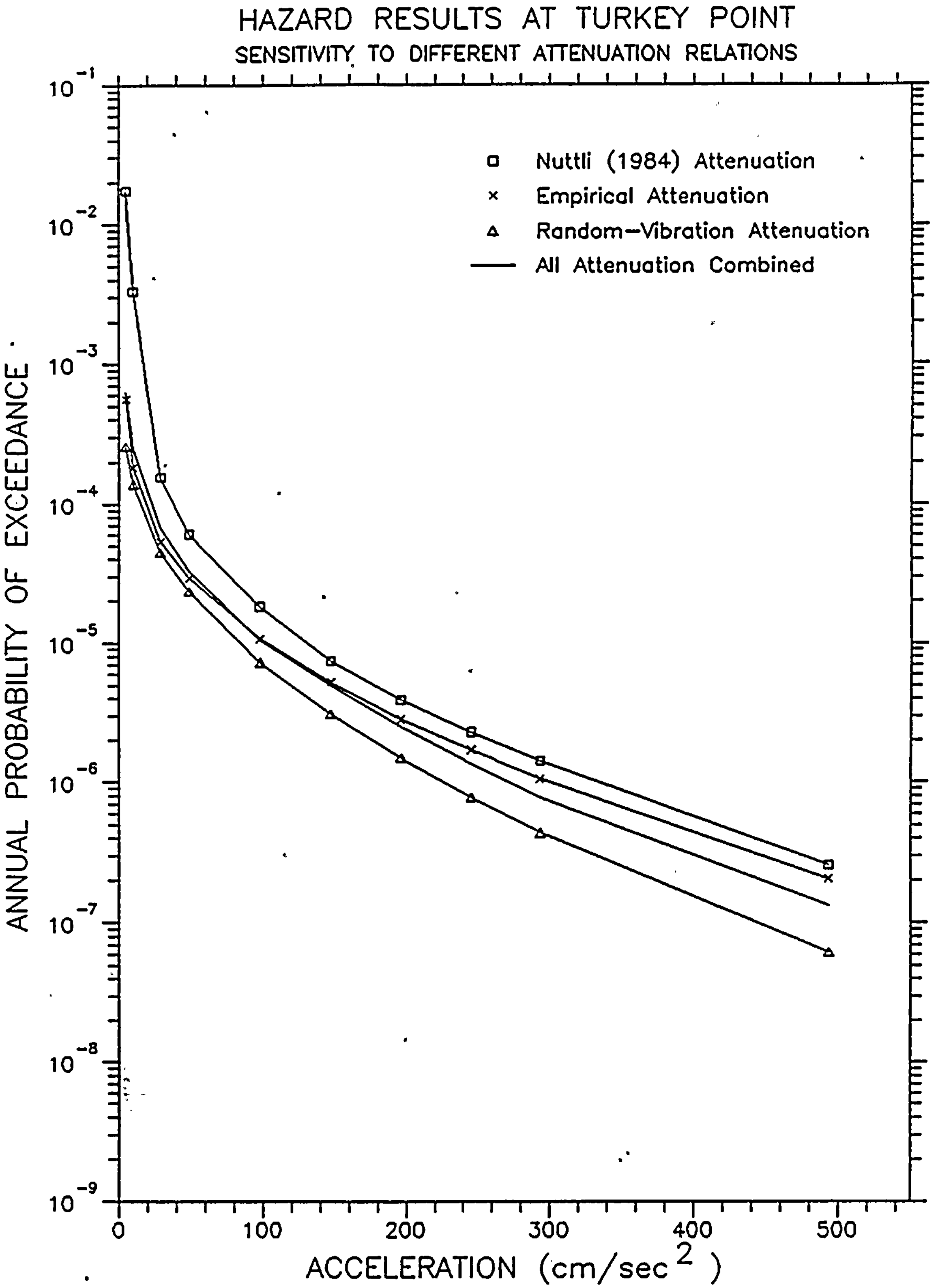


Figure 12. Sensitivity of hazard results (50th percentile) at Turkey Point for different attenuation relations

Table 1
Computerized Data Base Label No. of Source Zones

TEC Name	TEC Label No. (Used on TEC Maps)	Source Name	Data Base Label No. (Used on Computer Files)
Bechtel Group	13	Mesozoic Basins	01300
	30	New Madrid	03000
	31	Reelfoot Rift	03100
	H	Charleston Area	05200
	N-3	Charleston Faults	05900
	BZ-0	New Madrid Region	00100
	BZ-1	Gulf Coast Background	00600
	BZ-4	Atlantic Coast Background	02000
Dames & Moore	20	Southern Coastal Margin	02000
	21	New Madrid	02100
	22	Reelfoot Rift	02200
	22-21B	Reelfoot Rift-New Madrid	91500
	52	Charleston Rift	05200
	53	Southern Appalachian Default	05300
	54	Charleston Seismic Zone	05400
	65	Dunbarton Triassic Basin	06200
Law Engineering	04a	Reelfoot Rift(A)	00401
	04b	Reelfoot Rift(B)	00402
	08	Mesozoic Basins	00816
	18	Reelfoot Rift Faults	01800
	35	Charleston	03500
	108	Brunswick Background	04300
	126	Southern Coastal Block	06001
	M-37	Mafic Pluton	03837
	M-38	Mafic Pluton	03838
	M-39	Mafic Pluton	03839
	M-40	Mafic Pluton	03840
	M-41	Mafic Pluton	03841
	M-42	Mafic Pluton	03842
	M-43	Mafic Pluton	03843
	M-44	Mafic Pluton	03844
	M-45	Mafic Pluton	03845
	M-48	Mafic Pluton	03848
	M-49	Mafic Pluton	03849
	M-50	Mafic Pluton	03850

Table 1 - continued

Table 1 (Continued)
Computerized Data Base Label No. of Source Zones

TEC Name	TEC Label No. (Used on TEC Maps)	Source Name	Data Base Label No. (Used on Computer Files)
Rondout Associates	1	New Madrid	00100
	2	New Madrid Rift	00200
	24	Charleston	02400
	26	South Carolina	02600
	49-05	Appalachian Basement Background	04905
	51	Gulf Coast to Bahamas Background	05100
Weston Geophysical	25	Charleston	02500
	26	South Carolina	02600
	31	New Madrid	03100
	32	Reelfoot Rift	03200
	104	Southern Coastal Plain Background	05400
	107	Gulf Coast Background	05700
	Z032-Z031	Combination (C-11)	91100
	Z104-Z022	Combination (C-20)	92000
	Z104-Z025	Combination (C-21)	92100
	Z104-Z026	Combination (C-22)	92200
	Z104-Z022 -Z026	Combination (C-23)	92300
	Z104-Z022 -Z025	Combination (C-24)	92400
	Z104-Z028BCDE -Z022 -Z025	Combination (C-27)	92700
	Z104-Z028BCDE -Z022 -Z026	Combination (C-28)	92800
Woodward-Clyde	1	Continental Shelf Edge	00100
	29	South Carolina Option 1	02900
	$29A_1$	South Carolina Option 2	02901
	$29A_2$	South Carolina Option 2	02902
	29B	South Carolina Option 3	02903
	30	Charleston NOTA	03000
	40	Central Reelfoot Rift	04000
	41	Combination (C-8)	90800
	44	New Madrid Loading Zone	04400

TABLE 2
Scenarios for Contributing Source Zones[1]
St. Lucie

TEC Team	Scenario[2]	Weight[3]
Bechtel	00600 + 02000 + 01300 + 05200	0.05
	00600 + 02000 + 01300	0.05
	00600 + 02000 + 05200	0.45
	00600 + 02000	0.45
Background	00600	1.0
	02000	1.0
Dames and Moore	02000 + 05400	0.196
	02000 + 05400 + 05200	0.322
	02000 + 05400 + 05300	0.182
	02000 + 0540D	0.084
	02000 + 0540D + 05200	0.138
	02000 + 0540D + 05300	0.078
Background	02000	1.0
Law Engineering	04300 + 06001 + 02200	0.27
	04300 + 06001 + 00816	0.27
	04300 + 06001	0.46
Background	04300	0.42
	06001	0.49
Rondout Associates	02400 + 02600 + 04905 + 05100	1.0
Background	04905	1.0
	05100	1.0
Weston Geophysical Corporation	05700 + 92000	0.001
	05700 + 02500 + 92100	0.012
	05700 + 02600 + 92200	0.069
	05700 + 02600 + 92300	0.312
	05700 + 02500 + 92400	0.368
	05700 + 02500 + 92700	0.126
	05700 + 02600 + 92800	0.100
	05700 + 05400	0.012
Background	05700	1.0
Woodward Clyde Consultants	WCCBK	0.468
	WCCBK + 02903	0.105
	WCCBK + 02900	0.122
	WCCBK + 02901 + 02902	0.305
Background	WCCBK	1.0

TABLE 2 (continued)
Scenarios for Contributing Source Zones[1]
Turkey Point

TEC Team		Scenario[2]	Weight[3]
Bechtel		00600 + 02000 + CB001 + CB002	1.0
	Background	00600	1.0
		02000	1.0
Dames and Moore		02000 + CB001 + CB002	1.0
Law Engineering		04300 + 06001 + 02200 + CB001 + CB002	0.27
		04300 + 06001 + 00816 + CB001 + CB002	0.27
		04300 + 06001 + CB001 + CB002	0.46
	Background	04300	0.42
		06001	0.49
Rondout Associates		04905 + 05100 + CB001 + CB002	1.0
	Background	04905	1.0
		05100	1.0
Weston Geophysical Corporation		05700 + CB001 + CB002	1.0
	Background	05700	1.0
Woodward Clyde Consultants		WCCBK + CB001 + CB002	1.0
	Background	WCCBK	1.0

Notes: 1 Source Zone numbers correspond to those on Table 4-1 and on Figures 2 through 7.

2 Each TEC scenario is made up of the allowable source zone combinations whose total weights, or probability of activity add up to 1.0.

3 Weight is defined as the fractional probability of activity.

HISTORY OF SEISMOLOGICAL ACTIVITY IN FLORIDA: EVIDENCE OF A UNIQUELY STABLE BASEMENT

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ABSTRACT

The historical paucity of well-documented seismic events in Florida during the past three centuries has been attributed, in part, to the lack of local or regional recording equipment and to the sparse abundance and uneven distribution of the early population. Approximately a dozen low intensity events can be described for Florida since 1727, A.D. However, an approximate epicenter assignment can accompany only the three events reported in the last 35 years. The most recently felt tremor in Florida (December, 1975, Daytona) was assigned an estimated magnitude of 2.9 mbLg; no magnitudes are known for earlier events. Observations since 1978 at GAI in Gainesville, a single, vertical component, short-period station, have yielded no evidence of events within the state.

The general aseismicity of Florida is consistent with recently-developed concepts of the nature of the Florida basement. Based on drill-core analyses and geophysical investigations, the Florida basement is characterized by a Cambrian granitic batholithic complex and an undistorted overlying cover of early Paleozoic sedimentary rocks in the north and an early Mesozoic volcanic rock province in the south. Reconstructions of tectonic history place Florida and other parts of the Gulf Coast margin within a leading edge of a seismically active Paleozoic Africa-South America landmass which converged with North America to form Pangea. Rifting of this supercontinent began during the Triassic Period (approximately 200 million years ago), eventually producing the present continental configuration.

The Florida peninsula, constrained by rifting geometries, remained appended to North America and, today, represents the undynamic, tectonically stable, outboard trailing edge of a divergent plate margin. Accordingly, the Florida basement is geologically and tectonically distinct from the Appalachian and other crustal trends of the southeastern United States. Supracrustal rocks (Cenozoic sedimentary rocks covering the basement) further substantiate the lack of tectonic activity of the Florida peninsula. These carbonate/sand units are essentially undeformed structurally, indicating stable tectonic conditions for at least the past 65 million years.

Portrayals of seismicity source conditions for the eastern United States are not necessarily applicable for Florida. The distinctly different basement rocks and tectonic history of Florida provide a compelling explanation for aseismicity in this geographic region today.

INTRODUCTION

In his popular introductory text on seismology, Richter (1958) wrote: "Earthquakes are exciting and sometimes spectacular events, offering opportunity for mistakes and exaggeration. ...the serious student needs knowledge both of earthquakes and of the psychology of error." The study of seismology of the Florida peninsular epitomizes the applicability of Richter's statements. Distinguished by a paucity of indisputable seismic events and by an initially sparse and unevenly distributed population, peninsular Florida has yet to experience any events sufficiently well-documented to permit a characterization of the state beyond "aseismic."

Although limited, a list of earthquakes can be assembled for Florida. This report seeks not only to present a history of reported seismological activity in Florida, but also to depict the basement geology and tectonic history to be as distinct as the seismicity with respect to adjacent terranes. The tectonic stability of the Florida Plateau, as evidenced by its seismic history, contributed to the concept of its separate geologic origin, chronologically and spatially removed from North America and physically rooted in an older, uniquely quiescent lithospheric fragment.

EARTHQUAKES IN FLORIDA

The earliest attempt to compile a record of earthquakes in Florida (Campbell, 1943), was based largely on reviews of weather bureau records, private files, and early newspaper accounts. Fifteen dates, beginning in 1727, are cited for tremors, and Rossi-Forel intensities were assigned to approximately half of the events. Most of the reports, however, are characterized by vague locations, conflicting times, and apparent confusion with events outside the state. For example, reports of shocks on 31 Aug 1886 in north Florida are surely attributable to the well-known event in Charleston, S.C., on that date, and a disturbance felt in Key West on 22 Jan 1880 would have been the disastrous

Table 1. Listing of reported earthquakes in Florida. Data from Campbell (19843), Mott (1983) and Reagor et al. (1987). All locations (except 27 Oct 1973 event) are estimates. Intensity values are from the modified Mercalli scale; "F" indicates insufficient information to assign value.

Date	Time (UTC)	N. Lat.	W. Long.	Intensity	Comments
1727 Oct 12	-	-	-	-	"Severe" tremors felts in St. Augustine. Reported as 29 Oct by Campbell (1945)
1780 Feb 6	-	30.4	87.2	VI	Mott (1983) reports this event for 8 May 1781, and a mild tremor for this date. Description suggestive of hurricane.
1879 Jan 13	0445	29.5	82.0	VI	Two shocks of 30 sec duration. Felt throughout north Florida and south Georgia.
" " "	0445	29.5	82.0	F	
1886 Jan 8	1834	30.4	81.7	F	
1886 Sep 1	-	30.4	81.7	IV	Identical reports for 3, 4, 5, 8, 9 Sep; All aftershocks of Charleston, S.C., event.
1893 Jun 21	0707	30.4	81.7	IV	Reported as 2207 local time 20 Jun by Campbell (1943).
1900 Oct 10	-	30.3	81.7	III	Eight distinct shocks attributed to blasting.
1900 Oct 31	1615	30.4	81.7	V	Not reported by Campbell (1943) or Mott (1983).
1902 May 21	-	29.9	81.3	F	"noise like cannon fire" (Mott, 1983). Attributed to blasting.
" " "	-	29.9	81.3	II	
1905 Sep 4	09??	27.5	82.6	III	"Rumbling noises (Mott, 1983).
1930 Jul 19	1853	25.8	81.4	V	Numerous, widespread, evenly-spaced shocks. Attributed to blasting.
1935 Nov 14	0310	29.6	81.7	IV	Two short tremors.
1935 Nov 14	0330	29.6	81.7	IV	
1940 Dec 27	01??	28.0	82.5	F	Not reported by Campbell (1943); attributed to blasting.
1942 Jan 19	-	26.5	81.0	IV	Approximately 20 separate shocks reported in early afternoon throughout south Florida. Attributed to blasting or military activities.

Date	Time (UTC)	N. Lat.	W. Long.	Intensity	Comments
1945 Dec 22	1525	25.8	80.0	III	Newspaper accounts of citizens feeling tremor; event recorded at same time in Mobile, Alabama.
1948 Nov 8	1744	26.5	82.2	IV	Accompanied by sound of distant heavy explosion (Mott, 1983).
1952 Nov 18	2012	30.6	84.6	IV	Felt in Lake City and Quincy, but not reported for Tallahassee.
1953 Mar 26	-	28.6	81.4	IV	Slight tremor reported in Orlando.
1973 Oct 27	062102.0	28.476	80.654	V	5 km depth, 3.5 Mn magnitude assigned.
1973 Dec 5	1130	30.5	86.5	III	Attributed to blasting.
1975 Dec 4	1157	29.2	81.0	IV	2.9 Mn magnitude assigned.
1978 Jan 12	2110	28.1	81.6	IV	Not recorded by local seismograph.
1978 Nov 6	2300	30.20	82.65	IV	" " " " "
1978 Nov 14	2014	30.2	82.6	F	" " " " "
1978 Nov 16	1900	30.2	82.6	F	" " " " "

earthquake centered near Havana, Cuba (Campbell, 1943). Numerous reports of events in the weeks following the major 1886 earthquake in Charleston reflect the series of aftershocks as well as the general apprehension of a sensitized and fearful populace.

Campbell's compilation was included in an expanded report of Florida earthquakes presented by Mott (1983). Mott identified 33 events and attempted to estimate Modified Mercalli intensities, but admitted that "Many... seem to be related to seismic events elsewhere in North America." Using similar sources available to Mott, Reagor et al. (1987) prepared a seismicity map of Florida and compiled epicenter locations for Florida events. Table 1 represents a complete listing of those events presented as having been felt in Florida.

Modified Mercalli intensities are included, although most of the values were assigned on the basis of newspaper reports considerably after the earthquake reports. Most of the values are III or IV. Only six events exceed IV; two of those are attributed to blasting, and two others are from reports from more than a century ago.

Among those reported tremors compiled in Table 1, many listings are without convincing evidence, and others are more logically attributed to blasting activities. Campbell (1943) describes an event for 29 Oct 1727 which is based on secondary reports only and apparently coincided with reported disturbances in New England and the West Indies. Mott (1983) provides the same description, but give the date as 12 Oct 1727. In addition, Mott lists a "mild" tremor with no damage at Pensacola for 6 Feb 1780 and a severe event affecting a military installation at Pensacola on 8 May 1781. Reagor et al. (1987) do not list the 1727 event, but use a description for the 6 Feb 1780 event that Mott used for the 8 May 1781 event. Reagor et al. describe the event as having occurred during a violent thunderstorm with "raging seas." The possibility of a hurricane or other meteorological phenomena being the source of a perceived

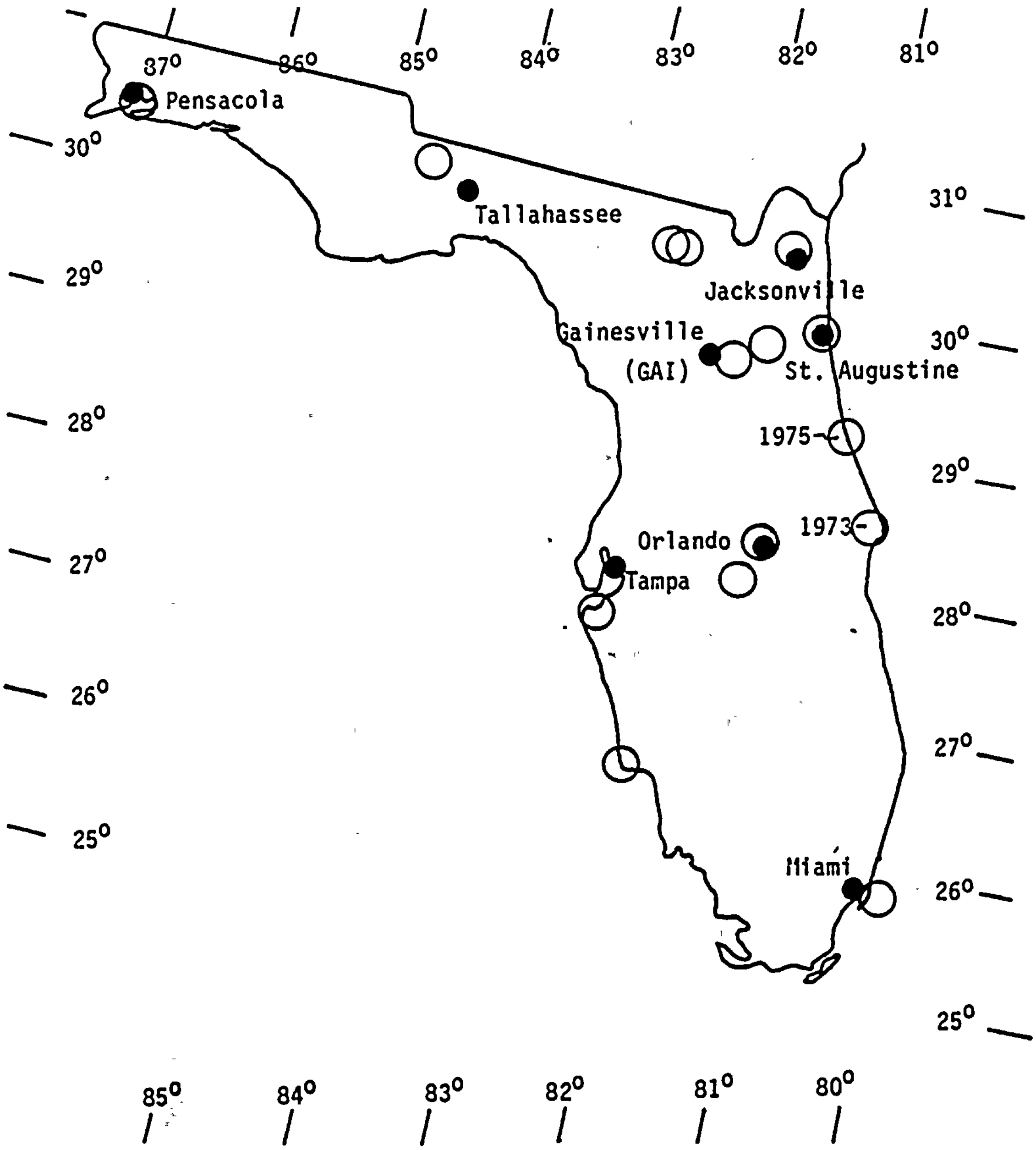

Figure 1. Distribution of Epicenters for Florida Earthquakes as reported by Reagor et al. (1987) (open circles). Closed circles depict cities. The 1973 and 1975 events are labeled. Station GAI in Gainesville began operations in late 1977.

disturbance and subsequent damage for that report must be considered as credible.

Eight "shocks" reported for 10 Oct 1900, disturbances associated with "noise(s) like hearing cannon fire" on 20-21 May 1902, and 5-7 shocks spaced at 3 minute intervals in south Florida on 19 Jan 1942 are examples of events which are best interpreted as results of blasting or military activities. An earthquake on 12 Jan 1879 appears to have been felt throughout a wide area of north Florida and south Georgia (Campbell, 1943) and was subsequently assigned a north central Florida location for its epicenter (Mott, 1983). Although this event appears to have been a major earthquake, its location in Florida is based entirely on newspaper accounts and not scientific observations.

The territory of Florida had a population of less than 35,000 in 1830. At that time, St. Augustine was the only recognized city, and it had been the center of population since its settlement in 1565. By 1860, the population was still only 140,000 and was concentrated in the St. Augustine and Appalachian River areas (Fernald, 1981). The population growth in south Florida did not occur until the last half century. Consequently, the geographic distribution of events reported as earthquakes was initially limited to the St. Augustine and other populated areas and gradually expanded to mimic the pattern of population growth.

The credibility of reports, however, has increased in recent decades. A small event occurred in 27 Oct 1973 and was felt throughout a large area centered around Seminole County (Fig. 1). Another event was felt around the Daytona area on 4 Dec 1975. Neither event was sufficiently severe to be recorded by seismograph stations near Mobile, Alabama, or Atlanta, Georgia, but estimated magnitudes (see Table 1) were 3.5 Mn or less. A single component, short-period seismograph station (GAI) was installed in Gainesville at the University of Florida in Autumn, 1977 (Smith, 1978). No reportable events in Florida have been recorded since that time.

Reports of "earthquakes" in Florida have occasionally appeared in the news media during the past ten years, but no substantiating evidence for these events has ever occurred in the seismographic records. The reports usually originate from credible lay observers who have actually sensed a disturbance. Reports of audible disturbances typically accompany the earthquake reports, and both sensations are commonly noticed over a broad time period (hours) and geographic area (e.g., Lake City to Panama City). These events are attributed to atmospheric phenomena, and, in the cases carefully investigated by local civilian authorities, have been shown to be a result of military aircraft activity. In addition, there is a long history of unexplained "mystery booms" endemic to Florida's coastal areas. Atmospheric shock fronts are apparently perceived by individuals as disturbances emanating from the subsurface. But continuous seismographic observations, including intensive field testing with USGS portable seismographs in 1981, have failed to detect any associated ground motion.

All four of the 1978 events listed in Table 1 failed to be recognized at station GAI. A subsequent review of the seismograms for the time periods reported reveals no evidence of a local earthquake. Accordingly, those events are relegated to a status of "probable atmospheric origin." Similarly, the 18 Nov 1952 event (Table 1) reported as having been felt in Quincy and Lake City (Mott, 1983) (but not in the interjacent Tallahassee), is not verified by seismographic records and can be attributed to atmospheric phenomena.

FLORIDA BASEMENT

Shallow-focus seismic events are manifestations of stress accumulations and releases, and are exemplified by the presence of active tectonic features, existing faults capable of accommodating displacement, or isostatic imbalances requiring adjustment among basement complexes. Deep- or intermediate-focus earthquakes appear implausible for Florida because the configuration of

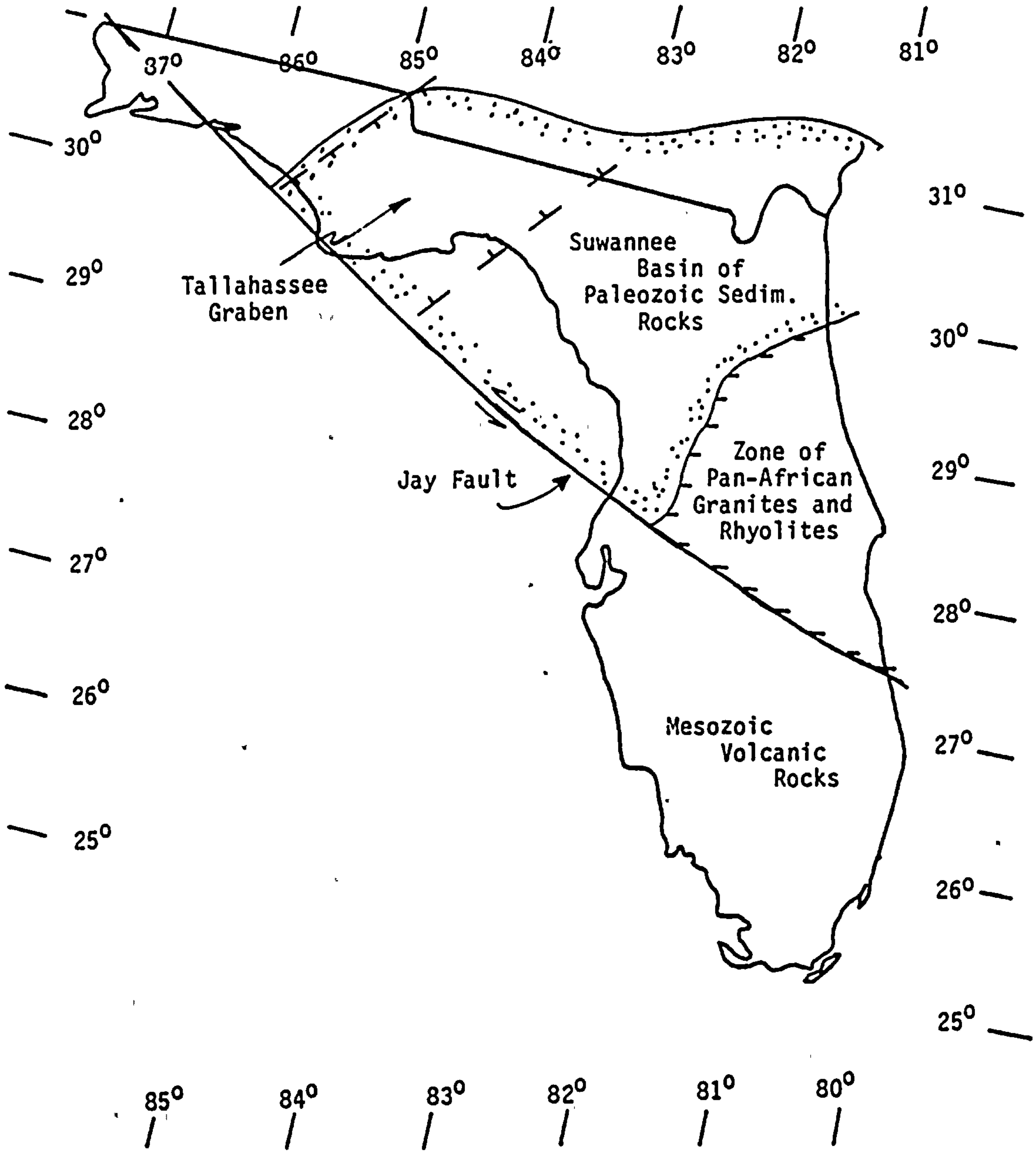

Figure 2. Simplified Map of Florida Basement Features (after Barnett, 1975, and Smith, 1982).

lithospheric plate margins with which such events are associated excludes the Florida Plateau from currently-recognized zones of dynamic tectonic activity. The geologic history of the Florida Plateau for the Cenozoic Era (Puri and Vernon, 1964) is one of the continual deposition of clastic and carbonate sedimentary rock layers of the Coastal Plain accompanied by uniform regional uplift.

There is no evidence for active faulting on a large scale during the Holocene Epoch, and quite probably for most of the Neogene Period. Proposed deformational movements of local extent have been based on variations in the thicknesses of surficial and subsurface formations. Any deformation within the overlying Coastal Plain sedimentary blanket, if verified, would be interpreted as indicative of differential motion of structural units in the pre-Cretaceous basement underlying Florida. An absence of significant evidence of subsurface differential motion is suggestive, although not demonstrative, of a probable seismic quiescence for the Florida peninsula.

Applin's (1951) early description of the relatively flay-lying, undeformed, and unmetamorphosed lower Paleozoic subsurface sedimentary rocks of north Florida emphasized the unconformity below the basal Cretaceous rocks of the Coastal Plains sequence. Basically, Applin portrayed a basal Florida as consisting of a Suwannee Basin (Banks, 1978) of Ordovician and Silurian sandstones and shales lapping onto a triangular-shaped granitoid batholith in central Florida. Subsequent descriptive and radiometric dating efforts by Bass (1969) and Milton and Grasty (1969) identified the granitic materials as having a Cambrian age similar to Pan African granites. Additional work by Barnett (1975) contributed to the realization that the south Florida basement consisted of early Mesozoic basalts and rhyolites.

Barnett (1975) presented a detailed map of subsurface Florida lithology and structure, but many proposed fault lines were imaginative and were based on

interpretations of gravity and magnetic anomaly patterns. His proposals included a northeast-trending Triassic graben underlying the Apalachicola Embayment. This feature was later described by Smith (1982) as the Tallahassee Graben (Figure 2) which was the site of abortive rifting in the Triassic Period. It underlies a zone of downwarped sedimentary layers, known as the "Suwannee Straits" (Puri and Vernon, 1964), within the Coastal Plain sequence. Although the graben is flanked by normal faults (e.g., Smith, 1983), and subsurface structural features suggest significant vertical adjustments among distinct basal blocks during the Jurassic Period, there is no evidence in the Coastal Plains rocks of continued displacement during the Cenozoic Era.

Including the Ordovician and Silurian sedimentary rocks as part of the Florida basement, Wicker and Smith (1978) presented isometric views of the peninsular basement. The depth of the basement varied from approximately 0.9 km to the Paleozoic sedimentary rocks in northern peninsular Florida to over 4.5 km to the Mesozoic volcanic rocks in southern Florida. Although no drill holes have completely penetrated the Paleozoic sediments, they are presumed to be underlain by the Pan African granitic rocks. Using gravity anomaly magnitudes, Wicker and Smith (1978) estimated their maximum thickness to be approximately 2.5 km. Nelson et al. (1985a,b) interpreted COCORP results in north Florida to indicate approximately 6 km of Paleozoic material over the granitic rocks, but they indicated that the bottom 3 km may be an extension of the volcanic material associated with the granitic batholith in the north Florida basement and dated as Ordovician (Mueller and Porch, 1983).

The isometric views presented by Wicker and Smith (1978) also emphasized the apparent abrupt truncation of the granitic batholith on its southern end. Puri and Vernon (1964) termed this feature the "Kissimmee Faulted Flexure" and the basal area to the south the "Osceola Low." This line of truncation was represented by a right-lateral fault by Barnett (1975). Smith (1983) named the

feature the "Jay Fault" and presented evidence for left lateral motion during the Jurassic Period. Klitgord et al. (1984) described the same feature as a Jurassic transform fault which aligned southern peninsular Florida with northern Florida. Recent articles by Dallmeyer (e.g., Dallmeyer et al., 1987) suggest extreme Triassic and Jurassic displacement to move the southern half of the Florida peninsula from a position in what is now the Gulf of Mexico into juxtaposition with northern peninsular Florida. There is no evidence from the overlying Cenozoic sedimentary strata to suggest any activity along this fault in the last 60 my.

The shallowest depth to the basement, approximately 0.9 km, is in north central Florida. Based on borehole samples and depths, this area of the basement became known as the "peninsular arch" (Puri and Vernon, 1964). This description inferred an anticlinal posture of the basement rocks with a north-south trending axis. Furthermore, an exposure of the Eocene Ocala Limestone in north central Florida led to the term "Ocala Uplift" (Vernon, 1951). Winston (1976) correctly pointed out that the feature is a result of anomalous thickening and not of Neogene tectonic activity. The peninsular arch has been redefined (Smith, 1982) as an erosional remnant of Paleozoic sedimentary rocks over which the Coastal Plain sedimentary rocks are draped. Neither the peninsular arch nor the Ocala Uplift, despite their misleading names, is a source of any faulting or other tectonic activity.

Citing previously published evidence for Gondwanan paleontological and geological affinities within the Paleozoic sedimentary rocks of north Florida, Smith (1982) proposed a tectonic history in which the Florida basement was an original component of an Afro-South American landmass during early Paleozoic time (Figure 3). Paleomagnetic evidence substantiates a southern hemisphere site for Florida during the Ordovician Period (Opdyke et al., 1987), and radiometric age correlations of Suwannee Basin detrital muscovite with west Africa Bove Basin sedimentary rocks suggest a West African terrane linkage

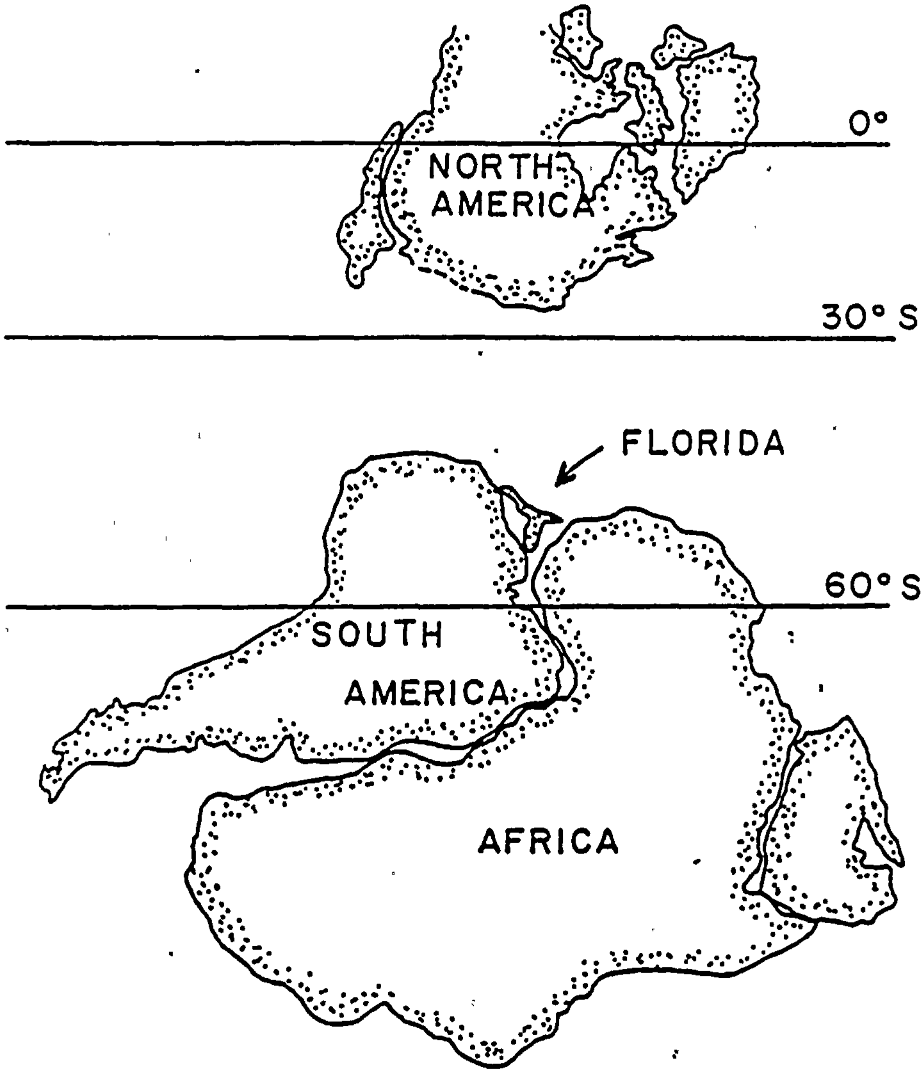

Figure 3. Middle Silurian paleogeographic reconstruction showing Florida Basement as part of an Afro-South American Landmass (from Opdyke et al., 1987).

(Dallmeyer, 1987). The proposed history involved subductive closure of an intervening ocean and a suture with the southern margin of the North American landmass. Nelson et al. (1985a,b) and Tauvers and Muehlberger (1987) have discussed the proximity of the suture zone with the well-known Brunswick Magnetic Anomaly.

Seismic activity during the late Paleozoic continental convergence would, of course, have been significant, perhaps similar to the present day situation in India. Furthermore, the subsequent rupturing of the continuous Pangaea landmass during the Triassic period and the divergent migration of the African and South American land masses from a new boundary line in the late Triassic-early Jurassic time are envisioned as very dynamic events associated with intense seismicity. The exact mechanism of the original interactions of rifting continental blocks remains unresolved (Smith, 1983; Klitgord et al., 1984; Dallmeyer, 1987), but an initially chaotic fragmentation of blocks occupying the present northern Gulf of Mexico appears probable (Figure 4). The Jay Fault also appears to have played a significant role in the early Mesozoic plate interactions.

BASEMENT RELATIONSHIP TO FLORIDA SEISMICITY

The reconstructions of the tectonic history of the Florida basement, which are based on very limited borehole samples and interpretations of geophysical field anomalies, suggest that the entire Florida peninsula and, indeed, much of south Georgia outboard of an inferred paleosuture zone is a displaced terrane of west African origin. Although the seismicity of the area was presumably much greater in the past, it is, consistent with expectations, virtually nil at present. The current tectonic nature of the Florida basement is not only distinct from the typical southeastern United States basement with continued Appalachian orogenic adjustments, but, by virtue of its distance from tectonically active lithospheric margins and its lithospheric stability, it is

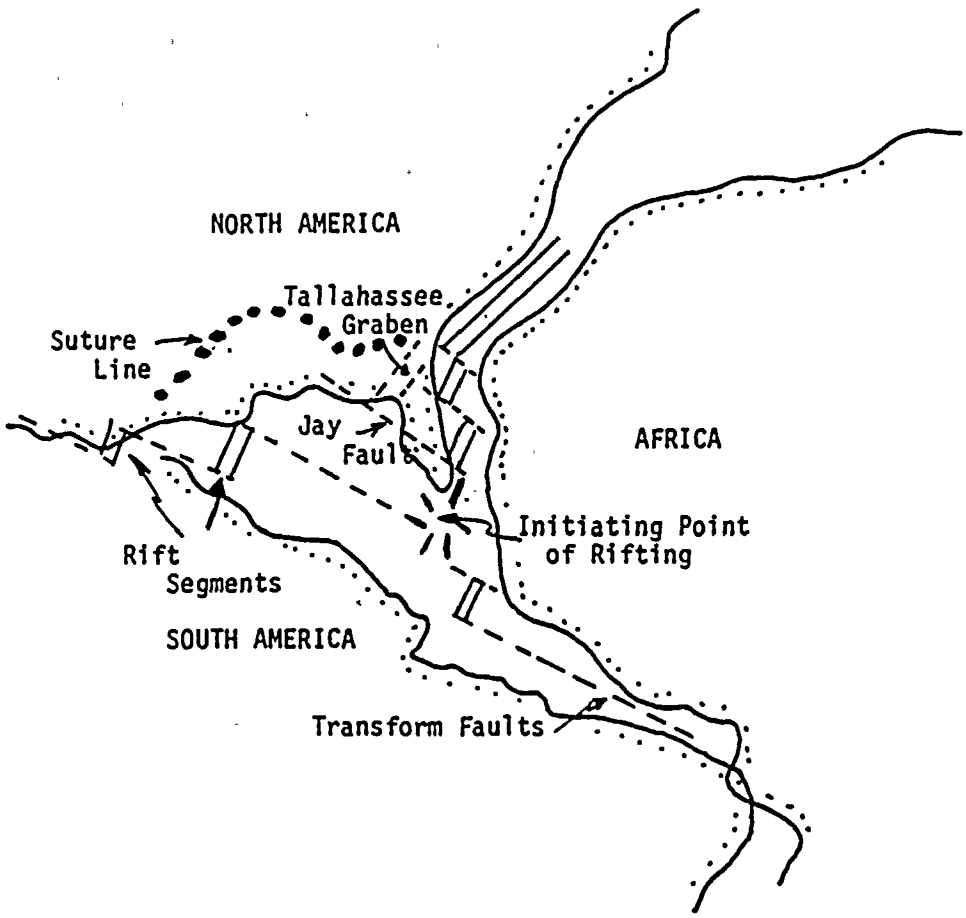

Figure 4. Theoretical Depiction of the Configuration of Landmasses and Tectonic Features at the Start of Triassic Rifting.

apparently free of potentially disruptive stresses or continuing fault displacement. Hoyt (1969) and Winker and Howard (1977) described an apparent irregularity among ancient Florida shorelines as evidence of tectonic motion of the Florida peninsula during the late Cenozoic. Opdyke et al. (1984), citing density changes from karstification of limestone formations as a cause of isostatic adjustments, attributed the elevation differences of ancient shorelines to epeirogenic uplift during the Pleistocene Epoch.

Although a fault mechanism to accommodate epeirogenic uplift has not been identified, nor have strain rates been computed for an uncompensated unloading of the peninsular crust, there remains no evidence of current conditions or features conducive to the stress accumulation characteristic of a shallow focus earthquake. Bollinger (1973), reporting on the seismicity of the southeastern United States, presented no listing of events in Florida, but attributed recent seismicity to strain development induced by crustal uplifting and concentrated by old Appalachian structures. A seismicity map of the United States includes for Florida only the 4 Dec 1975 event at Daytona for the period 1975 to 1984 (Stover, 1986). A compilation of earthquakes for the southeastern United States for the 1977-1983 period (SEUSSN contributors, 1985) listed no events in Florida. In fact, an abrupt decrease in seismicity appears to exist south (outboard) of the proposed suture zone separating Appalachian structures from the more stable Gondwanan basements.

According to available records, only one (the 22 Dec 1945 event) of the reported Florida earthquakes in Table 1 was recorded by a seismograph. Many recent (1978 to present) reports of tremors in Florida have been dismissed as non-tectonic because the existing seismograph station has recorded no ground motion. Accordingly, the tectonic origin of many of the events listed in Table 1 is not only subject to review, but probably doubtful.

Table 2. Seismic Events in Florida Attributed to Tectonic Origin. Exact locations given in Table 1.

Date	Location
13 Jan 1879	Uncertain; felt throughout north Florida and South Georgia
21 Jun 1893	Jacksonville
14 Nov 1935	Palatka
22 Dec 1945	offshore Miami
27 Oct 1973	Merritt Island
4 Dec 1975	Daytona

A revised list of known earthquakes from the Florida basement (Table 2, Figure 5) is based on a critical analysis of those events listed in Table 1. Of the six events listed, only three (1935, 1973, 1975) appear to be well-located. The 1893 and 1945 events are listed with the least confidence. Although the 1879 event is well-described in early newspaper accounts, an exact epicenter is difficult to identify, and the event could have originated throughout a wide spatial range of north Florida or south Georgia.

Figure 5 delineates those basement boundaries separating contrasting lithologies and the probable areas of old faults which conceivably could experience continued displacement. The events listed in Table 2 are positioned, and five of the six, given the uncertainties surrounding their epicentral determinations and speculation associated with fault placements, can be regarded as closely associated with supposed subsurface faults in the Florida basement. Given the absence of confirmed events associated with the Jay Fault and the Traissic graben faults, the stability of post-Paleozoic faults can be described as relatively substantial.

The five epicenters coinciding with proposed basement faults lie above either pre-Mesozoic or continental-oceanic boundaries. Continued adjustments on these features, even as infrequently and mildly as is shown herein, is plausible.

Conclusions

The major conclusions of this essay can be summarized as follows:

1. The number and magnitude of reported seismic events in Florida is very limited. This may be attributed in part to the sparse population of Florida prior to this century. Upon critical review, however, only six events (since 1879) emerge as having a probable tectonic origin.

2. Geological and geophysical evidence convincingly demonstrates the original Florida basement to have been a part of an early Paleozoic Afro-South American

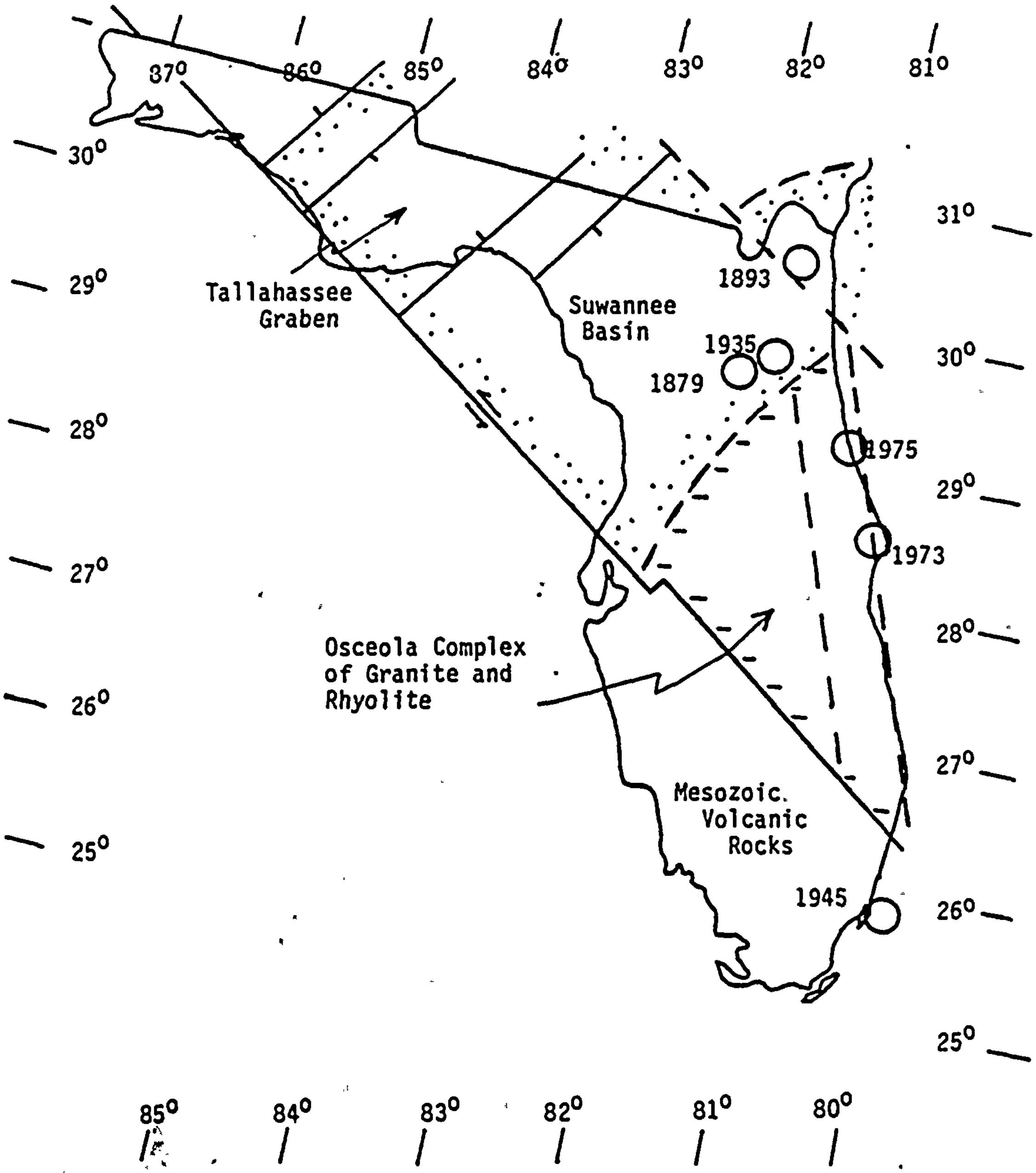

Figure 5. Revised version of Florida Basement Features with Epicenters and Dates of Florida Earthquakes Attributed to Tectonic Origin. Solid Lines are Faults of Mesozoic Age; Broken Lines Delineate Faults of Early Paleozoic Age.

landmass which converged with North America during the late Paleozoic.

3. Continental rifting of the Pangaea supercontinent during the Triassic period and subsequent divergence of landmasses left Florida, with south Georgia and Alabama, as an exotic or displaced terrane attached to North America along the original convergence suture line. Accordingly, the Florida basement is lithologically and tectonically distinct and more stable than the seismically active Appalachian area which was the original margin of North America.

4. The intensity of seismicity apparently is abruptly diminished south of the original Paleozoic suture line which crosses south-central Georgia on an approximate east-west trend.

5. The seismic nature of Florida cannot be compared with and is not related to that of the remainder of the eastern United States.

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DURATION OF STRONG GROUND MOTION

by

Bruce A. Bolt[I]

SYNOPSIS

Duration of strong seismic shaking is a sensitive function of wave frequency, amplitude threshold, and Richter magnitude. The magnitude dependence arises from the finite geometry of fault rupture. Frequency dependence enters through the exponential attenuation law for rock; for larger earthquakes (greater fault breakage), duration of higher frequency (> 1 Hz) horizontal waves with amplitudes above 0.05g ground acceleration is unlikely to exceed 35 to 40 sec. Lack of precise definition has led to exaggerated estimates of duration for some design purposes. Filtered records of ground acceleration yield a table for "bracketed duration" as a function of magnitude and source-to-site distance.

INTRODUCTION

The prediction of the duration D (in seconds) of strong seismic shaking is still rather rudimentary even though "duration is possibly the single most important factor in producing excessive damage" (H.M. Engle, in Richter, 1958). In two recent textbooks on earthquake engineering (Wiegel, 1970; Newmark and Rosenblueth, 1971) no explicit treatment of duration as a function of many variables is attempted. Housner's (1965) curve (see Figure 5) for "the strong phase of ground shaking" is essentially a linear law against magnitude M:

$$D = 11\,M - 53. \qquad (1)$$

Esteva and Rosenblueth (1964) define the duration $\underline{s}$ of an "equivalent" ground motion with uniform intensity per unit time (about half D for large M) as

$$\underline{s} = 0.02 \exp(0.74\,M) + 0.3r, \qquad (2)$$

where r km is the source distance (FS in Figure 5).

These formulae do express the key dependence of D on M which can be inferred at once from the rupture model of earthquakes (e.g. Bolt, 1970) illustrated by the diagram in Figure 5, i.e. M increases with AB. What the formulae lack is a stated threshold of ground acceleration A to define "strong" and a treatment of frequency. Seismic surface waves (Love and Rayleigh type) attenuate (assuming no dispersion) like

$$A = A_o E/\ r, \qquad (3)$$

where

$$E = \exp(-\pi f\, r/cQ). \qquad (4)$$

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f is frequency (in Hz), c is wave velocity and Q is the mean specific damping constant for the appropriate rocks and soils.

As (4) shows, because high frequency waves attenuate more strongly than low frequency ones, their duration is severely distance limited. Any linear law, such as (1), overassesses duration for large earthquakes, at least for 1 Hz and higher frequency waves (e.g. the frequency invariant estimates of Page et al., 1972). The last term of (2) is physically inadmissable for the same reason: as r increases, the amplitudes (and hence, in general, the mean durations above given thresholds of shaking) decrease like (3).

DEFINITION OF DURATION

Two definitions appear useful.

(a) "Duration at a particular frequency is the elapsed time between the first and last acceleration excursions greater than a given level (0.05g, say)." I propose to call this interval the "bracketed duration". It is sometimes measured by cumulatively adding the squared accelerations and adopting the 95 percentile time interval (Husid et al., 1969). Particularly for earthquakes with specially complex multiple sources (e.g. Wyss and Brune, 1967), this definition often leads to a non-physical upper estimate. Spectrograms like Figure 1 (Pacoima, 1971; R. Arms, personal communication) show well the complex amplitude spectrum as a function of time (e.g. Perez, 1973); peak accelerations of 2-3 Hz waves occur at 4 and 8 secs with reduced motion between (see also the quiet interval on the 2 Hz trace of the Olympia record (Figure 2) with unfiltered peak A equal to 0.31g.) For some design and liquefaction analyses the episodes of relatively weak motion may allow some structural recovery and should be excluded.

(b) "Duration at a particular frequency is the total time for which acceleration at that f exceeds a given value." This interval, called "uniform duration" here, may equal the corresponding "bracketed duration" (as on the 2 Hz trace (Figure 3) of the Castaic record ($A>0.05g$), with an unfiltered peak A of 0.39g) or be much less (as on the 1.0 Hz trace). Uniform duration appears to have a greater mechanical significance in some design tests. Circles and triangles plotted in Figure 5 are measured uniform durations from accelerograms.

DURATION AS A FUNCTION OF FREQUENCY

Nine strong motion records from the U.S. with large recorded horizontal accelerations were passed through a narrow-band Krohn-Hite filter at representative central frequencies (see Figures 2 and 3). For each record the attenuator setting was fixed for all frequencies. The measured durations are shown as dots in Figure 4. The great variability in shaking patterns is exemplified by the San Fernando earthquake which gave at Castaic (Figure 3) the largest motions at 4 Hz early in the shaking while at Pacoima high frequency bursts came towards the end (Bolt, 1972 and Figure 1). This real-time variability is, of course, lost if frequency spectra only are used in analysis.

The values in Figure 4 confirm that, generally, the greatest D (above

the modest level A=0.05g) occurs in the frequency band $1 < f < 5$ Hz. On the low-frequency side, seismological research indicates that earthquake source mechanisms decrease amplitudes roughly like f. For high frequencies, D is limited by attenuation along the propagation path.

Table 1 gives values of shear (or Love) wave attenuation calculated from (3) taking Q ·· 150, c = 3 km/sec. (The amplitude is set, at 5 km from the source, equal to $A_o \sqrt{5}$ E /.r, for large Q.) Suppose the site S (Figure 5) is near the end of a fault length AB. The empirical correlation between M and fault rupture length is listed in the first two columns of Table 1. Suppose, to obtain an upper bound, waves of all frequencies are generated at the moving rupture with an amplitude of 1.0g. Then, as the zig-zag line indicates, at each frequency, beyond a certain distance on the slipping fault, SA (=r) is too great for the site S to continue to receive waves with A > 0.05g. For example, after the rupture has propagated to 150 km (corresponding to M = 7.5) little 1 Hz (or greater) energy above 0.05g will ultimately arrive back at S. In other words, even for the greatest magnitude shocks ($M \geqslant 8.0$) the duration (A > 0.05g) at S ($f \geqslant 1$ Hz) would be no longer. The slope of this geometrical maximum is shown as a broken line in Figure 4.

CALIBRATION OF TABLES

Measurements of world-wide strong-motion records were used to fix the curves for D versus M in Figure 5. The curves represent nearly the upper bound so as to include 90 per cent of available data. Many published values (e.g. Donovan, 1972) fix the low magnitude end. Because no similar population is available for large magnitudes, the attenuation values of Table 1 provide the slope for M > 7.5, as explained above.

Four points above the curves in Figure 5 need discussion. The Hiroo record (from the 1970 Hidaka Sankei earthquake (M = 6.8)) shows an unusually long D of almost monochromatic shaking ($f \approx 5$ Hz) above 0.05g (Omote et al., 1970). In this case, the uniform duration almost equals the bracketed duration and a second energy burst arrives 14 sec from the P onset suggesting a significant multiple dislocation.

The 1906 earthquake value (Lawson, 1908) comes from timed estimates of 40 sec of "severe shaking" felt by the scientists A. McAdie (San Francisco) and A.O. Leuschner (Berkeley). The E-W component of the Ewing seismograph at Lick wrote an almost continuous record. It suggests that motions with periods less than 2 sec had fallen below A=0.01g after 40 sec; smaller fluctuating waves (periods > 3 sec) were recorded for 150 sec or so. Imamura (1925) reproduced the only other record available from the center of a major earthquake. In the 1923 Kwanto shock an E-W seismograph operated at Hongo almost uninterrupted (pendulum period 10 sec, magnification 2). Extreme (discontinuous) oscillations of high frequency ended about 30 sec after the onset of the S waves. Then, for over 2 minutes, the pendulum recorded longer period waves ($\approx$5 sec) of smaller A (<< 0.05g), followed by aftershocks.

There is, of course, much evidence that longer period waves than

considered in Table 2 and Figure 5 persist for a minute or more at accelerations $A < 0.05g$, because of sharply lower attenuation and surface wave dispersion (e.g. Mooney and Bolt, 1966). Figure 6 demonstrates this property 75 km from the 1969 Santa Rosa shock (M=5.7). The unfiltered top trace clipped in the recorders; vertical lines mark 10 sec). At 5 Hz, $D \approx 10$ sec while at 2 sec, $D \approx 70$ sec; however, the ground acceleration is less than 0.01g at all frequencies.

The long period vibrations, taken with the aftershocks, add to the human propensity to exaggerate the duration of shaking. (Humans can feel $A \geq 0.001g$). Some people in the 1964 Alaska earthquake reported feeling motions for 150 sec (Kachadoorian and Plafker, 1967). The only close "instrumental" record in 1964 is the tape recording of a radio announcer's reaction near Anchorage (Pate, 1965). Many replayings of this remarkable felt record convince me that the audible background noise and voice response ("...has not stopped shaking yet") are consistent with cessation ($A > 0.01g$) of high frequency shaking after 45 sec.

CONCLUSIONS

Durations of higher frequency shaking do not significantly increase above magnitude 7.5 for $A > 0.05g$ and above magnitude 7 for $A > 0.10g$. Bracketed durations ($f > 1$ Hz) within 25 km of the fault rupture are not likely to exceed the following values (see Figure 5) for $A > 0.05g$ and $A > 0.10g$, respectively:

$$D = 17.5 \tanh (M-6.5) + 19.0, \qquad (5)$$

and

$$D = 7.5 \tanh (M-6.0) + 7.5. \qquad (6)$$

Table 2 gives D as a function of magnitude and distance from the source (Δ km): It was constructed using (5), Table 1 applied to the fault rupture model of earthquake genesis, and spectrally filtered records such as Figures 2 and 3. The observational scatter indicates that the chance of exceeding the tabulated values by 20 per cent or more is about 1 in 10.

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TABLE 1 Ground Acceleration Attenuation Tables

M	r (km)	$1/\sqrt{r}$	8 Hz E	8 Hz A/A_o	5 Hz E	5 Hz A/A_o	2 Hz E	2 Hz A/A_o	1 Hz E	1 Hz A/A_o	0.5 Hz E	0.5 Hz A/A_o
	5	0.447	.756	.756	.840	.840	.933	.933	.966	.966	.983	.983
5.5	10	0.316	.572	.405	.705	.499	.870	.615	.933	.660	.966	.682
6.0	20	0.224	.327	.163	.498	.251	.756	.378	.870	.436	.933	.468
6.5	30	0.183	.187	.076	.351	.143	.658	.268	.811	.331	.900	.369
6-3/4	50	0.141	.061	.019	.175	.056	.498	.157	.705	.221	.840	.264
7.0	70	0.120			.086	.022	.376	.101	.613	.166	.783	.210
7-1/4	100	0.100					.248	.056	.498	.112	.705	.159
7.5	150	0.081					.123	.022	.351	.065	.592	.107
8.0	250	0.063							.175	.025	.418	.058

TABLE 2 Bracketed Duration (sec) (Acc ≥ 0.05g; freq ≥ 2 Hz)

Δ \ Mag	5.5	6.0	6.5	7.0	7.5	8.0	8.5
10	8	12	19	26	31	34	35
25	4	9	15	24	28	30	32
50	2	3	10	22	26	28	29
75	1	1	5	10	14	16	17
100	0	0	1	4	5	6	7
125	0	0	1	2	2	3	3
150	0	0	0	1	2	2	3
175	0	0	0	0	1	2	2
200	0	0	0	0	0	1	2

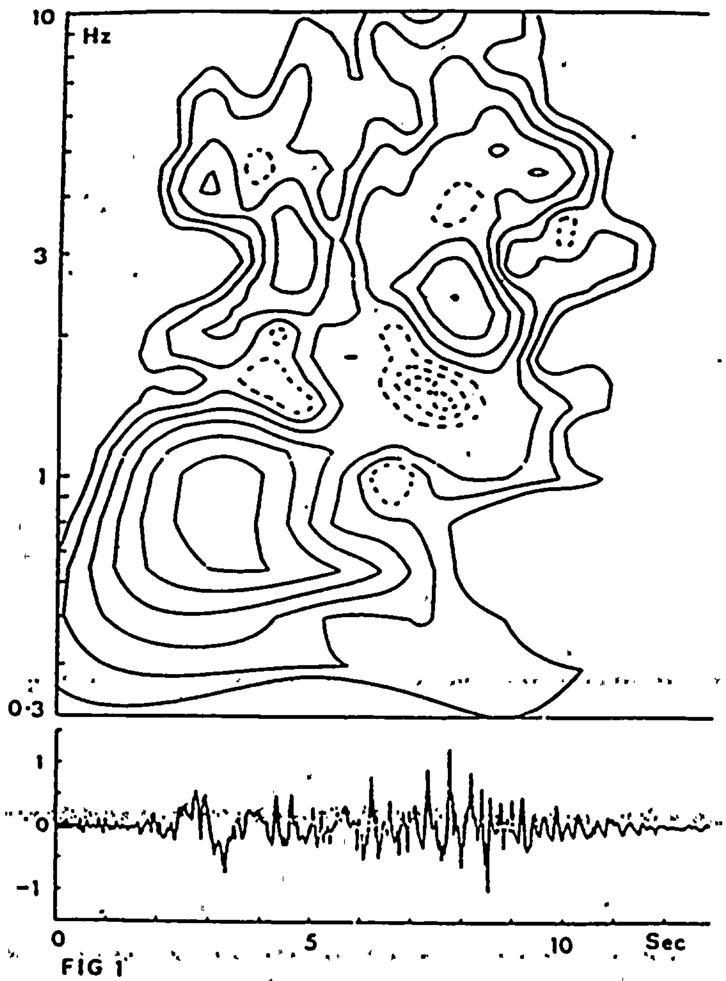


FIG 1

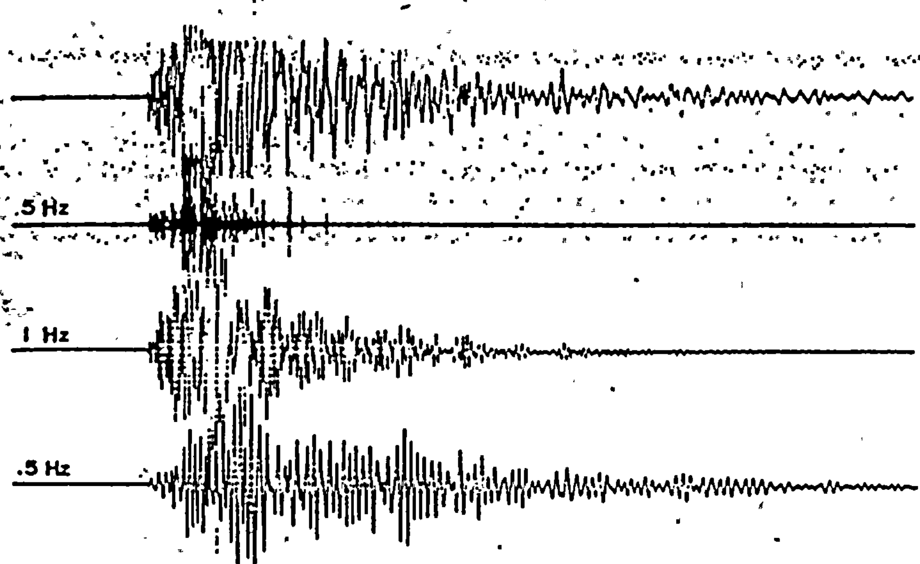


FIG 6. BERKELEY

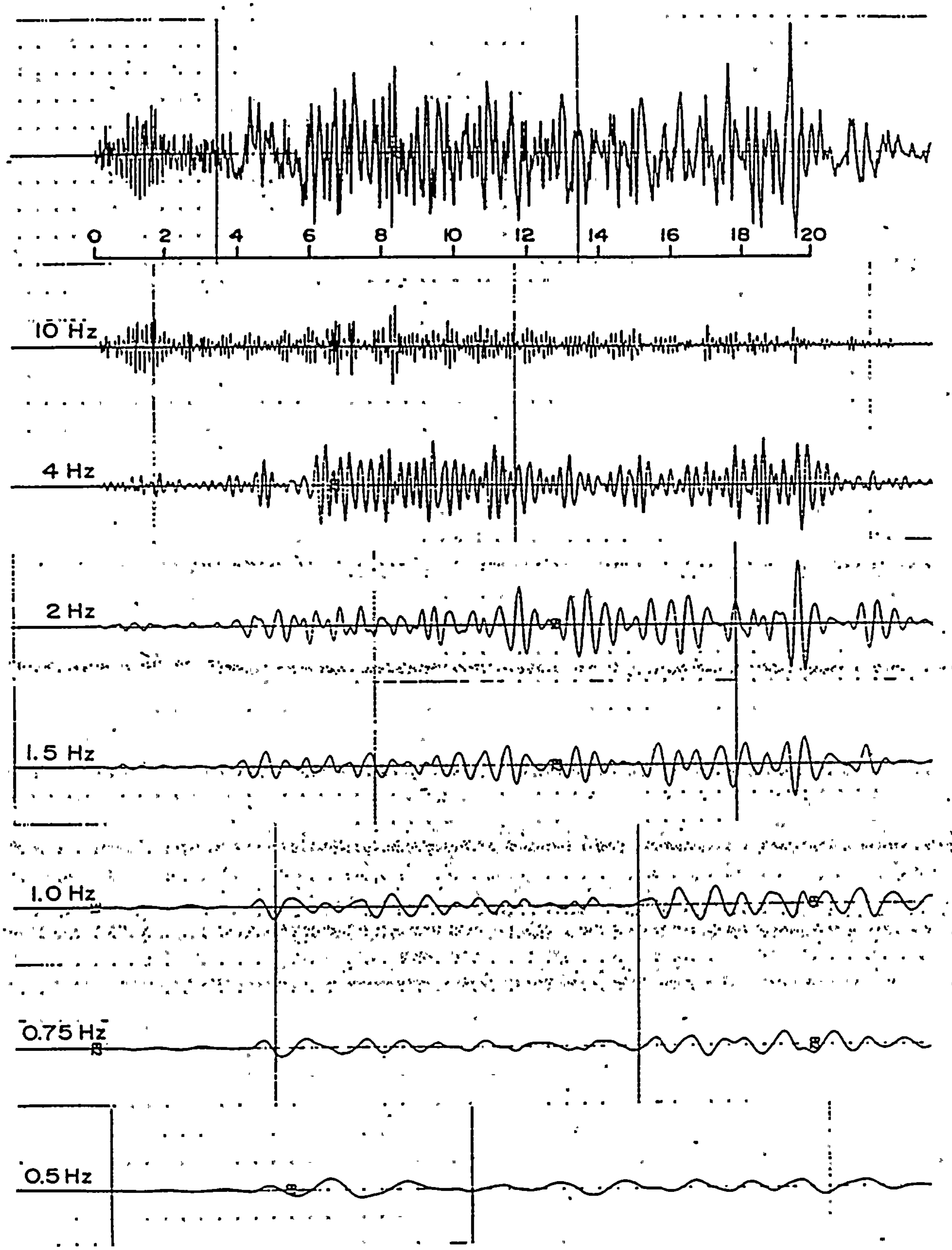


FIG 2

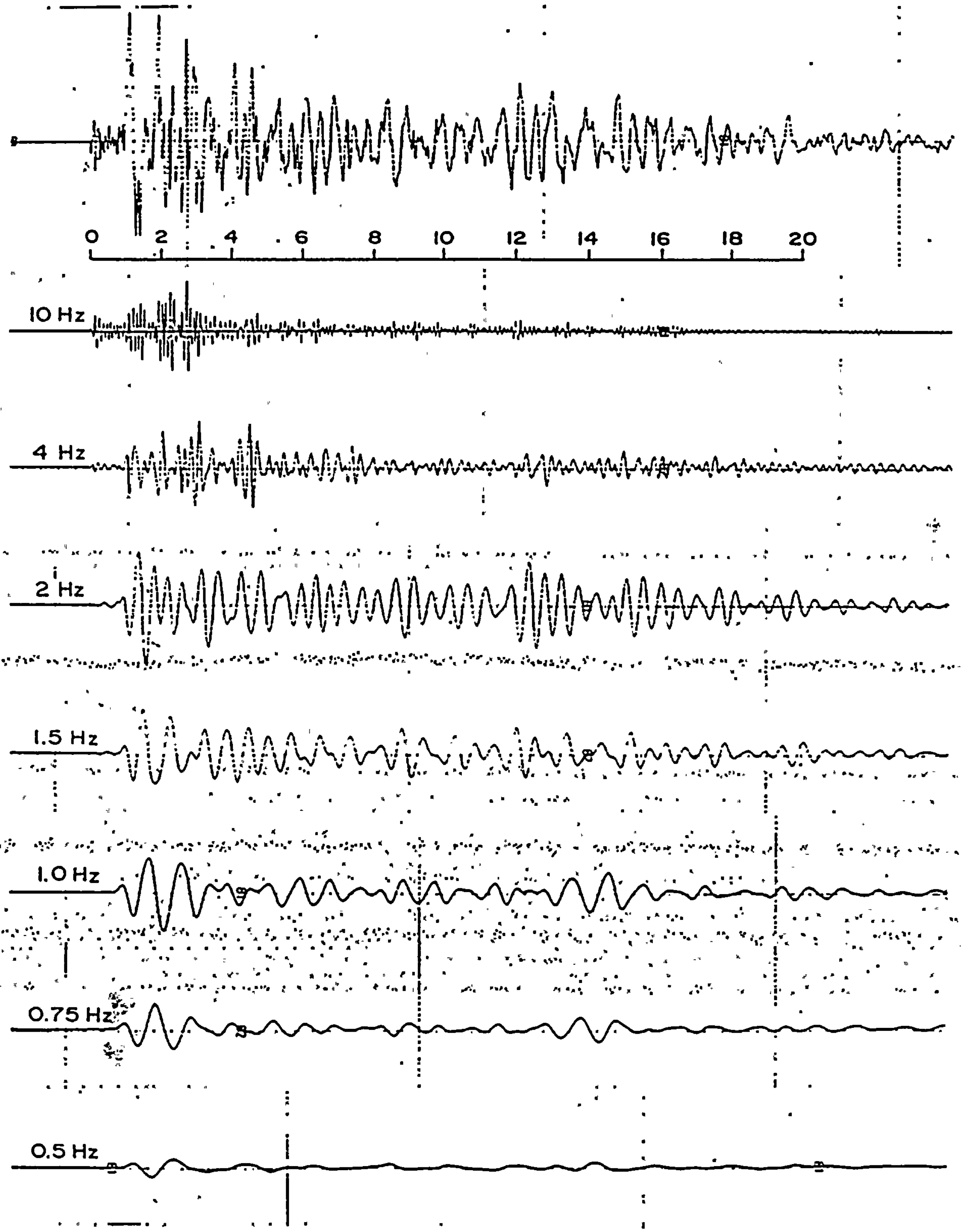


FIG 3

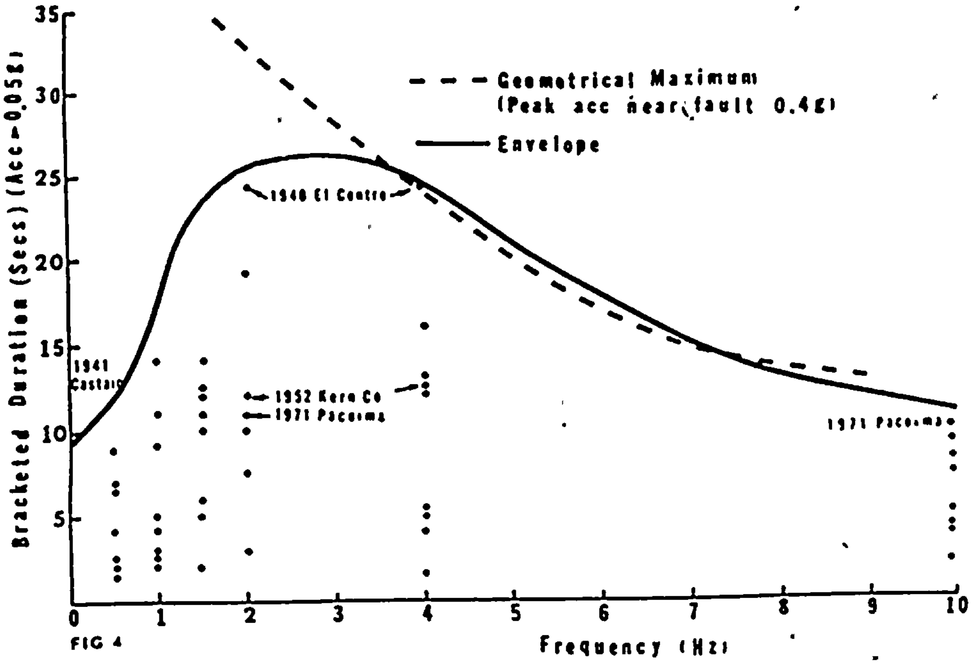

Geometrical Maximum
(Peak acc near fault 0.4g)
Envelope
1940 El Centro
1941 Castaic
1952 Kern Co
1971 Pacoima
1971 Pacoima
Bracketed Duration (Secs) (Acc>0.05g)
Frequency (Hz)
0
1
2
3
4
5
6
7
8
9
10
5
10
15
20
25
30
35

FIG 4

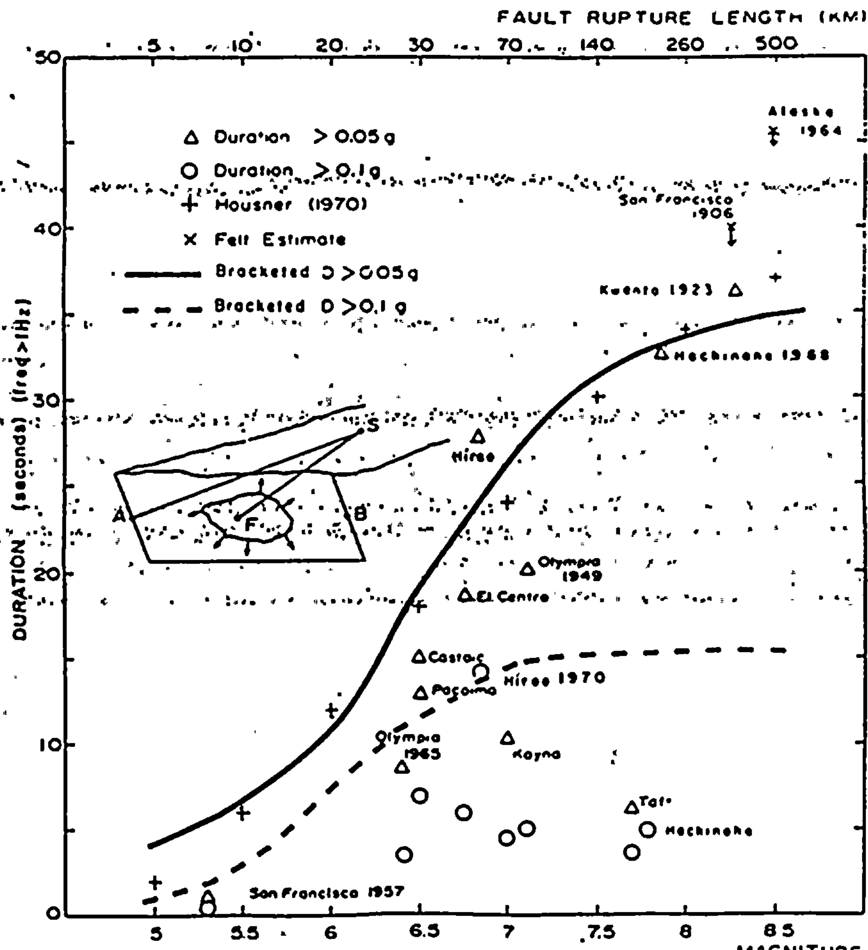

FAULT RUPTURE LENGTH (KM)
5
10
20
30
70
140
260
500
Δ Duration > 0.05g
O Duration > 0.1g
+ Housner (1970)
× Felt Estimate
Bracketed D > 0.05g
Bracketed D > 0.1 g
Alaska 1964
San Francisco 1906
Kwanto 1923
Hachinohe 1968
Hiroo
Olympia 1949
El Centro
Castaic
Hiroo 1970
Pacoima
Olympia 1965
Koyna
Taft
Hachinohe
San Francisco 1957
A
B
F
S
DURATION (seconds) (freq>1Hz)
MAGNITUDE
0
10
20
30
40
50
5
5.5
6
6.5
7
7.5
8
8.5

FIG 5

DURATION OF STRONG GROUND MOTION[I]

Discussion by

Yoshimasa Kobayashi[II]

The duration given by Bolt is likely that measured from filtered records and in such a case the result is necessarily strongly influenced by a bandpass filter employed. In measuring "filtered duration", therefore, the frequency characteristics of the filter should be clearly defined, since otherwise some arbitrariness would be introduced.

If an accelerogram with uniformly distributed frequency components from 0.25 to 7 Hz(approximate frequency range for SMAC record)[III] is passed through an Octave- or I/2-Octave-band-pass filter, the output levels will be lower than the over-all level by the amount given in Table A.

The writer has studied some twenty SMAC records obtained in Japan and derived an empirical formula for duration "exceeding"[IV] an arbitrary threshold acceleration α gals as

$$\log_{10} t_\alpha = -0.0088\alpha + 0.50M - 1.82 \text{ (sec)}$$

for

$$\log_{10} r \leq 0.51M - 1.57 \text{ (km)}$$

where M and r are the earthquake magnitude and hypocentral distance in km, respectively.(Fig.A)[1]

According to the relation the durations for threshold values 0.05g and 0.10g are respectively given by

$$\log_{10} t_{50} = 0.50M - 2.26 \text{ (sec) and } \log_{10} t_{100} = 0.50M - 2.70 \text{ (sec)}$$

Thus the durations at Hachinohe in the 1968 Tokachioki earthquake of M=7.8 would be

$$t_{50} = 43.65 \text{ (sec)} \quad \text{and} \quad t_{100} = 15.81 \text{ (sec)}$$

On the other hand the fluctuation of unfiltered horizontal accelerations at Hachinohe in the earthquake and the durations exceeding thresholds were as shown in Fig.B and C. From the figures

$$t_{50NS} = 63 \text{ (sec)}, \quad t_{100NS} = 27 \text{ (sec)}$$

$$t_{50EW} = 37 \text{ (sec) and } t_{100EW} = 12 \text{ (sec)}$$

The values determined above for Hachinohe except t_{50EW} are appreciably higher than those plotted by Bolt($D_{a05} \simeq 33$ sec and $D_{a10} \simeq 5$ sec in Fig.5). The differences are too great as to be attributable to the difference between "uniform" and "bracketed"durations and seem to be due to the effect of band-pass filtering as described above. In earthquake engineering the over-all acceleration(unfiltered acceleration) may be as well important as the filtered one according as each case involved and longer estimates referred to by the author (1) would not always be "over-assessing".

1 Kobayashi,Y.,Effects of Earthquakes on Ground(II),Journal of Physics of the Earth, Vol.19, No.3, pp 231/241,1971

I Paper No.292 by B.A.Bolt

II Assistant Professor, Disaster Prevention Research Institute, Kyoto University.

III Strong Motion Accelerograph

IV "bracketed duration" of unfiltered acceleration

Table A - Difference in Levels(dB) Between Filtered and Unfiltered Noise of Uniformly Distributed Frequency Components(0.25 - 7 Hz)

Filter\ Freq.	I Hz	2 Hz	4 Hz
Octave	- 9.8(0.33)	- 6.7(0.47)	-3.6(0.66)
I/2-Octave	-I2.9(0.23)	- 9.8(0.33)	-6.7(0.47)

( ) denote amplitude ratios

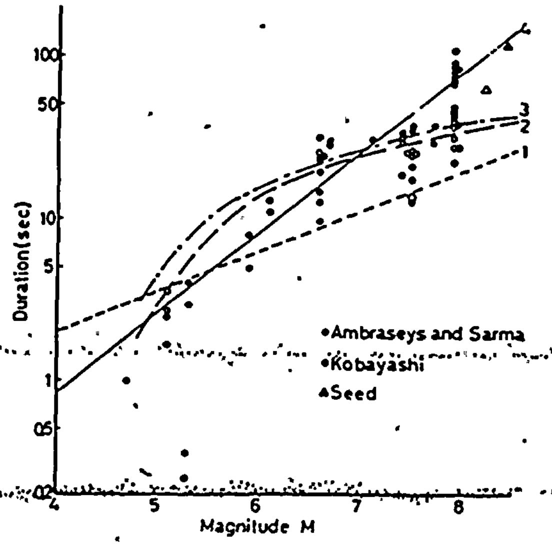


Fig.A Duration of strong shaking and the earthquake magnitude. 1. Gutenberg and Richter: $\log_{10}t_0=0.25M-0.7$, 2. Housner: $t_0=11M-52$, 3. Ambraseys and Sarma: $t_0=11.5M-53.0$, 4. Kobayashi; $\log_{10}t_{30}=0.50M-2.08$.

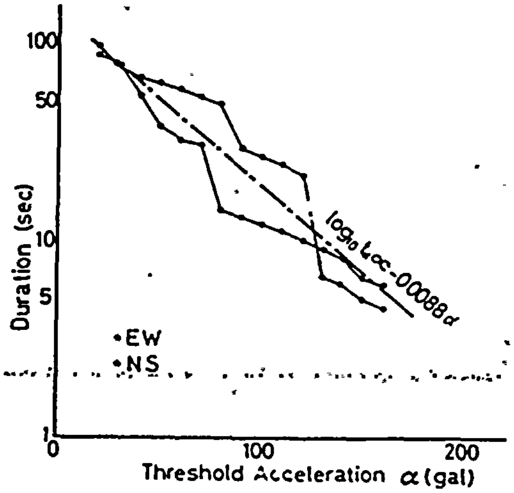


Fig.C Duration of ground motion exceeding arbitrary threshold values of acceleration: Tokachioki earthquake, May 16, 1968, M=7.9, recorded at Hachinohe harbor, Δ=180 km.

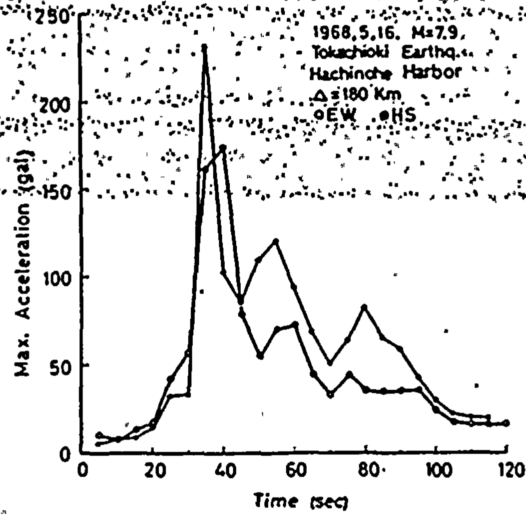


Fig.B Fluctuation of acceleration during an earthquake: Tokachioki earthquake, May 16, 1968, M=7.9, recorded at Hachinohe harbor, Δ=180 km.

UNIFORM HAZARD SPECTRA FOR THE ST. LUCIE AND TURKEY POINT NUCLEAR POWER PLANTS

Figures 1 through 6 show Uniform Hazard Spectra (constant annual probability of exceedance) developed using the approved Electric Power Research Institute (EPRI) methodology. Figures 4 through 6 are smoothed versions of Figures 1 through 3.

The NRC's Safety Goal Policy provides a performance objective, at Level 4, of 1×10^{-4} mean frequency of core damage. Plant equipment seismic ruggedness customarily contributes at least an order of magnitude, resulting in a reasonable value for mean frequency for a safety guideline for seismic core damage being 1×10^{-5}.

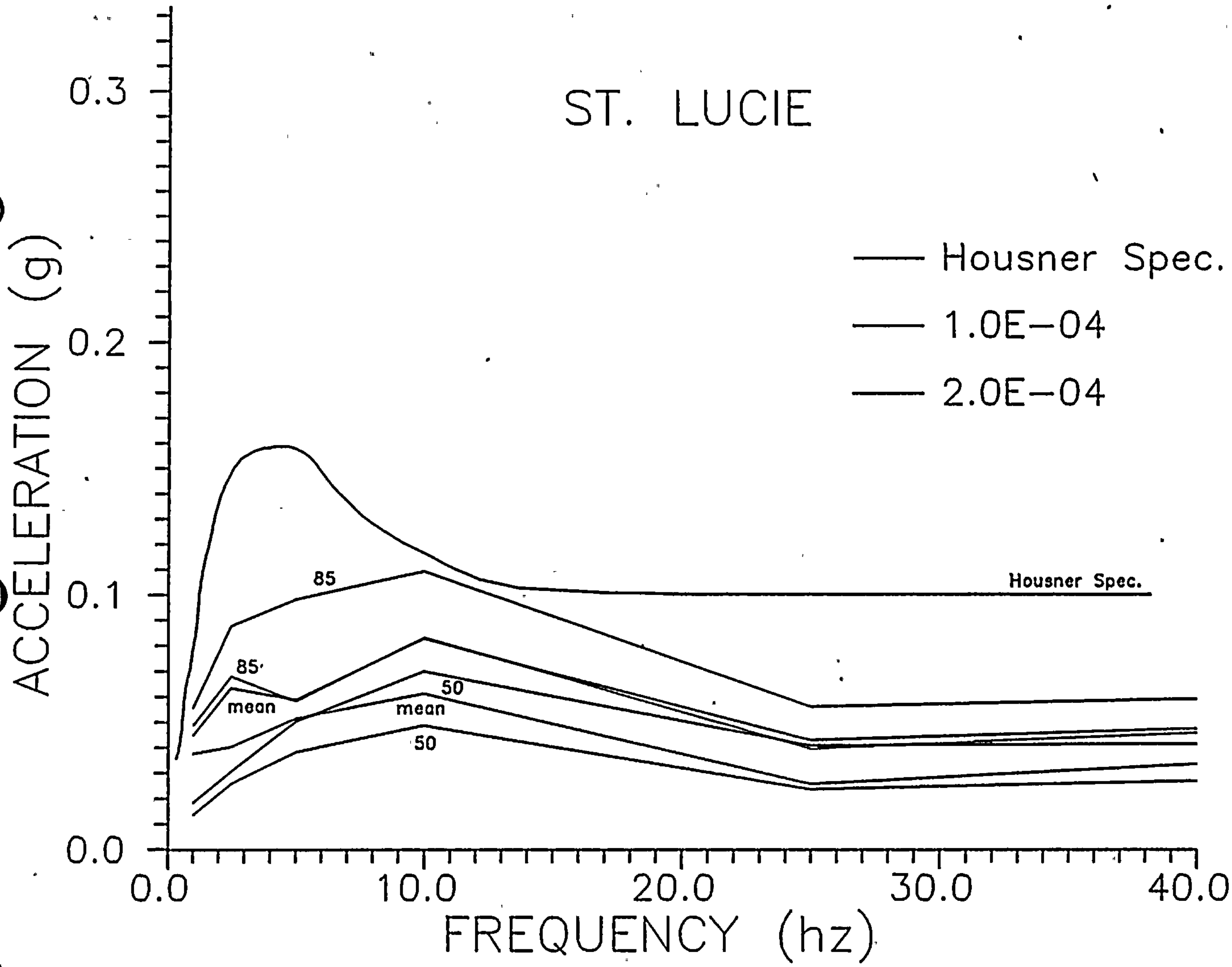
If it is hypothesized that plant equipment seismic ruggedness contributes nothing, then the mean frequency of core damage given an earthquake is the same as the mean frequency of the occurrence of the earthquake, and a "worst case" scenario is created.

As can be seen from Figures 1 through 6, even under this "worst case" scenario, all of FPL's Uniform Hazard Spectra at both the mean and the 85th percentile are bounded by the Housner and Reg. Guide 1.60 spectra anchored at 0.1g, the legal minimum permitted by 10 CFR 100.

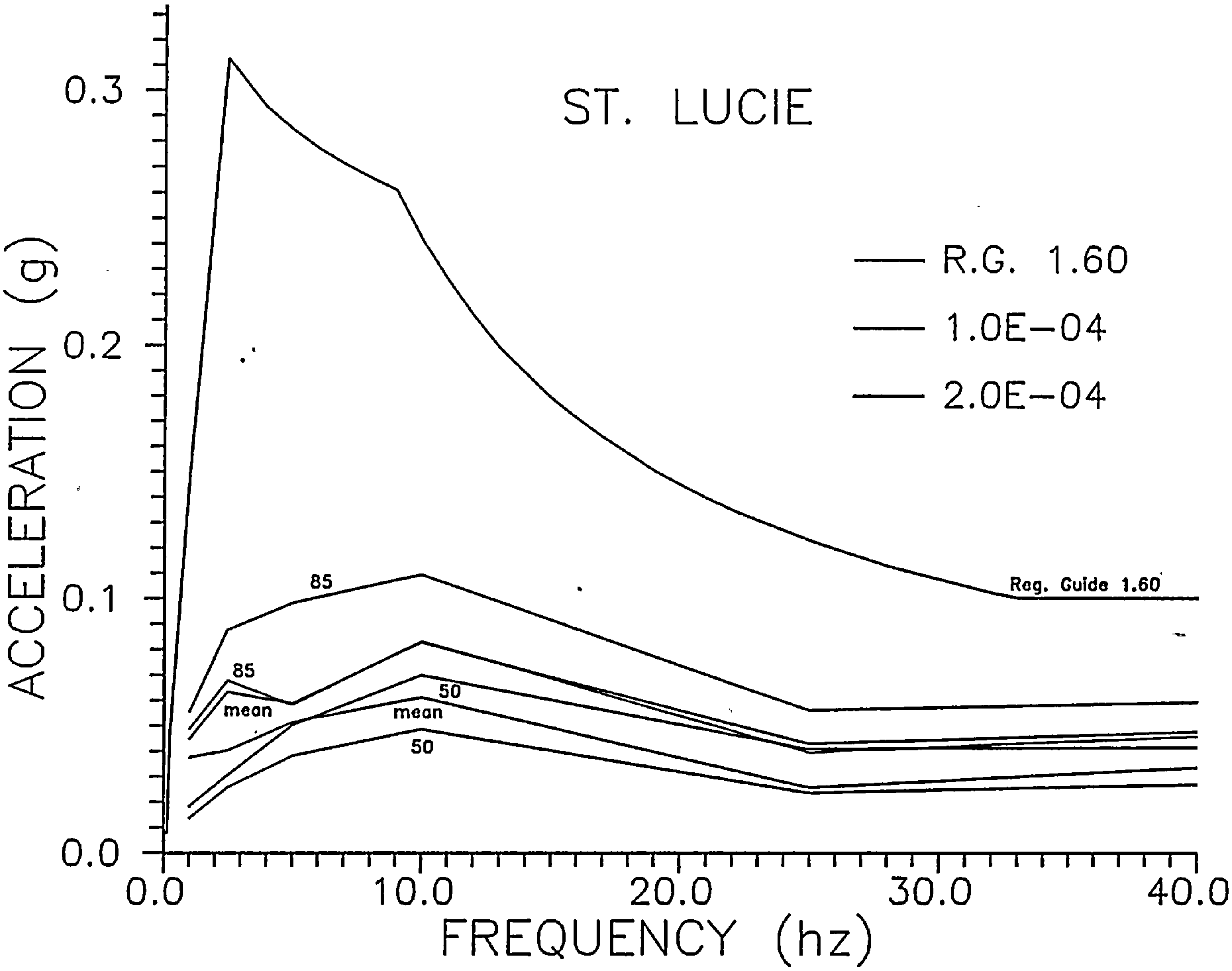
The (safe shutdown) Housner spectra for St. Lucie Unit 1 are presently anchored at 0.1g and the Housner spectra for Turkey Point are presently anchored at 0.15g. It is FPL's intention to relicense Turkey Point to a Safe Shutdown Earthquake of 0.10g in the coming year.

In the Regulatory analysis for A-46 (NUREG-1211) a probability of 2.5×10^{-4} was chosen by the NRC. The closest, more conservative, probability available to FPL using the EPRI Uniform Hazard Spectra methodology was 2×10^{-4} and Figures 1 through 6 also provide mean and 85th percentile spectra at this probability for comparative purposes. As can be seen, significant additional seismic margin exists at this probability.

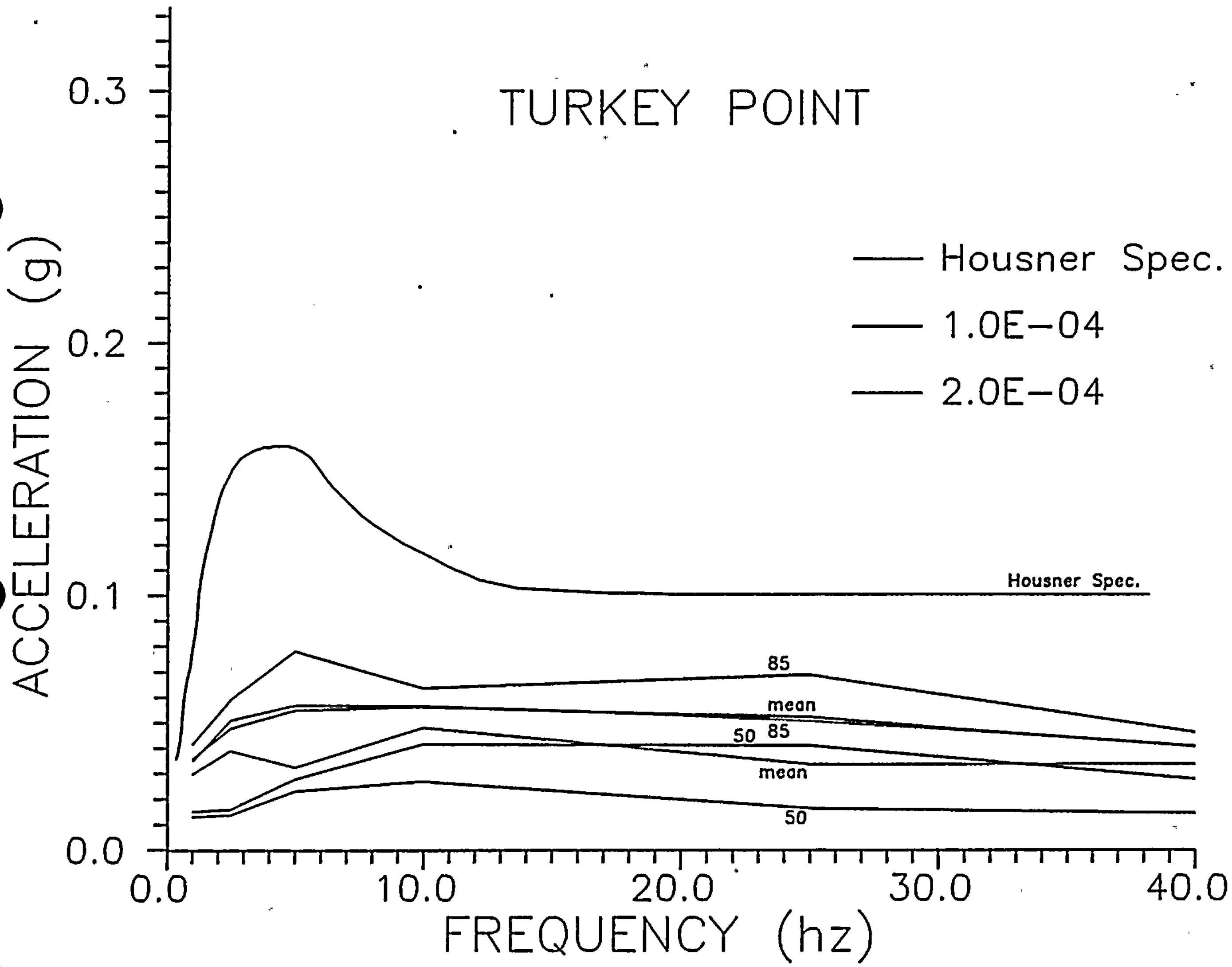
From the foregoing two examples it can be concluded that all of FPL's plants, if designed to Housner or Reg. Guide 1.60 spectra anchored at the legal minimum of 0.1g, clearly have the Safe Shutdown Earthquake design capacity needed to meet the NRC's performance objective of mean frequency of core damage, an objective beyond current licensing basis, without having to take credit for any earthquake resistance offered by any plant systems, structures, or equipment. It can be further concluded that at the NUREG-1211 probability of 2.5×10^{-4} on which the Regulatory Analysis for A-46 is based, that significant additional seismic margin exists.



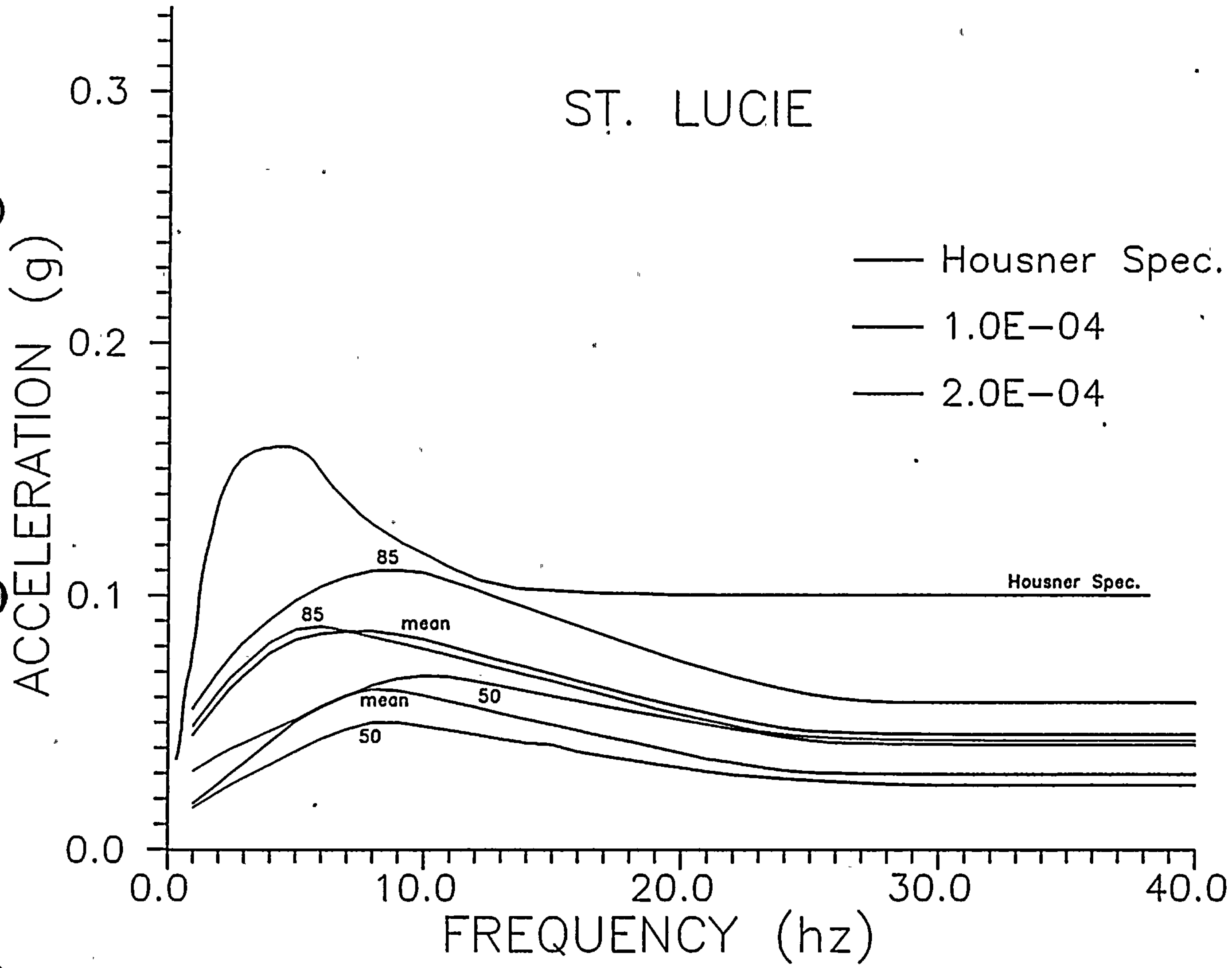
Florida Power and Light Company
EBASCO SERVICES INCORPORATED
Uniform Hazard Spectra St. Lucie Unit 1 FIGURE 1



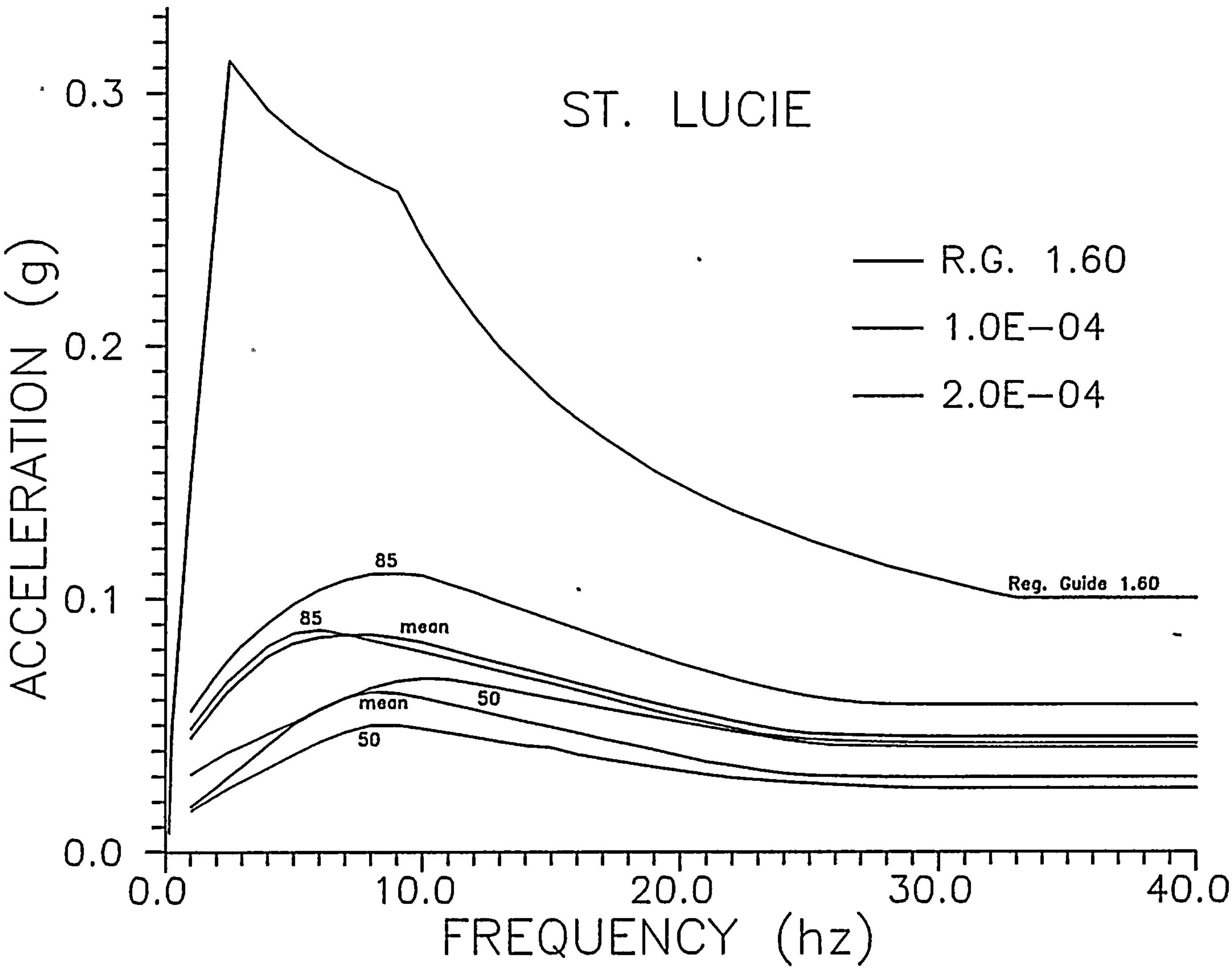
Florida Power and Light Company
EBASCO SERVICES INCORPORATED
Uniform Hazard Spectra St. Lucie Unit 2 FIGURE 2



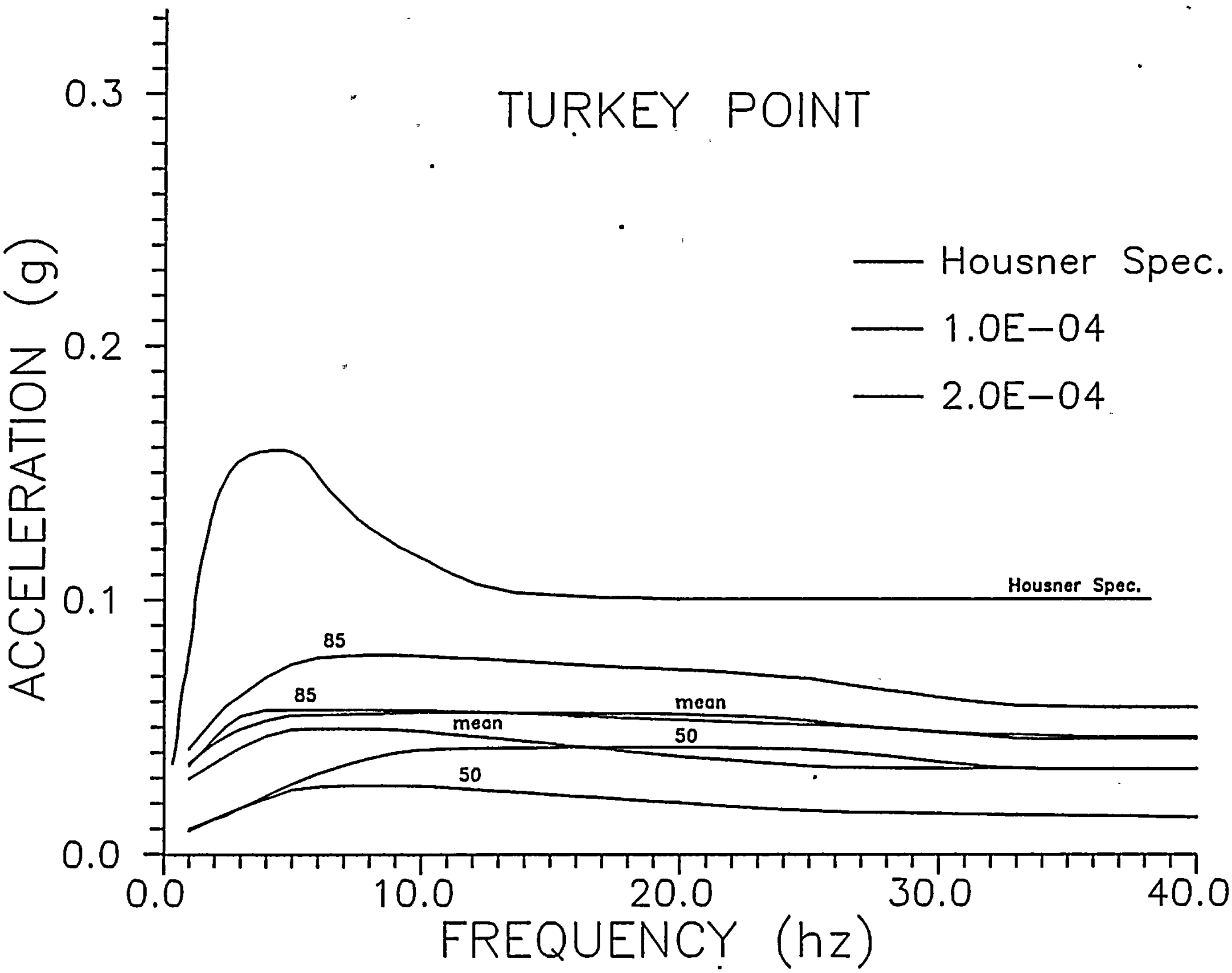
Florida Power and Light Company
EBASCO SERVICES INCORPORATED
Uniform Hazard Spectra Turkey Point Units 3/4 FIGURE 3



Florida Power and Light Company
EBASCO SERVICES INCORPORATED
Smoothed Uniform Hazard Spectra St. Lucie Unit 1 FIGURE 4



Florida Power and Light Company
EBASCO SERVICES INCORPORATED
Smoothed Uniform Hazard Spectra St. Lucie Unit 2 FIGURE 5



Florida Power and Light Company
EBASCO SERVICES INCORPORATED
Smoothed Uniform Hazard Spectra Turkey Point Units 3/4 FIGURE 6

PROBABILISTIC SEISMIC HAZARD EVALUATION AND UNIFORM HAZARD SPECTRA

St. Lucie and Turkey Point Nuclear Power Plant Sites

FLORIDA

Executive Summary
prepared for the

Florida Power & Light Company Nuclear Licensing Department

December 1989

EBASCO

EBASCO SERVICES INCORPORATED
Greensboro, N.C.

EXECUTIVE SUMMARY

1. Introduction

As a result of the unresolved questions regarding the cause and source of seismicity in the region of the United States east of 105°W longitude (Eastern U.S.), the U.S. Nuclear Regulatory Commission (NRC) is actively pursuing the use of probabilistic methods, as alternatives to the deterministic methods used in the past, to determine the adequacy of the seismic design of nuclear facilities in the Eastern U.S. The methodology takes into account the uncertainties in source geometry, seismicity parameters and ground motion for large earthquakes that could occur in the Eastern U.S. As part of the NRC-funded investigations, the Lawrence Livermore National Laboratory (LLNL) initially conducted probabilistic seismic hazard evaluations for ten "sample sites" whose locations are shown on Figure 1. Recently it published an eight volume report on seismic hazard characterization of 69 nuclear plant sites east of the Rocky Mountains, and presented comparisons to previous results for ten test sites (Bernreuter et al., 1989). A parallel probabilistic seismic hazard study, based on an intensive data collection and evaluation effort, was implemented by the Electric Power Research Institute (EPRI) (1986-87) with the assistance of six Technical Evaluation Contractors (TEC). Both the NRC-funded LLNL studies, and the EPRI investigations, funded by a group of nuclear power plant owners in the Eastern U.S., utilize comprehensive seismic and tectonic data bases and recent advances in the probabilistic methodologies to perform a state-of-the-art seismic hazard evaluation for sites located in the Eastern U.S.

In light of these recent advances in probabilistic seismic risk assessment, the Florida Power and Light Company (FP&L), Nuclear Licensing Department requested that Ebasco Services Incorporated (ESI) perform a state-of-the-art seismic hazard evaluation for its St. Lucie and Turkey Point nuclear power plant sites and generate the associated uniform hazard spectra for comparison purposes. The evaluation was performed under the Quality Assurance requirements of 10 CFR 50 Appendix B, and used the methodology, computer programs, and the tectonic and seismic input parameters developed as a result of the EPRI

investigations. In addition, the scope of the ESI investigation included an evaluation of the contribution to seismic hazard at the St. Lucie and Turkey Point sites from the possible occurrence of large magnitude earthquakes in the Northern Caribbean.

2. Procedure

Following the EPRI methodology, the seismic hazards and uniform hazard spectra were computed for the St. Lucie and Turkey Point sites using the seismic source zones and seismicity parameters established by each of the six EPRI Technical Evaluation Contractors (TEC), and the seismic source zones and seismicity parameters identified by ESI for the Northern Caribbean. The location and extent of the seismic source zones that were evaluated in this study are shown on Figures 2 through 8. The source zones that contributed to the seismic hazard at each of the two plant sites have also been listed on these figures. The TEC source zone names, labels, and the EPRI Data Base Manager code numbers are given in Table 1. Two of the Northern Caribbean sources, Cayman Trough and Jamaica-Western Hispaniola, that were identified during this study contributed to the seismic hazard at Turkey Point, but contributed to the hazard at St. Lucie for pseudo relative velocities at frequencies 5 hz and less only. Also contributions of New Madrid area sources to the seismic hazard at both plant sites for each of the six TECs were found to be negligible. The scenarios and weights for the source zones that contributed to seismic hazard at St. Lucie and Turkey Point sites are given in Tables 2 and 3, respectively. The seismic hazard values that were calculated from each TEC model were then aggregated in accordance with the EPRI methodology to generate the final hazard curves.

Site specific, frequency and amplitude dependent, amplification factors were used in the hazard computation as specified by the EPRI methodology (Toro, McGuire and Silva, 1988, and Toro, McGuire and McCann, 1989).

Hazard curves for pseudo relative velocities at different frequencies were used to derive constant percentile and mean uniform hazard spectra (UHS), at various specified risk levels.

3. Results

The mean and 15th, 50th, and 85th percentile hazard, in terms of annual probabilities of exceedance, for different peak ground accelerations at the St. Lucie site are shown in Table 4. The results for the St. Lucie site are presented as constant percentile hazard curves on Figure 9 for peak ground acceleration. On this figure the 15th, 50th, and 85th percentile curves represent the aggregated results of all TECs. The mean hazard curve is shown by a dashed line. Sensitivity of hazard results to different earth science teams is shown in Figure 10 by plotting the 50th percentile hazard curve of each TEC prior to aggregation. For reference, Figure 10 also includes the mean and 85th, 50th, and 15th percentile curves aggregated over all teams.

Figures 11 through 15 show uniform hazard spectrum plots for annual exceedance probabilities of 1.0E-05, 1.0E-04, 2.0E-04, 1.0E-03 and 2.0E-03, each showing the 15th, 50th, and 85th percentile uniform hazard spectra. Figure 16 is a uniform hazard spectrum plot, showing mean spectra for annual exceedance probabilities of 1.0E-05, 1.0E-04, 2.0E-04, 1.0E-03 and 2.0E-03.

Seismic hazard results for the Turkey Point site are presented on Table 5. In the same sequence as for St. Lucie, the hazard curves for peak ground acceleration and uniform hazard spectra for the Turkey Point site are shown on Figures 17 through 24.

The annual probability of exceedance and the corresponding return periods for the 50th percentile hazard at various levels of peak ground acceleration for the St. Lucie and Turkey Point sites are given in Tables 6 and 7, respectively, and for the 85th percentile hazard in Tables 8 and 9, respectively.

4. Summary and Conclusions

As one would expect from a general observation of seismicity of the Florida peninsula, within the context of the Eastern U.S. seismicity as seen on an epicenter map, the level of

seismic hazard at St. Lucie and Turkey Point sites is very low. Most of the contribution to the hazard at the two sites, for each of the earth science teams, comes from the background source containing the site. Background sources have been characteristically assigned low maximum magnitudes by all TEC teams in comparison to other sources in the eastern U.S. It was also noted that distant sources making contribution to the hazard at the two sites for low frequency ground motion make less contribution at the sites for high frequency ground motion. It appears that the high frequency components of ground motion attenuate at a more rapid rate with distance than lower frequency components. Thus some distant sources whose contribution was negligible in the computation of high frequency ground motion, were included in the computation of total annual probability of exceedance.

In summary, the results of the probabilistic seismic hazard evaluation for Florida Power and Light's St. Lucie and Turkey Point sites, using the EPRI methodology, yield very low values for each site's seismic hazard.

5. Bibliography

Bernreuter, D.L., J.B. Savy, R.W. Mensing and J.C. Chen (1989). "Seismic Hazard Characterization of 69 Nuclear Power Plant Sites East of the Rocky Mountains", Volumes 1-8, U.S. Nuclear Regulatory Commission, NUREG/CR-5250, UCID-21517.

Electric Power Research Institute (1986-87). "Seismic Hazard Methodology for the Central and Eastern United States", Volumes 1-10, Palo Alto, CA, EPRI NP-4726.

Toro, G.R., R.K. McGuire and W.J. Silva (1988). "Engineering Model of Earthquake Ground Motion for Eastern North America", Electric Power Research Institute, Palo Alto, CA, EPRI NP-6074, Research Project 2556-16.

Toro, G.R., R.K. McGuire and M.W. McCann (1989). "EQHAZARD Primer", Electric Power Research Institute, Palo Alto, CA, EPRI NP-6452-D, Research Project P101-46.

TABLE 1

Computerized Data Base Label No. of Source Zones

TEC Name	TEC Label No. (Used on TEC Maps)	Source Name	Data Base Label No. (Used on Computer Files)
Bechtel Group	13	Mesozoic Basins	01300
	30	New Madrid	03000
	31	Reelfoot Rift	03100
	H	Charleston Area	05200
	N-3	Charleston Faults	05900
	BZ-0	New Madrid Region	00100
	BZ-1	Gulf Coast Background	00600
	BZ-4	Atlantic Coast Background	02000
Dames & Moore	20	Southern Coastal Margin	02000
	21	New Madrid	02100
	22	Reelfoot Rift	02200
	22-21B	Reelfoot Rift-New Madrid	91500
	52	Charleston Rift	05200
	53	Southern Appalachian Default	05300
	54	Charleston Seismic Zone	05400
	65	Dunbarton Triassic Basin	06500
Law Engineering	04a	Reelfoot Rift(A)	00401
	04b	Reelfoot Rift(B)	00402
	22	Reactivated Eastern Seaboard	02200
	08	Mesozoic Basins	00816
	18	Reelfoot Rift Faults	01800
	35	Charleston	03500
	108	Brunswick Background	04300
	126	Southern Coastal Block	06001
	M-37	Mafic Pluton	03837
	M-38	Mafic Pluton	03838
	M-39	Mafic Pluton	03839
	M-40	Mafic Pluton	03840
	M-41	Mafic Pluton	03841
	M-42	Mafic Pluton	03842
	M-43	Mafic Pluton	03843
	M-44	Mafic Pluton	03844
	M-45	Mafic Pluton	03845
	M-48	Mafic Pluton	03848
	M-49	Mafic Pluton	03849
	M-50	Mafic Pluton	03850

Table 1 - continued

TABLE 1 (Continued)

Computerized Data Base Label No. of Source Zones

TEC Name	TEC Label No. (Used on TEC Maps)	Source Name	Data Base Label No. (Used on Computer Files)
Rondout Associates	1	New Madrid	00100
	2	New Madrid Rift	00200
	24	Charleston	02400
	26	South Carolina	02600
	49-05	Appalachian Basement Background	04905
	51	Gulf Coast to Bahamas Background	05100
Weston Geophysical	25	Charleston	02500
	26	South Carolina	02600
	31	New Madrid	03100
	32	Reelfoot Rift	03200
	104	Southern Coastal Plain Background	05400
	107	Gulf Coast Background	05700
	Z032-Z031	Combination (C-11)	91100
	Z104-Z022	Combination (C-20)	92000
	Z104-Z025	Combination (C-21)	92100
	Z104-Z026	Combination (C-22)	92200
	Z104-Z022 -Z026	Combination (C-23)	92300
	Z104-Z022 -Z025	Combination (C-24)	92400
	Z104 -Z028BCDE -Z022-Z025	Combination (C-27)	92700
	Z104 -Z028BCDE -Z022-Z026	Combination (C-28)	92800
Woodward-Clyde	1	Continental Shelf Edge	00100
	29	SC Gravity Saddle (extended)	02900
	29A	SC Gravity Saddle #2	0290A
	30	Charleston NOTA	03000
	40	Central Reelfoot Rift	04000
	41	Combination (C-8)	90800
	44	New Madrid Loading Zone	04400

TABLE 2
Scenarios for Contributing Source Zones[1]
St. Lucie (frequencies greater than 5hz)

TEC Team	Scenario[2]	Weight[3]
Bechtel	00600 + 02000 + 01300 + 05200	0.05
	00600 + 02000 + 01300	0.05
	00600 + 02000 + 05200	0.45
	00600 + 02000	0.45
Background	00600	1.0
	02000	1.0
Dames and Moore	02000 + 05400	0.28
	02000 + 05400 + 05200	0.46
	02000 + 05400 + 05300	0.26
Background	02000	1.0
Law Engineering	04300 + 06001 + 02200	0.27
	04300 + 06001 + 00816	0.27
	04300 + 06001	0.46
Background	04300	0.42
	06001	0.49
Rondout Associates	02400 + 02600 + 04905 + 05100	1.0
Background	04905	1.0
	05100	1.0
Weston Geophysical Corporation	05700 + 92000	0.001
	05700 + 02500 + 92100	0.012
	05700 + 02600 + 92200	0.069
	05700 + 02600 + 92300	0.312
	05700 + 02500 + 92400	0.368
	05700 + 02500 + 92700	0.126
	05700 + 02600 + 92800	0.100
	05700 + 05400	0.012
Background	05700	1.0
Woodward Clyde Consultants	WCCBK	0.573
	WCCBK + 02900	0.122
	WCCBK + 0290A	0.305
Background	WCCBK	1.0

Table 2 - continued

TABLE 2 (continued)
Scenarios for Contributing Source Zones[1]
St. Lucie (frequencies 5hz and less)

TEC Team	Scenario[2]	Weight[3]
Bechtel	00600 + 02000 + 01300 + 05200 + CB001 + CB002	0.05
	00600 + 02000 + 01300 + CB001 + CB002	0.05
	00600 + 02000 + 05200 + CB001 + CB002	0.45
	00600 + 02000 + CB001 + CB002	0.45
Background	00600	1.0
	02000	1.0
Dames and Moore	02000 + 05400 + CB001 + CB002	0.28
	02000 + 05400 + 05200 + CB001 + CB002	0.46
	02000 + 05400 + 05300 + CB001 + CB002	0.26
Background	02000	1.0
Law Engineering	04300 + 06001 + 02200 + CB001 + CB002	0.2700
	04300 + 06001 + 00816 + 03842 + 03848 + 03849 + 03850 + CB001 + CB002	0.1161
	04300 + 06001 + 00816 + CB001 + CB002	0.1539
	04300 + 06001 + 03842 + 03848 + 03849 + 03850 + CB001 + CB002	0.1978
	04300 + 06001 + CB001 + CB002	0.2622
Background	04300	0.42
	06001	0.49
Rondout Associates	02400 + 02600 + 04905 + 05100 + CB001 + CB002	1.0
Background	04905	1.0
	05100	1.0
Weston Geophysical Corporation	05700 + 92000 + CB001 + CB002	0.001
	05700 + 02500 + 92100 + CB001 + CB002	0.012
	05700 + 02600 + 92200 + CB001 + CB002	0.069
	05700 + 02600 + 92300 + CB001 + CB002	0.312
	05700 + 02500 + 92400 + CB001 + CB002	0.368
	05700 + 02500 + 92700 + CB001 + CB002	0.126
	05700 + 02600 + 92800 + CB001 + CB002	0.100
	05700 + 05400 + CB001 + CB002	0.012
Background	05700	1.0

Table 2 - continued

TABLE 2 (continued)
Scenarios for Contributing Source Zones[1]
St. Lucie (frequencies 5hz and less)

TEC Team	Scenario[2]	Weight[3]
Woodward Clyde Consultants	WCCBK + CB001 + CB002	0.573
	WCCBK + 02900 + CB001 + CB002	0.122
	WCCBK + 0290A + CB001 + CB002	0.305
Background	WCCBK	1.0

Notes: [1] Source Zone numbers correspond to those on Table 1 and on Figures 2 through 7.

[2] Each TEC scenario is made up of the allowable source zone combinations whose total weights, or probability of activity add up to 1.0.

[3] Weight is defined as the fractional probability of activity.

TABLE 3
Scenarios for Contributing Source Zones[1]
Turkey Point (frequencies greater than 5hz)

TEC Team	Scenario[2]	Weight[3]
Bechtel	00600 + 02000 + CB001 + CB002	1.0
Background	00600	1.0
	02000	1.0
Dames and Moore	02000 + CB001 + CB002	1.0
Law Engineering	04300 + 06001 + 02200 + CB001 + CB002	0.27
	04300 + 06001 + 00816 + CB001 + CB002	0.27
	04300 + 06001 + CB001 + CB002	0.46
Background	04300	0.42
	06001	0.49
Rondout Associates	04905 + 05100 + CB001 + CB002	1.0
Background	04905	1.0
	05100	1.0
Weston Geophysical Corporation	05700 + CB001 + CB002	1.0
Background	05700	1.0
Woodward Clyde Consultants	WCCBK + CB001 + CB002	1.0
Background	WCCBK	1.0

Table 3 - continued

TABLE 3 (continued)
Scenarios for Contributing Source Zones[1]
Turkey Point (frequencies 5hz and less)

TEC Team	Scenario[2]	Weight[3]
Bechtel	00600 + 02000 + CB001 + CB002	1.0
Background	00600	1.0
	02000	1.0
Dames and Moore	02000 + 05400 + CB001 + CB002	0.28
	02000 + 05400 + 05200 + CB001 + CB002	0.46
	02000 + 05400 + 05300 + CB001 + CB002	0.26
Law Engineering	04300 + 06001 + 02200 + CB001 + CB002	0.2700
	04300 + 06001 + 00816 + 03842 + 03848 + CB001 + CB002	0.1161
	04300 + 06001 + 00816 + CB001 + CB002	0.1539
	04300 + 06001 + 03842 + 03848 + CB001 + CB002	0.1978
	04300 + 06001 + CB001 + CB002	0.2622
Background	04300	0.42
	06001	0.49
Rondout Associates	02400 + 02600 + 04905 + 05100 + CB001 + CB002	1.0
Background	04905	1.0
	05100	1.0
Weston Geophysical Corporation	05700 + 92000 + CB001 + CB002	0.001
	05700 + 02500 + 92100 + CB001 + CB002	0.012
	05700 + 02600 + 92200 + CB001 + CB002	0.069
	05700 + 02600 + 92300 + CB001 + CB002	0.312
	05700 + 02500 + 92400 + CB001 + CB002	0.368
	05700 + 02500 + 92700 + CB001 + CB002	0.126
	05700 + 02600 + 92800 + CB001 + CB002	0.100
	05700 + 05400 + CB001 + CB002	0.012
Background	05700	1.0

Table 3 - continued

TABLE 3 (continued)
Scenarios for Contributing Source Zones[1]
Turkey Point (frequencies 5hz and less)

TEC Team	Scenario[2]	Weight[3]
Woodward Clyde Consultants	WCCBK + CB001 + CB002	0.573
	WCCBK + 02900 + CB001 + CB002	0.122
	WCCBK + 0290A + CB001 + CB002	0.305
Background	WCCBK	1.0

Notes: [1] Source Zone numbers correspond to those on Table 1 and on Figures 2 through 7.

[2] Each TEC scenario is made up of the allowable source zone combinations whose total weights, or probability of activity add up to 1.0.

[3] Weight is defined as the fractional probability of activity.

TABLE 4
St. Lucie
Annual Probability of Exceedance for Peak Ground Acceleration (PGA)

PGA (cm/sec^2)	PGA (g)	Mean	Percentiles 15	50	85
7.00	0.007	7.36E-04	1.82E-05	4.97E-04	1.60E-03
65.00	0.07	3.89E-05	7.80E-07	3.15E-05	6.84E-05
120.00	0.12	1.24E-05	2.00E-07	1.05E-05	2.29E-05
225.00	0.23	1.61E-06	1.40E-08	1.04E-06	2.75E-06
400.00	0.41	1.78E-07	5.82E-10	7.48E-08	3.08E-07
560.00	0.57	5.08E-08	1.97E-10	1.32E-08	8.60E-08
800.00	0.82	1.22E-08	1.91E-10	1.51E-09	1.41E-08

TABLE 5
Turkey Point
Annual Probability of Exceedance for Peak Ground Acceleration (PGA)

PGA (cm/sec^2)	PGA (g)	Mean	Percentiles 15	50	85
5.00	0.005	3.90E-03	1.02E-04	3.27E-04	1.34E-02
50.00	0.05	3.18E-05	7.89E-07	2.75E-05	5.61E-05
100.00	0.10	1.08E-05	1.87E-07	9.57E-06	2.02E-05
250.00	0.26	1.39E-06	1.29E-08	9.19E-07	2.58E-06
500.00	0.51	1.52E-07	7.26E-10	5.95E-08	2.85E-07
700.00	0.71	4.33E-08	3.91E-10	9.89E-09	7.16E-08
1000.00	1.02	1.04E-08	3.91E-10	1.17E-09	1.21E-08

TABLE 6
Peak Ground Acceleration (PGA)
Annual Probability of Exceedance and Return Periods

Seismic Hazard Results
Summary for St. Lucie Site
50th Percentile

Acceleration (g)	Annual Probability of Exceedance	Estimated Return Period (yrs)
0.007	4.97E-04	2,012
0.07	3.15E-05	31,746
0.12	1.05E-05	95,238
0.23	1.04E-06	961,538
0.41	7.48E-08	13,368,984
0.57	1.32E-08	75,757,576
0.82	1.51E-09	662,251,655

TABLE 7
Peak Ground Acceleration (PGA)
Annual Probability of Exceedance and Return Periods

Seismic Hazard Results
Summary for Turkey Point Site
50th Percentile

Acceleration (g)	Annual Probability of Exceedance	Estimated Return Period (yrs)
0.005	3.27E-04	3,058
0.05	2.75E-05	36,364
0.10	9.57E-06	104,493
0.26	9.19E-07	1,088,139
0.51	5.95E-08	16,806,723
0.71	9.89E-09	101,112,234
1.02	1.17E-09	854,700,854

TABLE 8
Peak Ground Acceleration (PGA)
Annual Probability of Exceedance and Return Periods

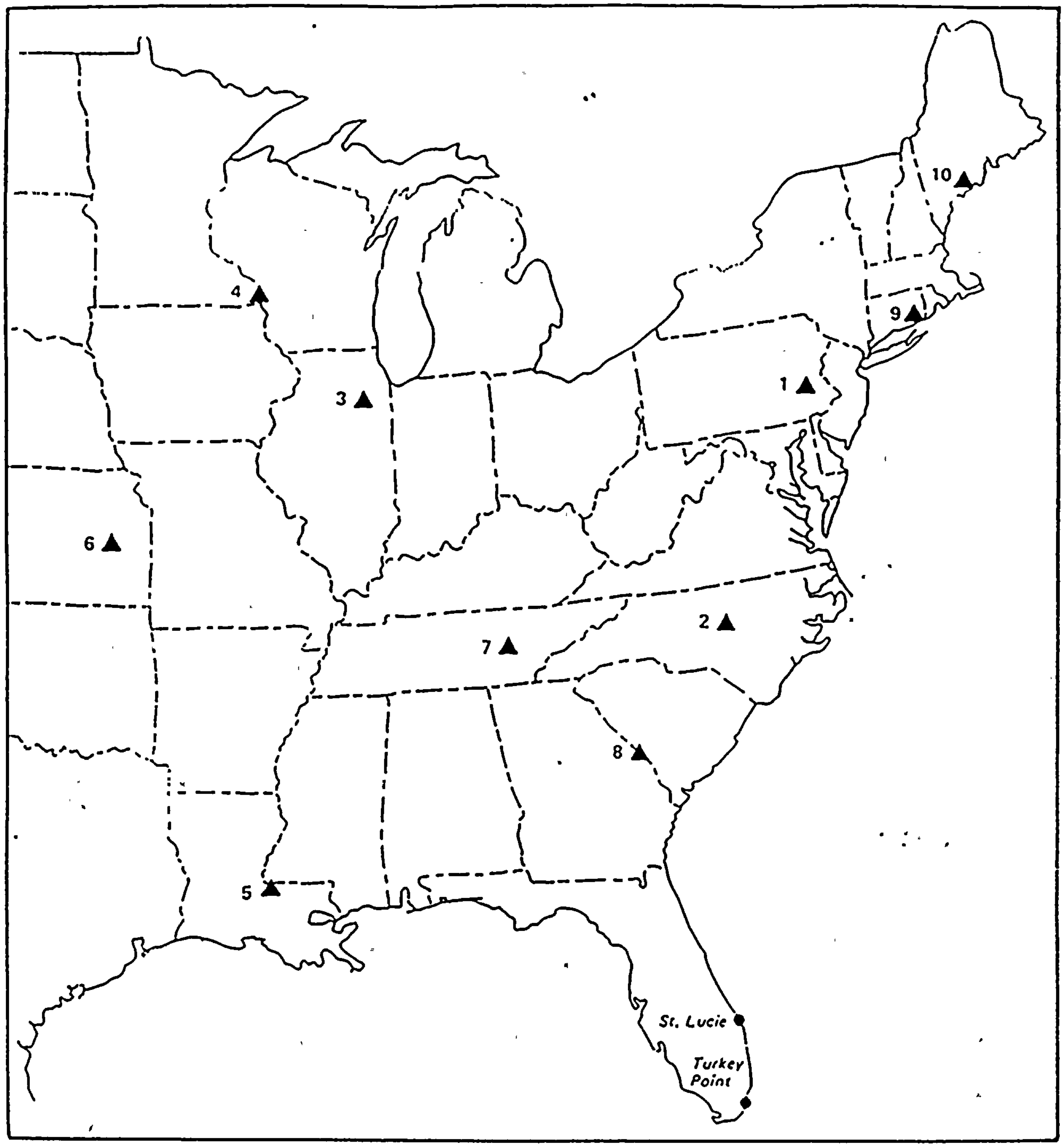
Seismic Hazard Results
Summary for St. Lucie Site
85th Percentile

Acceleration (g)	Annual Probability of Exceedance	Estimated Return Period (yrs)
0.007	1.60E-03	625
0.07	6.84E-05	14,620
0.12	2.29E-05	43,668
0.23	2.75E-06	363,636
0.41	3.08E-07	3,246,753
0.57	8.60E-08	11,627,907
0.82	1.41E-08	70,921,986

TABLE 9
Peak Ground Acceleration (PGA)
Annual Probability of Exceedance and Return Periods

Seismic Hazard Results
Summary for Turkey Point Site
85th Percentile

Acceleration (g)	Annual Probability of Exceedance	Estimated Return Period (yrs)
0.005	1.34E-02	75
0.05	5.61E-05	17,825
0.10	2.02E-05	49,505
0.26	2.58E-06	387,597
0.51	2.85E-07	3,508,772
0.71	7.16E-08	13,966,480
1.02	1.21E-08	82,644,628



Key to Site Index Numbers

* Sites considered by LLNL to fall in the Southeastern Region of the U.S.

1. Limerick *
2. Shearon Harris *
3. Braidwood
4. La Crosse
5. River Bend
6. Wolf Creek
7. Watts Bar *
8. Vogtle *
9. Millstone
10. Maine Yankee

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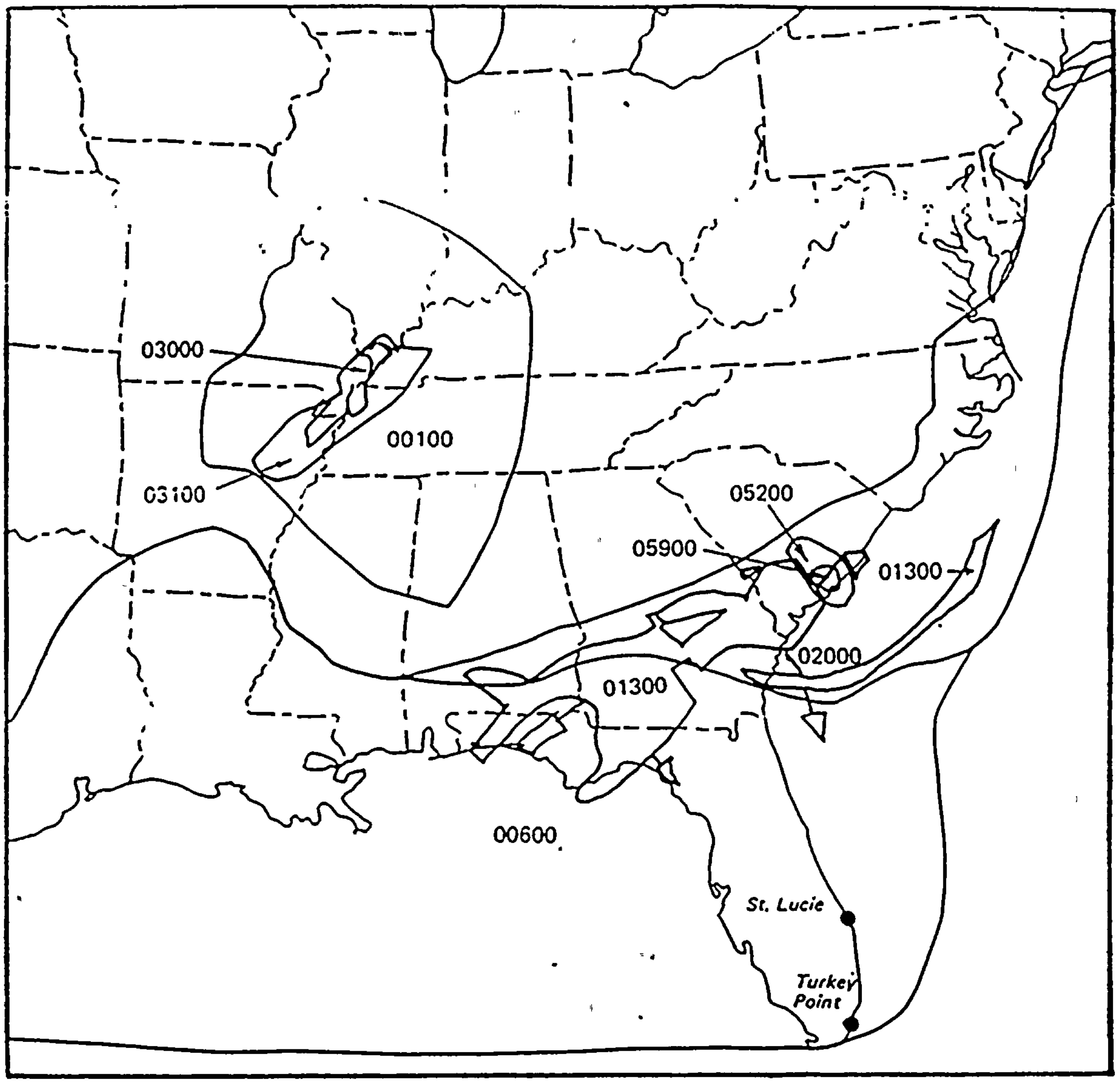
Location of the LLNL Sample Sites and St. Lucie and Turkey Point

FIGURE 1



Source Zone		Source Zone Contributing to Hazard	
Number	Name	St. Lucie	Turkey Point
01300	Mesozoic Basins	01300	
03000	New Madric		
03100	Reelfoot Rift		
05200	Charleston Area	05200	
05900	Charleston Faults		
00100	New Madrid Background		
00600	Site Background	00600	00600
02000	Adjacent Background	02000	02000

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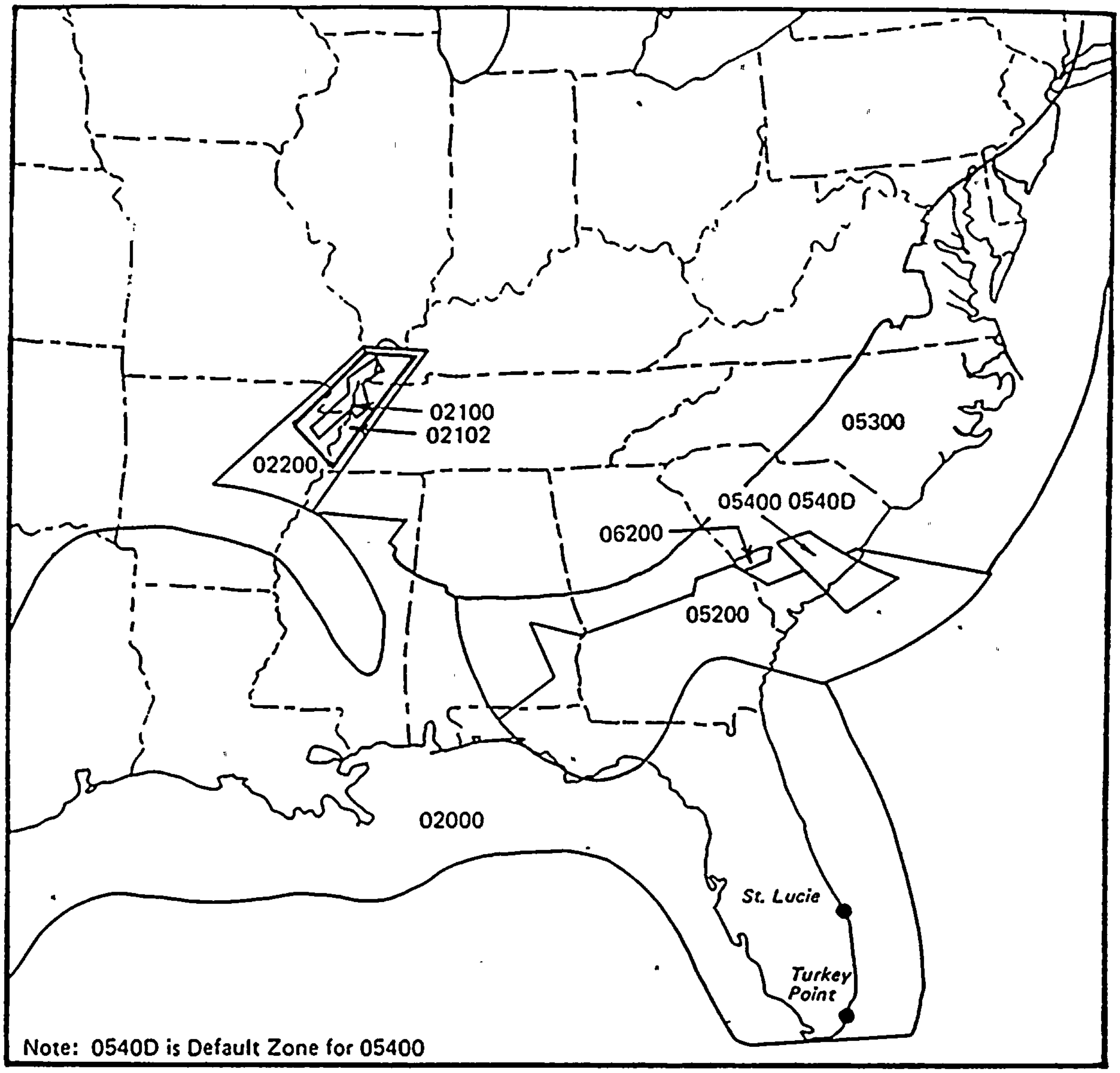
Seismic Source Zones Considered for the Florida Power and Light Company (Bechtel Group Inc. Model)

FIGURE 2



Source Zone		Source Zone Contributing to Hazard	
Number	Name	St. Lucie	Turkey Point
02000	Southern Coastal Margin	02000	02000
02100	New Madrid		
02200	Reelfoot Rift		
05200	Charleston Rift	05200	05200
05300	Southern Appalachian Default	05300	05300
05400	Charleston Seismic Zone	05400	05400
0540D	Charleston Default Zone	0540D	0540D
06200	Dunbarton Triassic Basin		

NOTE: THE UNDERLINED SOURCES CONTRIBUTE TO LOW FREQUENCY (5hz AND LESS) GROUND MOTION

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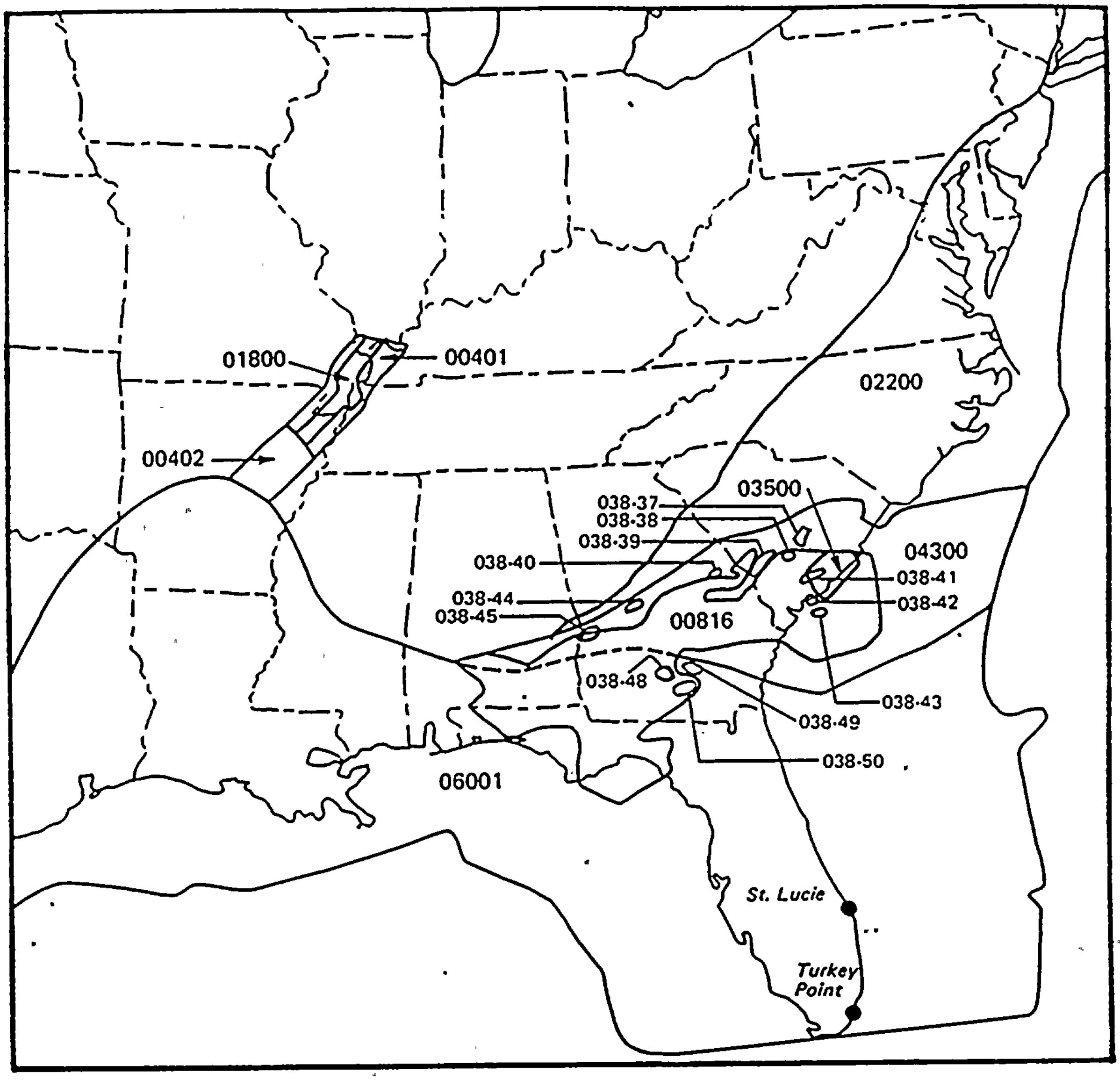
Seismic Source Zones Considered for the Florida Power and Light Company (Dames and Moore Model)

FIGURE 3



Source Zone Number	Name	Source Zone Contributing to Hazard: St. Lucie	Turkey Point
00401	Reelfoot Rift (A)		
00402	Reelfoot Rift (B)		
00816	Mesozoic Basins	00816	00816
01800	Reelfoot Rift Faults		
02200	Reactivated Eastern Seaboard	02200	02200
03500	Charleston		
04300	Brunswick	04300	04300
06001	Southern Coastal Block	06001	06001
03837 to 03845	Mafic Plutons	03842 03848	03842 03848
03848 to 03850	Mafic Plutons	03849 03850	

NOTE: THE UNDERLINED SOURCES CONTRIBUTE TO LOW FREQUENCY (5hz AND LESS) GROUND MOTION

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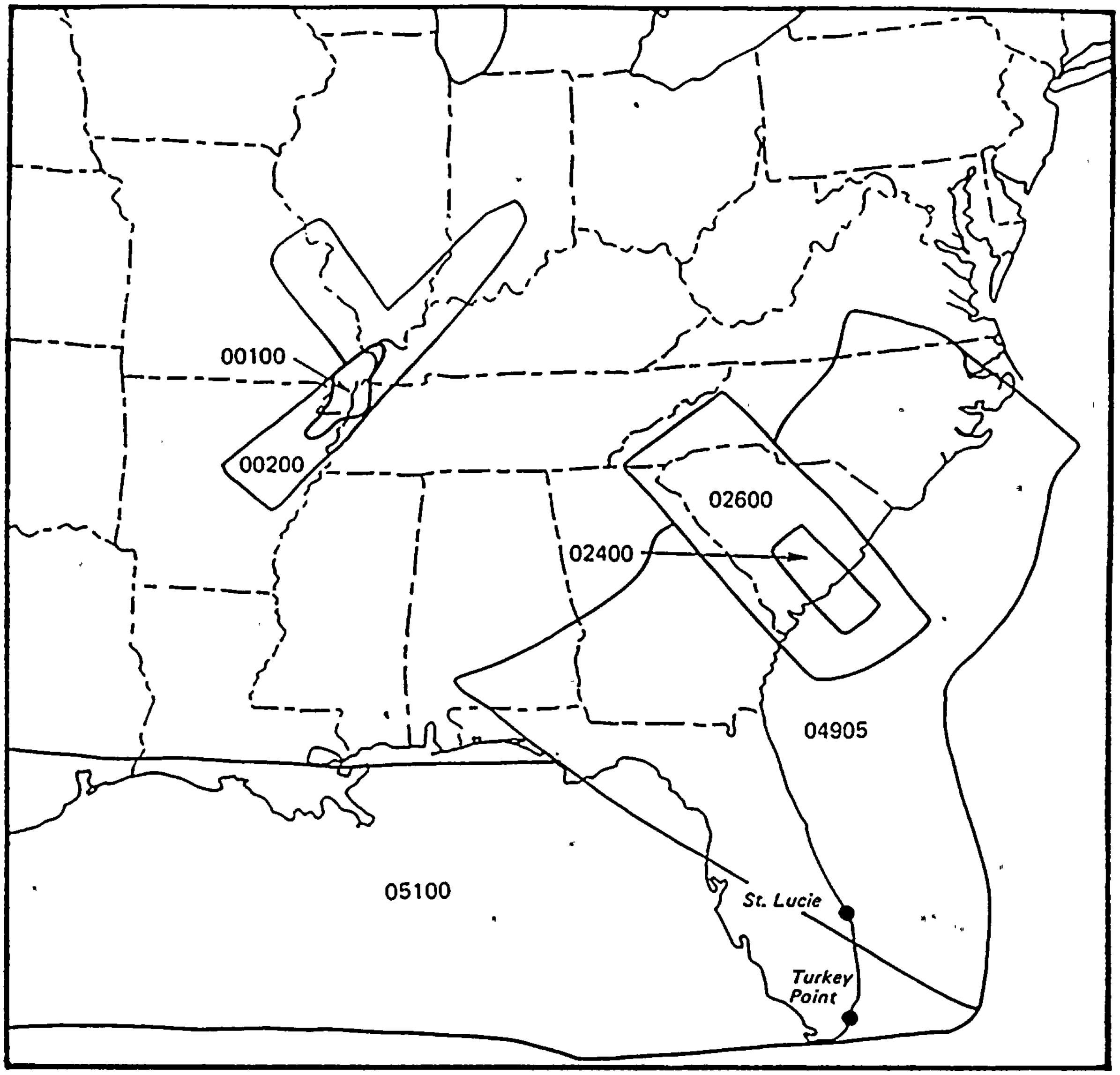
Seismic Source Zones Considered for the Florida Power and Light Company (Law Engineering Company Model)

FIGURE 4



Source Zone Number	Name	Source Zone Contributing to Hazard: St. Lucie	Source Zone Contributing to Hazard: Turkey Point
00100	New Madrid		
00200	New Madric R'ft		
02400	Charleston	02400	02400
02600	South Carolina	02600	02600
04905	Appalachian Basement Background	04905	04905
05100	Gulf Coast to Bahamas Background	05100	05100

NOTE: THE UNDERLINED SOURCES CONTRIBUTE TO LOW FREQUENCY (5hz AND LESS) GROUND MOTION

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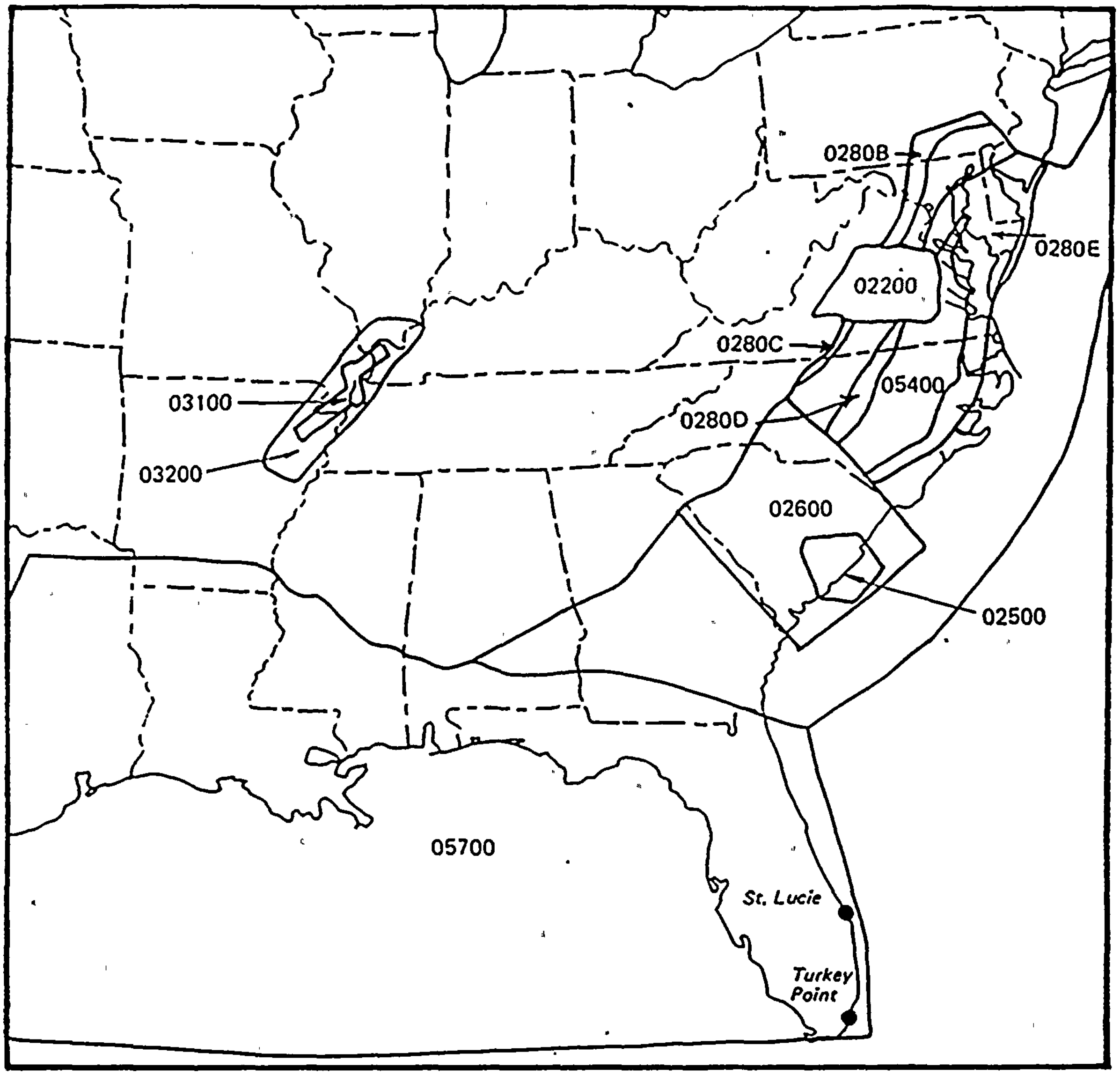
Seismic Source Zones Considered for the Florida Power and Light Company (Rondout Associates Model)

FIGURE 5



Source Zone Number	Name	Source Zone Contributing to Hazard: St. Lucie	Turkey Point
02500	Charleston	02500	02500
02600	South Carolina	02600	02600
03100	New Madrid		
03200	Reelfoot Rift		
05400	Southern Coastal Plain	05400	05400
05700	Gulf Coast Background	05700	05700
91100*	Combination 11		
92000* to 92400*	Combinations 920 to 924	92000 to 92400	92600 92400
92700*	Combination 927	92700	92700
92800*	Combination 928	92800	92800

*Geometry of Combination Sources Given in Table 1.

NOTE: THE UNDERLINED SOURCES CONTRIBUTE TO LOW FREQUENCY (5hz AND LESS) GROUND MOTION

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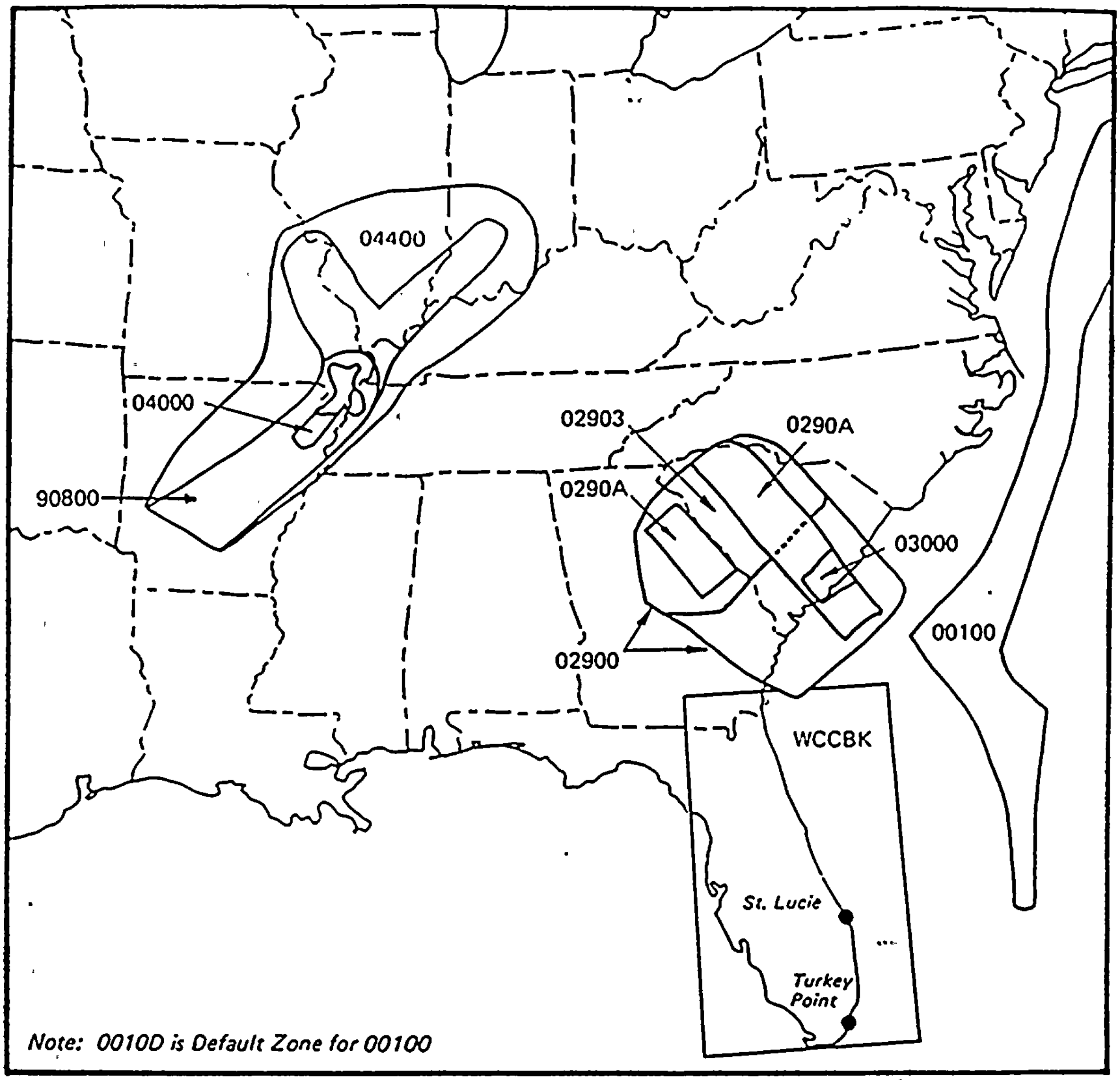
Seismic Source Zones Considered for the Florida Power and Light Company (Weston Geophysical Corp. Model)

FIGURE 6



Source Zone		Source Zone Contributing to Hazard	
Number	Name	St. Lucie	Turkey Point
00100	Continental Shelf Edge		
02900	South Carolina Gravity Saddle (extended)	02900	02900
0290A	South Carolina, Gravity Saddle No. 2	0290A	0290A
03000	Charleston NOTA		
04000	Central Reelfoot Rift		
90800	Reelfoot Rift		
04400	New Madrid Loading Zone		
WCCBK	Background	WCCBK	WCCBK

NOTE: THE UNDERLINED SOURCES CONTRIBUTE TO LOW FREQUENCY (5hz AND LESS) GROUND MOTION

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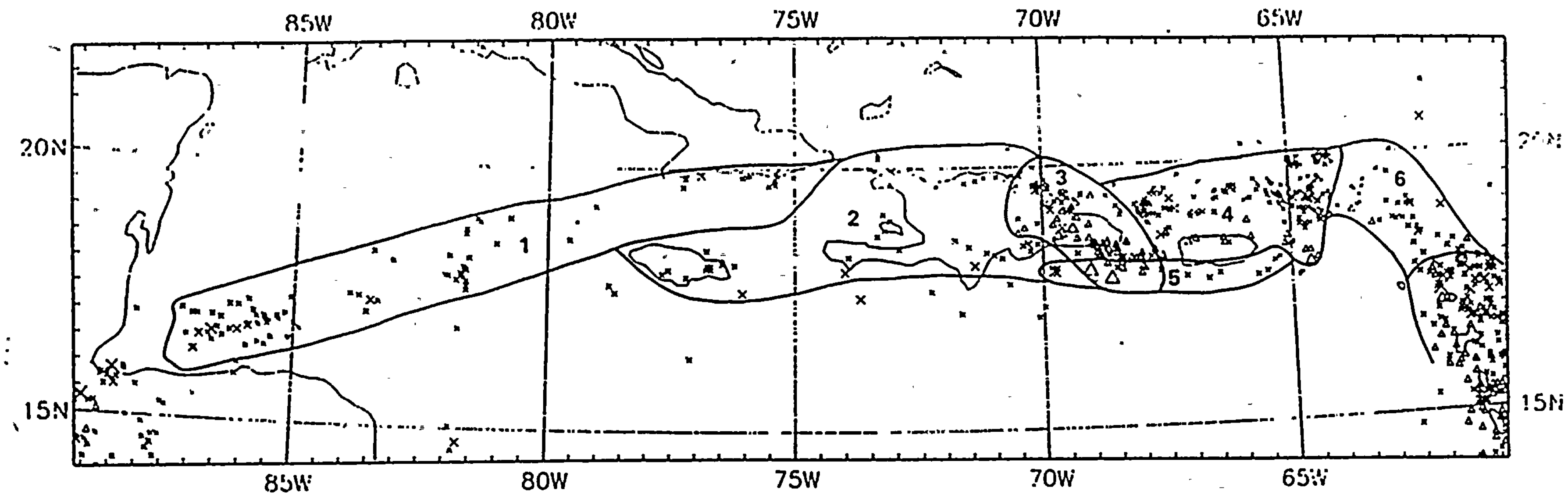
Seismic Source Zones Considered for the Florida Power and Light Company (Woodward Clyde Consultants Model)

FIGURE 7:



Source Zone			Source Zone Contributing to Hazard	
Number		Name	St. Lucie	Turkey Point
1	CB001	Cayman Trough	1	1
2	CB002	Jamaica–Western Hispaniola	2	2
3	CB003	Eastern Hispaniola		
4	CB004	Puerto Rico Trench		
5	CB005	Muertos Trench		
6	CB006	Greater Antilles– Lesser Antilles Transition		

NOTE: THE UNDERLINED SOURCES CONTRIBUTE TO LOW FREQUENCY (5hz AND LESS) GROUND MOTION

Florida Power and Light Company

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Seismic Source Zones Considered for the Florida Power and Light Company in the Northern Caribbean

FIGURE 8

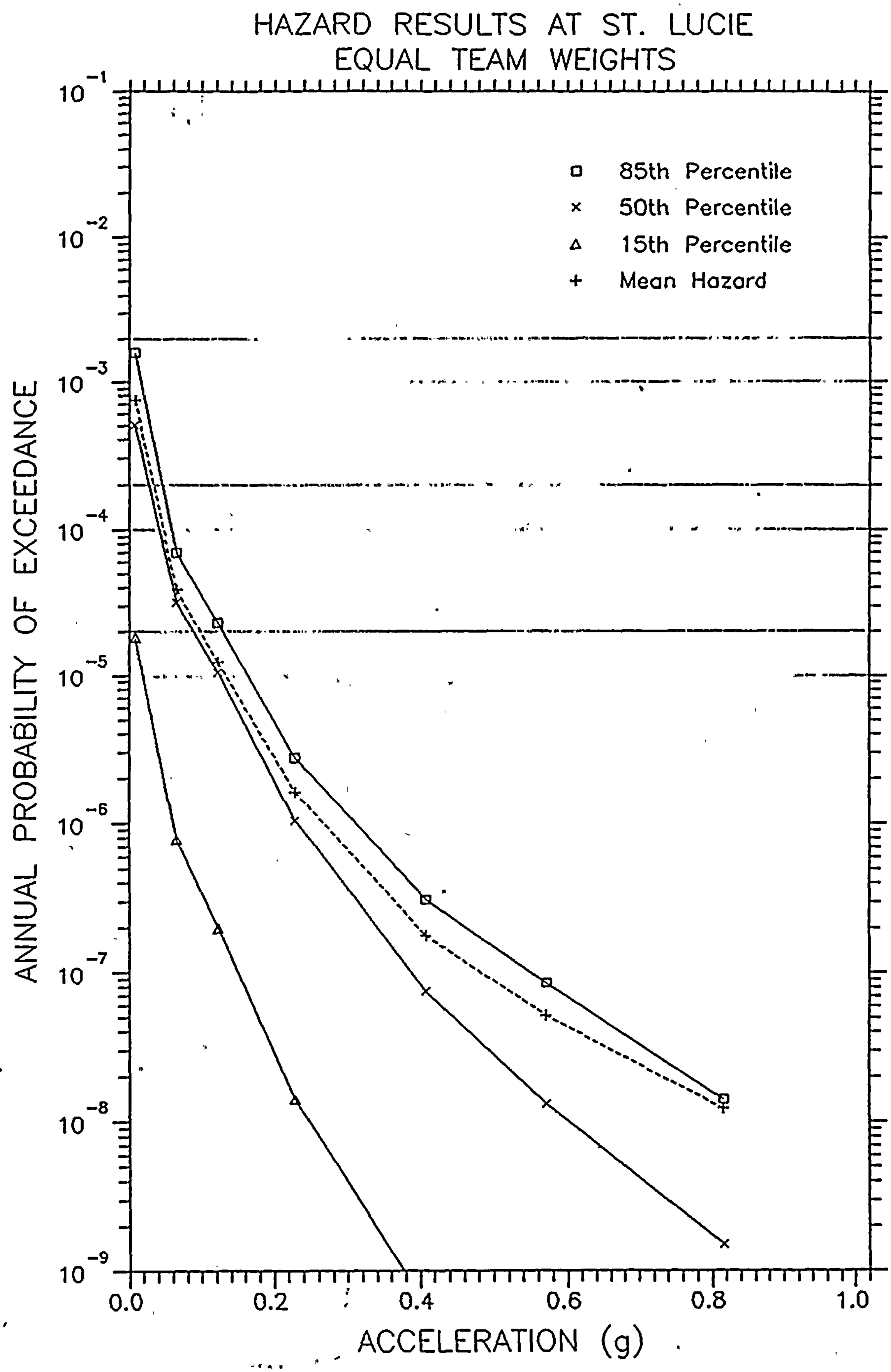

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FIGURE 9

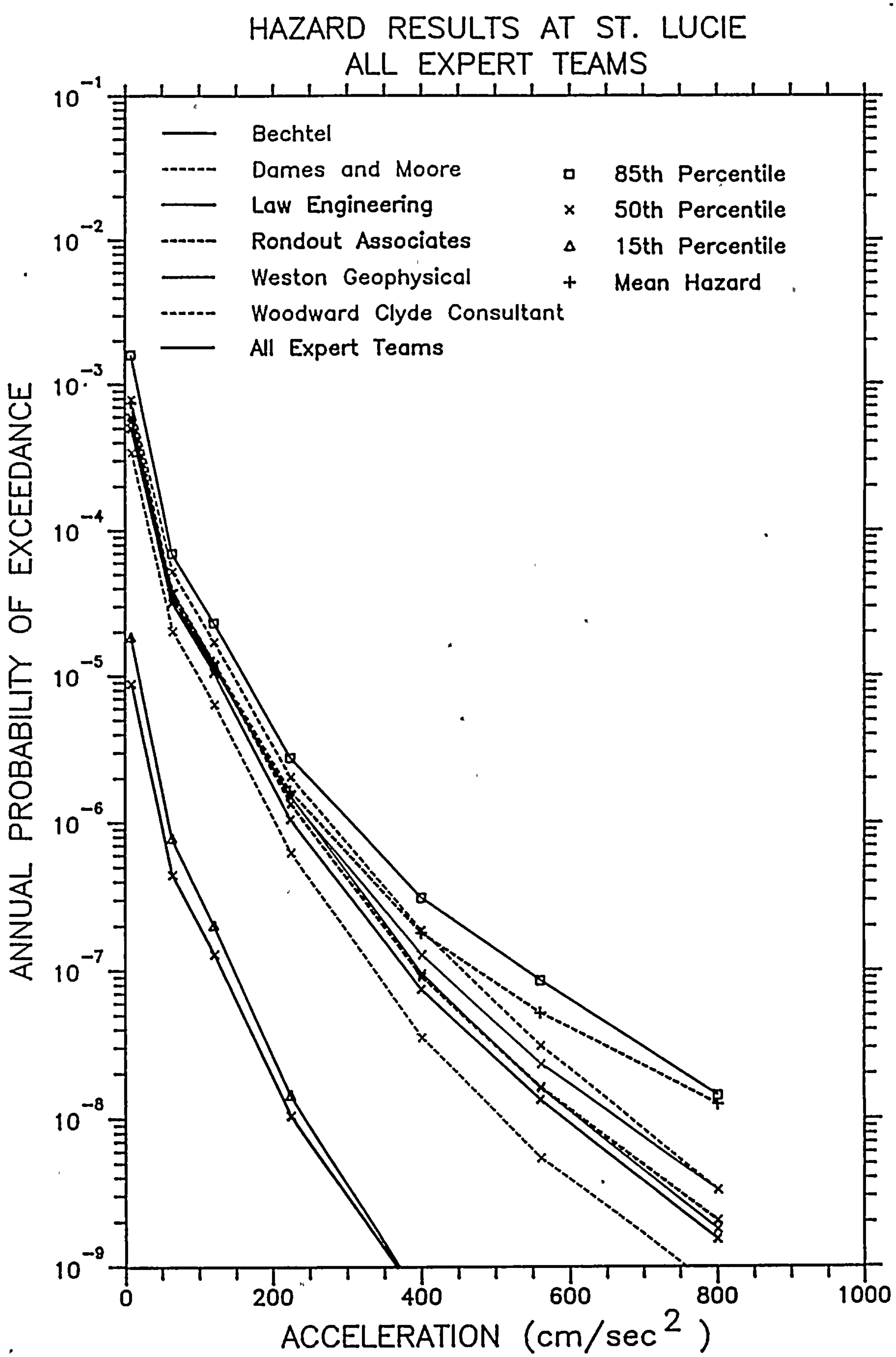

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FIGURE 10

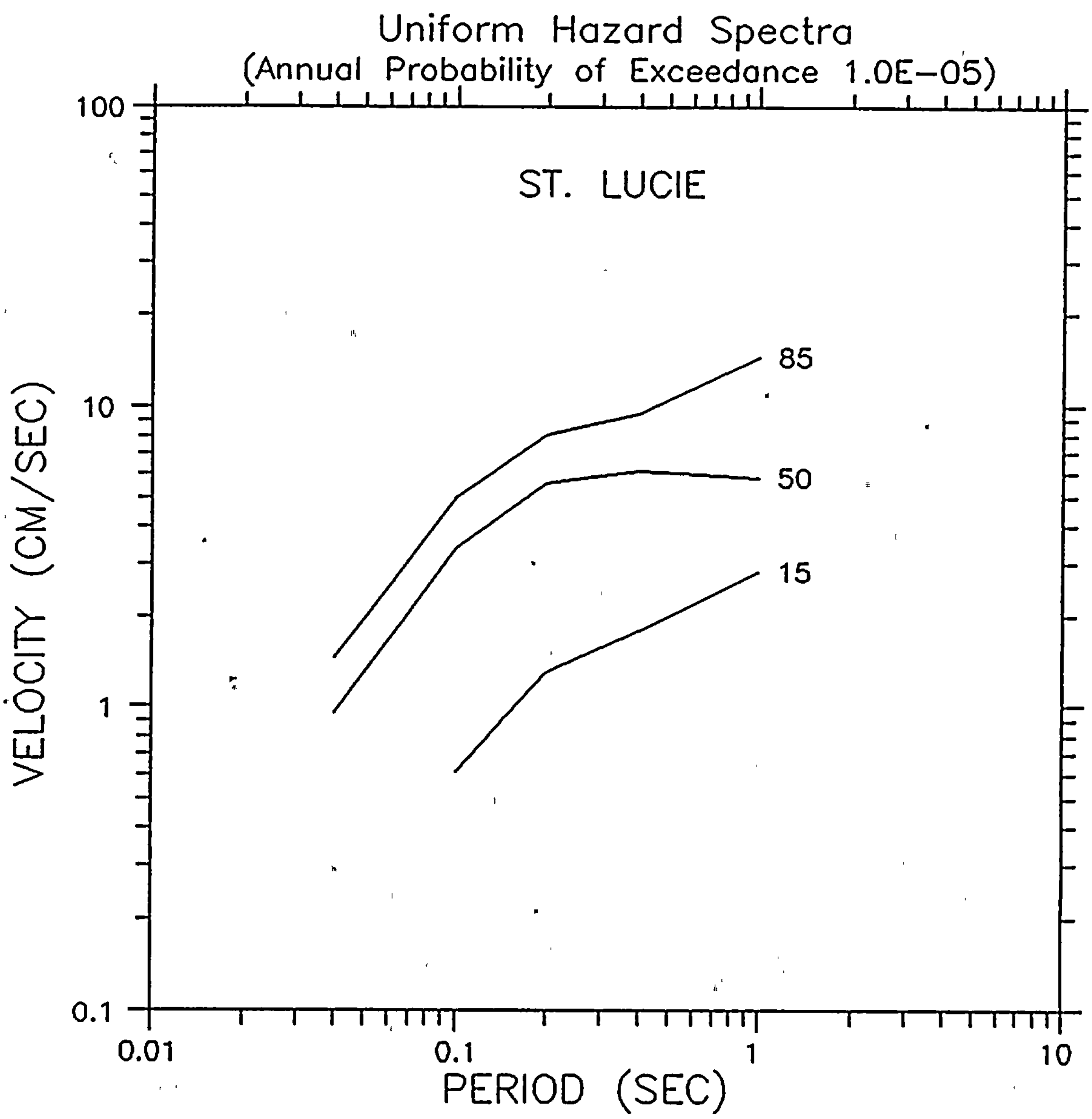

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FIGURE 11

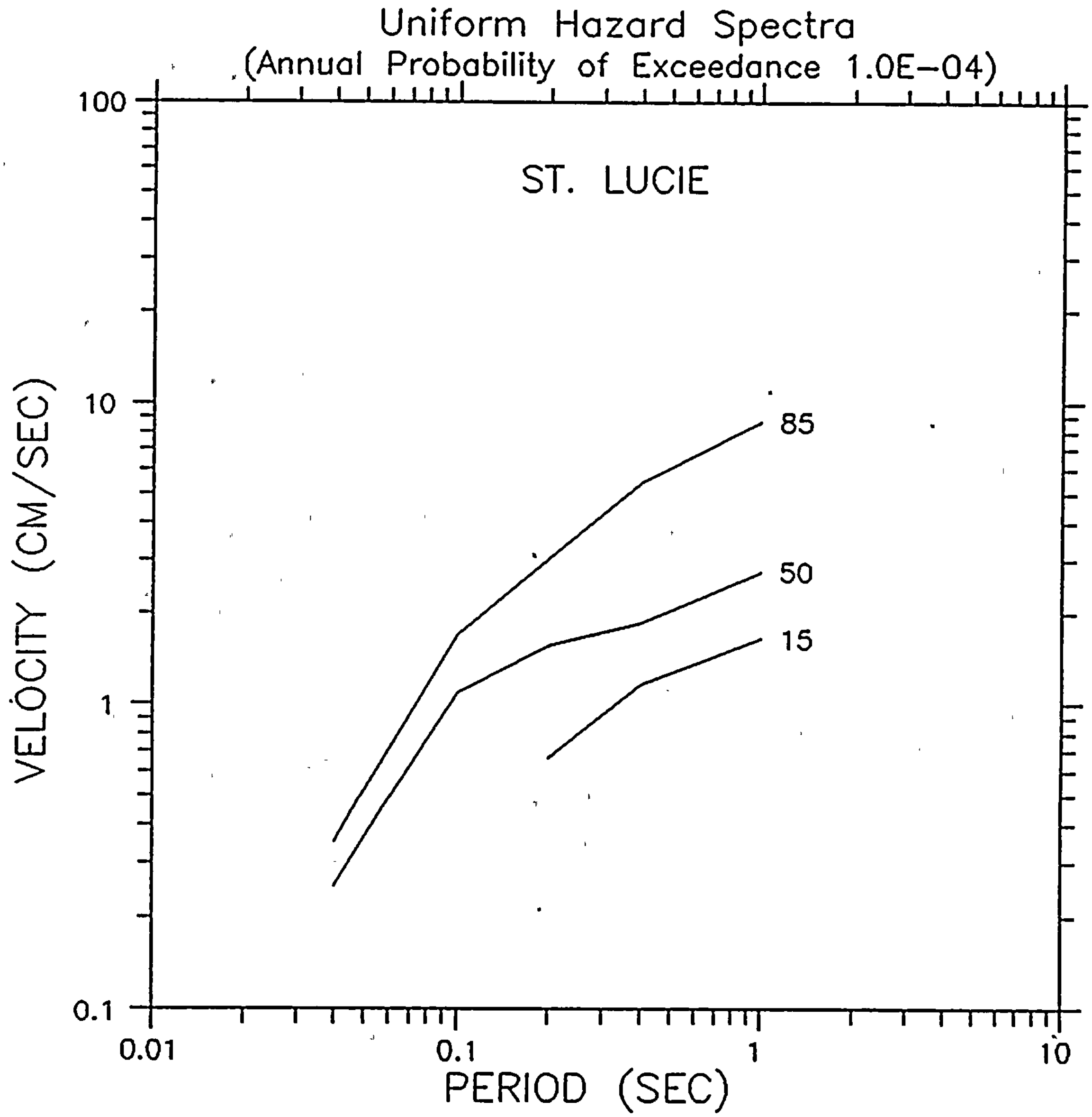

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FIGURE 12

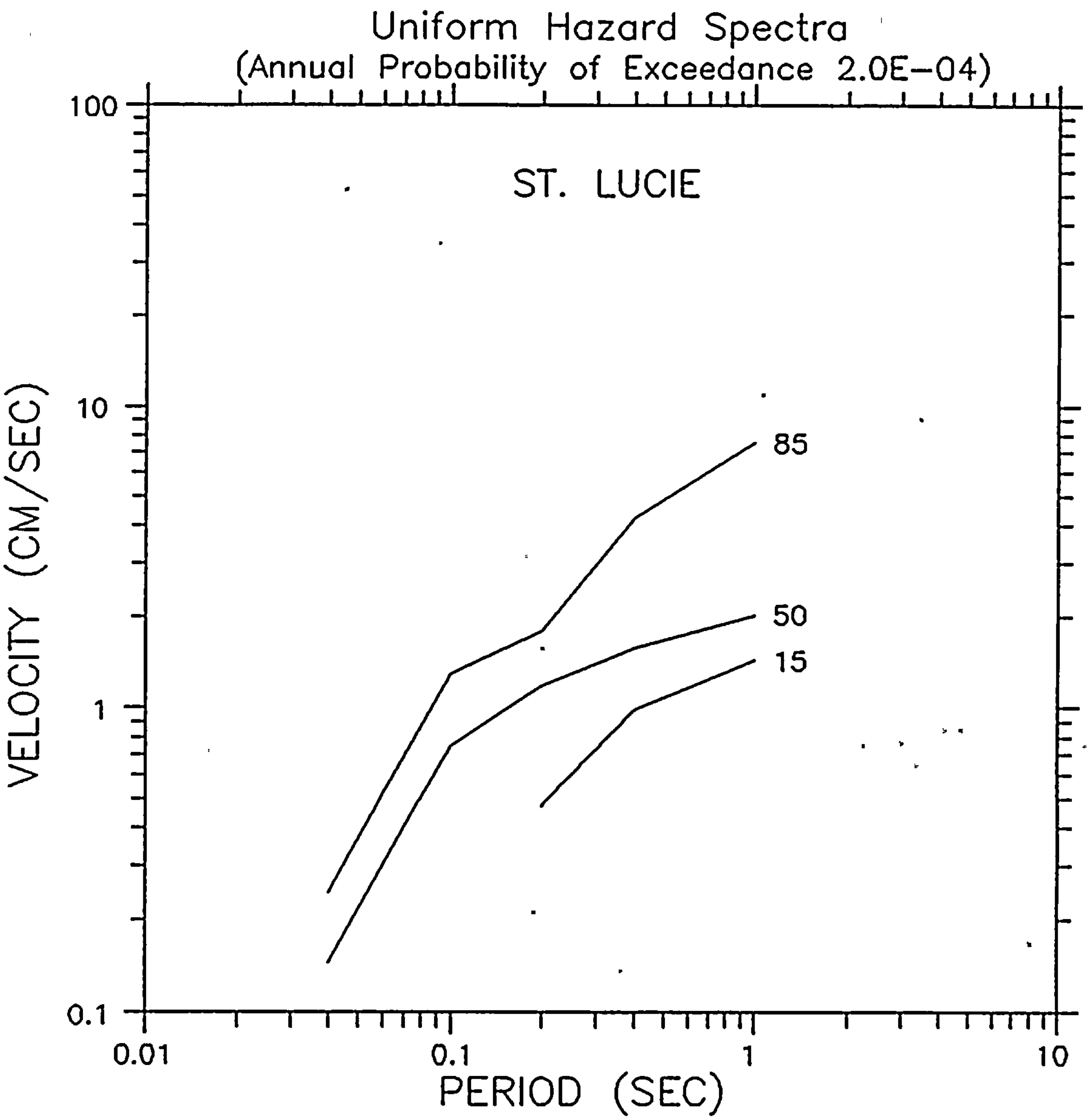

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FIGURE 13

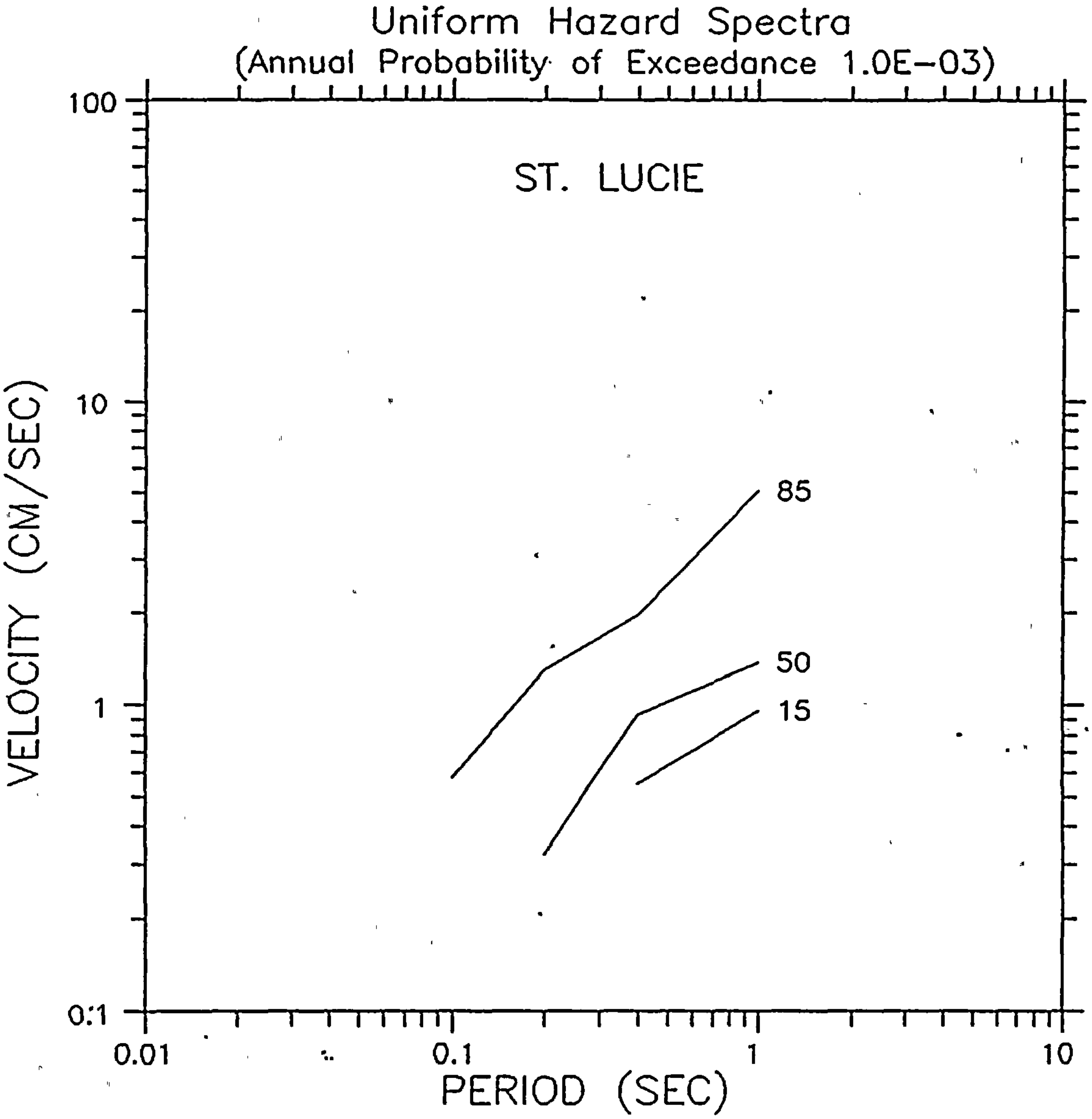

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FIGURE 14

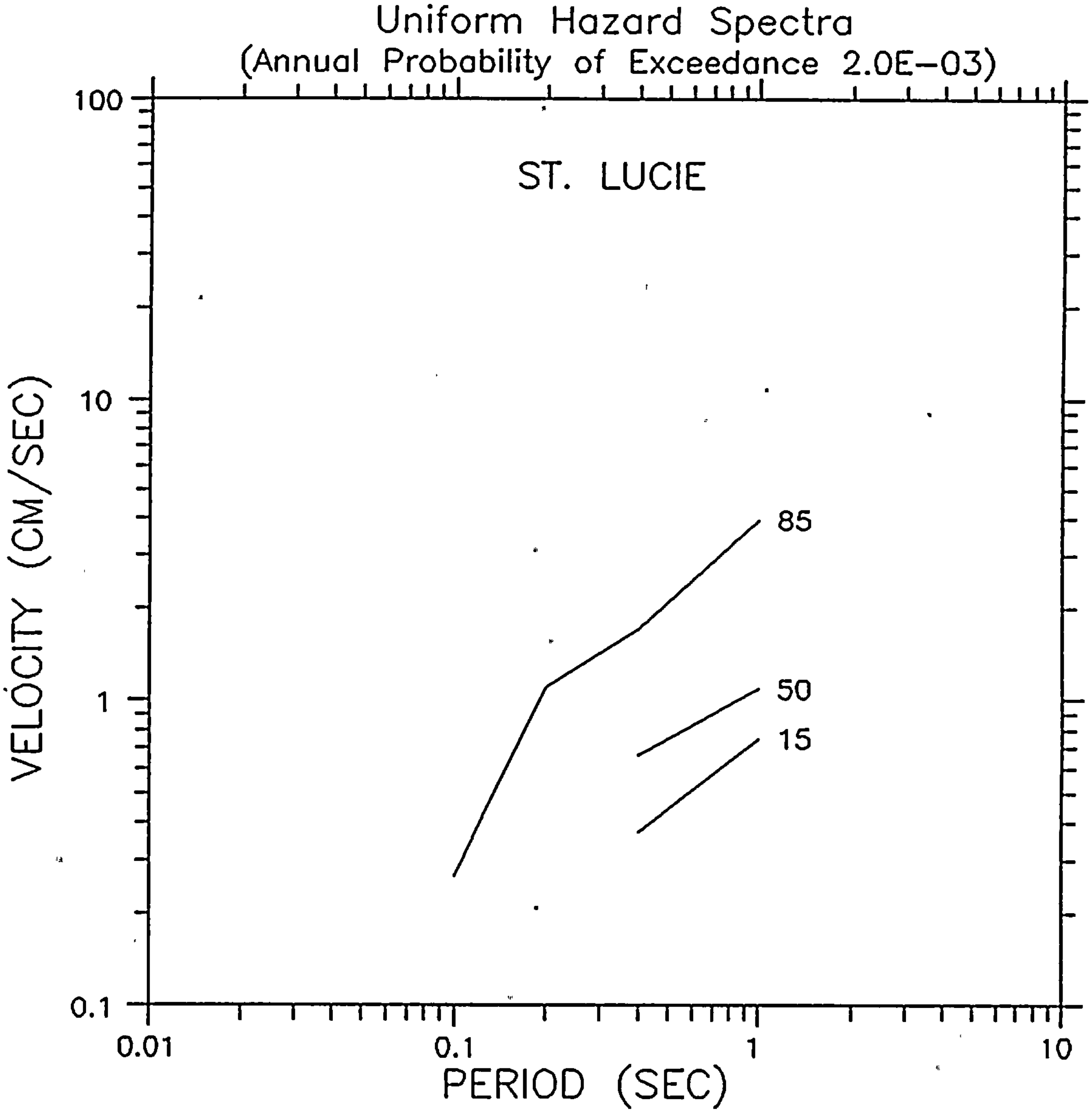

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FIGURE 15

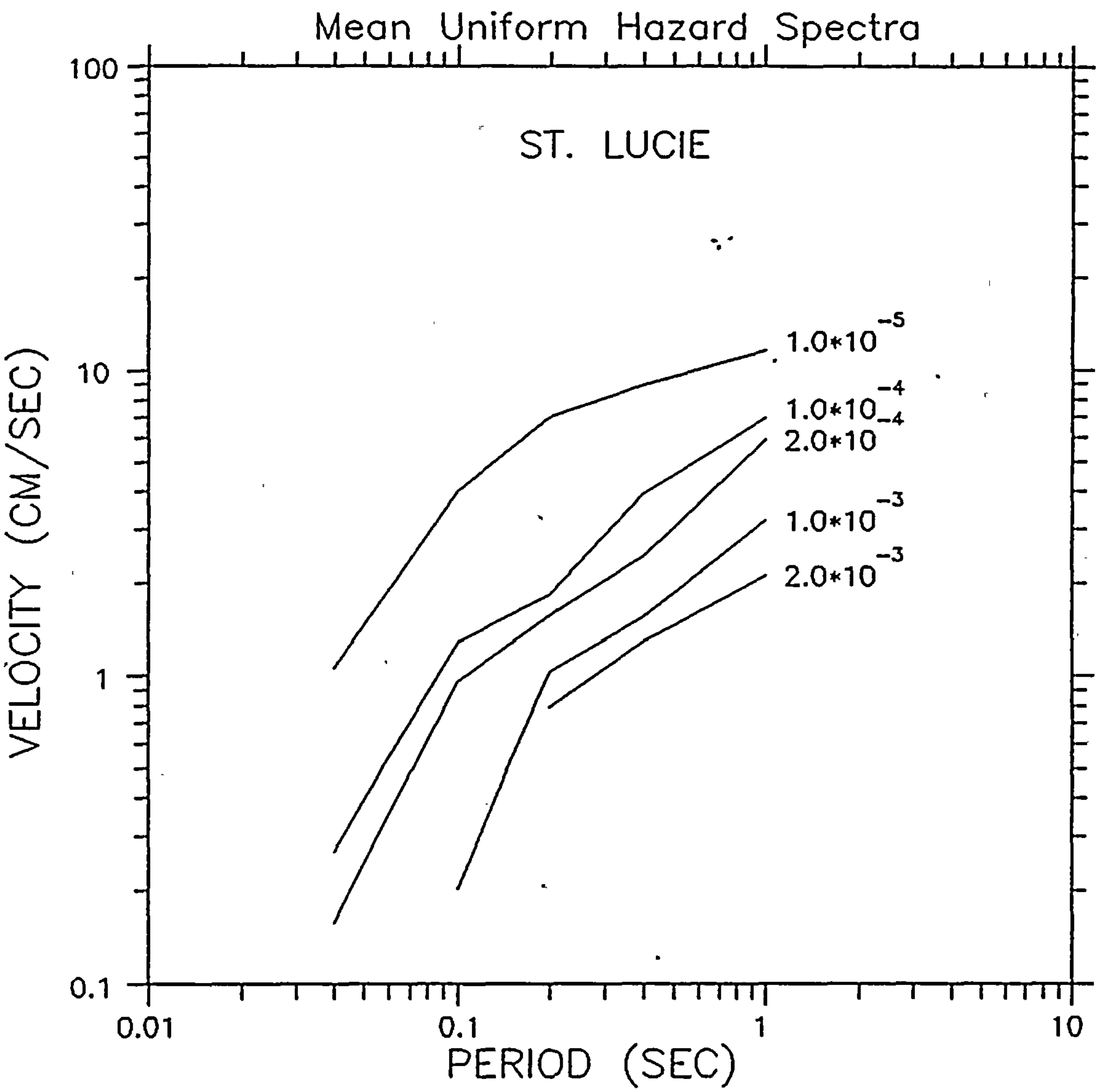

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FIGURE 16

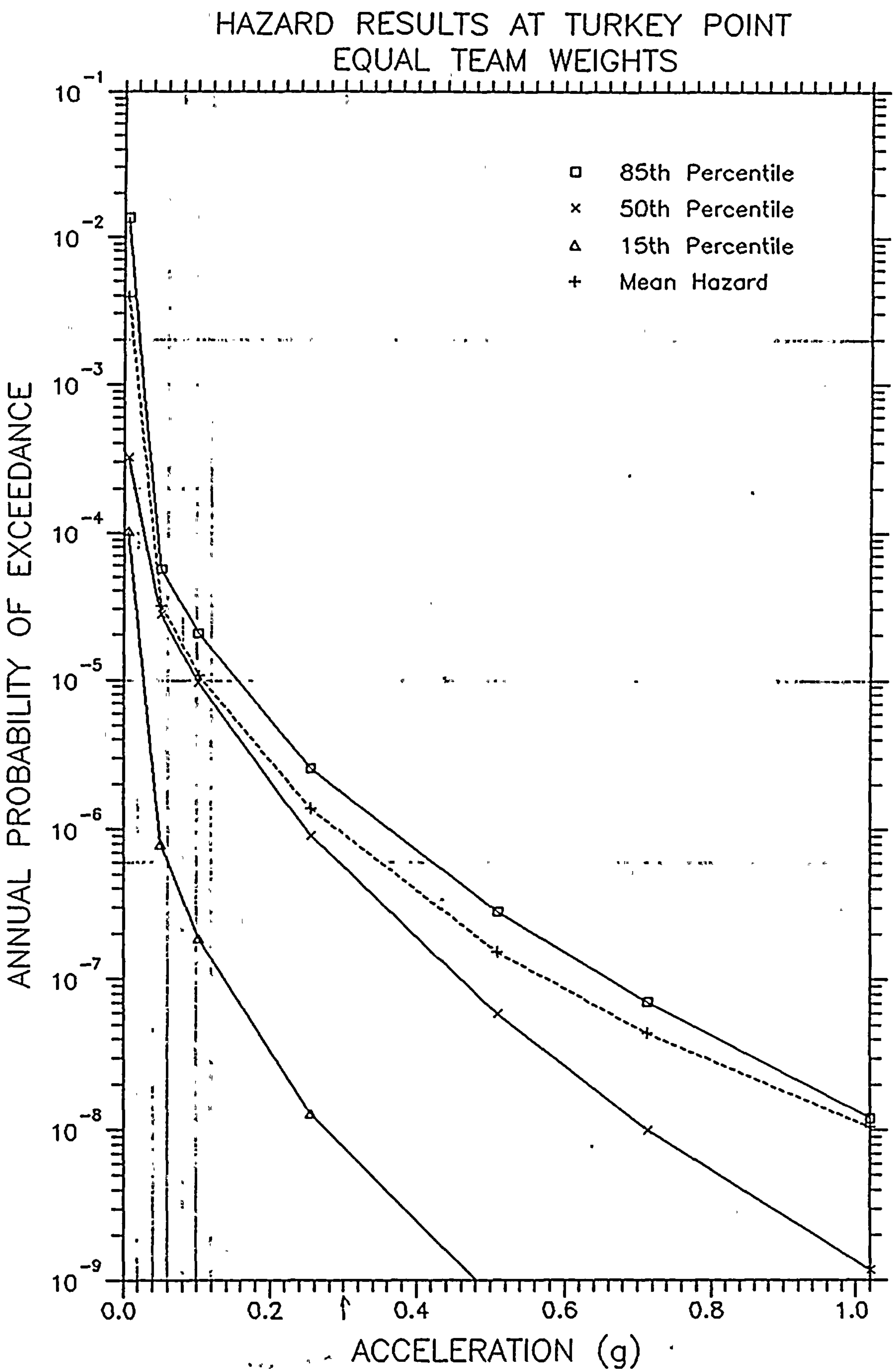

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FIGURE 17

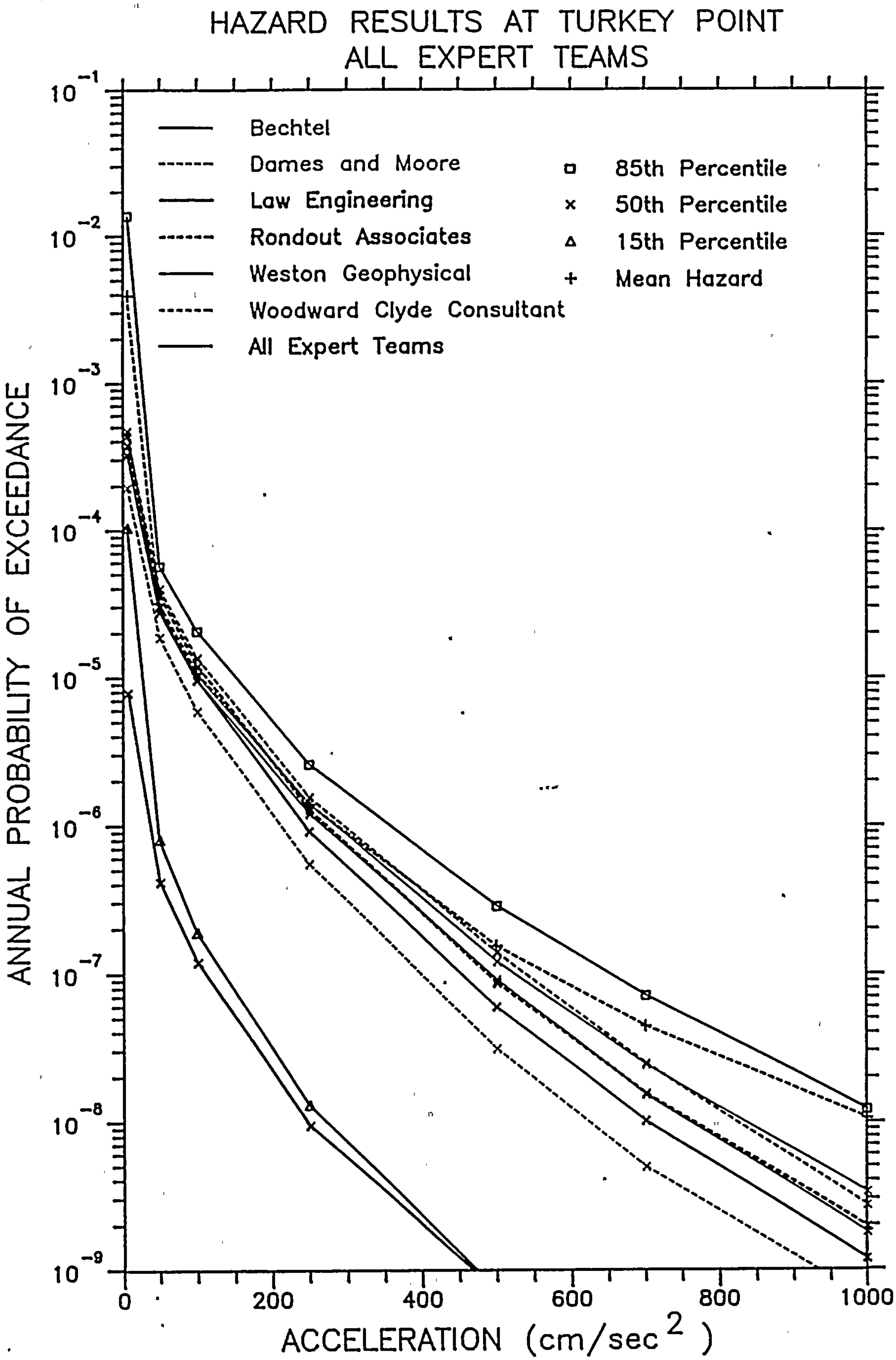

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FIGURE 18

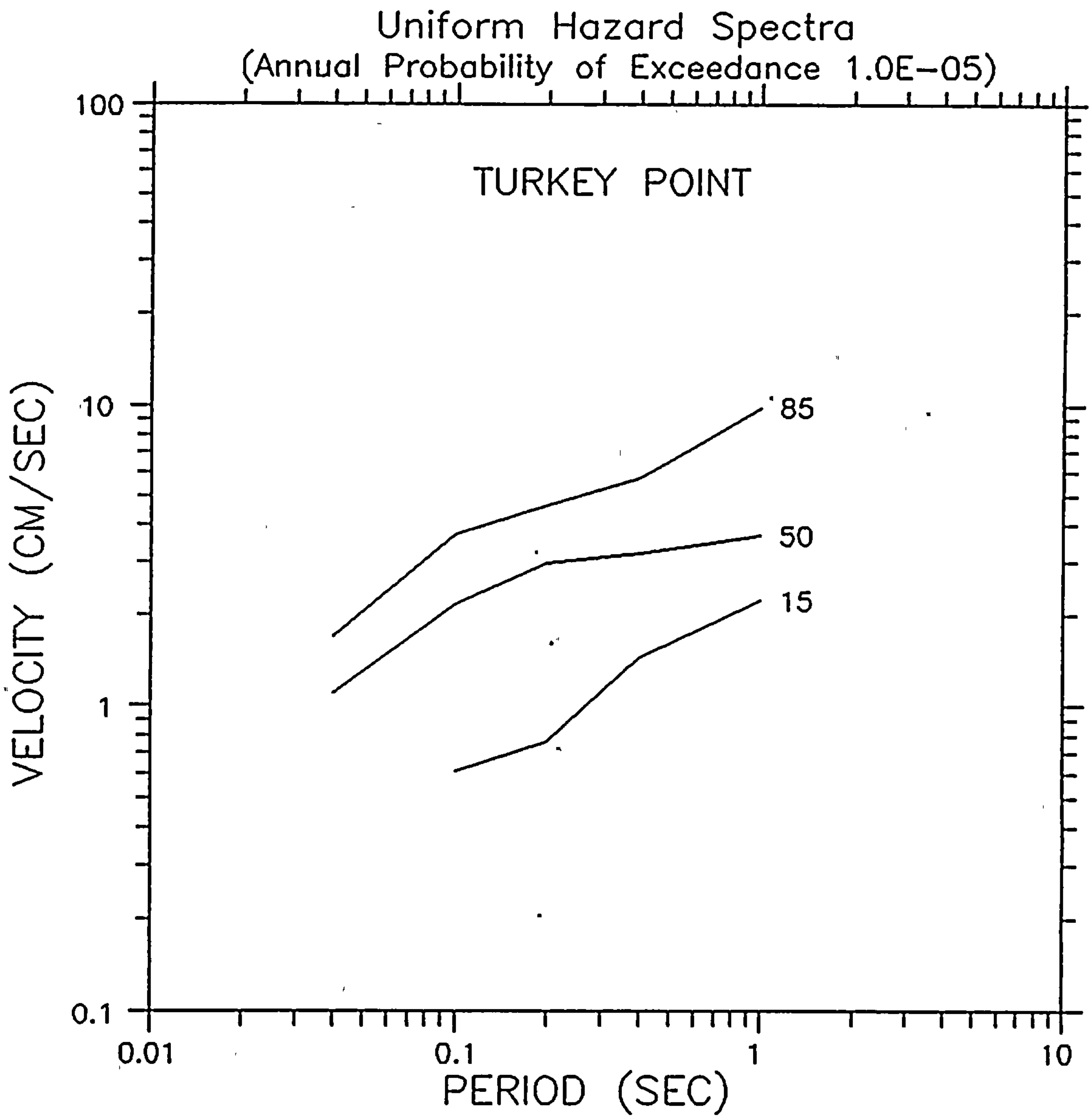

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FIGURE 19

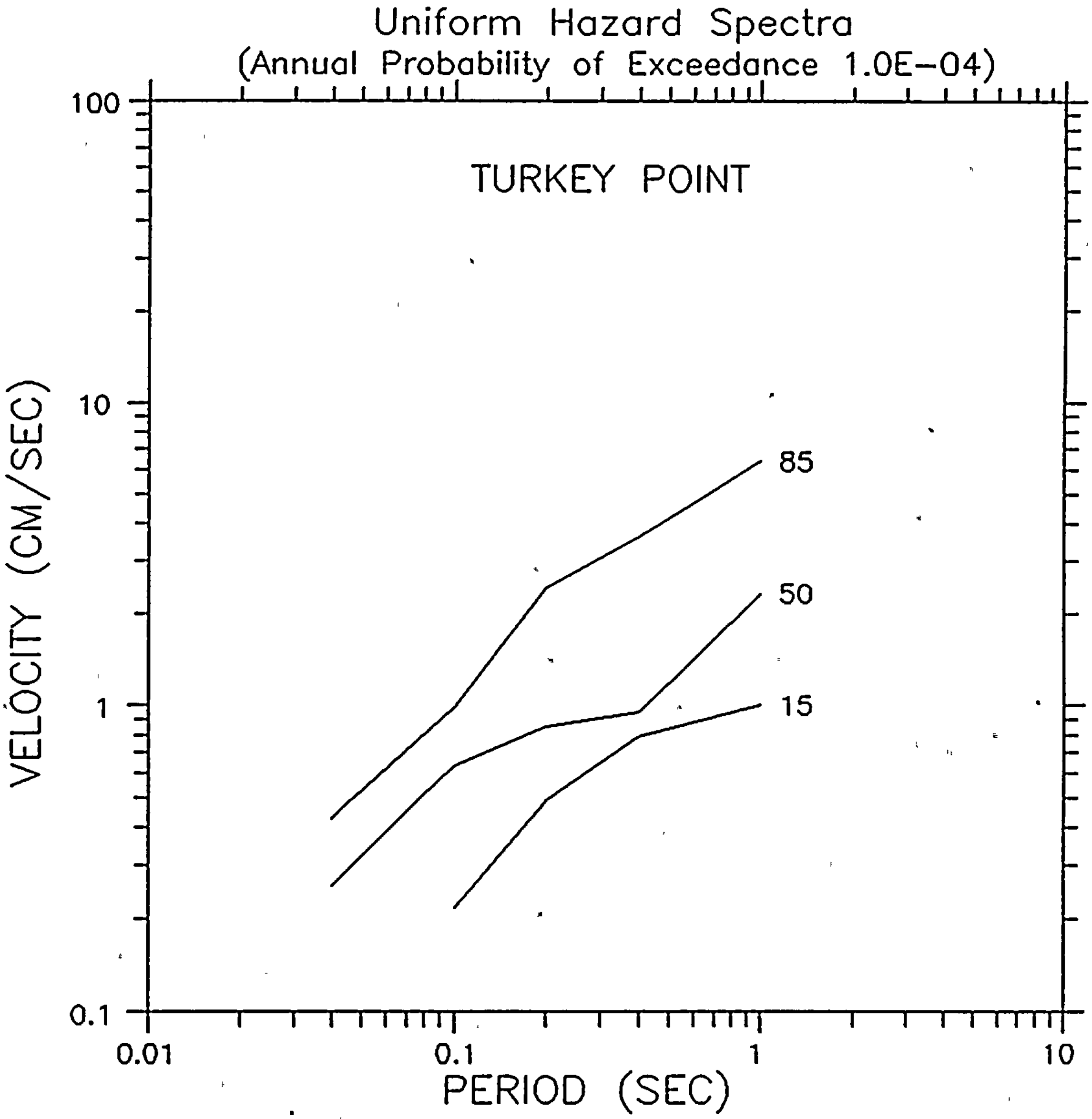

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FIGURE 20

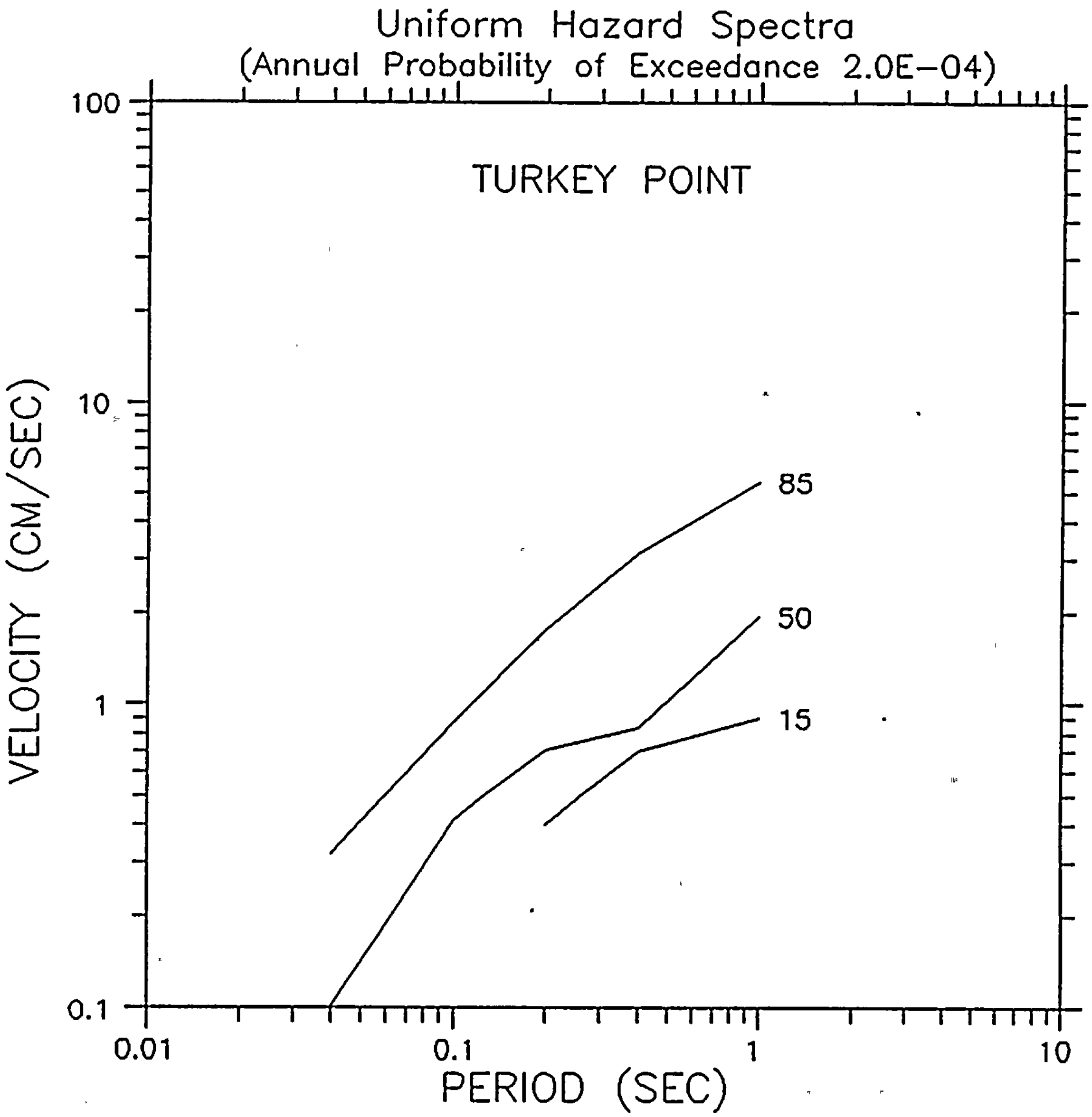

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FIGURE 21

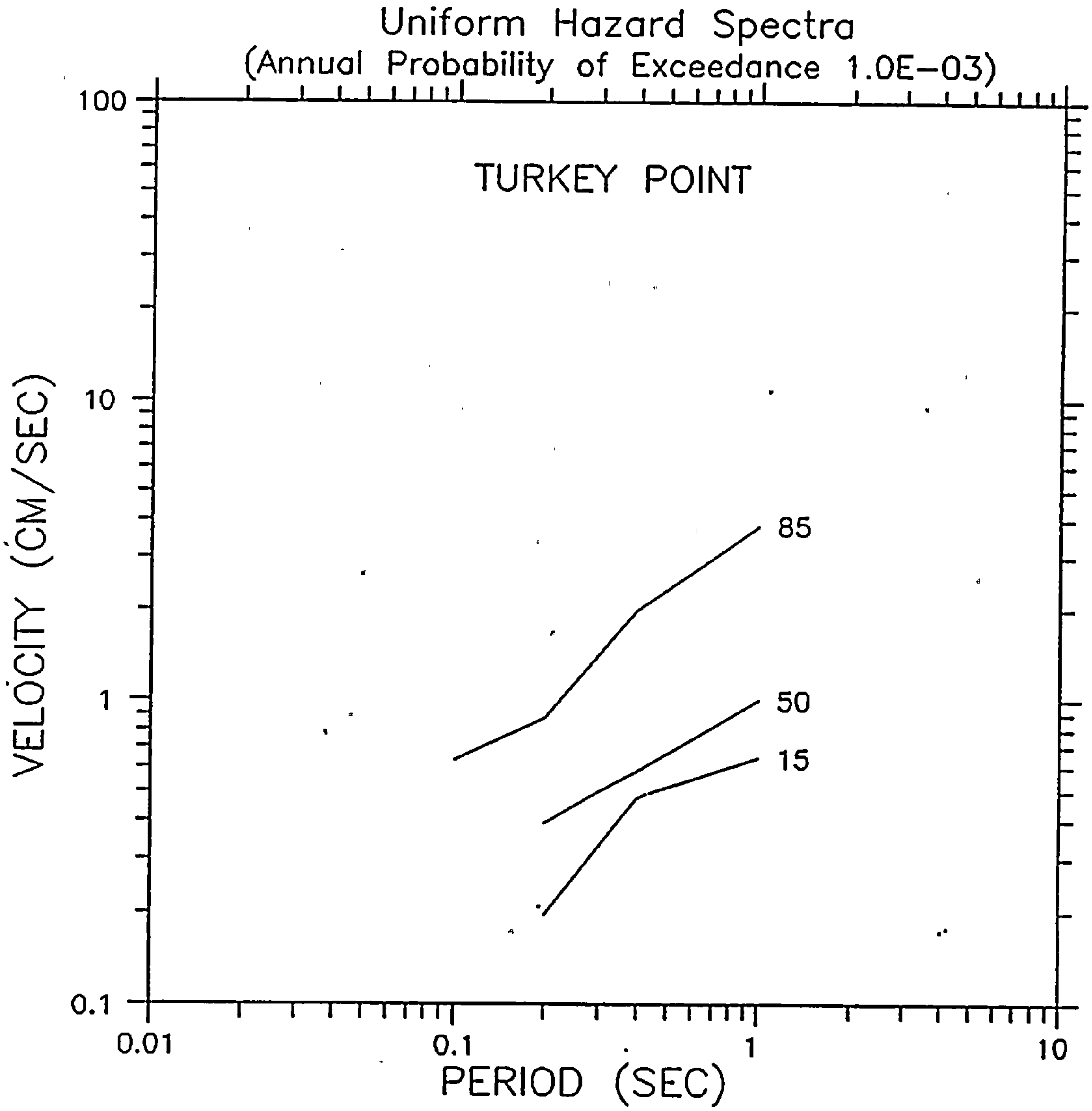

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FIGURE 22

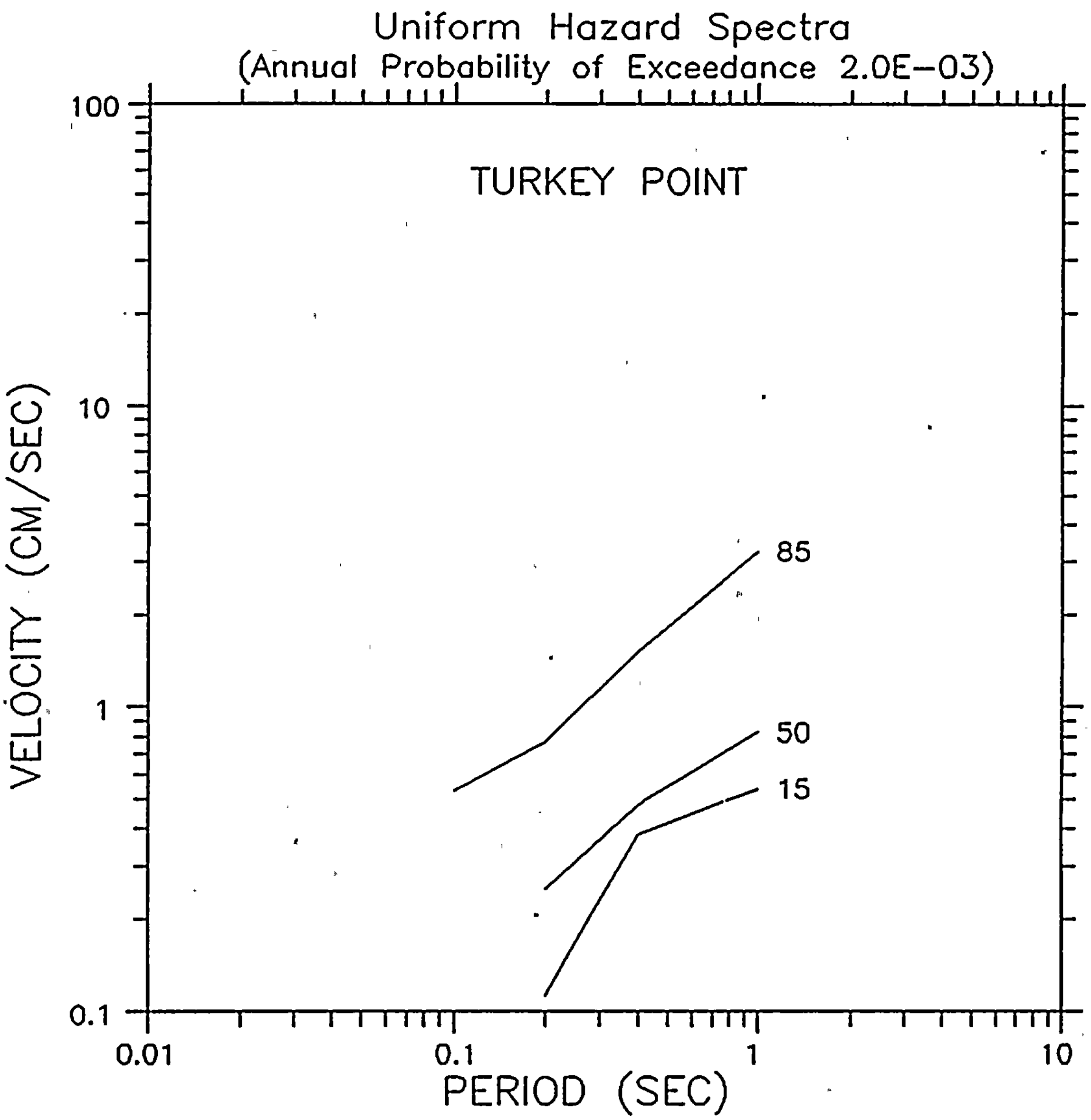

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FIGURE 23

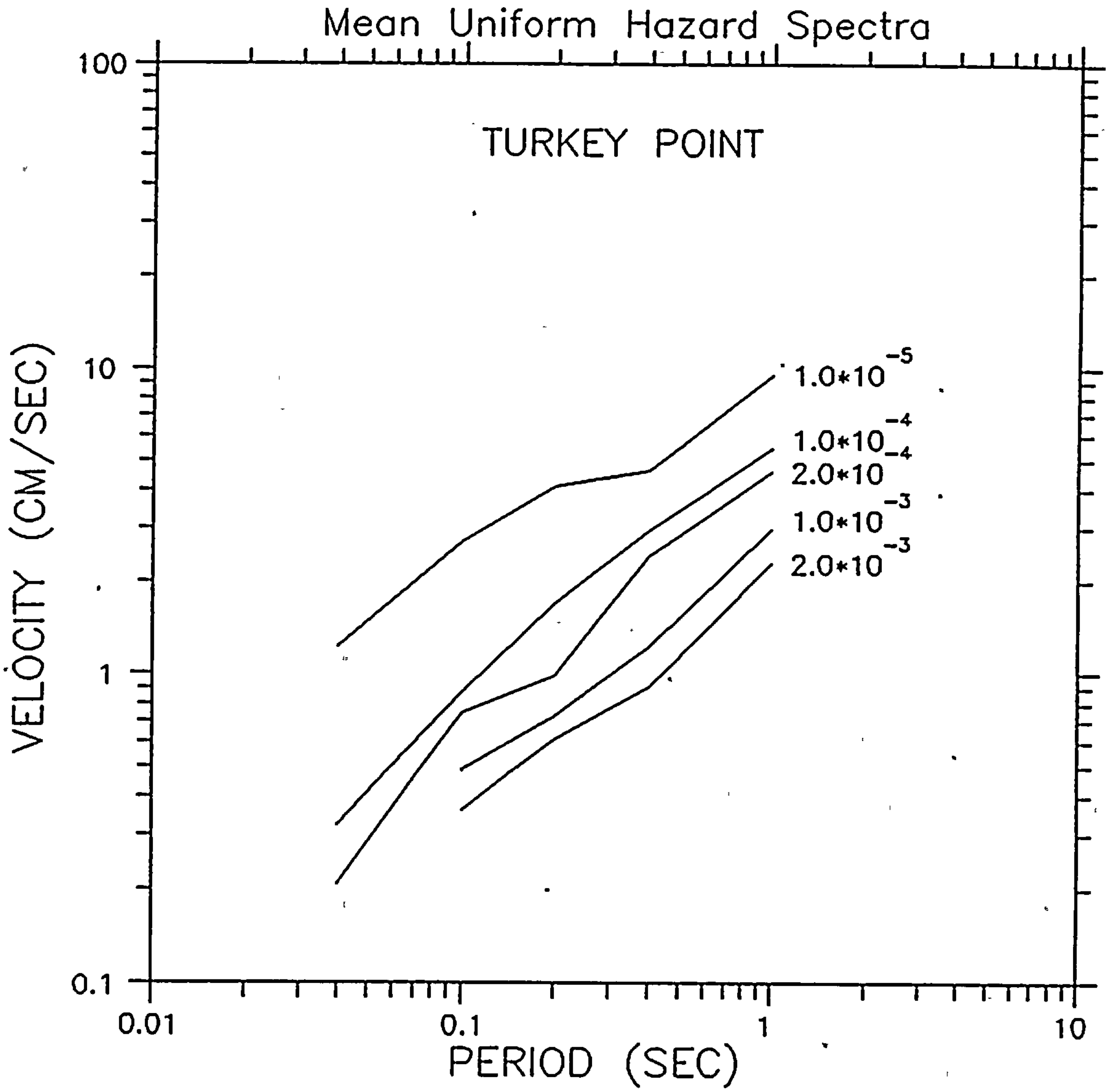

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FIGURE 24

21