Department of Energy
Washington, D.C. 20545

Dock No. 50-537
HQ:S:82:045

JUN 08 1982

Mr. Paul S. Check, Director
CRBR Program Office
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Check:

RESPONSES TO REQUEST FOR ADDITIONAL INFORMATION - GEOLOGY AND SEISMOLOGY

Reference: Letter, P.S. Check to J. R. Longenecker, "CRBRP Request for Additional Information," dated April 9, 1982

This letter formally responds to your request for additional information contained in the referenced letter.

Enclosed are responses to Questions CS 230.1, 2, 4, and 5 and CS 231.1, 2, and 3. These responses will also be incorporated into the PSAR Admendment 69, scheduled for submittal in June.

Sincerely,

John R. Longenecker

John R. Longenecker
Acting Director, Office of the
Clinch River Breeder Reactor
Plant Project
Office of Nuclear Energy

Enclosures

cc: Service List
Standard Distribution
Licensing Distribution

D001

Question 230.1

The last earthquake listed in both Table 2.5-2 and Table 2.5-3 of the PSAR is dated November 30, 1973. Update both of these seismicity lists to include all more recent pertinent events. Include in Table 2.5-3 all earthquakes of maximum Modified Mercalli intensity greater than IV or magnitude greater than 3 which have been reported in all tectonic provinces any parts of which are within 200 miles of the site. Where available, for each earthquake provide epicenter coordinates, depth of focus, origin time, highest intensity, magnitude, seismic moment, source mechanism, source dimensions, source rise time, rupture velocity, total dislocation, fractional stress drop and any strong motion recordings; references from which the specified information was obtained should be identified. All magnitude designations such as m_b, M_L, M_S, etc. should be identified. The epicenters of all earthquakes listed in Table 2.5-3 should be plotted on a map such as Figure 2.5-8. Provide a larger scale map showing earthquake epicenters of all known events within 50 miles of the site.

Response

INTRODUCTION

The response to this question is in the form of a computer generated listing of pertinent data for earthquakes of maximum Modified Mercalli intensity greater than IV and/or magnitude greater than 3.0 within the geographic area 29.0°N - 42.0°N latitude and 69.0°W - 94.0°W longitude. This area includes all tectonic provinces any part of which is within 200 miles of the CRBRP site. We have also prepared a computer generated listing of all reported earthquakes within 50 miles of the CRBRP site. The locations of the earthquakes in these listings have been plotted in a series of four figures. Available information concerning focal mechanisms for pertinent earthquakes has also been included. Other requested information has been provided where data is available.

During the literature search conducted in response to this question, it came to our attention that an extensive listing of central United States

earthquakes has recently been compiled by Dr. O. W. Nuttli (PSAR Sec. 2.5 Ref. 164) of St. Louis University. Some difference in the number of very early events or low intensity (generally less than V MM) and in the number of more recent events of small magnitude (generally less than 3.5) detected by St. Louis University are believed to exist between the listing presented herein and that compiled by Dr. Nuttli. However, these differences are not considered to be major and would not impact seismic design of the CRBRP. Consequently, they have not been included in this response.

Historical Earthquake Listings

See revised PSAR Section 2.5.2.5, Tables 2.5-2 and 3, and Figure 2.5-18 for the requested information.

FOCAL MECHANISMS FOR PERTINENT EVENTS

November 30, 1973, Maryville, Tennessee

The magnitude 4.6 m_b November 30, 1973 earthquake near Maryville, Tennessee is one of the few southeastern United States earthquakes for which focal mechanism solutions are available. Bollinger et al., (1976) (PSAR Sec. 2.5 Ref. 166) obtained two solutions, one showing normal faulting on northeast or northwest striking nodal planes, the other defining reverse faulting with nodal planes striking northwest. Bollinger et al., (1976) favored the reverse faulting solution on a northwest striking fault plane based on additional data (aftershock epicenters, vertical distribution of aftershock hypocenters and regional in-situ stress measurements). Herrmann (1979) (PSAR Sec. 2.5 Ref. 167) obtained a strike-slip mechanism with nodal planes striking either north-northeast or west-northwest, with steep dips.

July 27, 1980, Sharpsburg, Kentucky

Mauk et al (1982) (PSAR Sec. 2.5 Ref. 168) reported the following favored mechanism for the magnitude 5.1 m_b July 27, 1980 Sharpsburg, Kentucky earthquake: fault plane striking N42^{o}E, dipping 50^{o}E with a slip vector 184^o east of strike. This implies right-lateral strike-slip displacement with a small component of thrust. The other (unfavored) nodal plane strikes N135^{o}E and dips 85^o to the southwest.

Intensity estimates provide the basis for the epicentral locations of earthquakes prior to about 1960. Before 1800, much of the region was so sparsely populated that the epicentral locations were identified with the scattered towns, possibly tens of miles from the actual epicenters. Since then, the greater population density, better communications, and more seismograph stations have made it possible to locate areas of greatest intensity within a few miles. Within the past few years strong motion seismographs have been installed at several nuclear power plants being constructed in the general region.

Surface intensities at the site have not been directly observed. The intensities which occurred at the site have been estimated based on the epicentral intensity and distance from the CRBRP site (Ref. 111).

The site area has experienced numerous light to moderate earthquakes. The maximum site intensity associated with these earthquakes is VI-VII MM. The site investigation has not produced any physical evidence which can be associated with any earthquakes.

2.5.2.4 <u>Engineering Properties of Materials Underlying the Site</u>

The engineering properties of materials underlying the site are discussed in section 2.5.4.2.

2.5.2.5 <u>Earthquake History</u>

Two historical earthquake listings are compiled. One listing, Table 2.5-2 includes historical earthquakes occurring within the region between 29.0°N - 42.0°N latitude and 69.0°W - 94.0°W longitude. This list contains events with epicentral intensities exceeding IV MM and/or assigned magnitudes greater than 3.0. The list also contains information on some significant early historical events for which neither magnitude nor intensity data are available.

A second listing, Table 2.5-3 contains all earthquakes reported to have occurred within a 50 mile radius of the CRBRP site, regardless of intensity or magnitude estimates.

Figure 2.5-18 includes the data contained in the two historical earthquake listings, Tables 2.5-2 and 3.

Figure 2.5-18, sheet 1 of 4 shows all earthquakes with maximum intensities exceeding IV MM and/or magnitudes equal to or greater than 3.0, reported within the geographic region 30°-41.5°N latitude; 73.5°-93°W longitude. The open circles indicate all events with intensities exceeding IV MM. The X's represent those events (Magnitude greater than or equal to 3.0) which were either unfelt or had reported intensities of IV MM or less. The X's also include several significant early historical events with unreported magnitudes and intensities.

Figure 2.5-18, sheet 2 of 4 also shows all earthquakes with maximum intensity exceeding IV MM and/or magnitudes equal to or greater than 3.0, reported within the geographic regin 30°-41.5°N latitude; 73.5°-93°W longitude. The square symbols indicate all events with magnitudes equal to or greater than 3.0. The X's represent those events (I>IV MM) with unreported magnitude or magnitude less than 3.0. The X's also include several significant early historical events with unreported magnitudes and intensities.

Figure 2.5-18, sheet 3 of 4 includes all historical earthquakes within 50 miles of the site. Maximum Modified Mercalli Intensity is shown by open circles. Unfelt events and events with unreported intensity are shown by the X's.

Figure 2.5-18, sheet 4 of 4 also includes all historical earthquakes within 50 miles of the site. Magnitude is shown by the square symbols. Events with unreported magnitude are shown by the X's.

(162) Gutenberg, B. 1956 — (and Richter, C. F.) Magnitude and energy of earthquakes: Annali di Geofisica, Vol. 9, No. 1, pp. 1-15.

(163) Bath, Markus 1966 — Earthquake energy and magnitude, In Physics and Chemistry of the Earth, Vol. 7: Oxford and New York, Pergamon Press, pp. 115-165.

(164) Nuttli, O. W. 1973 — Seismic wave attenuation and magnitude relations for eastern North America: Journ. Geophys. Res., Vol. 78, No. 5, pp. 876-885.

(165) Richter, C. F. 1958 — (and Freeman, W. H.) Elementary Seismology: San Francisco, California, p. 768.

(166) Bollinger, G. A. 1976 — (Langer, C. J. and Harding, S. T.) The eastern Tennessee earthquake sequence of October through December, 1973, Bull. Seism. Soc. Am., Vol. 66, No. 2, pp. 525-547.

(167) Herrmann, R. B. 1979 — Surface wave focal mechanisms for eastern North American earthquakes with tectonic implications, Journ. Geophys. Res., Vol. 84, pp. 3543-3552.

(168) Mauk, F. J. 1982 — (Christensen, D. and Henry S.) The Sharpsburg, Kentucky, earthquake July 27, 1980: main shock parameters and isoseismal maps, Bull. Seism. Soc. Am., Vol. 72, No. 1, pp. 221-236.

EARTHQUAKES IN CHRONOLOGICAL ORDER FROM SITE AT
5/6/82 CRBRP MG2200
N. LAT. = 35.89, W. LONG. = 84.38

SELECTED BY REGIONAL CRITERIA WHERE

REGION C-W CORNER COORD.S (LAT-LONG)... 42.00- 94.00, 42.00- 69.00, 29.00- 69.00, 29.00- 94.00,

HISTORICALS 1- 38

(SEE NOTES AT END OF TABLE)

YEAR	MO	DA	HR	COORDS. LAT.	COORDS. LONG.	INTENSITY M.M.	INTENSITY R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1737	12	18	23:00	40.80	74.00	7					656.3	55.8	1	NEAR NEW YORK CITY
1758	4	24	21:30	38.90	76.50						479.9	62.0	1	ANNAPOLIS MD
1774	2	21	14:00	37.50	78.00					58000.0	370.6	70.6	1	EASTERN VIRGINIA (*COORDS)
1776	7	5	08:00	39.50	82.00	6					281.4	26.9	10	MUSKINGUM R. OHIO (*COORDS-DATE)
1776	11	6	00:00	35.50	83.20	4-5					71.6	111.8	2	WEST N. CAROLINA (*COORDS,TIME,DATE)
1779	1	1	00:00	38.00	84.00						147.3	8.1	1	FELT IN KENTUCKY (*DATE-COORDS)
1791	4	1	07:00	38.00	84.00						147.3	8.1	1	APRIL OR MAY 1791 OR 1792 IN KENTUCKY
1791	5	18	22:00	41.50	72.50	8				35000.0	747.9	55.2	1	EAST HADDAM, CONN.
1792	8	28	22:00	41.50	72.50						747.9	55.2	1	EAST HADDAM, CONN.
1793	1	11	08:00	41.50	72.50						747.9	55.2	1	EAST HADDAM CONN
1794	3	6	14:00	41.50	72.50						747.9	55.2	1	EAST HADDAM,CONN.
1795	1	8	03:00	39.00	89.00						332.1	311.7	1	KASKASKIA,ILL. AND KY. (*COORDS)
1800	3	17	00:00	39.80	75.20						568.8	58.9	1	PHILADELPHIA, PA.
1800	11	29	00:00	39.80	75.20						568.8	58.9	1	PHILADELPHIA PA
1804	8	24	14:10	42.00	87.80	5-6	6			30000.0	460.3	337.5	7	FORT DEARBORN,ILLINOIS (INT.-REF.7)
1805	8	11	19:00	41.50	72.50						747.9	55.2	1	EAST HADDAM CONN
1807	5	30	04:00	37.50	77.50	5					397.1	71.7	1	RICHMOND, VA. (*DATE-MAY31)
1811	12	16	02:00	36.60	89.60	12		7.2		2000000.0	294.8	281.1	1	NEW MADIRD, MO. (*MAG. 7.2 MB)
1812	1	23	09:00	36.60	89.60	12		7.1			294.8	281.1	1	NEW MADRID, MO. (*MAG. 7.1 MB)
1812	2	7	03:45	36.60	89.60	12		7.4			294.8	281.1	1	NEW MADRID, MO. (*MAG. 7.4 MB)
1818	3	1	00:00	35.00	90.00	4-5					322.1	260.6	2	MISSISSIPPI VALLEY (*COORDS, DATE, TIME)
1820	11	9	16:00	37.30	89.50	4-5					300.1	290.5	1	CAPE GIRARDEAU, MO.
1827	8	6	22:30	38.30	85.80	6					183.9	335.3	1	NEW ALBANY IND.
1827	8	23	00:30	41.40	72.70	4-5					735.5	55.3	1	NEW LONDON, CONN. (*TIME)
1828	3	9	22:00	37.00	78.00	5				218000.0	362.9	75.9	1	PROBABLY VIRGINIA (*COORDS) TIME 22-2300
1833	8	27	06:00	37.00	78.00	5				52000.0	362.9	75.9	1	CENTRAL VIRGINIA (*COORDS)
1834	11	20	13:40	37.00	86.00	5					119.2	310.9	1	NORTHERN KENTUCKY (*COORDS)
1837	4	12	00:00	41.70	72.70	5					745.3	53.9	1	HARTFORD, CONN. (*TIME)
1838	6	9	08:45	39.00	89.50	6		5.7			353.4	309.0	9	SOUTHERN ILLINOIS (*MAG. 5.7 MB)
1840	8	9	15:30	41.50	72.90	5				7500.0	729.6	54.4	1	SOUTH CONNECTICUT
1840	11	11	00:00	39.80	75.20						568.8	58.9	1	PHILADELPHIA, PA. (*TIME)
1840	11	14	00:00	39.80	75.20						568.8	58.9	1	PHILADELPHIA, PA. (*TIME)
1841	1	25	00:00	42.00	75.00						656.9	47.2	1	NEW YORK IN THE MORNING (*COORDS)
1841	12	27	23:50	36.40	89.20	5					271.1	278.9	1	NEAR HICKMAN, KY. (*COORDS)
1843	1	4	20:05	35.50	90.50	8				400000.0	344.3	267.3	9	EASTERN ARKANSAS (INT. IX-X - REF.2)
1844	11	28	07:00	36.00	84.00	6					22.7	70.3	1	KNOXVILLE, TENNESSEE
1847	8	8	10:00	42.00	71.00						832.5	55.5	1	SOUTH MASSACHUSETTS
1848	9	9	22:00	41.00	74.00						662.9	54.7	1	R.I.,CONN.,N.J., AND PENN.(*COORDS)

* ESTIMATE

Table 2.5-2 (cont.)

HISTORICALS 39- 86

YEAR	MO	DA	HR	COORDS. LAT.	LONG.	INTENSITY M.M.	R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1852	4	29	13:00	36.60	81.60	6				162000.0	162.6	71.6	11	VIRGINIA, N.C., AND TENN.
1853	5	2	09:20	38.00	77.00	5				72000.0	331.0	62.3	1	VIRGINIA-WEST VIRGINIA (*COORDS)
1855	2	2	03:00	37.00	78.60	5				9000.0	330.4	74.9	1	CHARLETTE COURT HOUSE, VA.
1855	5	2	21:33	37.00	89.20	4-5					278.5	287.4	2	CAIRO, IL. (*COORDS)
1856	11	9	00:00	37.00	89.00	4-5					267.8	288.0	2	IL., KY., TN. (*COORDS, TIME)
1857	10	8	04:00	38.70	89.20	6		5.4		7500.0	328.3	307.7	9	ILLINOIS (2 SHOCKS) (*MAG, 5.4 MB)
1857	12	19	09:04	32.90	80.00						324.2	128.3	1	CHARLESTON SOUTH CAROLINA
1858	6	30	22:45	41.80	73.00	5				1000.0	735.2	52.8	1	NEW HAVEN CONN
1861	8	31	05:22	37.00	78.00	6				300000.0	362.9	75.9	1	PROBABLY VIRGINIA (*COORDS)
1865	8	17	09:00	36.00	89.50	7				24000.0	286.3	273.0	9	DYERSBURG, TN.
1871	10	9	09:40	39.70	75.50	7					551.5	58.8	1	WILMINGTON, DELAWARE
1872	6	17	15:00	33.10	83.30	5					202.4	162.0	1	MILLEDGEVILLE GA
1872	7	11	05:25	40.90	73.80	5				100.0	668.8	55.7	1	WESTCHESTER COUNTY N Y
1874	2	10	00:00	35.70	82.10	5					128.6	95.2	1	MCDOWELL CO., N.C. FELT LOCAL (SERIES)
1874	2	22	00:00	35.70	82.10	7					128.6	95.2	2	MCDOWELL CO., N.C. IN P.M.
1874	4	17	30:00	35.70	82.10	5					128.6	95.2	3	MCDOWELL, CO., N.C., (*TIME)
1874	12	10	22:25	40.90	73.80	6				5000.0	668.8	55.7	1	WESTCHESTER,N.Y.
1875	6	18	07:43	40.20	84.00	7				40000.0	298.5	3.9	1	OHIO
1875	7	28	04:10	41.80	73.20	5				2000.0	726.3	52.4	1	CONNECTICUT
1875	11	1	21:55	33.80	82.50	6				25000.0	179.6	143.0	1	NORTH GEORGIA
1875	12	22	23:45	37.60	78.50	7				50000.0	346.4	68.3	1	ARVONIA VA
1876	9	25	00:15	38.50	87.70	6				60000.0	256.6	315.6	1	EVANSVILLE, IND.
1877	9	10	09:59	40.30	74.90	4-5				300.0	598.5	56.6	1	DELAWARE RIVER
1877	11	16	02:38	35.50	84.00	5				5000.0	34.5	141.3	1	WESTERN NORTH CAROLINA AND EASTERN TENN
1878	3	12	04:00	36.80	89.20	5					275.4	284.6	1	COLUMBUS, KY. (FELT LOCALLY)
1878	10	4	02:30	41.50	74.00	5				600.0	680.2	52.1	1	HUDSON RIVER N Y
1878	11	18	23:52	36.70	90.40	6				150000.0	339.7	281.3	1	SE. MISSOURI (INT. VI-VIII;REF. 2)
1879	1	12	23:45	29.50	82.00	6				25000.0	462.7	161.9	1	NORTH FLORIDA (2 SHOCKS, 10 MIN. APART)
1879	3	25	19:30	39.20	75.50	4-5				600.0	537.4	62.2	1	DELAWARE RIVER
1879	12	13	02:00	35.20	80.80	5					207.0	102.3	1	CHAROLOTTE, NORTH CAROLINA
1882	2	9	14:00	40.40	84.20	5					311.8	1.8	10	OHIO
1882	7	20	04:00	38.00	90.00	5				3000.0	342.7	296.8	1	SOUTHERN ILLINOIS
1882	9	27	04:20	39.00	90.00	6				40000.0	375.6	306.6	1	SOUTH ILLINOIS
1882	10	15	00:00	39.00	90.00	5				40000.0	375.6	306.6	1	S. ILLINOIS (2 SHOCKS, 5 HRS. APART)
1882	10	22	16:15	35.00	94.00	6-7				135000.0	544.6	266.3	1	ARKANSAS
1883	1	11	01:12	37.00	89.20	6				80000.0	273.5	287.4	1	CAIRO, IL.
1883	2	27	22:30	41.50	71.50	5					794.4	56.9	1	RHODE ISLAND
1883	3	11	18:57	39.50	76.40	4-5					502.4	57.9	1	HARFORD CO., MD. (3 SHOCKS W/I 6 HRS.)
1883	4	12	02:30	37.00	89.20	6-7					278.5	287.4	1	CAIRO, IL. (FELT LOCALLY)
1883	7	14	01:30	37.00	89.20	4-5					278.5	287.4	2	CAIRO, IL.
1883	12	5	09:20	36.30	91.80	5					415.0	276.1	1	IZARD CO., AR. (FELT LOCALLY)
1884	1	18	08:00	34.30	78.00	5					377.1	105.1	1	WILMINGTON, N.C. FELT LOCALLY
1884	5	31	00:00	40.60	75.50	5					581.1	53.3	1	ALLENTOWN PA. FELT ONLY LOCALLY (*TIME)
1884	8	10	14:07	40.60	74.00	7				70000.0	650.0	56.8	1	NEAR NEW YORK CITY
1884	9	19	14:14	40.70	84.10	6				125000.0	332.7	2.6	1	COLUMBUS OHIO
1885	1	2	21:16	39.20	77.50	5				3500.0	440.8	56.7	1	MARYLAND AND VIRGINIA
1885	8	6	08:00	36.20	81.60	4-5					156.9	81.3	1	WATUGA CO., N.C. FELT LOCALLY (*TIME)
1885	10	9	23:35	37.70	78.80	6				20000.0	333.2	66.3	1	VIRGINIA

* ESTIMATE

Table 2.5-2 (cont.)

HISTORICALS 87- 134

YEAR	MO	DA	HR	COORDS. LAT.	LONG.	INTENSITY M.M.	R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1886	2	4	20:00	32.80	88.00	5				1600.0	296.9	225.1	1	ALABAMA
1886	2	13	00:00	32.80	88.00						296.9	225.1	1	ALABAMA (*TIME, INT)
1886	8	31	21:51	32.90	80.00	10		6.8		2000000.0	324.2	128.3	1	CHARLESTON, S.C. (*MAG, 6.8 MB)
1886	10	22	14:45	32.90	80.00	7				30000.0	324.2	128.3	1	CHARLESTON, S.C. (2 SHOCKS)
1886	11	5	12:20	32.90	80.00	6				30000.0	324.2	128.3	2	CHARLESTON S.C.
1887	2	6	16:15	38.70	87.50	6				75000.0	258.9	319.5	1	VINCENNES IND
1887	8	2	12:36	37.00	89.20	5					278.5	287.4	1	CAIRO, IL. (WIDESPREAD EFFECTS)
1889	3	8	18:40	40.00	76.00	5				4000.0	537.5	55.6	1	PENNSYLVANIA
1889	7	19	19:32	35.20	90.00	6					319.4	263.1	1	MEMPHIS, TN. (INT, V-VII, REF, 2)
1891	7	26	20:28	37.90	87.50	6					221.3	309.8	1	EVANSVILLE, IN.
1891	9	26	22:55	37.00	89.20	5					278.5	287.4	2	CAIRO, IL. (*COORDS)
1893	3	4	00:30	40.60	74.00	5					650.0	56.8	1	NEAR NEW YORK CITY FELT LOCALLY
1895	9	1	06:09	40.70	74.80	6				35000.0	616.3	54.5	1	NEW JERSEY FELT TO EAST AND NORTHEAST
1895	10	31	05:08	37.00	89.40	9		6.2		1000000.0	289.2	286.9	9	MISSOURI (*MAG, 6.2 MB)
1897	4	30	22:00	36.00	89.00	4-5					258.4	273.0	1	TENNESSEE AND ILLINOIS (*COORDS)
1897	5	3	12:18	37.10	80.70	6				29000.0	221.0	66.7	1	PULASKI, VA. (INT, 7-REF, 2)
1897	5	31	13:58	37.30	80.70	8				265000.0	226.3	63.4	6	GILES CO., VIRGINIA
1897	10	21	22:20	37.00	81.00	5				23000.0	203.0	66.8	1	WYTHEVILLE VA
1897	12	18	18:45	37.70	77.50	5				7500.0	400,[illegible]	69.8	1	ASHLAND, VA.
1898	2	5	15:00	37.00	80.70	6				34000.0	218.6	68.4	1	PULASKI,VA.
1898	11	25	15:00	36.90	81.10	5				65000.0	195.4	68.1	1	WYTHEVILLE, VA. (*COORDS)
1899	2	13	04:30	37.00	81.00	5				115000.0	203.0	66.8	1	VIRGINIA
1899	4	29	20:05	38.50	87.00	6-7				40000.0	230.8	322.2	1	SOUTHWEST INDIANA AND SOUTHEAST ILLINOIS
1900	10	31	11:15	30.40	81.70	5					409.8	157.0	1	JACKSONVILLE, FLA. FELT LOCALLY
1901	5	17	01:00	39.30	82.50	5				7000.0	257.2	23.1	1	OHIO
1902	1	24	04:48	38.60	90.30	6				40000.0	375.4	301.7	1	MISSOURI
1902	5	29	02:30	35.10	85.30	5					75.1	223.7	1	CHATTANOOGA TENN FELT LOCALLY
1902	10	18	17:00	35.00	85.30	5				1500.0	80.3	220.3	1	SOUTHEAST TENN AND NORTHWEST GA
1903	1	23	20:15	32.10	81.10	6				10000.0	322.3	143.4	1	GEORGIA AND SOUTH CAROLINA
1903	2	8	18:21	38.50	90.30	6				70000.0	372.2	300.7	1	ST LOUIS MO
1903	11	4	12:18	38.50	90.30	6-7				70000.0	372.2	300.7	1	ST. LOUIS, MO. (2 SHOCKS, 56 MIN. APART)
1903	11	27	03:20	36.50	89.50	5				70000.0	288.4	279.9	1	NEW MADRID, MO.
1904	3	4	19:30	35.70	83.50	5				5000.0	51.2	104.6	1	EAST TENN
1905	4	13	10:30	40.40	91.40	5				5000.0	442.2	311.4	1	KEOKUK IOWA
1905	8	21	23:08	36.00	90.00	6				40000.0	314.3	273.0	1	MISSISSIPPI VALLEY (*COORDS)
1906	5	8	12:41	38.70	75.70	5				400.0	515.0	65.3	1	DELAWARE
1906	5	11	09:15	38.50	87.20	5				800.0	237.8	320.2	1	PETERSBURG, IND.
1906	5	21	13:00	38.80	88.50	5					302.6	312.9	1	FLORA, ILL.
1906	6	27	16:10	41.40	81.60	5				400.0	409.2	20.7	1	FAIRPORT, OHIO
1907	2	11	08:22	37.70	78.40	6				5600.0	353.8	67.5	1	ARVONIA VA.
1907	4	19	03:30	32.90	80.00	5				10000.0	324.2	128.3	1	CHARLESTON S.C.
1907	7	4	03:00	37.70	90.40	4-5				400.0	355.6	292.4	1	FARMINGTON, MO.
1908	2	5	03:20	42.00	73.00						742.2	51.9	1	HOUSATONIC VALLEY CONN (*COORDS)
1908	5	31	12:42	40.60	75.50	6					581.1	53.3	1	ALLENTOWN, PA. FELT LOCALLY
1908	8	23	04:30	37.50	77.90	5				1500.0	375.9	70.9	1	POWHATAN, VA.
1908	9	28	13:34	36.50	89.50	4-5				5000.0	288.4	279.9	1	NEW MADRID, MO.
1908	10	27	18:27	37.00	89.20	5				5000.0	278.5	287.4	1	CAIRO, IL.
1909	4	2	02:25	39.40	78.00	5-6				2500.0	425.0	53.3	1	VA W VA MD AND PA

* ESTIMATE

Z.5-2

Table 4 (cont.)

HISTORICALS 135- 162

YEAR	MO	DA	HR	COORDS. LAT.	LONG.	INTENSITY M.M.	R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1909	7	18	22:34	40.20	90.00	7				40000.0	426.6	316.0	1	ILLINOIS
1909	8	16	16:45	38.30	90.20						361.2	299.2	1	SOUTHWEST ILLINOIS
1909	9	22	00:00	38.70	86.50	5				4000.0	226.4	329.7	1	,OHIO VALLEY (*TIME)
1909	9	27	03:45	39.00	87.60	7				30000.0	278.0	321.6	1	INDIANIA (2 SHOCKS, 5 MIN. APART)
1909	10	8	05:00	35.00	85.00	4-5				800.0	70.6	209.7	11	NORTHEAST GEORGIA
1909	10	23	01:10	37.00	89.50	5				40000.0	294.6	286.6	1	MISSOURI (INT. V-VI, REF. 2)
1909	10	23	03:47	39.00	87.70	5				8000.0	281.6	320.7	1	ROBINSON, ILLINOIS
1910	5	8	16:10	37.70	78.40	5				4000.0	353.8	67.5	1	ARVONIA VA
1911	3	31	10:57	33.80	92.20	5				18000.0	466.1	254.2	1	RISON, AR. (2 SHOCKS, 73 MIN. APART)
1911	4	20	00:00	35.20	82.70	5				600.0	105.9	116.3	1	N.C.-S.C. BORDER (*TIME)
1912	1	2	10:21	41.50	88.50	6				40000.0	446.6	331.5	1	ILLINOIS
1912	6	12	05:30	33.00	80.20	7				35000.0	310.9	128.8	1	SUMMERVILLE S C
1912	6	20	00:00	32.00	81.00	5					331.4	143.2	1	SAVANNAH, GA. (*TIME)
1913	1	1	13:28	34.70	81.70	7				43000.0	172.2	117.7	6	UNION COUNTY, S. C.
1913	3	28	16:50	36.20	83.70	7				2700.0	43.7	60.5	1	EASTERN TENNESSEE
1913	4	17	23:30	35.30	84.20	5				3500.0	42.0	165.8	1	E. TENN.(*TIME 1130)(INT. 5-6 - REF.2)
1914	1	23	22:24	35.60	84.50	5					21.1	198.2	1	EAST TENNESSEE FELT ONLY LOCALLY
1914	3	5	15:05	33.50	83.50	6				50000.0	172.6	162.9	1	S.E. OF ATLANTA, GEORGIA
1914	9	22	02:04	33.00	80.20	5				30000.0	310.9	128.8	1	SUMMERVILLE, S.C.
1915	4	28	17:40	36.40	89.50	4-5				200.0	287.7	278.5	1	NEW MADRID, MO.
1915	10	26	01:40	36.70	88.60	5					241.4	284.6	1	MAYFIELD, KY. (FELT LOCALLY)
1915	10	29	01:00	35.80	82.70	5				1200.0	94.4	93.3	1	NORTH CAROLINA (*TIME)
1915	12	7	12:40	36.70	89.10	5-6				60000.0	268.6	283.4	1	NEAR MOUTH OF OHIO RIVER
1916	2	21	17:39	35.50	82.50	6				200000.0	109.0	103.8	1	NORTH CAROLINA (INT. 7 - REF.)
1916	3	2	00:02	34.50	82.70	4-5					135.1	134.8	11	ANDERSON, S.C. (6 SHOCKS)
1916	6	8	16:15	41.00	73.80	4-5					672.1	55.1	1	NEAR NEW YORK CITY FELT ONLY LOCALLY
1916	8	26	14:36	36.00	81.00	5				3800.0	189.4	86.7	1	WESTERN NORTH CAROLINA
1916	10	18	16:04	33.50	86.20	7				100000.0	194.8	212.5	1	IRONDALE, AL.
1916	12	18	23:42	36.60	89.30	6-7					278.4	281.6	1	HICKMAN, KY. (FELT LOCALLY)
1917	4	9	14:52	38.10	90.60	6				200000.0	375.5	295.8	1	ST. GENEVIEVE, MO.
1917	6	29	20:23	32.70	87.50	5					283.3	219.8	1	ALABAMA (FELT LOCALLY)
1918	1	16	10:45	36.00	84.00	5					22.7	70.3	2	KNOXVILLE, TENN. (*COORDS)
1918	4	9	21:09	38.70	78.40	6				60000.0	381.8	57.7	1	VIRGINIA
1918	6	21	20:00	36.10	84.10	5				3000.0	21.4	47.3	1	LENOIR CITY, TENN.
1918	10	4	03:21	34.70	92.30	5					453.9	261.9	1	ARKANSAS
1918	10	13	03:30	36.10	91.10	5					375.7	274.2	1	ARKANSAS
1918	10	15	21:30	35.20	89.20	5				20000.0	275.0	261.4	1	WEST TENNESSEE
1919	5	25	03:45	38.50	87.50	5				18000.0	248.9	317.4	1	SOUTH INDIANA
1919	9	5	21:46	38.80	78.20	6					394.5	57.5	1	VIRGINIA
1919	11	3	14:40	36.20	90.90	4-5					364.7	275.3	1	ARKANSAS (FELT LOCALLY)
1920	5	1	09:15	38.50	90.50	5				10000.0	381.9	300.0	1	MISSOURI
1920	12	24	02:30	36.00	85.00	5					35.4	282.6	1	EAST TENNESSEE FELT LOCALLY
1921	1	26	18:40	40.00	75.00	5				150.0	584.4	58.1	1	NEW JERSEY
1921	7	15	00:00	36.60	82.30	6					126.0	66.5	1	VIRGINIA, FELT LOCALLY (*TIME)
1921	8	7	01:30	37.80	78.40	5				2800.0	356.1	66.5	1	VIRGINIA
1921	12	15	08:20	35.80	84.00	5				5000.0	13.7	243.0	2	EASTERN TENN. (*COORDS)
1922	3	22	16:30	37.30	88.60	5				25000.0	253.4	293.9	1	SOUTHERN ILLINOIS (*COORDS, 2 SHOCKS)
1922	3	23	15:45	37.00	88.00	5					215.2	291.9	1	WESTERN KENTUCKY (*COORDS)

* ESTIMATE

2.5-2
Table 1 (cont.)

~~Q 230.1-1~~

230.1-12

HISTORICALS 183- 230

YEAR	MO	DA	HR	COORDS. LAT.	COORDS. LONG.	INTENSITY M.M.	INTENSITY R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1922	3	29	20:20	35.00	86.00	5					109.9	236.4	2	CENTRAL TENNESSEE (*COORDS)
1922	3	30	10:53	35.20	90.60	5					352.7	264.0	2	MISSISSIPPI VALLEY
1922	11	26	21:31	37.00	90.50	5					348.5	284.5	2	MISS. R. VALLEY (*COORDS)
1923	10	28	11:10	35.50	90.30	7				40000.0	333.1	267.1	1	MARKED TREE, ARKANSAS
1923	11	9	22:00	39.00	88.00	5					292.5	318.4	1	TALLULA ILL (*COORDS)
1923	11	26	17:25	35.40	90.40	6					339.5	266.0	9	MISSISSIPPI VALLEY (*COORDS)
1923	12	31	20:06	34.80	82.50	4-5					130.1	124.8	11	GREENVILLE, SC
1923	12	31	21:05	35.40	90.30	5				30000.0	333.9	265.9	1	ARKANSAS
1924	3	2	05:18	36.90	89.10	5				15000.0	271.5	286.3	1	KENTUCKY
1924	10	20	03:30	35.00	82.60	5				56000.0	117.7	121.0	1	PICKENS COUNTY S C
1924	12	25	23:30	37.30	79.90	5					267.0	67.3	1	ROANOKE, VA.
1925	3	26	22:06	39.50	84.00	5					250.3	4.7	10	S.W. OHIO
1925	4	24	02:56	41.80	70.80	5				1600.0	835.9	56.7	1	SOUTHEAST MASSACHUSETTS
1925	4	26	22:05	38.00	87.50	5				100000.0	225.6	311.2	1	INDIANA
1925	5	13	06:00	36.70	88.60	5				3000.0	241.4	284.6	1	KENTUCKY
1925	9	2	05:55	37.80	87.60	5-6				75000.0	221.5	307.5	1	HENDERSON, KY.
1925	11	14	08:04	41.50	72.50	6				850.0	747.9	55.2	1	HARTFORD CONN
1926	5	11	22:30	40.90	73.90	5				150.0	664.2	55.4	1	NEW ROCHELLE N Y
1926	7	8	04:50	35.90	82.10	6					127.8	89.0	1	S. MITCHELL CO., N.C. (INT. 7 - REF. 2)
1926	11	5	09:53	39.10	82.10	6-7				350.0	254.6	28.7	1	SOUTHEASTERN OHIO
1927	5	7	02:28	36.50	89.00	7				130000.0	260.9	280.7	1	MISSISSIPPI VALLEY
1927	6	1	07:20	40.30	74.00	7				3000.0	641.0	58.5	1	NEW JERSEY
1927	6	10	02:16	38.00	79.00	5				2500.0	331.0	62.3	1	VIRGINIA
1927	6	16	07:00	34.70	86.00	5				2500.0	122.8	228.4	1	SCOTTSBORO, AL.
1927	8	13	10:00	36.40	89.50	5					287.7	278.5	2	MISSISSIPPI VALLEY (*COORDS)
1927	10	8	07:56	35.00	85.00	5					70.6	209.7	2	CHATTANOOGA,TENN(*COORDS)
1928	9	9	15:00	41.50	82.00	5				1500.0	408.3	17.6	1	LORAIN AND CLEVELAND OHIO
1928	11	2	23:03	36.00	82.60	6				40000.0	100.0	85.1	1	MADISON CO., N.C. (INT. 7 - REF.2)
1929	3	8	04:06	40.40	84.20	5				5000.0	311.8	1.8	1	BELLEFONTAINE, OHIO
1929	12	26	21:56	38.10	78.50	6					358.7	63.1	1	CENTRAL VIRGINIA
1930	8	29	00:27	37.00	89.00	5					267.8	288.0	2	KY., TN., IL., MO. (*COORDS)
1930	8	30	04:28	35.90	84.40	5					1.2	305.9	2	NEAR KNOXVILLE, TENN.
1930	9	30	14:40	40.30	84.30	7					304.8	0.8	1	OHIO
1930	10	16	16:50	36.00	84.00	5					22.7	70.3	3	EAST TENNESSEE
1930	10	19	06:17	30.00	91.00	5-6				18000.0	559.1	225.2	6	DONALDSONVILLE, LA.
1931	1	5	20:51	39.00	87.00	5				500.0	258.4	327.0	3	ELLISTON IND
1931	5	5	07:18	33.70	86.60	5				6500.0	196.8	220.4	3	CULLMAN, AL. (INT. V-VI, REF. 1)
1931	9	20	17:05	40.40	84.20	7				40000.0	311.8	1.8	3	ANNA OHIO
1931	12	16	21:36	34.10	89.80	6				65000.0	330.6	249.6	3	BATESVILLE, MS. (INT. VI-VII, REF. 1)
1933	1	24	21:00	40.20	74.70	5				600.0	604.7	57.6	3	NEAR TRENTON, N.J.
1933	5	28	10:10	38.70	83.70	5				600.0	197.8	10.7	1	MAYSVILLE KY
1933	12	9	02:40	35.80	90.20	5				100.0	325.9	269.4	3	MANILA, AR. (INT. VI, REF. 1)
1933	12	19	09:12	33.00	80.20	4-5					310.9	128.8	1	SUMMERVILLE, S.C. LOCAL (INT. 4-REF.3)
1934	8	19	18:47	37.00	89.20	6				28000.0	278.5	287.4	3	RODNEY, MO. (INT. VII, REF. 1)
1934	10	29	15:07	42.00	80.20	5					478.1	26.7	3	ERIE PA FELT ONLY LOCALLY
1934	11	12	08:45	41.50	90.50	5					508.7	321.5	3	ROCK ISLAND, ILL. (INT. 6-REF. 1)
1935	1	1	03:15	35.10	83.60	5				7000.0	70.1	140.9	3	NORTH CAROLINA GEORGIA BORDER
1935	11	1	03:30	38.90	79.90	5					322.1	48.5	3	ELKINS, WEST VIRGINIA

* ESTIMATE

2.5-2

Table 1 (cont.)

HISTORICALS 231- 278

YEAR	MO	DA	HR	COORDS. LAT.	COORDS. LONG.	INTENSITY M.M.	INTENSITY R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1937	3	2	08:48	40,40	84,20	6-7				70000,0	311,8	1,8	3	ANNA, OHIO (INT. 7-REF. 1)
1937	3	3	03:50	40,60	84,20	5					311,8	1,8	10	ANNA, OHIO (AFTER SHOCK)
1937	3	8	23:45	40,40	84,20	7-8				150000,0	311,8	1,8	1	ANNA, OHIO
1937	5	16	18:50	36,10	90,60	4-5				25000,0	347,8	274,2	1	NORTHEASTERN ARKANSAS (INT. III, REF. 3)
1937	11	17	11:05	38,60	89,10	5				8000,0	319,9	307,2	3	CENTRALIA ILL
1938	7	15	17:45	40,40	78,20	5				100,0	458,0	45,3	3	SOUTHERN BLAIR CO., PA. (INT. 6-REF. 1)
1938	8	22	22:35	40,10	74,50	5				5000,0	611,2	58,6	3	CENTRAL N.J.
1938	9	17	21:34	35,50	90,30	4-5				90000,0	333,1	267,1	1	NORTHEASTERN ARKANSAS (INT. IV, REF. 3)
1939	5	4	21:45	33,70	85,80	5					171,4	208,4	3	ANNISTON ALA
1939	6	19	15:43	34,10	93,10	5					508,5	258,5	3	ARKADELPHIA, AR. (FELT LOCALLY)
1939	11	14	21:54	39,60	75,20	5				6000,0	563,0	60,2	3	SALEM COUNTY N J
1939	11	23	09:15	38,20	90,10	5				150000,0	353,3	298,6	3	GRIGGS ILL
1940	1	28	18:12	41,60	70,80	5				2000,0	830,2	57,5	1	BUZZARDS BAY, MASS. (INT. 4-REF. 3)
1940	5	31	13:02	37,00	88,00	4-5				1000,0	215,2	291,9	2	OHIO RIVER (*COORDS)
1940	11	23	15:15	38,20	90,10	6					353,3	298,6	3	WATERLOO ILL FELT OVER A WIDE AREA
1940	12	25	01:50	36,00	82,80	5				7000,0	88,8	84,6	2	EAST TENN. AND WESTERN N.C. (*COORDS)
1941	11	16	21:09	35,50	89,70	5-6					299,6	266,4	3	COVINGTON TN. (FELT LOCALLY)
1942	3	1	00:00	41,00	89,70	5					455,3	322,4	7	HENRY COUNTY, ILLINOIS (*TIME)
1943	3	8	21:26	41,60	81,30	4-5				40000,0	428,0	21,9	1	LAKE ERIE (INT. 4-REF. 3)
1945	6	13	22:25	35,00	84,50	5					61,9	186,2	3	CLEVELAND, TENN.
1945	7	26	05:32	34,30	81,40	4-5				25000,0	201,2	122,2	1	LAKE MURRAY, S.C. (INT. 4 - REF.3)
1947	6	29	22:24	38,40	90,20	6				15000,0	364,2	300,2	1	NEAR ST. LOUIS, MO.
1947	8	9	20:47	42,00	85,00	6				50000,0	423,5	355,7	3	SOUTH CENTRAL MICHIGAN
1947	9	20	15:30	31,90	92,70	4-5					550,7	242,3	12	WINNFIELD, LA.
1947	12	15	21:27	35,50	90,00	5				10000,0	316,3	266,8	2	NEAR OSCEOLA, AR. (*COORDS)
1948	2	9	19:04	36,00	84,50	5-6					10,0	319,2	2	NEAR LAFOLLETTE,TENN (*COORDS)
1949	1	13	21:45	36,40	89,50	5				7000,0	287,7	278,5	2	MISSISSIPPI VALLEY (*COORDS)
1949	9	17	02:30	36,80	83,20	4-5					91,0	46,0	2	PENNINGTON GAP VA. (*COORDS)
1950	2	8	04:37	37,40	92,40	5					456,4	285,6	3	LEBANON, MO.
1951	9	3	20:26	41,20	74,10	5				5500,0	665,2	53,4	3	ROCKLAND COUNTY N Y
1952	2	20	16:35	36,40	89,50	5					287,7	278,5	3	TN.-MO. BORDER
1952	6	20	03:38	39,70	82,20	6				10000,0	289,0	23,7	3	SOUTHEASTERN OHIO
1952	7	16	17:48	36,20	89,60	6					292,2	275,7	3	DYERSBURG, TN.
1952	10	8	16:40	41,70	74,00	5					687,5	51,1	3	POUGHKEEPSIE NY
1952	11	19	00:00	32,90	80,00	5					324,2	128,3	3	CHARLESTON, S. C. (*TIME)
1953	3	27	03:50	41,10	73,50	5					689,1	55,2	3	STAMFORD CONN
1953	9	11	12:26	38,60	90,10	6					365,9	302,5	3	SOUTHWEST ILLINOIS
1954	1	1	21:25	36,60	83,70	6					62,1	37,6	3	MIDDLESBORO KY
1954	1	7	02:25	40,30	76,00	6					547,9	53,7	3	SINKING SPRING PA
1954	1	22	00:00	35,30	84,40	5					40,8	181,4	3	ATHENS, TENN. IN P.M.
1954	2	2	10:53	36,70	90,30	6					334,2	281,4	3	POPLAR BLUFF, MO.
1954	2	21	15:00	41,20	75,90	7					586,7	48,7	3	WILKES-BARRE, PA. FELT ONLY LOCALLY
1954	2	23	22:55	41,20	75,90	6					586,7	48,7	3	WILKES-BARRE, PA.
1954	4	26	20:09	35,20	90,00	5					319,4	263,1	3	MEMPHIS, TN.
1955	1	25	01:24	35,60	90,30	6				30000,0	332,4	268,3	3	TN., AR., MO.
1955	2	1	08:45	30,40	89,10	5					467,2	217,1	3	GULFPORT, MS.
1955	3	29	03:03	36,00	89,50	6					286,3	273,0	3	FINLEY, TN.
1955	4	9	[illegible]	[illegible]	[illegible]	6				20000,0	335,6	298,7	3	WEST OF SPARTA ILL

* ESTIMATE

Table 2.5-2 (cont.)

Q 230.1-1

HISTORICALS 274- 326

YEAR	MO	DA	HR	COORDS. LAT.	LONG.	INTENSITY M.M.	R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1955	5	26	12:09	41.59	81.70	5					413.7	19.6	3	CLEVELAND OHIO FELT ONLY LOCALLY
1955	6	28	19:16	41.50	81.70	5					413.7	19.6	3	CLEVELAND OHIO FELT ONLY LOCALLY
1955	9	5	19:45	36.00	89.50	5					286.3	273.0	3	FINLEY, TN.
1955	9	28	02:02	36.60	81.30	5				1700.0	178.6	73.2	11	VA-NC BORDER (*COORDS)
1955	12	13	01:43	36.00	89.50	5					286.3	273.0	3	DYER CO., TN. (*TIME)
1956	1	27	06:03	40.40	84.20	5					311.8	1.8	10	WEST CENTRAL OHIO
1956	1	28	22:14	35.60	89.60	6				11500.0	293.3	267.6	3	TN.-AR. BORDER
1956	9	7	08:36	35.50	84.00	6				8300.0	34.5	141.3	3	EASTERN TENN.
1956	9	7	08:49	35.50	84.00	5					34.5	141.3	3	EASTERN TENN.
1956	10	29	03:24	36.10	89.40	5					280.8	274.4	3	CARUTHERSVILLE, MO.
1956	11	25	22:13	37.10	90.60	6				21500.0	355.3	285.4	3	WAYNE CO., MO.
1957	3	23	14:03	40.80	74.80	6					619.7	53.9	3	WEST CENTRAL NEW JERSEY
1957	3	26	02:27	37.00	88.40	5					236.1	290.1	3	PADUCAH, KY. (FELT LOCALLY)
1957	4	23	04:24	34.50	86.80	6				11500.0	166.9	235.6	3	BIRMINGHAM, AL.
1957	5	13	09:25	35.80	82.00	6				8100.0	133.6	92.0	3	WESTERN NORTH CAROLINA
1957	6	23	01:34	35.50	84.50	5					42.7	351.2	2	EAST CENTRAL TENNESSEE
1957	7	2	04:33	35.50	82.50	6					109.0	103.8	3	WESTERN NORTH CAROLINA
1957	11	24	15:06	35.00	83.50	6				4100.0	79.1	140.8	3	NORTH CAROLINA-TENNESSEE BORDER
1958	1	26	10:56	35.20	90.00	5					319.4	263.1	3	MEMPHIS, TN. (FELT LOCALLY)
1958	1	27	23:57	37.00	89.00	5				300.0	267.8	288.0	3	IL.-KY.-MO. BORDER
1958	3	5	06:54	34.30	77.80	5					387.9	104.5	3	WILMINGTON, N.C. (SERIES 2/10-3/15)
1958	4	8	16:26	36.20	89.10	5				400.0	264.4	276.0	3	OBION CO., TN.
1958	4	26	01:30	36.30	89.50	5					287.1	277.2	3	LAKE CO., TN.
1958	5	1	16:47	41.50	81.70	5					413.7	19.6	3	CLEVELAND, OHIO FELT LOCALLY
1958	10	20	01:16	34.50	82.80	5					131.2	136.6	3	ANDERSON, S.C. FELT LOCALLY
1958	11	7	20:02	38.40	87.90	6				33000.0	260.0	312.9	3	ILL.-IND. BORDER
1958	11	19	12:15	30.30	91.10	5					547.8	227.1	3	BATON ROUGE, LA. (FELT LOCALLY)
1959	2	13	02:37	36.20	89.50	5				170.0	286.7	275.8	3	BOGOTA, TN.
1959	4	23	15:59	37.50	80.50	6				1100.0	242.1	61.5	3	GILES CO., VA.
1959	8	3	01:08	33.00	79.50	6				25000.0	342.4	124.3	3	COAST OF S. CAROLINA
1959	8	12	13:06	35.00	87.00	6				2800.0	159.7	248.1	3	AL.-TN. BORDER
1959	10	26	21:07	34.50	80.30	6				4800.0	249.7	111.4	3	NORTHEASTERN S. CAROLINA
1959	12	21	10:25	36.00	89.50	5				400.0	286.3	273.0	3	FINLEY, TN.
1960	1	28	15:38	36.00	89.50	5					286.3	273.0	3	DYER CO., TN. (FELT LOCALLY)
1960	3	12	07:48	33.00	79.00	5				3500.0	365.9	121.5	3	COAST OF SOUTH CAROLINA
1960	4	15	05:10	35.80	84.00	5				1300.0	22.3	106.1	3	EASTERN TENN. (*COORDS)
1960	4	21	04:45	36.30	89.50	5					287.1	277.2	3	LAKE CO., TN. (FELT LOCALLY)
1960	7	23	22:38	33.00	80.00	5					319.7	127.4	3	CHARLESTON, S.C. FELT LOCALLY
1961	2	22	03:45	41.20	83.40	5					370.7	7.9	3	NORTHWESTERN OHIO
1961	9	14	21:17	40.80	75.50	5					588.4	52.1	3	LEHIGH VALLEY, PA. FELT LOCALLY
1961	12	27	12:06	40.50	74.80	5					609.6	55.6	3	PA.-N.J. BORDER
1962	2	2	00:44	36.50	89.60	6			15.0	35000.0	293.9	279.8	3	NEW MADRID, MO.
1962	6	20	19:29	37.70	88.50	5		5.5			259.9	300.0	3	SOUTHERN ILLINOIS (MAG. 5.5 M)
1962	7	23	00:05	36.10	89.80	6			11.0		303.2	274.3	3	SOUTHERN MISSOURI
1963	3	3	11:30	36.70	90.10	6		4.5		100000.0	323.2	281.7	3	SOUTHEASTERN MISSOURI (MAG. 4.5 M)
1963	7	8	17:52	37.00	90.50	5		4.1	15.0		348.5	284.5	4	SE. MISSOURI (*INT.) (MAG. 4.1 MB)
1963	8	2	18:38	37.00	88.80	5		3.6	11.9		257.2	286.7	3	IL.-KY. BORDER (MAG. 3.6 MB)
1963	10	28	17:39	36.70	81.00	5				1300.0	196.5	72.5	3	GALAX, V.A. (2 SHOCKS)

* ESTIMATE

HISTORICALS 327- 374

YEAR	MO	DA	HR	COORDS. LAT.	LONG.	INTENSITY M.M.	R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1964	1	16	23:10	36.80	89.50	6		4.5	11.0		291.6	284.0	4	SE. MISSOURI (*INT.) (MAG. 4.5 MB)
1964	2	18	04:31	34.80	85.50	5		4.4	9.0		98.2	220.2	3	ALABAMA/GEORGIA BORDER (MAG. 4.4 MB)
1964	3	12	20:20	33.20	83.40	5		4.4	24.0	400.0	194.1	163.0	1	MACON, GEORGIA (MAG. 4.4 MB)
1964	4	20	14:05	34.00	81.00	5					231.8	123.3	3	NEAR COLUMBIA, S.C. (*COORDS)
1964	4	23	19:21	31.50	93.80	5		3.7			620.2	243.4	3	WESTERN LOUISIANA (MAG. 3.7 MB)
1964	4	24	01:34	31.60	93.80	5		3.7			616.5	244.0	3	WESTERN LOUISIANA (MAG. 3.7 MB)
1964	4	27	18:31	31.50	93.80	5		3.4			620.2	243.4	3	WESTERN LOUISIANA (MAG. 3.4 MB)
1964	4	28	15:19	31.70	93.60	5		4.4			602.9	243.9	3	WESTERN LOUISIANA (MAG. 4.4 MB)
1964	5	12	04:45	40.20	76.50	6		4.5	20.0		521.8	52.8	3	SOUTHEASTERN PA. (MAG. 4.5 MB)
1964	5	23	05:26	36.50	90.00	5		4.5	11.0		316.0	279.3	4	SE. MISSOURI (*INT.) (MAG. 4.5 MB)
1964	5	23	09:01	36.50	89.90	6		4.3	11.0		310.5	279.4	4	SE. MISSOURI (*INT.) (MAG. 4.3 MB)
1964	6	2	20:27	31.30	94.00	4		4.2			637.5	242.9	3	TX-LA BORDER (MAG. 4.2 MB)
1964	8	16	05:36	31.40	93.80	5					623.8	242.9	3	HEMPHILL, TX.
1964	11	17	12:08	41.20	73.70	5					683.3	54.3	3	ARMONK, N.Y.
1965	2	10	21:40	36.40	89.70	6		4.6	11.0		298.8	278.3	4	SE. MISSOURI (*INT.) (MAG. 4.6 MB)
1965	3	6	15:09	37.83	91.17			5.3			398.4	291.7	3	MISSOURI (MAG.5.3 MB)
1965	8	13	23:46	37.20	89.30			5.0			287.6	289.8	3	SW. ILLINOIS (FELT) (MAG. 5.0 MB)
1965	8	14	07:14	37.10	89.20	7		5.0			280.3	288.8	3	SOUTHWESTERN ILLINOIS (MAG. 5.0 MB)
1965	8	15	00:07	37.40	89.50	5		5.1			302.2	291.7	3	SOUTHWESTERN ILLINOIS (MAG. 5.1 MB)
1965	8	15	22:19	37.40	89.47	5					300.7	291.8	3	SOUTHWESTERN ILLINOIS
1965	9	8	23:37	34.80	81.20	5					194.5	111.9	6	CHESTER, S.C. (4 EVENTS, 9/8 - 9/12)
1965	9	9	09:42	34.80	81.20	5					194.5	111.9	6	CHESTER, S. C.
1965	9	10	02:32	34.80	81.20	5					194.5	111.9	6	CHESTER, S. C.
1965	9	12	13:25	34.80	81.20	5					194.5	111.9	6	CHESTER, S. C.
1965	10	20	20:05	37.80	91.00	6		5.2		160000.0	388.9	291.8	3	EASTERN MISSOURI (MAG. 5.2 MB)
1965	10	24	12:45	41.30	70.10	5					855.7	59.8	3	NANTUCKET, MASS.
1965	11	4	01:44	37.10	91.00	5		4.5	2.0		376.9	284.8	4	SE. MISSOURI (*INT.) (MAG. 4.5 MB)
1965	12	7	22:03	41.70	71.40	5				375.0	804.9	56.2	3	NARRAGANSETT BAY, R.I.
1965	12	19	16:19	35.90	89.90	7		5.3	3.0		308.8	271.7	4	NE. ARKANSAS (*INT.) (MAG. 5.3 MB)
1966	2	11	22:32	35.90	90.00	4		4.3			314.4	271.8	3	ARKANSAS (MAG. 4.3 MB)
1966	2	13	17:20	37.10	91.00	5		4.7	4.0		376.9	284.8	4	SE. MISSOURI (*INT.) (MAG. 4.7 MB)
1966	2	26	02:10	37.20	91.00	5		3.8	20.0		378.2	285.8	4	SE. MISSOURI (*INT.) (MAG. 3.8 MB)
1966	5	31	01:19	37.60	78.00	5		3.1		28000.0	372.5	69.6	3	CENTRAL VIRGINIA (MAG. 3.1 MB)
1967	2	2	08:40	41.40	71.40	5		2.4		350.0	796.2	57.5	3	NARRAGANSETT BAY, R.I. (MAG. 2.4 M)
1967	4	8	00:41	39.60	82.50	5		4.2		4000.0	276.2	21.3	3	CENTRAL OHIO (MAG. 4.2 MB)
1967	6	4	10:14	33.60	90.90	6		3.8		25000.0	402.3	248.7	3	GREENVILLE, MS. (MAG. 3.8 MB)
1967	6	29	07:57	33.60	90.90	5		3.4			402.3	248.7	3	GREENVILLE, MS. (MAG. 3.4 MB)
1967	7	21	03:15	37.50	90.40	6		3.9			351.4	290.2	3	SOUTHEASTERN MISSOURI (MAG. 3.9 MB)
1967	10	23	04:04	33.40	80.70	5		3.8			270.9	128.4	3	CHARLESTON AREA OF S.C. (MAG. 3.8 MB)
1967	11	22	17:10	41.00	73.70	5				400.0	676.7	55.3	3	WESTCHESTER CO. N.Y.
1968	2	9	19:35	36.50	89.90			3.8			310.5	279.4	3	SE. MISSOURI (MAG. 3.8 MB) (FELT)
1968	3	8	00:38	37.00	80.50	4		3.9		3200.0	229.0	69.3	3	VIRGINIA (MAG. 3.9 M)
1968	9	22	16:41	34.00	81.50			3.7		400.0	209.1	127.8	3	SOUTH CAROLINA (MAG. 3.7 MB)
1968	11	3	03:34	41.00	72.00	5					756.4	58.5	3	SOUTHERN CONN. (*COORDS)
1968	11	9	11:02	38.00	88.50	7		5.3		580000.0	270.1	303.9	3	SOUTHERN ILLINOIS (MAG. 5.3 MB)
1968	12	10	04:13	39.70	74.60	5		2.5			595.0	60.8	3	NEW JERSEY (MAG. 2.5 M)
1968	12	11	10:00	38.00	85.50	5					158.3	337.4	3	NEAR LOUISVILLE, KY. (*COORDS)
1969	1	1	17:36	34.80	92.60	6		4.2		23000.0	469.1	263.2	3	CENTRAL ARKANSAS (MAG. 4.2 MB)

* ESTIMATE

Table 2.5-2 (cont.)

HISTORICALS 375- 422

YEAR	MO	DA	HR	COORDS. LAT.	LONG.	INTENSITY M.M.	R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1969	7	13	16:51	36.10	83.70	5		3.5		20000.0	40.8	69.0	3	EASTERN TENNESSEE (MAG. 3.5 M)
1969	11	19	20:00	37.40	81.00	6		4.3		100000.0	214.6	59.9	3	WEST VIRGINIA (MAG. 4.3 MB)
1969	12	11	18:45	37.80	77.40	5				3500.0	407.9	69.1	3	VIRGINIA, RICHMOND AREA
1969	12	13	05:20	35.10	83.00	5				3500.0	95.0	124.7	3	WESTERN N. C.
1970	3	26	21:44	36.50	89.70			3.5	3.0		299.5	279.7	3	SE. MISSOURI (MAG. 3.5 M) (FELT)
1970	9	9	20:41	36.10	81.40	5			20.0	2000.0	167.4	84.2	3	NORTHWESTERN N. C.
1970	11	16	20:14	35.90	89.90	6		3.6	11.8	78000.0	308.8	271.7	3	ARKANSAS (MAG. 3.6 MB)
1970	12	24	04:18	36.70	89.50	4		4.8	7.5		290.4	282.6	3	NEW MADRID, MO. (MAG. 4.8 MB)
1971	3	14	10:28	33.10	87.90			3.9	1.0		278.0	227.1	3	CARROLLTON, AL. (MAG. 3.9 M) (FELT)
1971	5	19	07:54	33.30	80.60	5		3.4	15.0		279.8	128.7	3	ORANGEBURG, S.C. (MAG. 3.4 MB)
1971	7	12	21:03	36.00	84.00	5				2000.0	22.7	70.3	3	EASTERN TENNESSEE (*COORDS)
1971	7	13	03:15	34.59	82.75	6				2000.0	128.7	133.8	3	WESTERN SOUTH CAROLINA
1971	9	11	19:06	38.10	77.40	5			11.0	1900.0	414.4	66.3	3	SPOTSYLVANIA, VA.
1971	10	1	12:50	35.80	90.40	5			12.0	55000.0	337.0	269.3	3	NORTHEASTERN ARKANSAS
1971	10	9	11:40	35.90	83.50	5		3.4	11.0		49.4	89.0	3	EASTERN TENNESSEE (MAG. 3.4 MB)
1972	1	31	23:42	36.40	90.80			4.1	10.6		359.7	277.5	5	NEW MADRID, MO. (MAG. 4.1 MB)
1972	2	3	18:11	33.50	80.40	5		4.5	3.0	26000.0	280.1	125.0	3	CENTRAL SOUTH CAROLINA (MAG. 4.5 MB)
1972	3	29	14:39	36.20	89.60	5		3.7	6.0	65800.0	292.2	275.7	3	NEW MADRID.MO. (MAG. 3.7 MB)
1972	6	18	23:46	37.00	89.08	4		4.5	8.1		272.1	287.8	3	CAPE GIRARDEAU, MO. (MAG. 4.5 MB)
1972	8	14	10:05	33.00	80.00	3		3.0		2500.0	319.7	127.4	3	SOUTH CAROLINA (MAG. 3.0 M) (*COORD.)
1972	9	5	11:00	37.60	77.70	5		3.3		2300.0	388.3	70.3	3	RICHMOND, VA. (MAG. 3.3 M)
1972	9	14	23:22	41.60	89.40	6		3.7	3.0	250000.0	478.1	327.?	3	LEE CO., ILLINOIS (MAG. 3.7 MB)
1972	12	7	22:01	40.10	76.20	5			2.0	460.0	531.8	54.4	3	LANCASTER AND BERKS COS., PA.
1973	1	7	16:56	37.40	87.30			3.2	9.0		192.5	303.7	3	KENTUCKY (MAG. 3.2 M)
1973	1	8	03:12	33.80	90.60			3.5	4.2		380.9	249.5	3	MISSISSIPPI (MAG. 3.5 M)
1973	1	12	05:57	37.90	90.50	4		3.2	12.0		365.4	294.2	5	EASTERN MISSOURI (MAG. 3.2 M)
1973	2	3	12:15	42.00	71.00	5					832.5	55.5	3	R.I.--E. MASS., NOT REPT BY SEIS. STNS.
1973	2	28	03:22	39.72	75.44	5		3.8	8.4	15440.0	554.9	58.8	3	NEW JERSEY (MAG. 3.8 M)
1973	5	25	03:12	33.80	90.60	5		3.5	4.2		380.9	249.5	3	MISSISSIPPI (MAG. 3.5 M)
1973	10	2	21:50	35.91	90.00	4		3.4	5.2		31?.4	271.9	3	ARKANSAS (MAG. 3.4 MBLG)
1973	10	7	14:15	36.51	89.59	4		3.8	1.0		293.5	279.9	3	NEW MADRID, MO. (MAG. 3.8 MBLG)
1973	10	30	17:58	35.75	84.00	5		3.4	20.5	2400.0	23.5	114.2	3	KNOX AND BLOUNT CO. TN. (MAG. 3.4 MBLG)
1973	11	30	02:48	35.80	83.96	6		4.6	1.8	54300.0	24.5	104.6	3	MARYVILLE,TENN. (MAG. 4.6 MS)
1973	12	20	04:45	36.16	89.58			3.4	6.2		291.0	275.2	3	NEW MADRID, MO. (MAG. 3.4 MBLG)
1974	1	7	19:13	36.20	89.39	5		4.3	1.0		280.6	275.8	3	TENNESSEE (MAG. 4.3 MBLG)
1974	2	15	16:36	34.05	93.13	2		3.5	1.0		511.2	258.1	3	ARKANSAS (MAG. 3.5 MBLG)
1974	2	15	16:49	33.96	93.03	5		4.0	1.0	6600.0	507.5	257.3	3	ARKANSAS (MAG.4.0 MBLG)
1974	2	24	01:54	35.82	90.38			3.2	3.7		335.9	269.1	3	ARKANSAS (MAG.3.2 MBLG)
1974	3	4	08:24	35.68	90.35			3.0	3.1		334.8	269.3	3	ARKANSAS (MAG. 3.0 MBLG)
1974	3	9	22:34	36.20	89.50	4-5		2.5	3.0		286.7	275.8	5	NEW MADRID, MO. (*INT.)
1974	3	12	06:30	35.66	89.79			3.2	3.1		303.5	268.6	3	TENNESSEE (MAG. 3.2 MBLG)
1974	3	27	10:11	38.55	90.13	3		5.6	6.0		365.7	301.9	5	EASTERN MO. (*INT.) (MAG. 5.3 MB)
1974	4	3	17:05	38.59	88.09	6		4.7	6.8	243000.0	276.4	313.6	3	SOUTHERN ILLINOIS (MAG.4.7 MBLG)
1974	4	5	13:41	38.59	90.91	5		2.6	0.6		404.5	299.4	8	EASTERN MO. (*INT.)
1974	5	13	00:52	36.71	89.39	6		4.1	1.0		284.5	283.0	3	NEW MADRID, MO. (MAG. 4.1 MBLG)
1974	5	30	16:29	37.38	80.42	5		3.6	5.0	2084.0	242.6	63.7	3	VIRGINIA (MAG. 3.6 MBLG)
1974	6	4	19:17	38.60	84.77			3.2	9.3		188.5	353.6	3	KENTUCKY (MAG. 3.2 MBLG)
1974	6	5	02:06	38.62	89.94	5		3.6	6.8		359.1	303.3	3	SOUTHERN ILLINOIS (MAG. 3.6 MBLG)

* ESTIMATE

Table 2.5-2 (cont.)

HISTORICALS 423- 470

YEAR	MO	DA	HR	COORDS. LAT.	LONG.	INTENSITY M.M.	R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1974	6	7	14:46	41.57	73.94	6		2.9	1.2		685.4	51.9	3	NEW YORK (MAG. 2.9 M)
1974	8	2	03:52	33.87	82.49	5		4.9	1.0	14000.0	176.0	141.9	3	GEORGIA (MAG. 4.9 MBLG)
1974	8	11	08:30	36.92	91.17	5		3.6	2.0		384.0	282.7	3	FREMONT, MO. (MAG. 3.6 MBLG)
1974	8	22	16:34	38.23	89.73	5		2.5	7.0		336.2	300.3	5	MARISSA, ILLINOIS (MAG. 2.5 M)
1974	9	28	21:26	41.24	83.36	2		3.0	1.0		373.8	8.2	3	OHIO (MAG. 3.0 MBLG)
1974	10	20	10:14	39.10	81.59	5		3.4	6.6		269.5	33.8	3	WEST VIRGINIA (MAG. 3.4 MBLG)
1974	11	22	00:26	32.90	80.15	6		4.7	11.2	50000.0	317.6	129.4	3	SOUTH CAROLINA (MAG. 4.7 MB)
1974	12	10	00:02	31.35	87.47	5		3.0	6.2		360.5	210.4	3	ALABAMA (MAG.3.0 MBLG)
1974	12	12	23:04	34.67	91.88	5		3.4	3.0		431.1	260.9	3	NORTHEASTERN ARKANSAS (MAG. 3.4 MBLG)
1974	12	25	07:21	35.78	90.01			3.0	6.1		315.3	269.7	8	ARKANSAS (MAG. 3.0 ML)
1975	1	10	09:31	38.20	91.03			3.2			399.7	295.5	8	MISSOURI (MAG. 3.2 MBLG)
1975	2	13	13:44	36.52	89.56	5		3.3	3.1		291.	280.1	3	NEW MADRID, MO. (MAG. 3.3 MBLG)
1975	2	16	18:22	39.05	82.42	4		3.3	3.1		243.4	25.6	3	OHIO (MAG. 3.3 MBLG)
1975	3	1	05:50	33.55	87.99	4		3.2	11.2		261.0	232.8	3	ALABAMA (MAG. 3.2 MBLG)
1975	3	7	07:45	37.32	80.48	2		3.0	3.1		237.9	64.3	3	VIRGINIA (MAG. 3.0 ML)
1975	4	28	00:47	32.97	80.23	4		3.0	3.1	77.0	310.9	129.3	3	SOUTH CAROLINA (MAG. 3.0 MBLG)
1975	6	13	16:40	36.54	89.68	6		4.3	1.2		298.7	280.2	3	NEW MADRID, MO. (MAG. 4.3 MBLG)
1975	6	24	05:12	33.72	87.84	4		4.5	6.2		246.9	233.6	3	ALABAMA (MAG. 4.5 MB)
1975	7	6	02:48	36.19	89.49	4-5		2.9	3.0		286.1	275.7	5	NEW MADRID, MO. (MAG. 2.9 MBLG, *INT.)
1975	8	20	03:14	36.56	89.80	4-5		2.9	3.0		305.5	280.3	5	NEW MADRID, MO. (MAG. 2.9 MBLG, *INT.)
1975	8	24	18:44	37.23	90.89	4-5		2.7	3.0		372.8	286.3	5	EASTERN MISSOURI (MAG. 2.7 MBLG, *INT.)
1975	8	24	21:01	37.23	90.88	4-5		2.8	3.0		372.2	286.3	5	EASTERN MISSOURI (MAG. 2.8 MBLG, *INT.)
1975	8	25	01:11	36.05	89.84			3.0	6.6		305.4	273.7	5	NEW MADRID, MO. (MAG. 3.0 MBLG, *INT.)
1975	8	28	22:23	33.82	86.60	6		4.4	3.1	10000.0	190.4	222.0	3	NORTHERN ALABAMA (MAG. 4.4 MBLG)
1975	11	7	17:40	33.55	87.36	2		3.5	3.1		233.9	227.1	3	ALABAMA (MAG. 3.5 MBLG)
1975	11	11	03:11	37.19	80.84	6		3.2	9.3		216.2	64.4	3	S.W. VIRGINIA (MAG. 3.2 MBLG)
1975	11	25	10:17	34.87	82.96	4		3.2	3.1		106.7	130.9	3	NORTHWESTERN SC (MAG. 3.2 MBLG)
1975	12	2	21:01	36.54	89.57	5		2.8	3.1		292.6	280.4	3	NEW MADRID, MO. (MAG. 2.8 MBLG)
1976	1	16	13:43	35.92	92.12	5		3.2	8.7		432.9	272.5	3	NORTHERN ARKANSAS (MAG. 3.2 MBLG)
1976	1	19	01:21	36.88	83.82	6		4.0	3.0		75.2	24.4	3	KENTUCKY (MAG.4.0 MB)
1976	1	30	13:59	39.68	78.17	4-5		2.8	9.0		428.4	50.5	5	WEST VA. (MAG. 2.8 MBLG)(*INT.)
1976	2	2	16:14	41.96	82.67			3.4	6.0		429.4	11.0	[illegible]	S. ONTARIO (MAG. 3.4 MBLG)(*INT.)
1976	2	4	14:54	35.00	84.75	6		3.0	3.0		64.9	198.7	5	TENNESSEE (MAG. 3.0 MBLG)
1976	3	11	03:30	41.56	71.21	6		3.5			809.7	57.1	3	RHODE ISLAND (MAG.3.5 MBLG)
1976	3	11	16:07	40.96	74.37	6		2.4	2.5		644.7	54.1	3	NORTHEASTERN NEW JERSEY (MAG. 2.4 MBLG)
1976	3	14	18:12	41.66	69.97	5		3.0			871.2	58.4	5	SOUTHERN NEW ENGLAND (MAG. 3.0 MBLG)
1976	3	24	18:41	35.59	90.48	6		4.9	9.0	108000.0	342.5	268.3	3	ARKANSAS (MAG.4.9 MB)
1976	3	24	19:00	35.61	90.48	2		4.1	9.3		342.4	268.5	3	NORTHEASTERN ARKANSAS (MAG. 4.1 MB)
1976	4	8	01:39	39.35	86.58	5		3.0	12.4		270.1	333.0	3	CENTRAL INDIANA (MAG. 3.0 MBLG)
1976	4	13	10:39	40.84	74.05	6		3.1	1.2	19.0	655.3	55.4	3	NORTHEASTERN NEW JERSEY (MAG. 3.1 MBLG)
1976	4	15	01:04	37.40	87.30	5		3.3	9.0		192.5	303.7	3	KENTUCKY (MAG. 3.3 MBLG)
1976	5	9	20:34	41.54	71.01	5		2.7			818.6	57.5	5	SO. NEW ENGLAND (MAG. 2.7 MBLG)
1976	5	22	01:41	36.04	89.84	5		3.2	6.0		305.4	273.5	3	NEW MADRID, MO. (MAG. 3.2 MBLG)
1976	6	19	00:54	37.36	81.62	5		3.0	3.1		183.8	55.6	3	SOUTHERN WEST VIRGINIA (MAG. 3.0 MBLG)
1976	9	13	13:55	36.60	80.81	6		3.3	3.1	6800.0	205.0	75.1	3	TOAST,N.C. (MAG. 3.3 MBLG)
1976	9	25	08:07	35.61	90.45	5		3.6	3.0		340.7	268.5	3	ARKANSAS (MAG. 3.6 MBLG)
1976	10	22	18:41	32.20	88.73	5		3.0	3.0		356.2	225.5	5	MISSISSIPPI (MAG. 3.0 MBLG)(*INT.)
1976	12	11	01:05	38.12	91.07			4.2			399.8	294.7	8	MISSOURI (MAG. 4.2 MB)

* ESTIMATE

HISTORICALS 471- 519

YEAR	MO	DA	HR	COORDS. LAT.	LONG.	INTENSITY M.M.	R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1976	12	13	02:36	37.80	90.24	5		3.5	3.0		349.7	293.9	3	EASTERN MISSOURI (MAG.3.5 MBLG)
1976	12	27	01:57	32.22	82.46	5		3.7	3.1		276.4	156.0	3	SOUTHEASTERN GEORGIA (MAG. 3.7 MBLG)
1977	1	3	16:57	37.55	89.79	6		3.4	3.1		320.7	292.6	3	CAPE GIRARDEAU, MO. (MAG.3.4 MBLG)
1977	1	18	13:29	33.07	80.20	6		3.0	3.1		307.7	128.1	3	SOUTH CAROLINA (MAG. 3.0 MBLG)
1977	2	27	15:06	37.90	78.63	5		2.4	3.1		346.8	64.7	3	VIRGINIA (MAG. 2.4 MBLG)
1977	3	30	01:28	32.88	80.20	5		1.5	6.2		316.4	129.9	3	SOUTH CAROLINA (MAG. 1.5 ML)
1977	5	3	20:00	31.98	88.42	5		3.6	3.1		355.7	221.7	3	MISSISSIPPI (MAG. 3.6 MBLG)
1977	6	17	10:40	40.71	84.58	6		3.2	3.1	212.0	333.2	358.2	3	OHIO (MAG. 3.2 MBLG)
1977	7	27	17:03	35.42	84.42	5		3.5	4.3		32.5	183.7	3	TENNESSEE (MAG. 3.5 MBLG)
1977	8	24	23:20	33.39	80.69	4		3.1	6.2		271.8	128.4	3	SOUTH CAROLINA (MAG. 3.1 MBLG)
1977	11	4	05:21	33.83	89.28	4		3.4	3.1		312.0	244.3	3	MISSISSIPPI (MAG. 3.4 MBLG)
1977	11	25	22:18	34.52	92.46	4		3.1	3.1		493.3	261.4	3	ARKANSAS (MAG. 3.1 MBLG)
1977	12	15	14:17	32.92	80.22	5		3.0	5.6		313.7	129.7	3	SOUTH CAROLINA (MAG.3.0 MBLG)
1977	12	20	12:44	41.84	70.70	5		3.1			841.7	56.6	5	SOUTHERN NEW ENGLAND (MAG. 3.1 MBLG)
1978	1	8	05:34	32.76	88.24			3.0	3.1		308.5	226.6	8	AL-MS BORDER (MAG. 3.0 MBLG)
1978	3	17	13:26	36.75	80.74	5		2.8	4.0		211.3	72.6	13	GALAX, VA. (MAG. 2.8 MBLG)
1978	4	3	06:24	36.62	90.00			3.1	3.1		317.0	280.8	8	MISSOURI (MAG. 3.1 MBLG)
1978	4	26	14:30	39.70	78.24			3.1	9.0		426.2	50.0	8	MARYLAND (MAG. 3.1 MBLG)
1978	6	1	20:07	38.42	88.46	4		3.5	:2.4		284.5	309.1	8	ILLINOIS (MAG. 3.5 MBLG)
1978	6	9	17:15	32.09	88.58			3.3	6.2		356.0	223.7	8	MS-AL BORDER (MAG.3.3 MBLG)
1978	7	16	01:40	39.93	76.34	5		3.0	3.1		519.4	55.1	15	PENNSYLVANIA (MAG. 3.0 MBLG)
1978	8	10	16:12	40.45	71.13			3.5	16.8		784.8	62.4	5	OFF COAST OF NEW ENG. (MAG. 3.5 MBLG)
1978	8	30	18:31	36.08	84.42			3.5	2.5		281.9	274.1	5	NEW MADRID, MO. (MAG. 3.5 MBLG)
1978	9	20	06:24	38.57	90.28	5		3.0	1.2		373.5	301.5	5	MISSOURI (MAG. 3.0 MBLG)
1978	9	23	01:34	33.65	91.89			3.1	1.2		453.2	252.2	5	ARKANSAS (MAG. 3.1 MBLG)
1978	10	6	14:25	39.97	76.51	5		2.8	3.1		513.1	54.3	8	SOUTHEASTERN PA. (MAG. 2.8 MBLG)
1978	12	4	19:48	38.62	88.36	5		3.5	15.0	4400.0	288.8	312.0	8	SOUTHERN ILLINOIS (MAG. 3.5 MBLG)
1978	12	10	20:07	31.95	88.48	5		3.5	3.1		359.5	222.0	8	MISSISSIPPI (MAG. 3.5 MBLG)
1979	1	30	11:31	40.32	74.20	5		3.5	3.1	2800.0	629.2	57.9	8	NEW JERSEY (MAG. 3.5 MBLG)
1979	2	4	23:31	35.84	90.08	4		3.2	8.7		319.0	268.9	8	ARKANSAS (MAG. 3.2 MBLG)
1979	2	27	16:55	35.92	91.24	5		3.1	5.6		383.7	272.3	8	ARKANSAS (MAG.3.1 MBLG)
1979	3	9	23:50	40.72	74.50	5		3.1	1.9		630.7	55.1	8	NEW JERSEY (MAG.3.1 MBLG)
1979	6	10	22:12	36.17	89.65	4		3.8	7.5		294.9	275.3	8	NEW MADRID, MO. (MAG. 3.8 MBLG)
1979	6	25	11:11	35.53	90.43	4		3.2	6.8		340.2	267.6	8	ARKANSAS (MAG. 3.2 MBLG)
1979	7	8	06:35	36.89	89.29	4		3.1	1.9		281.5	285.7	8	MISSOURI (MAG. 3.1 MBLG)
1979	8	7	14:32	34.22	81.30			3.0	1.2		209.1	122.6	15	SOUTH CAROLINA (MAG. 3.0 ML)
1979	8	13	00:19	35.24	84.38	5		3.7	3.1		44.9	180.0	8	SOUTHEASTERN TN (MAG. 3.7 MBLG)
1979	8	25	20:31	34.93	82.97	6		3.7	1.0	4400.0	103.6	129.4	8	TAMASEE, SC (MAG. 3.7 MBLG)
1979	9	12	01:24	35.59	83.90	5		3.2	3.1		34.1	127.3	8	EAST TN. (MAG. 3.2 MBLG)
1979	11	9	1-:30	38.42	82.88			3.5	6.2		193.4	24.9	9	NE KENTUCKY (MAG. 3.5 MBLG)
1979	12	30	09:15	41.16	73.71	4		3.0	2.5		681.5	54.5	8	SE NEW YORK (MAG.3.0 MBLG)
1980	3	5	12:07	40.19	75.16	4		3.5	3.1		582.8	56.6	8	SE PENN. (MAG. [illegible].5 MBLG)
1980	3	11	01:00	40.16	75.10	5		3.7	3.1		584.6	56.9	8	SE PENN. (MAG. 3.7 MBLG)
1980	3	12	20:23	37.93	88.45			3.3	11.8		265.2	303.3	8	SOUTHERN ILLINOIS (MAG. 3.3 MBLG)
1980	3	23	16:38	37.63	86.69	4		3.3	3.7		175.4	314.0	15	KENTUCKY (MAG. 3.3 MBLG)
1980	5	2	14:02	40.26	75.03			3.0			591.1	56.5	8	PENNSYLVANIA (MAG. 3.0 MBLG)
1980	6	10	18:47	35.45	82.88			3.0			89.7	109.4	15	NORTH CAROLINA (MAG. 3.0 MBLG)
1980	6	25	13:02	35.78	84.05	4		3.3	3.1		20.1	112.1	8	TENNESSEE (MAG. 3.3 MBLG)

* ESTIMATE

Table ~~1~~ 2.5-2 (cont.)

~~Q230.1-1~~

HISTORICALS 519- 535

YEAR	MO	DA	HR	COORDS. LAT.	COORDS. LONG.	INTENSITY M.M.	INTENSITY R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF.	REMARKS
1980	7	5	02155	36.61	89.58	4		3.5	7.5		293.8	281.3	8	NEW MADRID, MO. (MAG. 3.5 MBLG)
1980	7	27	13152	38.17	83.91	7		5.1	3.0	231600.0	159.7	9.3	8	NORTHERN KENTUCKY (MAG. 5.1 MB)
1980	8	2	12121	40.43	74.15			3.1	5.0		637.7	57.5	8	NEW JERSEY (MAG. 3.1 MBLG)
1980	8	2	22149	37.99	84.92	3		3.1	3.1		148.1	348.6	8	NORTHERN KENTUCKY (MAG. 3.1 MBLG)
1980	8	22	21149	37.99	84.92	3		3.1	1.9		148.1	348.6	8	KENTUCKY (MAG. 3.1 MBLG)
1980	8	30	04119	39.84	74.86			3.0	1.2		586.3	59.4	8	NEW JERSEY (MAG. 3.0 MBLG)
1980	9	3	23131	41.11	73.78	4		3.2	8.1		676.6	54.6	8	SOUTHEASTERN N.Y. (MAG. 3.2 MBLG)
1980	12	2	02159	36.21	89.43	5		3.8	6.8		282.8	276.0	5	NEW MADRID, MO. (MAG. 3.8 MBLG)
1981	2	8	11153	35.62	89.60	5		3.0	3.1		293.1	267.9	5	WEST TENN. (MAG. 3.0 MBLG)
1981	2	11	08143	37.05	89.13	4		3.0	1.2		275.7	288.3	5	CAPE GIRARDEAU, MO. (MAG. 3.0 MBLG)
1981	4	3	04124	41.59	71.22	5		2.7	1.0		810.1	56.9	5	SOUTHERN NEW ENG. (MAG. 2.7 MBLG)
1981	4	7	19153	38.87	89.39			3.8	4.3		343.4	308.3	5	SOUTHERN ILLINOIS (MAG. 3.8 MBLG)
1981	4	9	02111	35.48	82.07	5		3.0	3.1	4800.0	132.8	101.6	5	NORTH CAROLINA (MAG. 3.0 MBLG)
1981	5	5	16122	35.33	82.43	6		3.5	8.1	9800.0	116.3	108.9	5	NORTH CAROLINA (MAG. 3.5 MBLG)
1981	6	9	08116	37.83	89.03	5		3.5	11.8		289.8	298.9	5	ILLINOIS (MAG. 3.5 MBLG)
1981	6	26	02133	35.85	90.07	5		3.6	5.6		318.4	268.8	5	ARKANSAS (MAG. 3.6 MBLG)
1981	8	7	05154	35.95	89.11	6		4.0	6.8		264.5	272.3	5	WEST TN. (MAG. 4.0 MBLG)

* ESTIMATE

TABLE 2.5-2 NOTES

In both Tables 2.5-2 and 3, the data are in chronological order. Pertinent abbreviations are as follows:

Year, month (mo), day (da): Date of occurrence

Hour (hr): Local time of occurrence, rounded to the nearest minute in either Central or Eastern Standard Time.

Geographical Coordinates of Epicenter (COORDS): Latitude and longitude of epicenter in decimal degrees (north latitude; west longitude).

Intensity (M.M.) (R.F.): Maximum reported Modified Mercalli (M.M.) or Rossi-Forrel (R.F.) intensity.

Magnitude (Mag.) (MB, MS, MBLG, ML, M):

Five distinctions concerning magnitude are made in the listings. Body wave magnitudes defined by Gutenberg and Richter (1956) (Ref. 162) are identified as such in the remarks by the symbol MB. Surface wave magnitudes as adopted by the International Association of Seismology and Physics of the Earth's Interior (IASPEI; Bath, 1966, p. 153) (Ref. 164) are identified by the symbol MBLG. Local magnitudes calculated using formulae defined by Richter (1958) (Ref. 165) are identified by the symbol ML. Reported values for magnitude which were not defined by type in the source reference are identified by the symbol M.

Depth:

Hypocentral depth in miles.

Area:

Felt area in square miles.

Distance from site (DIST):

Calculated distance from epicenter to site in miles.

Aximuth (AXIMUTH):

Aximuth in degrees measured east of north from site to epicenter.

Remarks:

Brief description of geographical location, type of magnitude, and other pertinent information. An asterisk (*) indicates information which is uncertain or taken from a source other than that identified as a primary reference.

SEISMICITY REFERENCES
(refer to historical listing)

Ref.
No.

1) Coffman, J. L. and Von Hake, C. A., 1973, Earthquake History of the United States, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, No. 41-1 (through 1970).

2) Moneymaker, B. C., 1954, Some early earthquakes in Tennessee and adjacent states 1699 to 1850: Tennessee Academy of Science Journal, v. 29, no. 3.

Moneymaker, B. C., 1955, Earthquakes in Tennessee and nearby portions of neighboring states 1851 to 1900: Tennessee Academy of Science Journal, v. 30, no. 3.

Moneymaker, B. C., 1957, Earthquakes in Tennessee and nearby sections of neighboring states 1901 to 1914: Tennessee Academy of Science Journal, v. 32, no. 2.

Moneymaker, B. C., 1958, Earthquakes in Tennessee and nearby sections of neighboring states 1926 to 1950: Tennessee Academy of Science Journal, v. 33, no. 3.

Moneymaker, B. C., 1972, Earthquakes in Tennessee and nearby sections of neighboring states, 1951-1970, Tennessee Academy of Science Journal, v. 47, no. 4.

3) United States Earthquakes 1928-1978, published annually by the U.S. Department of Commerce, coast and Geodetic Survey from 1928 through 1972 and jointly by the U.S. Department of Commerce, National Oceanic and Atmospheric Administration and U.S. Department of Interior, Geological Survey from 1973 through 1978.

4) U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service, earthquake data file: an unpublished listing of earthquake locations; Earthquake Data Services and Publications, Key to Geophysical Records Documentation No. 15, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service, Boulder, Colorado, 1981.

5) U.S. Department of Interior, Geological Survey, Preliminary Determination of Epcenters, monthly listing, January 1972 to September, 1981.

6) Law Engineering Testing Company, Earthquake data files, unpublished data.

7) Helgold, P. C., 1972, Notes on the earthquake of September 15, 1972, in northern Illinois, Illinois Geological Survey, Environmental Geology Notes, no. 59, 13 p.

8) U.S. Department of Interior, Geological Survey, Earthquakes in the United States, circular published quarterly, 1974 through 1980.

9) Nuttli, O. W., 1974, Magnitude-recurrence relation for central Mississippi Valley earthquakes, Bull. Seism. Soc. Am., vol. 64, no. 4, pp. 1189-1207.

10) Bradley, E. A., and Bennett, T. J., 1965, Earthquake History of Ohio, Bull. Seism. Soc. Am., v. 55, no. 5, pp. 745-752.

11) Bollinger, G. A., 1975, A catalog of southeastern United States earthquakes 1754 through 1974, Research Division Bull. no. 101, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, 68 p.

12) McClain, W. W., and Meyers, O. M., 1970, Seismic history and seismicity of the southeastern region of the United States, Oak Ridge National Laboratory, Oak Ridge, Tennessee, Union Carbide Corporation, for the U.S. Atomic Energy Commission p. 1-43.

13) United States Department of the Interior, Geological Survey, Earthquake Information Bulletin, published bi-monthly 1969 through 1981.

14) Docekal, J., 1970, Earthquakes of the stable interior, with emphasis on the Midcontinent, unpublished Phd. dissertation, University of Nebraska.

15) Bollinger, G. A., and Ellen Mathena, Seismicity of the southeastern United States, Bulletins 1 through 8, April 1978 through November, 1981, Virginia Polytechnic Institute, Blacksburg, Virginia.

16) Stover, C. W., Reagor, B. G., and S. T. Algermissen, 1979, Seismicity map of the State of Tennessee, U.S. Department of Interior, Geological Survey, Miscellaneous Field Studies map MF1157.

17) Nuttli, O. W., and R. B. Herrmann, 1978, Credible earthquakes for the central United States, state-of-the-art for assessing earthquake hazards in the United States, Report 12, prepared for the office, Chief of Engineers, U.S. Army, p. 1-99.

Table 2.5-3

EARTHQUAKES IN CHRONOLOGICAL ORDER FROM SITE AT
5/10/82 CRBRP MG2200
N, LAT, = 35,89, W, LONG, = 84,38

SELECTED BY RADIAL CRITERIA WHERE

MAX, RADIUS = 50,0 MI,

HISTORICALS 1- 38

(SEE NOTES END OF TABLE 2.5-2)

YEAR	MO	DA	HR	COORDS, LAT,	COORDS, LONG,	INTENSITY M,M,	R,F,	MAG,	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZIMUTH	REF,	REMARKS
1777	11	16	02:00	36,00	84,00	4					22,7	70,3	16	E, TN, (ADD, REF, 17) (*TIME)
1844	11	28	07:00	36,00	84,00	6					22,7	70,3	1	KNOXVILLE, TENNESSEE
1875	11	12	02:00	36,00	84,00	3					22,7	70,3	16	E, TN, (ADD, REF, 2)
1877	5	25	00:00	36,00	84,00	3					22,7	70,3	16	E, TN, (ADD, REF, 2) (*TIME)
1877	11	16	02:38	35,50	84,00	5				5000,0	34,5	141,3	1	WESTERN NORTH CAROLINA AND EASTERN TENN
1884	8	25	19:45	36,00	84,00	4					22,7	70,3	16	E, TN, (ADD, REF, 2)
1913	3	28	16:50	36,20	83,70	7				2700,0	43,7	60,5	1	EASTERN TENNESSEE
1913	4	17	23:30	35,30	84,20	5				3500,0	42,0	165,8	1	E, TENN,(*TIME 1130)(INT, 5-6 = REF,2)
1913	5	2	01:00	35,50	84,40	3					27,0	182,0	16	E, TN, (ADD, REF, 2)
1913	8	3	11:45	36,00	84,00	4					22,7	70,3	16	E, TN, (ADD, REF, 2)
1914	1	23	22:24	35,60	84,50	5					21,1	198,2	1	EAST TENNESSEE FELT ONLY LOCALLY
1917	3	4	21:07	36,00	84,00	3					22,7	70,3	16	E, TN, (ADD, REF, 2)
1918	1	16	10:45	36,00	84,00	5					22,7	70,3	2	KNOXVILLE, TENN, (*COORDS)
1918	6	21	20:00	36,10	84,10	5				3000,0	21,4	47,3	1	LENOIR CITY, TENN,
1920	12	24	02:30	36,00	85,00	5					35,4	282,6	1	EAST TENNESSEE FELT LOCALLY
1921	12	15	08:20	35,80	84,60	5				5000,0	13,7	243,0	2	EASTERN TENN, (*COORDS)
1930	8	30	04:28	35,90	84,40	5					1,2	305,9	2	NEAR KNOXVILLE, TENN,
1930	10	16	16:50	36,00	84,00	5					22,7	70,3	3	EAST TENNESSEE
1938	3	31	05:10	35,60	83,60	4					48,2	114,3	16	E, TN, (ADD, REF, 12,2)
1941	3	4	01:15	36,00	83,90	3					28,0	78,1	16	E, TN, (ADD, REF, 17,12)
1947	6	6	07:55	36,00	84,00	3					22,7	70,3	16	E, TN, (ADD, REF, 2)
1948	2	9	19:04	36,00	84,50	5-6					10,0	319,2	2	NEAR LAFOLLETTE,TENN (*COORDS)
1950	6	18	23:19	35,80	84,00	4					22,3	106,1	16	E, TN, (ADD, REF, 17,12)
1953	11	10	09:45	36,00	84,00	4					22,7	70,3	16	E, TN, (ADD, REF, 2)
1953	12	5	08:45	36,00	84,00	4					22,7	70,3	16	E, TN, (ADD, REF, 12,2)
1954	1	14	00:00	36,00	84,00	4					22,7	70,3	16	E, TN, (ADD, REF, 2) (*TIME)
1954	1	22	00:00	35,30	84,40	5					40,8	181,4	3	ATHENS, TENN, IN F,M,
1955	1	12	01:25	35,80	84,00	4					22,3	106,1	16	E, TN, (ADD, REF, 2,3)
1955	1	15	14:34	36,00	84,00	4					22,7	70,3	16	E, TN, (ADD, REF, 3)
1956	9	7	08:36	35,50	84,00	6				8300,0	34,5	141,3	3	EASTERN TENN,
1956	9	7	08:49	35,50	84,00	5					34,5	141,3	3	EASTERN TENN,
1957	6	23	01:34	36,50	84,50	5					42,7	351,2	2	EAST CENTRAL TENNESSEE
1957	11	7	12:15	36,00	84,00	4					22,7	70,3	16	E, TN, (ADD, REF, 2)
1959	6	12	20:00	35,40	84,30	4					34,2	172,2	16	E, TN, (ADD, REF, 2,3)
1960	4	15	05:10	35,80	84,00	5				1300,0	22,3	106,1	3	EASTERN TENN, (*COORDS)
1964	7	28	00:00	36,00	84,30	3					8,9	31,3	16	E, TN, (ADD, REF, 3,2) (*TIME)
1964	10	13	11:30	36,00	84,00	3					22,7	70,3	16	E, TN, (ADD, REF, 3,2)
1966	8	24	01:00	35,80	84,00	4					22,3	106,1	16	E, TN, (ADD, REF, (17,3)

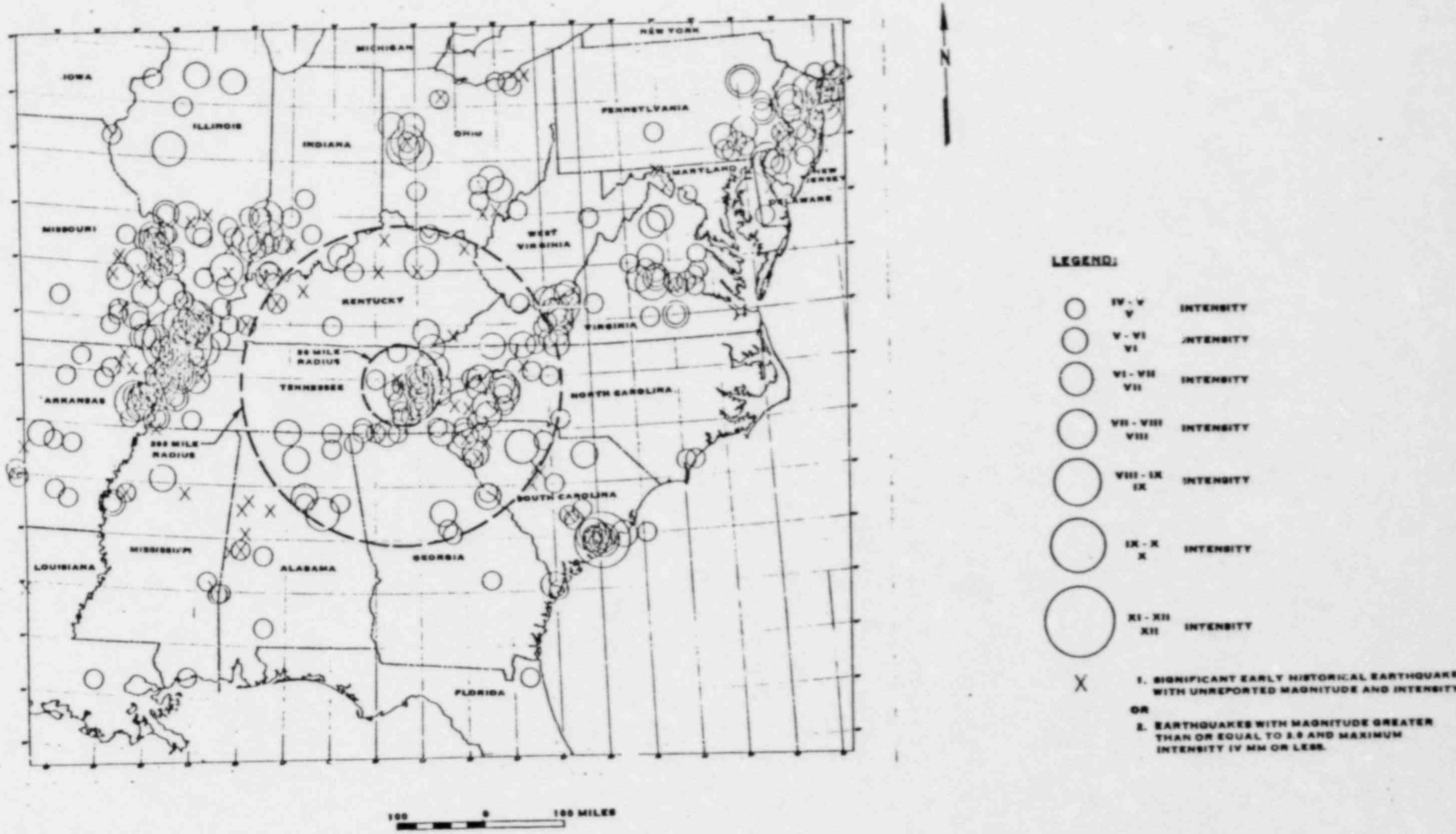
* ESTIMATE

Table 2.5-3 (cont.)

HISTORICALS 39- 62

YEAR	MO	DA	HR	COORDS. LAT.	LONG.	INTENSITY M.M.	R.F.	MAG.	DEPTH (MI)	AREA (MI SQ)	DIST (MI)	AZI-MUTH	REF.	REMARKS
1969	7	13	16:51	36,10	83,70	5		3,5		20000,0	40,8	69,0	3	EASTERN TENNESSEE (MAG, 3,5 M)
1969	7	14	04:13	36,10	83,70	2					40,8	69,0	16	E, TN, (ADD, REF, 12)
1969	7	14	06:15	36,00	84,00	3					22,7	70,3	16	E, TN, (ADD, REF, 3,2)
1969	7	24	13:10	36,00	84,00	3					22,7	70,3	16	E, TN, (ADD, REF, 3)
1971	7	12	21:03	36,00	84,00	5				2000,0	22,7	70,3	3	EASTERN TENNESSEE (*COORDS)
1971	10	9	11:44	35,90	83,50	5		3,4	11,0		49,4	69,0	3	EASTERN TENNESSEE (MAG, 3,4 MB)
1973	10	30	17:58	35,75	34,00	5		3,4	20,5	2400,0	23,5	114,2	3	KNOX AND BLOUNT CO, TN, (MAG, 3,4 MBLG)
1973	11	30	02:48	35,80	83,96	6		4,6	3,8	54300,0	24,5	104,6	3	MARYVILLE,TENN, (MAG, 4,6 MB)
1973	11	30	03:51	35,80	83,96	2					24,5	104,6	16	E, TN, (ADD, REF, 3)
1973	12	13	10:00	35,80	83,96	3					24,5	104,6	16	E, TN, (ADD, REF, 3) (*TIME)
1973	12	14	00:00	35,80	83,96	3					24,5	104,6	16	E, TN, (ADD, REF, 3) (*TIME)
1973	12	21	03:00	35,80	83,96	3					24,5	104,6	16	E, TN, (ADD, REF, 3) (*TIME)
1973	12	21	13:30	35,80	83,96	3					24,5	104,6	16	E, TN, (ADD, REF, 3)
1975	5	2	11:23	35,92	84,45	3		2,6	9,1		4,3	298,5	16	E, TN, (MAG, 2,6 MBLG) (ADD, REF, 8)
1975	5	14	18:03	35,95	85,25	2		2,7	3,0		48,7	275,1	16	E, TN, (MAG, 2,7 MBLG) (ADD, REF, 8)
1977	7	27	17:03	35,42	84,42	5		3,5	4,3		32,5	183,7	3	TENNESSEE (MAG, 3,5 MBLG)
1979	7	19	05:27	35,30	84,84			2,0	[illegible]		48,2	212,4	15	SE, TENN, (MAG, 2,0 ML)
1979	8	13	00:19	35,24	84,38	5		3,7	3,1		44,9	180,0	8	SOUTHEASTERN TN (MAG, 3,7 MBLG)
1979	9	12	01:24	35,59	83,90	5		3,2	3,1		34,1	127,3	8	EAST TN, (MAG, 3,2 MBLG)
1979	10	29	15:28	35,32	[illegible],84			2,0	[illegible]		47,0	213,3	15	NC-TN BORDER (MAG, 2,0 ML)
1980	1	23	23:12	35,56	84,26			2,0	4,0		23,8	163,2	15	E, TN, (MAG, 2,0 M)
1980	6	25	13:02	35,78	84,05	4		3,3	3,1		20,1	112,1	8	TENNESSEE (MAG, 3,3 MBLG)
1981	2	3	09:27	35,45	84,83			2,0	1,0		39,4	219,7	15	E, TN, (MAG, 2,0 ML)
1981	4	2	01:33	35,41	84,71			2,1	4,0		37,9	209,1	15	E, TN, (MAG, 2,1 ML)

* ESTIMATE

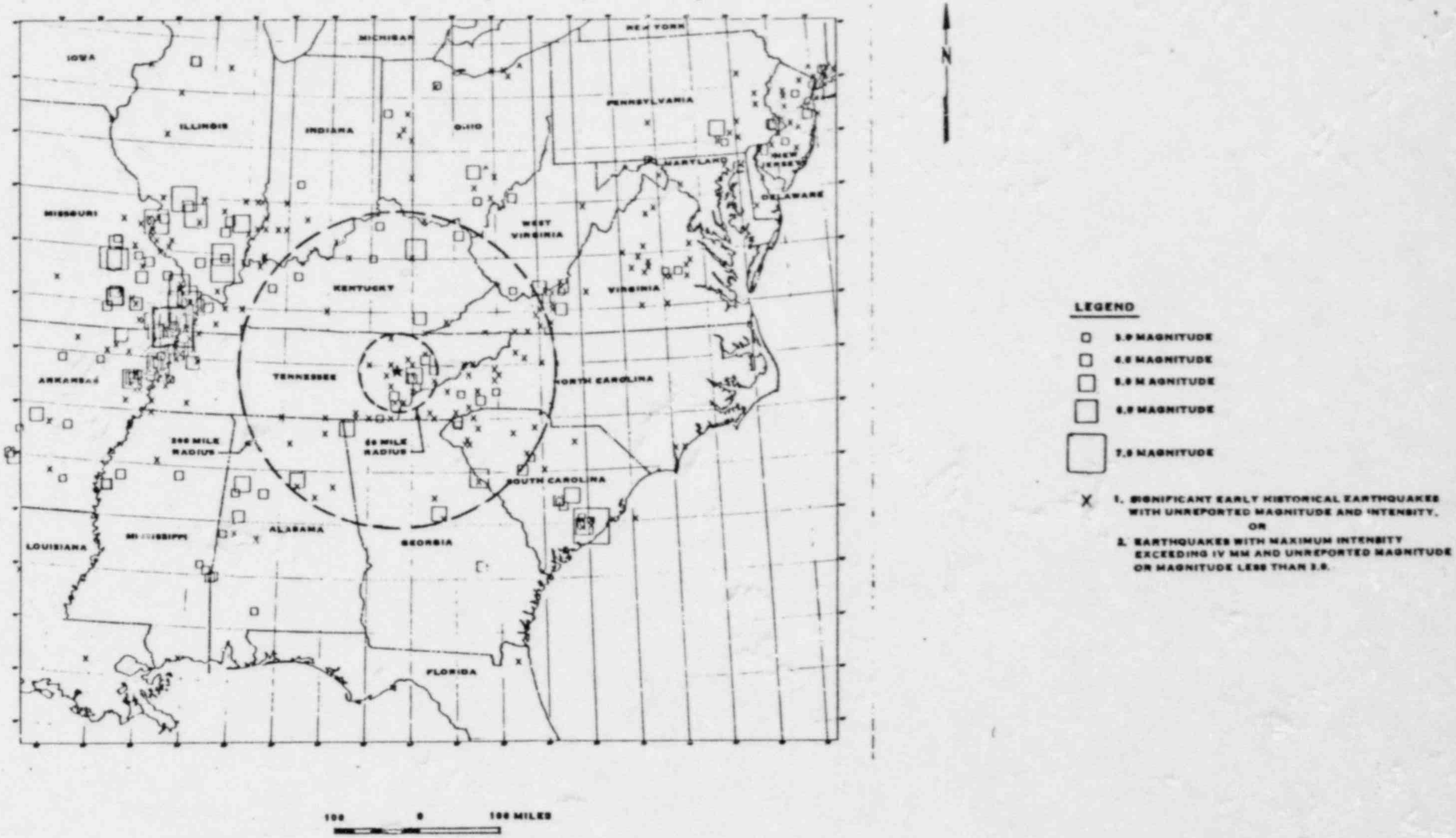


REGIONAL EARTHQUAKES WITH MAXIMUM INTENSITY EXCEEDING IV MM

~~LAW ENGINEERING TESTING COMPANY~~

FIGURE ~~Q 230.1-1~~

figure 25-18, sheet 1 of 4



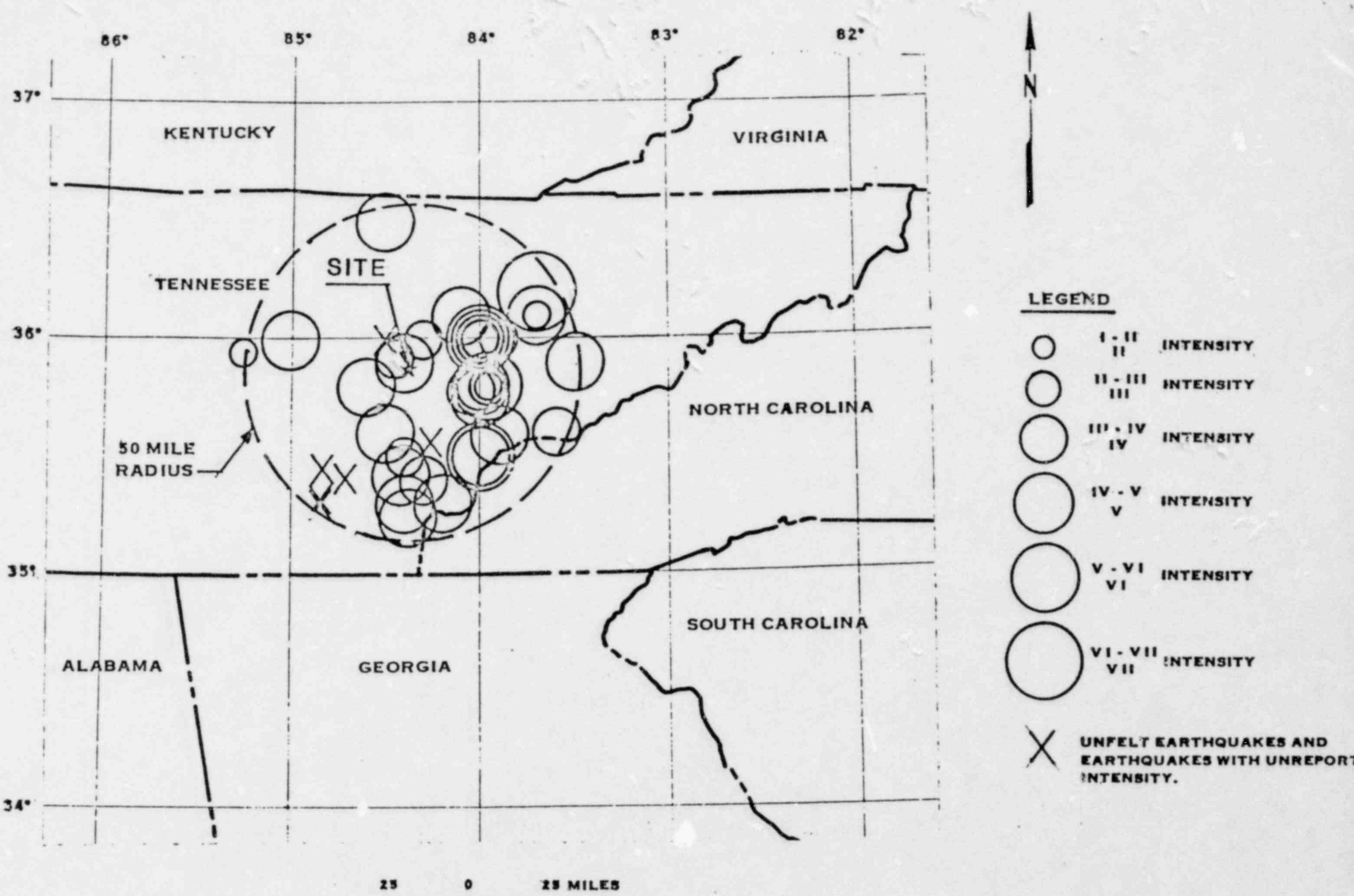
~~LAW ENGINEERING TESTING COMPANY~~

REGIONAL EARTHQUAKES WITH MAGNITUDE 3.0 AND GREATER

FIGURE ~~Q 230.1-2~~

figure 2.5-18, sheet 2 of 4

230.1-25

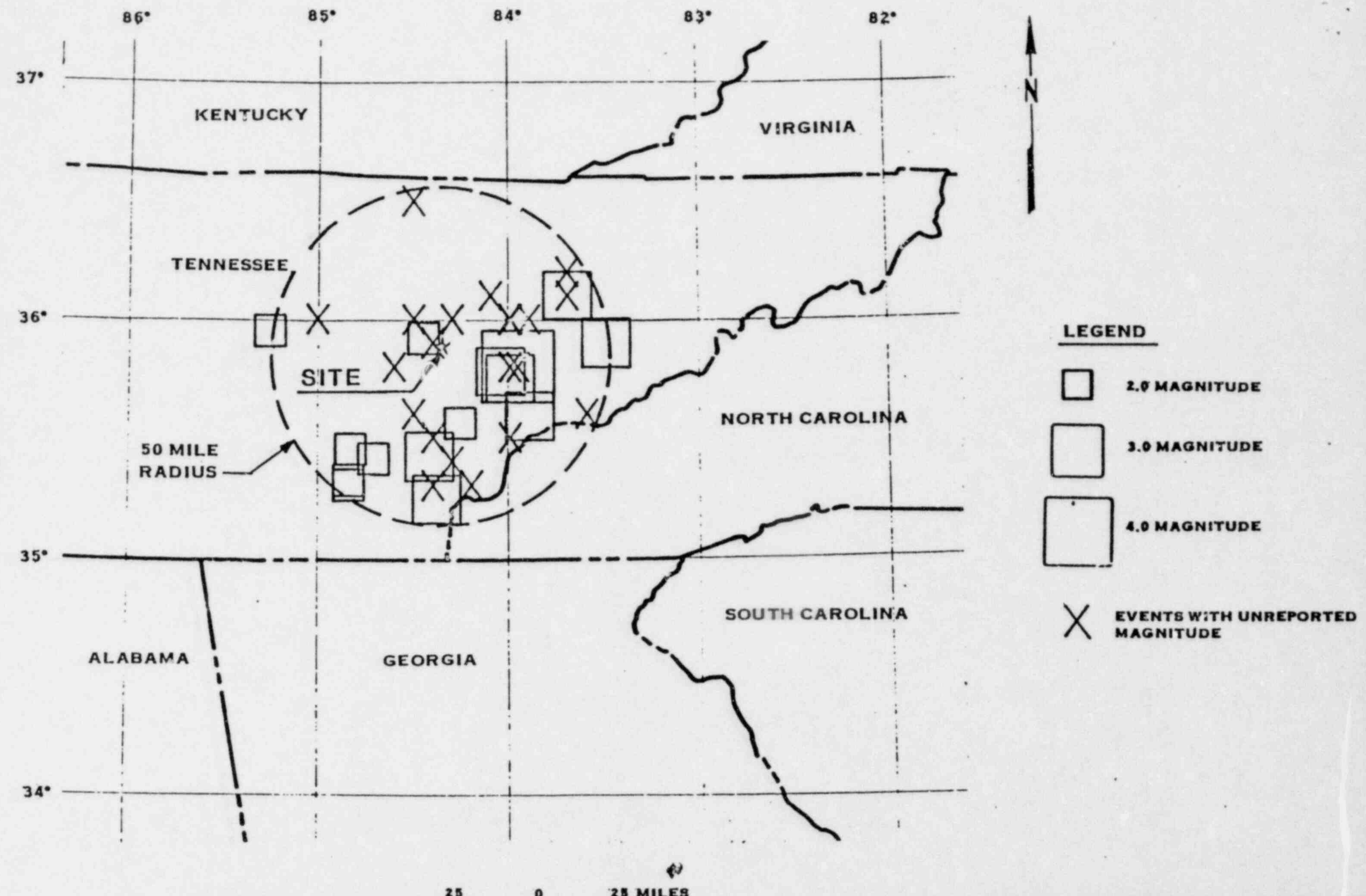


230.1-26

EARTHQUAKES WITHIN 50 MILE RADIUS
OF THE SITE (INTENSITY)

~~LAW ENGINEERING~~
~~TESTING COMPANY~~

Figure 2.5-18, sheet 3 of 9



230.1-27

EARTHQUAKES WITHIN 50 MILE RADIUS OF THE SITE (MAGNITUDE)

~~LAW ENGINEERING TESTING COMPANY~~

figure 2.5-18, sheet 4 of 4

~~Q 230.1-4~~

Question CS230.2

On Page 2.5-25 the PSAR states "This province has been designated as the Southern Appalachian Tectonic Province by the NRC in their evaluation of the Sequoyah Nuclear Plant." The NRC staff's position as stated in both the Sequoyah and Watts Bar SER's is that these sites are in the Southern Valley and Ridge Tectonic Province. Change the tectonic province statement by either correcting the name of the tectonic province or by not attributing the designation to the NRC.

Response

The response to this question has been incorporated into revised PSAR Sections 2.5.1 and 2.5.2.

The Kentucky River fault zone (see Figures 2.5-2 and 2.5-2A) trends east-west from eastern Kentucky westward across the Cincinnati arch. This fault zone dies out on the western flank of the Cincinnati arch. The fault zone has a total length of about 150 mil and a width of about 25 miles. The closest fault to the CRBRP site within this zone is approximately 90 miles to the north.

Faults in the Kentucky River fault zone are mostly steep, en echelon normal faults, and bound small grabens. These faults also show some strike-slip movements. The maximum displacement along the River fault zone is approximately 600 feet (Reference 145). Underlying basement rocks are faulted, with movement having begun early in the Paleozoic (Reference 81, Section 2.5). Latest movements along this are post-Pennsylvanian (310 MYBP) (Reference 165).

The Rough Creek fault zone begins west of the Cincinnati and extends across western Kentucky into southern Illinois. This fault has an east-west trend similar to that of the Kentucky River fault zone. Near Shawneetown, Illinois, the Rough Creek fault zone curves southwestward around Hicks dome and merges with the New Madrid faulted zone (Reference 145). This fault zone has a length of about 120 miles and a width of approximately 25 miles. The nearest point of this fault zone to the site is about 120 miles to the northwest.

The Rough Creek fault zone includes horsts, grabens, and en echelon normal faults. These faults also show some strike-slip movement (Reference 81, Section 2.5) The Rough Creek fault zone has displacements up to 3000 feet (Reference 147). East of Shawneetown, Illinois, movement along this fault zone was probably pre0Cretaceous (References 153 and 166). However, west of Shawneetown the portion of the Rough Creek fault that curves southwestward has been postulated as being active since Pliocene (5 to 2 MYBP) and maybe into the Recent (Reference 147).

Both of these fault zones are outside the Southern Valley and Ridge Tectonic Province and are 90 to 120 miles from the CRBRP site. Neither of the faults affects the geologic or seismic design at the CRBRP site.

2.5.1.1.3 Physiographic, Lithologic, Stratigraphic and Structural Settings

Areas of similar lithology, stratigraphy, structure and geomorphic history are associated with physiographic provinces. The physiographic provinces within 200 miles of the CRBRP site include the Interior Low Plateaus, Appalachian Plateaus, Valley and Ridge, Blue Ridge, and Piedmont, as shown on Figure 2.5-1. The lithologic and stratigraphic relationships are shown on the Regional Geologic Map, Figure 2.5-3, which may be regarded as a bedrock map.

2.5.1.1.3.1 Valley and Ridge Physiographic Province

The CRBRP Site is located in the southeast section of the Valley and Ridge Physiographic Province. This section of the Province is about

Scattered earthquakes occur in the Valley and Ridge and their "normal" focal depth is 50,000 to 65,000 feet, well within the basement rocks. On February 8, 1964, an earthquake was reported by the U.S. Coast and Geodetic Survey southwest of the site with its epicenter in the Valley and Ridge at a focal depth of 15 kilometers - 49,000 feet (Ref. 101). As shown in section 2.5.1.1.2, the tectonic structures in the Valley and Ridge terminate at a sole fault which occurs at a depth of about 9000 feet. Obviously, earthquakes which occur at depths of 40,000 feet below these shallow structures are in no way related to the structures. When plotted in relation to each other, earthquake epicenters and the ancient, inactive faults exposed at the surface within the Valley and Ridge Province are in no way related.

Since epicentral locations can not reasonably be correlated with tectonic structures, earthquakes are identified with the tectonic province in which the site is located. This province has been designated as the Southern Valley and Ridge Tectonic Province by the NRC in their evaluation of the Sequoyah Nuclear Plant. The Province is bounded on the east by the western margin of the Piedmont Province; on the west by the western limits of the Cumberland Plateau; on the south by the overlap of the Gulf Coastal Plain Province; and on the north by re-entrant in the Valley and Ridge Province near Roanoke, Virginia (Ref. 101).

2.5.2.7 Identification of Capable Faults

There is no geologic evidence of surface faulting within the Valley and Ridge or adjacent geologic regions that is even remotely related to earthquakes that have occurred in historic time. This is supported in Bonilla's review of Historic Surface Faulting in the Continental United States and Adjacent Parts of Mexico (Ref. 113).

It is concluded that there are no identifiable capable faults that could be expected to produce surface displacement anywhere within the Southern Valley and Ridge Tectonic Province, within 200 miles of the site.

2.5.2.8 Description of Capable Faults

There is no evidence for any capable faulting within 200 miles of the CRBRP site which may be of significance in establishing the Safe Shutdown Earthquake.

2.5.2.9 Maximum Earthquake

The largest historic earthquake which has occurred in the Southern Valley and Ridge Tectonic Province was the May 31, 1897 earthquake in Giles County, Virginia, with a reported epicentral inten-

Question CS230.4

The Giles County Virginia earthquake of 1897 is the controlling earthquake for the seismic design of nuclear plants in the Southern Valley and Ridge tectonic province. The Clinch River Breeder Reactor is located in this province.

Dr. G. A. Bollinger has been conducting research on the Giles County, Virginia seismic zone. He has recently written a report titled "The Giles County, VA Seismic Zone - Configuration and Hazard Assessment" which was presented at a conference (Earthquakes Engineering - Eastern United States, September 14-16, 1981)

Based on the local seismic activity, Dr. Bollinger implies the existence of a buried fault in the Giles County area. He uses the largest extent of the seismic zone, taking into account errors in hypocenter location, in order to calculate a possible maximum earthquake of surface wave magnitude M_s = 7 for this zone.

Provide a discussion on any effects this hypothesis has on the following with respect to the Clinch River Breeder Reactor.

a) The potential of the 1897 earthquake being associated with this specific geologic structure;

b) The potential of an earthquake up to M_s = 7.0 located in Giles County, and any far field ground motion effect (both peak valus and response spectrum) at the site from an M_s = 7.0 event located in Giles county.

c) The potential of similar seismogenic structures being located near the Clinch River site, and any effects at the site from earthquakes on these seismogenic structures.

Response

Part a

Both supporting and contradictory evidence exists for the hypothesis that the 1897 Giles County Virginia earthquake occurred in association with the seismogenic zone proposed by Dr. G. A. Bollinger.

The following factors lend credence to the hypothesis that the May 31, 1897 Giles County, Virginia earthquake was associated with the seismic zone proposed by Bollinger (1981):

1) The proposed seismogenic zone is centered on Pearlsburg, Virginia, the locality with highest reported intensity effects from the 1897 earthquake. (Law Engineering Testing Company in conjunction with Burns and Roe, Inc. 1975 (ref. QCS230.4-2); Bollinger and Hooper, 1971 (ref. QCS230.4-3)).

2) The magnitude of the 1897 event has been estimated as 5.8mb; 5.8 Ms (Nuttli et al., ref.QCS230.4-4; Bollinger 1981, ref. QCS230.4-1). The estimate of the maximum possible fault plane for the proposed seismogenic zone is 80 km^2) is considered by Bollinger (1981 ref. QCS230.4-1). The smaller estimate (80 km^2) is considered by Bollinger (1981 ref. QCS230.4-1) as capable of producing a maximum earthquake of magnitude 6.0 Ms, an event approximately equivalent to the 1897 shock.

Although the location of maximum intensity effects and modern estimates of the magnitude of the 1897 event are compatible with an assumed association with the proposed seismogenic zone, it is to be noted that Pearlsburg was the largest population center of the Giles County, Virginia area and, therefore, the possibility of some bias in the reporting of intensity effects for the 1897 event exists. In addition, not all instrumentally located earthquakes in the Giles County area show close spatial association with the proposed seismogenic zone. The most notable of the apparently non-associated earthquake is the second largest shock reported to have occurred in the Giles County area: the magnitude 4.6 m_b, November 20, 1969 Elgood, West Virginia event. The epicenter for the Elgood, West Virginia shock was approximately 20 km northwest of the proposed seismogenic zone.

An opinion has been expressed in response to parts (b) and (c) of this question regarding potential impact of the specific geologic structure suggested by Bollinger on the CRBRP site.

Parts (b) and (c)

The responses to these two parts of the question are included in Reference QCS230.4-5 transmitted herewith as Attachment A. Summary responses are presented below.

Summary of Response to Part (b) -

Two approaches have been used to estimate ground motion at the site from an Ms=7.0 earthquake on the Giles county, Virginia seismogenic zone. The first approach, based on results by Nuttli (ref. QCS230.4-4), indicates a peak acceleration of 0.010g and a site intensity of V MM or less. The second approach, which utilizes the specific intensity attentuation data and source characteristics for the Gildes County zone developed by Bollinger (ref. QCS230.4-1), indicates a site intensity of VI MM and a corresponding peak horizontal acceleraton of 0.036g. The two approaches give results which are in good agreement considering that they are based upon two different physical phenomena, i.e, the attenuation of peak acceleration and Modified Mercalli intensity, respectively.

As noted above, the Modified Mercalli intensity associated with the peak horizontal ground acceleration considered possible at the site (0.036g) is VI MM. Present CRBRP design assumes a site intensity of VIII MM. Thus, the proposed maximum earthquake proposed by Bollinger for the Giles county seismogenic zone does not imply the need for a higher design intensity.

Regarding the subject of response spectra, which is not addressed in Reference (QCS230.4-5), response spectra as presented in Regulatory Guide 1.60 have been used in the design of safety-related structures. Since the peak acceleration at the site associated with the maximum hypothetical Giles County event (0.036g) is less than that assumed for the Safe shutdown Earthquake (0.25g), and the CRBRP response spectra considers a broad frequency band, there is no impact to the CRBRP from the Giles County event.

Summary of Response to Part (c) -

An examination of the distribution of historical seismicity in the CRBRP site area did not reveal any discernible spatial trend suggestive of a seismogenic zone similar to that proposed by Bollinger (Ref. QCS230.4-1) for Giles County, Virginia. In addition, inferred basement structures apparent on published magnetic and gravity anomaly maps of the area appear non-seismogenic.

The single existing earthquake focal mechanism investigation in the area is inconclusive, due to sparcity of data. The computed solutions only indicate that a northeast striking basement fault cannot be ruled out as the actual fault plane of the November 30, 1973 Maryville earthquake. Other equally likely solutions were obtained from the same data set.

From an examination of available information, it is concluded that there is no evidence for the existence of a seismogenic structure in the site area similar to that proposed by Bollinger (ref. QCS230.4-1) for Giles County, Virginia.

References

QCS230.4-1 Bollinger, G.A., 1981, The Giles County, Virginia, seismogenic zone-configuration and hazard assessment: in Earthquakes and Earthquake Engineering in the Eastern United States, J. E. Bevers, ed., Vol. 1, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, p. 277-308.

QCS230.4-2 Law Engineering Testing Company in conjunction with Burns and Roe, Inc., 1975, Report on evaluation of intensity of Giles County, Virginia earthquake of May 31, 1897.

QCS230.4-3 Bollinger, G.A., and M.G. Hopper, 1971, Virginia's two largest earthquakes - December 22, 1875 and May 31, 1897, Bull. Seism. Soc. Am., Vol. 61, pp. 1033-1039.

QCS230.4-4 Nuttli, O.W., G.A.Bollinger and D.W. Griffiths, 1979, On the relations between modified Mercalli intensity and body-wave magnitude, Bull. Seism. Soc. Am., Vol. 69, pp. 893-909.

QCS230.4-5 Law Engineering Testing Company Final Report: "Review and Assessment of Recent Findings Concerning the Seismicity of Giles County, Virginia" prepared for Burns and Roe, Inc., dated May 17, 1982.

reference QCS 230.4-5

FINAL REPORT OF

REVIEW AND ASSESSMENT OF RECENT FINDINGS CONCERNING THE SEISMICITY OF GILES COUNTY, VIRGINIA

PREPARED FOR

BURNS AND ROE, INC.
800 KINDERKAMACK ROAD
ORADELL, NEW JERSEY 07649

BY

LAW ENGINEERING TESTING COMPANY
2749 DELK ROAD, S.E.
MARIETTA, GA 30067

MAY 17, 1982

TABLE OF CONTENTS

LIST OF FIGURES

1.0 Introduction

This report reviews some recent findings concerning the seismicity of the Giles County, Viriginia area, and assesses the implications of these findings in regard to seismic design for the Clinch River Breeder Reactor Project.

The report incorporates information obtained as the result of an August 26, 1981 meeting with Dr. G. A. Bollinger, held to discuss some recently published results of his work in the Giles County, Virginia area. Persons in attendance at this meeting were M. C. Chapman and L. T. Long of Law Engineering Testing Company, R. C. Macken of Burns and Roe, Inc., and J. M. Siegel of the Project Office.

Section 2.0 of the report reviews and discusses the technical assumptions and methodology used by Dr. Bollinger to estimate the maximum magnitude earthquake for the proposed Giles County, Virginia seismogenic zone. In Section 3, ground motions at the CRBRP site are estimated, assuming the occurrence of the estimated maximum earthquake on the seismogenic zone. In Section 4, the earthquake potential of the site area is assessed, in light of the recent findings in Giles County.

Subsequent to the preparation of this report, the Nuclear Regulatory Commission requested the Project Office to provide a series of discussions relating to the potential impact of Dr. Bollinger's work on the CRBRP (question 230.4). The contents of this report serve to respond to parts b and c of that question.

2.0 Recent Findings Concerning the Giles County, Virginia Seismogenic Zone.

This section contains a review of the methodology and results presented by Bollinger (1981) in his recent study of seismic hazard associated with the Giles County, Virginia seismogenic zone. The technical content of the study and the usefulness of the results will be discussed in the context of engineering seismic hazard assessment for the CRBRP site.

2.1 Review

Recently, Bollinger and Wheeler (1980); Bollinger (1981) reported the existence of a tabular zone of seismic activity in the Giles County, Virginia area. This seismogenic zone strikes N 36° E, has a near vertical dip, a horizontal length of 40 km, vertical depth from 5 to 25 km and horizontal width 10 km. This tabular zone is defined by the hypocentral locations of earthquakes in the area. The data consist of 8 recent microearthquakes detected by a recently installed (1977) seismic network and by 4 larger pre-1977 felt events, which have recently been relocated.

The orientation and dimension of the Giles County seismogenic zone was determined from the statistical accuracy of the computed hypocentral locations. Specifically, the computational procedure used to locate the earthquakes defines an ellipsoid, within which the hypocenter is located at a particular confidence level. In the case of the 8 micro-

earthquakes, this confidence level is 68%. For the pre-1977 events, the confidence level is 90%. The dimensions of the zone are estimated by moving the computed hypocenters inside their error ellipsoids to achieve maximum and minimum spatial dispersals. Figures 2-1 and 2-2, taken from Bollinger (1981), show the epicentral locations of the earthquakes. The seismogenic zone is represented by the northeasterly trend of epicenters centered near Pearisburg, Virginia. Figures 2-3 and 2-4 show the vertical distribution of hypocenters parallel and perpendicular, respectively, to the northeast trending zone. As in Figure 2-2, the lines from the earthquake locations represent the axes of the error ellipsoids.

Under the assumption that the hypocenters define a single fault plane, the fault plane area is estimated by arbitrarily moving the hypocenters toward or away from their centroid. This is illustrated in Figure 2-5. This results in a range of fault plane area of 80 to 800 km^2.

Bollinger (1981) estimates the maximum magnitude of earthquakes associated with this seismogenic zone by assuming that the 80 km^2 and 800 km^2 values also represent the range of maximum potential rupture area. He invokes empirically determined relationships between fault rupture area and earthquake magnitude. This results in a range of possible maximum earthquake magnitudes. The 80 km^2 estimate of maximum rupture area is assumed capable of producing an earthquake with

surface wave magnitude (Ms) 6.0. The larger estimate of maximum rupture area, 800 km^2, would produce Ms = 7.0. Bollinger (1981) adopts the value Ms = 7.0 as the largest possible earthquake for the Giles County seismogenic zone.

2.2 Discussion

Bollinger (1981) presents a methodology for estimating the seismic hazard of the Giles County seismogenic zone. The study does not attempt to quantitatively estimate ground motion nor does it assess the likelihood of occurrence of the maximum magnitude event. Thus, it cannot be directly used to establish engineering seismic design criteria. However, the major result of the study is a useful estimate of the maximum expectable magnitude earthquake for a specific area in the eastern United States. In addition, hypothetical isoseismal maps are developed which can be readily incorporated in the engineering seismic hazard assessment procedure. These results can be incorporated in future quantitative seismic hazard studies for specific sites in the region. Because of the importance of this study, the technical assumptions and methods used deserve attention.

2.2.1 Evidence for the Seismogenic Zone

The seismogenic zone is defined by an alignment of earthquakes, historic and otherwise. These earthquakes

represent a range in magnitude of four units ($0<M<4$) and two decades in time (1959-1980). Thus, the zone is defined not only on the basis of an alignment of 8 microearthquakes, but also by four events which were felt in the area.

During the August 26, 1981 meeting, Dr. Bollinger noted that additional evidence is actively being sought to further define the nature of the seismogenic zone. In addition to continued earthquake monitoring, other lines of evidence might include seismic reflection profiles, gravity and magnetic surveys, detailed surface mapping and drilling.

2.2.2 Evidence for a Fault or Fault Zone

From the distribution of earthquake hypocenters which define the tabular seismogenic zone, Bollinger (1981) infers the existence of a single fault plane in order to estimate the magnitude of the maximum possible earthquake associated with the zone. As noted by Bollinger during the August 26, 1981 meeting, this inference would be strengthened by the existence, orientation and slip on one or more faults defined from geophysical data, especially seismic reflection profiles.

Bollinger and Wheeler (1981) report that focal mechanism solutions for Giles County events to date have proved to be inconclusive. Although the evidence for mode of faulting is mixed, a predominantly dip-slip type of motion is favored for the events in the seismogenic zone. Additional data of this type will help establish whether these events occur on

one or more faults, and will also establish the directions of principal stress.

It is important to note that not all historical earthquakes in the Giles County area have occurred within the seismogenic zone. This may imply the existence of multiple faults in the area. The most notable example is the second largest historical event, the 1969 Elgood, West Virginia shock, which occurred some 20 km to the northwest of the zone (Bollinger and Wheeler, 1981). The largest historical shock, which occurred on May 31, 1897 is assumed, but cannot be proven, to have originated in the zone (Bollinger, 1981). Evidence for this is based upon reports that the highest intensities were reached in Pearisburg, Virginia, which is centrally located on the inferred seismogenic zone. However, Pearisburg is also the largest population center in the area, so the possibility of population bias in reporting of intensity does exist.

The May 31, 1897 event is the largest historic earthquake which has occurred in the Southern Valley and Ridge Tectonic Province, with a reported epicentral intensity of VII-VIII MM (Langer and Bollinger, 1971). A subsequent re-assessment of the intensity was performed by Law Engineering Testing Company in conjunction with Burns and Roe, Inc., which confirmed the VII-VIII intensity value of the earthquake (Law Engineering in conjunction with Burns and Roe, Inc., 1975). However, in conformance with Nuclear Regulatory Commission direction, an intensity rating of VIII MM was used in CRBRP design.

2.2.3 Estimation of Maximum Magnitude Event

Bollinger (1981) estimates the maximum magnitude earthquake for the Giles County zone by invoking published relationships between fault rupture area and earthquake magnitude. In applying these relationships to the Giles County zone, the following assumptions are made:

(1) Earthquakes in the Giles County zone occur on a single fault plane.

(2) The maximum potential rupture area on this fault plane, and hence, the maximum magnitude earthquake, is defined by the spatial distribution of earthquakes.

(3) The published relationships between fault rupture area and magnitude are valid for the Giles County zone.

The first assumption has been discussed in the preceeding section. Regarding the second assumption, the traditional method for estimating earthquake magnitude has been to utilize correlations between surface rupture length (which may represent the entire known length of the fault) and earthquake magnitude. Wyss (1980) has recently noted that practical difficulties arise in the development and use of such correlations. For example, difficulty arises in judging whether a future earthquake could rupture the entire geological mapped fault, a fraction of it, or a multiple of it (this latter situation could arise in the case of a partly concealed fault). Also, it is important to recognize that surface rupture length may be less than the total source rupture length at depth. If the

correlation involves the entire mapped fault, it should be recognized that the surface trace may be the result of many ruptures occurring over geologic time. To obviate some of these ambiguities, Wyss (1979) proposed that the source rupture area be used in the correlation instead of mapped fault length or surface rupture length. In establishing the maximum magnitude event, Wyss (1980) advocates the following general practice.

First, the extent of the active fault(s) are identified by geologic and microseismic mapping. Then, on the basis of the segmentation of such fault(s), historic seismicity and geomorphic features, one must decide whether an earthquake could rupture the entire fault or only a portion of it. Then, using the available information, the size of the maximum rupture area is estimated and the maximum magnitude is determined from the physical relation between rupture area and magnitude.

In estimating the maximum earthquake for the Giles County zone, Bollinger (1981) has followed the above procedure and has postulated, for a worst case situation, that the entire mapped fault plane could rupture.

Regarding the third assumption, Nuttli (1981) has pointed out that for a given surface wave (Ms) magnitude, large (M>6) mid-plate and plate margin earthquakes may have very different seismic moments. A consequence of this is that events in mid-plate regions such as the eastern United States may have larger magnitudes than events in plate margin regions such as California,

given the same rupture area. For example, Singh, et al. (1980) presented theoretically derived relations which suggest that for a given rupture area, the surface wave magnitude of a mid-plate earthquake may exceed that of a plate margin earthquake by about 0.5 units.

Because the available data used to establish empirical relations between rupture area and magnitude come almost exclusively from plate margin earthquakes, the validity of such relationships in mid-plate areas is debatable.

2.2.4 Types of Fault Potentially Responsible for the Seismogenic Zone

Bollinger and Wheeler (1981) note that the Giles County seismogenic zone involves the upper half of the crust, beneath the Valley and Ridge thrust sheets, and that data is not now publicly available with which to identify clearly such deep structures. However, Bollinger and Wheeler (1981) consider the geologic history and existing information for the Giles County locale in an attempt to constrain the probable type, age and motion of the seismogenic structure, as well as the geographic area within which there may occur analogous structures with similar potential for seismic hazard.

Bollinger and Wheeler (1981) consider three types of basement faults as potentially responsible for the Giles Couny zone. The existence of these faults in the Giles County area is as yet hypothetical. However, of the three potential types, the type considered most likely to be the

causal fault of the Giles County zone is a hypothetical basement fault of early Paleozoic or Precambrian age, reactivated by the modern stress field. Bollinger and Wheeler (1981) propose that these faults occurred as a result of the opening of the Paleozoic Iapetan ocean, which separated the Eurasian and North American cratons. Such Precambrian and Paleozoic age faults may have formed as a result of extensional stress along the North American cratonic edge. Bollinger and Wheeler (1981) suggest that the eastern boundary of the cratonic edge and thus, the eastern limit for the area in which Iapetan normal faults are to be expected to occur is marked in general by the gradient in the non-filtered Bouguer gravity anomaly field. Citing examples from other passive plate margin areas, they propose that the western limit of expected Iapetan normal faults lies 100 to 200 km to the west of the gravity gradient. In general, this gravity gradient follows the eastern margin of the Blue Ridge physiographic province in Virginia, and from North Carolina southwestward into Alabama, follows the Brevard zone.

In regards to the CRBRP site, it is to be noted that the entire Valley and Ridge geologic province of the Southern Appalachians lies less than 200 km to the west of the gravity gradient, and thus lies above the cratonic edge within which Bollinger and Wheeler (1981) postulate the possible existence of Iapetan normal faults.

3.0 Site Ground Motion

The effect of the Giles County seismogenic zone on seismic hazard at the CRBRP site was assessed by estimating the expected ground motion at the site due to an intensity IX MM (Ms 7.0) earthquake occurring on the zone.

3.1 Methodology

Two approaches were used to estimate ground motion. For one approach, the recent work of Nuttli (1979) was used to estimate directly the peak ground acceleration at the site, without recourse to intensity data. The second approach utilizes the isoseismal maps developed by Bollinger (1981) which were specifically developed to include the source characteristics of the postulated magnitude 7.0 (Ms) Giles County earthquake, and regional attenuation properties of the Appalachian highlands.

Nuttli (1979) has evaluated the existing United States strong motion data and has derived curves showing the attenuation of acceleration as a function of magnitude and epicentral distance. Using theoretical results and observations of central United States earthquakes, Nuttli (1979; 1981) has specified regionally dependent scaling laws which allow strong motion data obtained in the Western United States to be reliably utilized in other regions. Figure 3-1 shows the latest results (Nuttli, 1981) for the central United States. It should be noted that these curves incorporate minor modifications made subsequent to publication by Nuttli (1979).

The curves are expressed in terms of "sustained horizontal acceleration" and body wave magnitude (mb) rather than as peak horizontal acceleration and surface wave magnitude (Ms).

Nuttli (1979) gives the following formula for conversion of Ms to mb:

$$mb = 0.61\ Ms + 1.93$$

Thus, the proposed magnitude Ms = 7.0 Giles County event would exhibit body wave magnitude mb of about 6.2. Nuttli (1979) determined the ratio of sustained horizontal acceleration to peak horizontal acceleration. His estimate of this ratio is 0.700 ± 0.152, derived from 367 strong motion records.

Using the above conversions, peak horizontal acceleration for the site, located 360 km from the assumed epicenter, can be determined directly from Figure 3-1. The value is 0.010 g. In addition, Bollinger (1981) assumes that the Ms = 7.0 earthquake corresponds to mb = 6.4. Using this value and the procedure outlined above, Figure 3-1 indicates a peak horizontal site acceleration of 0.014 g.

The above values can be converted to Modified Mercalli intensity, using results developed by Nuttli (1979). Because of the large epicentral distance (360 km), we assume that high frequency motions will be substantially attenuated. As pointed out by Nuttli (1979), the correlation between intensity and acceleration is frequency dependent. There is a tendency for acceleration to decrease as wave frequency decreases for a given MM intensity. Thus, at large epicentral distances, relatively small accelerations may correspond to relatively high intensities. If we conservatively assume that peak

accelerations occur at frequencies less than 2 Hz, the results of Nuttli (1979) indicate that 0.010 g peak horizontal acceleration corresponds to intensity V MM or less.

The second approach to estimating the ground motion at the site utilizes the hypothetical isoseismal maps developed by Bollinger (1981). These maps are reproduced as Figures 3-2 and 3-3. Figure 3-2 is representative of hypothetical intensity data contoured at the 50% fractile, whereas the isoseismals of Figure 3-3 are anticipated to envelope 70% or more of the individual observations.

The distinction between these two maps is important. In Figure 3-2 the site is located upon the intensity VI MM isoseismal. This means that it lies very near to the mean distance at which observations of VI MM will hypothetically be reported. This does not mean, however, that higher intensities cannot occur at this distance. This is illustrated by Figure 3-3, which incorporates an added degree of conservatism, by contouring the hypothetical data at the 70% fractile. In a statistical sense, the two maps represent the effect of uncertainty in the intensity-distance relationships. For our second approach, we choose the "most likely" or 50% fractile map (Figure 3-2) which indicates a site intensity of VI MM. Because it represents the 50% fractile, this map is compatable with mean-centered attenuation functions, such as Nuttli (1979).

To convert intensity VI MM to site acceleration, we once again assume that the peak acceleration will occur at frequencies of 2 Hz or less, and invoke the results of Nuttli (1979). The resulting mean value for peak horizontal acceleration is 0.036 g.

In contrast to the procedures used above, the site design acceleration was determined by utilizing a relationship between site intensity (assuming site intensity VIII MM) and peak horizontal acceleration based on period-acceleration graphs published by Neumann (1954). For comparison with the above results, the Neumann (1954) relation for site intensity VI gives a peak horizontal acceleration of 0.065 g. A similar value of 0.066 g may be reached by using the Trifunac and Brady (1975) intensity-acceleration relationship.

3.2 Summary

We have used two approaches to estimate ground motion at the site from a Ms 7.0 earthquake on the Giles County, Virginia seismogenic zone.

The first approach, based on results by Nuttli (1979), indicates a peak acceleration of 0.010 g and a site intensity of V MM or less. The second approach, which utilizes the specific intensity attenuation data and source characteristics for the Giles County zone developed by Bollinger (1981), indicates a site intensity of VI MM and a corresponding peak horizontal acceleration of 0.036 g.

The two approaches give results which are in good agreement considering that they are based upon two different physical phenomena: i.e., the attenuation of peak acceleration and Modified Mercalli intensity, respectively.

4.0 Earthquake Potential of Site Area

This section details the historic seismicity of eastern Tennessee in the vicinity of the site. In view of the recent findings in Giles County, Virginia (Bollinger, 1981; Bollinger and Wheeler, 1981), the spatial distribution of earthquakes was carefully examined to determine if any linear trends suggestive of seismogenic zones similiar to that postulated by Bollinger (1981) are discernable in the site area. In addition, published information concerning basement structure was reviewed, and inferred basement lineations were examined for possible correlation with historic seismicity.

4.1 Historic Seismicity

Table 1 lists 67 earthquakes occurring in that portion of Tennessee between longitude 83^0 and 85^0 W. This list was compiled largely from Seismicity Map of Tennessee (Stover et al., 1979). Original source references used by Stover et al. (1979) are noted in Table 1 and are listed in this report under "Seismicity References".

The epicentral locations of the 67 historic earthquakes are shown on Figure 4-1. On Figure 4-1, the intensities and dates of occurrence refer to the largest event reported at a particular location. Figure 4-1 indicates that 22 of the 67 earthquakes have been attributed to the Knoxville area. Bollinger et al. (1976) noted that this apparent concentration of seismicity near Knoxville may result from population bias in

the reports of pre-instrumental events. Only during the past decade has instrumental location capability approached adequacy in the region. Stover et al. (1979) have estimated the locational uncertainty of each of the events shown in Figure 4-1. For the majority of these events, the uncertainty is greater than ± 0.5 degrees.

Figure 4-2 plots 26 earthquakes which have an estimated locational uncertainty of less than ± 0.5 degrees. Of immediate interest is the fact that 11 of these 26 earthquakes occurred in the Maryville area. However, of these 11 events, 8 were reported foreshocks or aftershocks of the intensity VI MM November 30, 1973 Maryville earthquake (Bollinger et al., 1976). Taking this into consideration, Figure 4-2 indicates that epicenters of well located events in the area form no discernible spatial pattern. However, it should be recognized that the region has been adequately monitored for only the past 10 to 15 years. As a result, unequivocal conclusions as to the existence or non-existence of spatial trends in seismicity cannot be made at this time.

4.2 Inferred Basement structures

The Giles County, Virginia seismogenic zone is attributed to faults within the basement and is presumably not evident in the surface geological structure (Bollinger and Wheeler, 1981). Thus, published interpretations of magnetic and gravity data covering eastern Tennessee were reviewed and compared with the spatial distribution of historic earthquakes.

Watkins (1964) reported the existence of a pronounced northeast trending magnetic and gravity lineation paralleling the western margin of the Valley and Ridge province in eastern Tennessee. More recently, King and Zietz (1978) noted that this lineament is part of a much larger feature which can be traced on magnetic and Bouguer gravity maps from Alabama to New York. Watkins (1964) interpreted this lineament as marking a discontinuity beneath the sedimentary section, and suggested that the feature is seismically active, noting that several historic earthquakes have occurred within about 15 miles of the axis of the lineament (Figure 4-1). However, King and Zietz (1978) do not imply that the feature is seismically active: on the contrary, they propose that it marks a basement discontinuity separating a seismically active crustal block on the southeast from a seismically inactive crustal block on the northwest. This is substantiated by Figure 4-2, which plots those earthquakes reliably located in eastern Tennessee. It is important to recognize that the Blue Ridge province of western North Carolina exhibits a level of seismicity similar to that of eastern Tennessee. In addition, further to the northeast in West Virginia, the lineament passes through an essentially aseismic area. In accordance with King and Zietz (1978) we conclude that the lineament is not a seismogenic structure, but may in fact represent the western boundary of a seismically active region lying to the southeast.

The November 30, 1973 Maryville earthquake is one of the few southeastern United States earthquakes for which focal mechanism solutions are available. Unfortunately the data are sparce and as a result, the focal mechanism is inconclusive. For the main shock, Bollinger et al. (1976) obtained two equally likely solutions, one showing normal faulting on northeast or northwest striking nodal planes, the other defining reverse faulting with nodal planes striking northwest. Bollinger et al. (1976) favored the reverse faulting solution on a northwest striking fault plane based on other data (aftershock epicenters, vertical distribution of aftershock hypocenters and regional in-situ stress measurements). Herrmann (1979) obtained a strike-slip mechanism with nodal planes striking either north-northeast or west-northwest, with steep dips.

Both investigators noted that their solutions were poorly constrained. However, both studies indicate the possibility of a northeast striking fault plane, which Bollinger and Wheeler (1981) cite as supporting evidence for seismically active, northeast striking basement faults in the same geologic-physiographic province as the Giles County, Virginia zone.

4.3 Summary

An examination of the distribution of historical seismicity in the site area does not reveal any discernible spatial trend suggestive of a seismogenic zone similar to that proposed by Bollinger (1981) for Giles County, Virginia. In addition, inferred basement structures apparent on published magnetic and gravity anomaly maps of the area appear non-seismogenic.

The single existing earthquake focal mechanism investigation in the area is inconclusive, due to sparcity of data. The computed solutions only indicate that a northeast striking basement fault cannot be ruled out as the actual fault plane of the November 30, 1973 Maryville earthquake. Other equally likely solutions were obtained from the same data set.

From an examination of available information, we conclude that there is no evidence for the existence of a seismogenic structure in the site area similar to that proposed by Bollinger (1981) for Giles County, Virginia. However, the quality of the available data is such that the existence of such a structure cannot be definitely ruled out. In order to conclusively assess the likelihood of such a structure in the site area, a program of microseismic monitoring would be required.

5.0 Summary and Conclusions

The study by Bollinger (1981) represents the first instance in the eastern United States where a seismogenic zone and associated maximum earthquake has been defined on the basis of observed earthquake activity, except for a few reservoir induced seismicity studies. The methods used by Bollinger (1981) to estimate the maximum possible earthquake are accepted as valid by the seismological community. Application of these methods is fundamental to the practical problem of assessing seismic hazard in regions where capable faults are observed. In the eastern United States, this is a novel approach primarily because of the general low level of seismicity and the absence of obvious capable faults at the ground surface.

The estimate of the maximum earthquake for the Giles County seismogenic zone incorporates the statistical uncertainty of the observational data. This results in a range of magnitude: $6.0 < Ms < 7.0$. For a worst case situation, Bollinger (1981) adopts the upper limit of this range (Ms 7.0) as the maximum magnitude. This corresponds to an epicentral intensity of IX MM. Ideally, a probabilistic assessment of seismic hazard posed by the Giles County zone would incorporate a mean value of the maximum magnitude, with associated statistical uncertainty, and an estimate of the probability of occurrence. As pointed out by Dr. Bollinger during the August 26, 1981 meeting, these elements would require additional study.

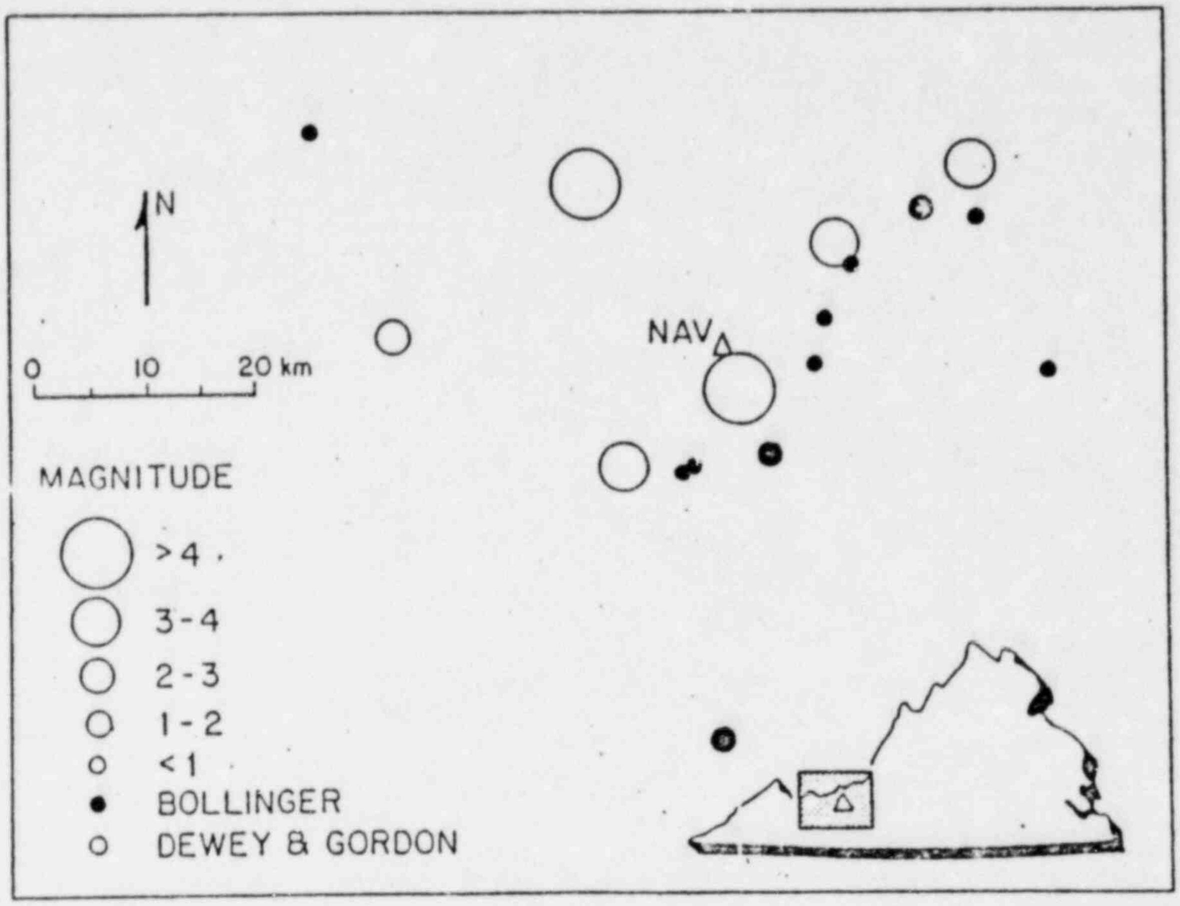
Potential ground motion at the CRBRP site due to occurrence of an Ms 7.0 event on the Giles County zone has been estimated using recently developed results. The peak horizontal ground acceleration expected at the site is 0.036 g: This corresponds to Modified Mercalli intensity VI. Present CRBRP design assumes a site intensity of VIII MM. Thus, the proposed maximum earthquake for the Giles County seismogenic zone does not imply the need for a higher design intensity.

It has been hypothetically proposed that faults similar to those considered potentially responsible for the Giles County zone may exist elsewhere in the basement of the Southern Valley and Ridge Tectonic Province. Proven existence of any seismogenic structures potentially capable of generating site intensities exceeding VIII MM could require upgrading the design intensity.

We have addressed this problem by assuming that the critical seismogenic structure would exhibit characteristics similar to those of the Giles County seismogenic zone. Thus, this hypothetical feature might be a seismically active, northeast trending basement fault located in eastern Tennessee.

Our investigation of the distribution of historic epicenters and inferred basement features in eastern Tennessee shows no evidence for the existence of such a structure. Therefore, we conclude that a site intensity of VIII MM, which is being used for the CRBRP design as directed by NRC, will not be impacted by the Bollinger (1981) Giles County seismic hazard study.

We feel that in areas influenced by the Giles County, Virginia seismogenic zone, the derivation of the vibratory ground motion design could be affected. To date, there is no evidence indicating the existence of a similar structure elsewhere in the Southern Valley and Ridge Tectonic Province. It concluded that the siting evaluations arising from the existence of the Giles County zone for proposed facilities in these areas will require only that the intensity IX MM Giles County maximum event be attenuated to the site in question.



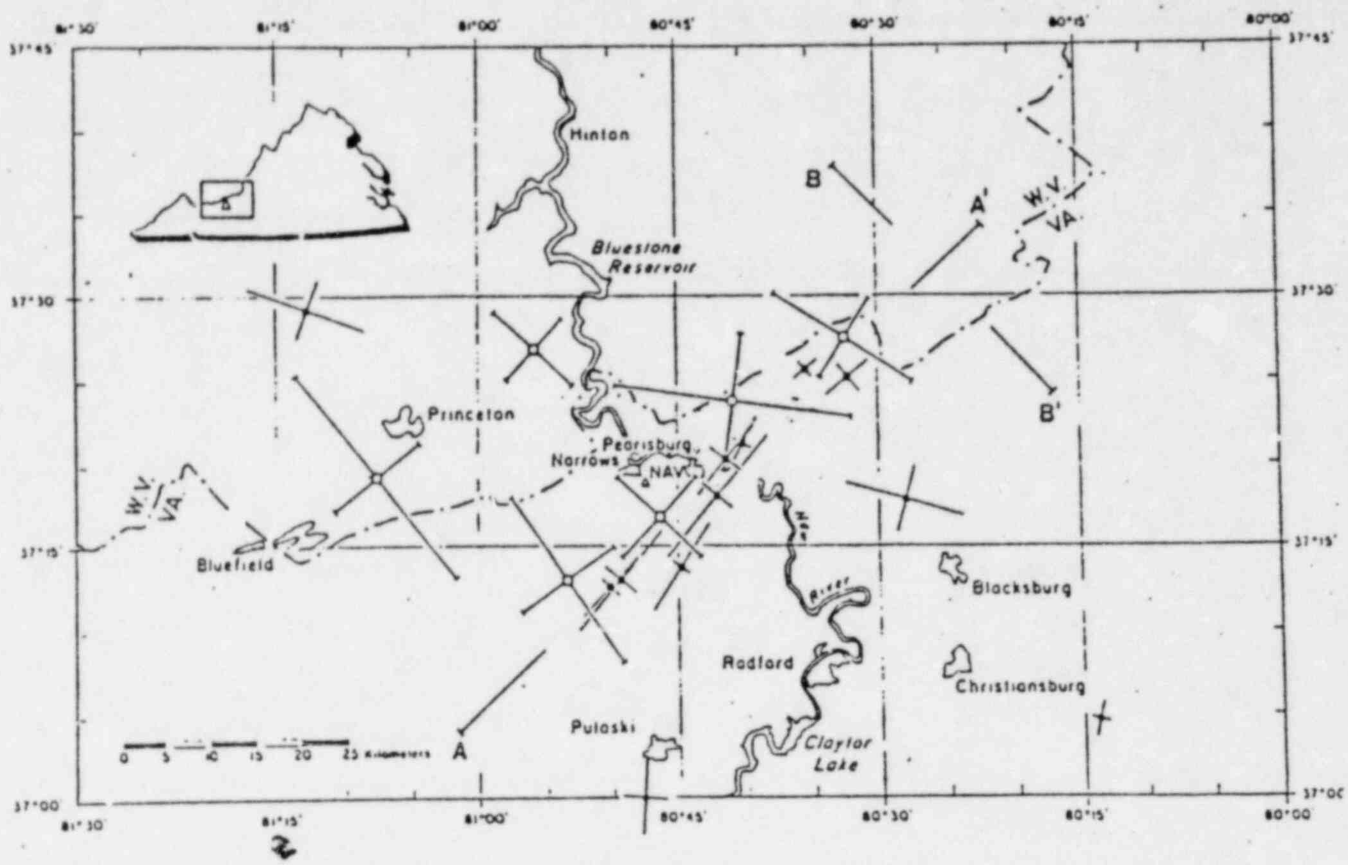
LEGEND

● MICROEARTHQUAKES (BOLLINGER, 1981)

○ EARTHQUAKES BY DEWEY AND GORDON (1980)

MODIFIED FROM BOLLINGER (1981)

CLINCH RIVER BREEDER REACTOR PROJECT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	INSTRUMENTAL EPICENTER LOCATIONS OF EARTHQUAKES IN THE GILES COUNTY AREA JOB NO. MG1319 FIGURE 2-1

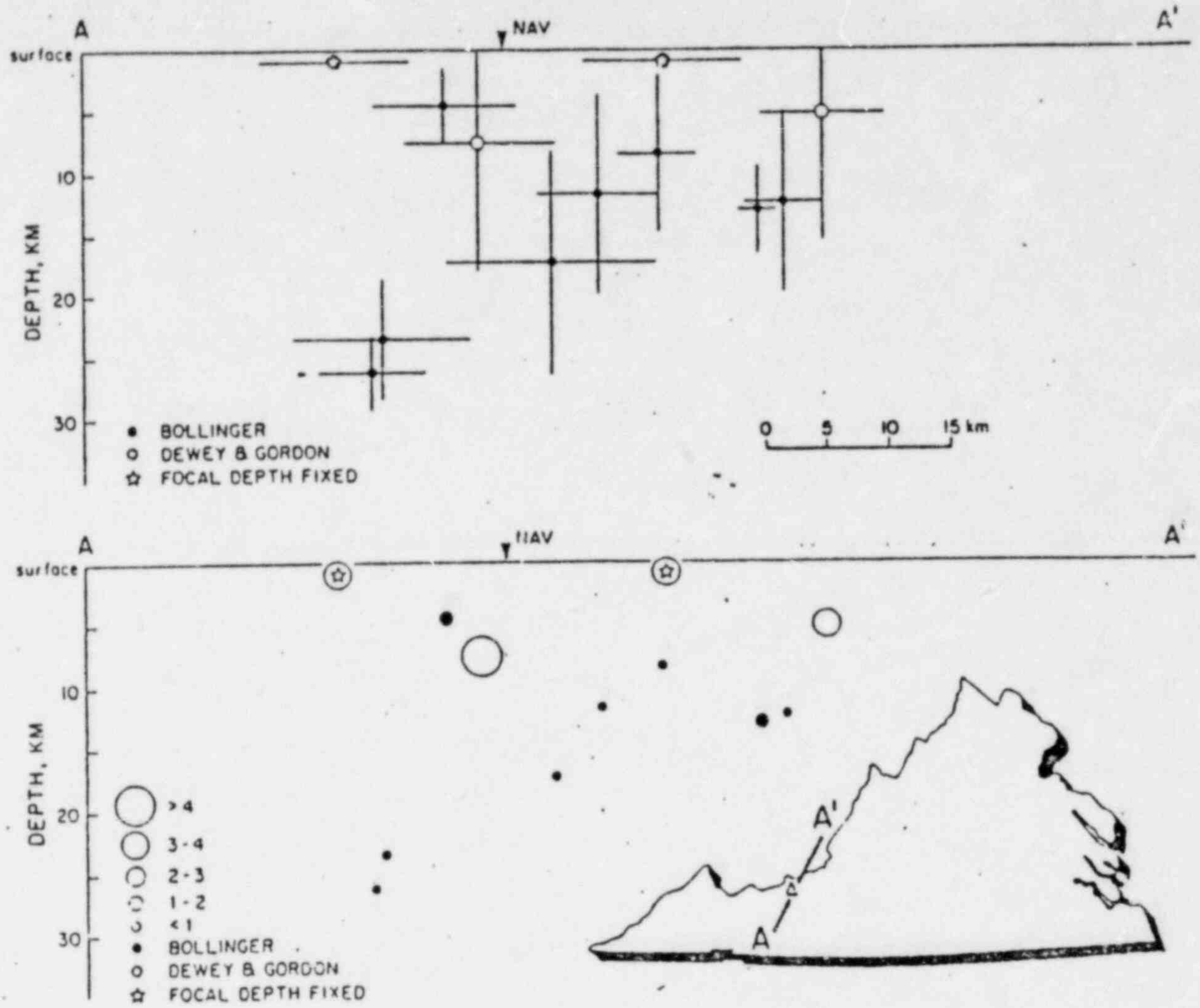


LEGEND

- EARTHQUAKE LOCATION BY BOLLINGER (1981)
- o EARTHQUAKE LOCATION BY DEWEY AND GORDON (1980)
- EPICENTER LOCATION ERROR ELLIPSOID AXES

MODIFIED FROM BOLLINGEN (1981)

CLINCH RIVER BREEDER REACTOR PROJECT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	EPICENTER LOCATIONS WITH ERROR ELLIPSOIDS JOB NO. MG1319 FIGURE 2-2



LEGEND

EARTHQUAKE MAGNITUDE

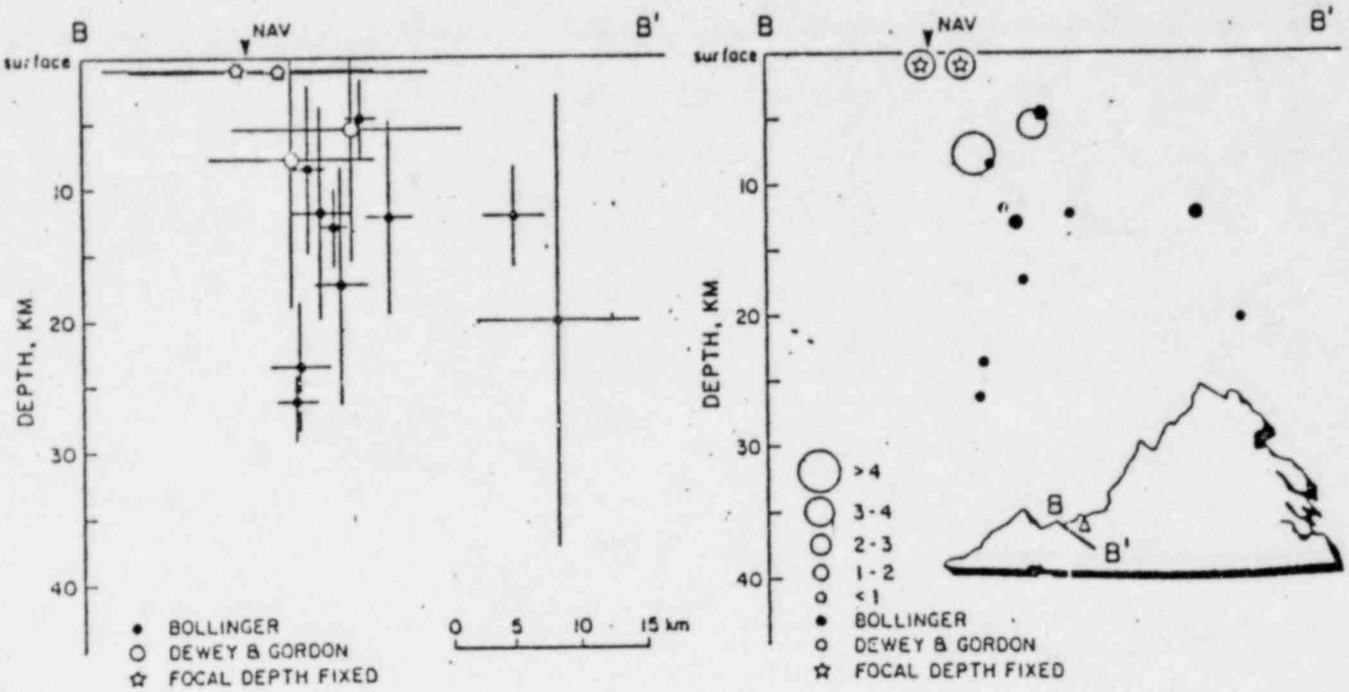
EARTHQUAKE LOCATION BY BOLLINGER (1981)

EARTHQUAKE LOCATION BY DEWEY AND GORDON (1980)

HYPOCENTER LOCATION ERROR ELLIPSOID AXES

MODIFIED FROM BOLLINGER (1981)

CLINCH RIVER BREEDER REACTOR PROJECT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	EARTHQUAKE HYPOCENTERS PARALLEL TO SEISMOGENIC ZONE JOB NO. MG1319 FIGURE 2-3

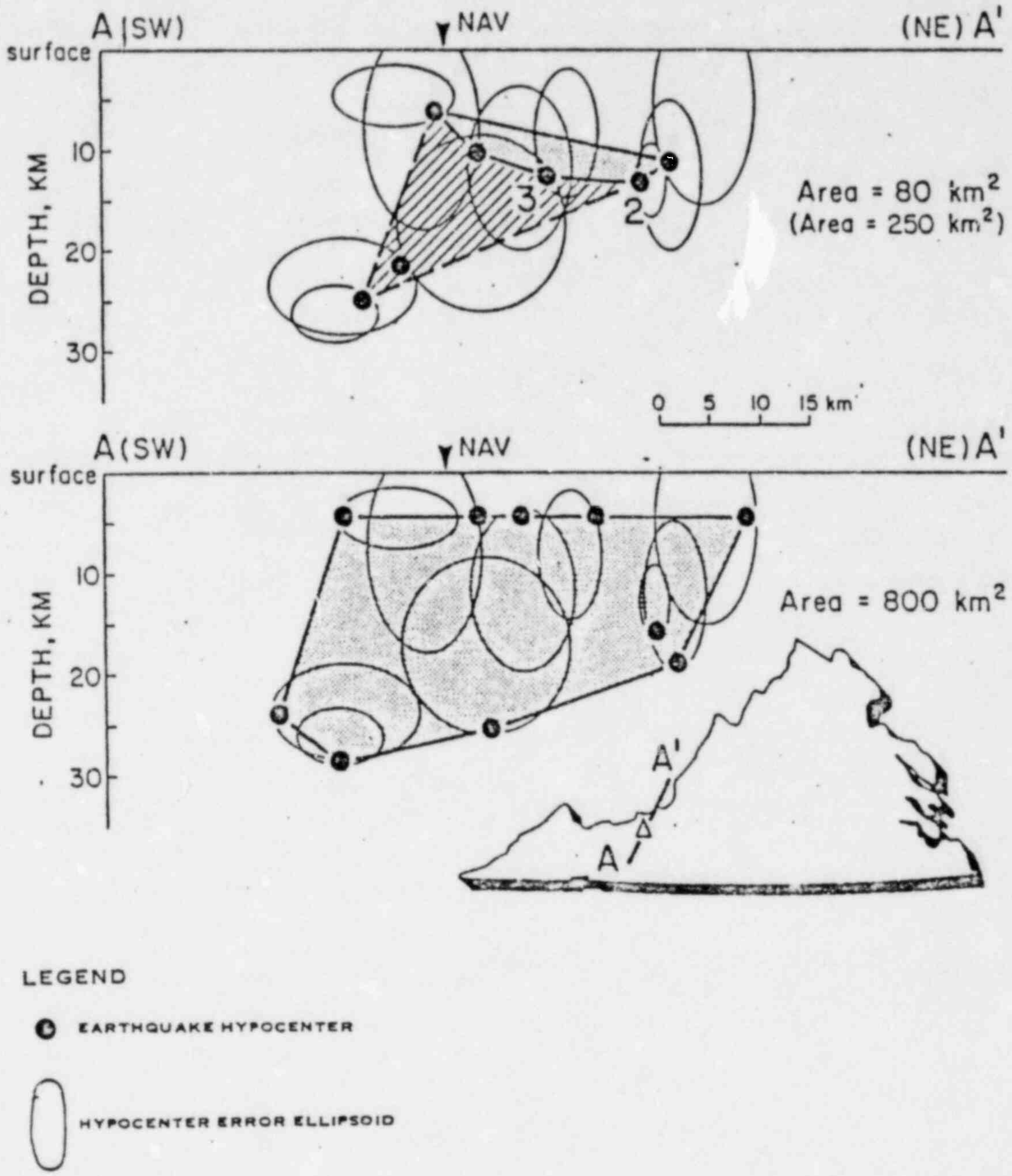


LEGEND

- EARTHQUAKE MAGNITUDE
- EARTHQUAKE LOCATION BY BOLLINGER (1981)
- EARTHQUAKE LOCATION BY DEWEY AND GORDON (1980)
- HYPOCENTER LOCATION ERROR ELLIPSOID AXES

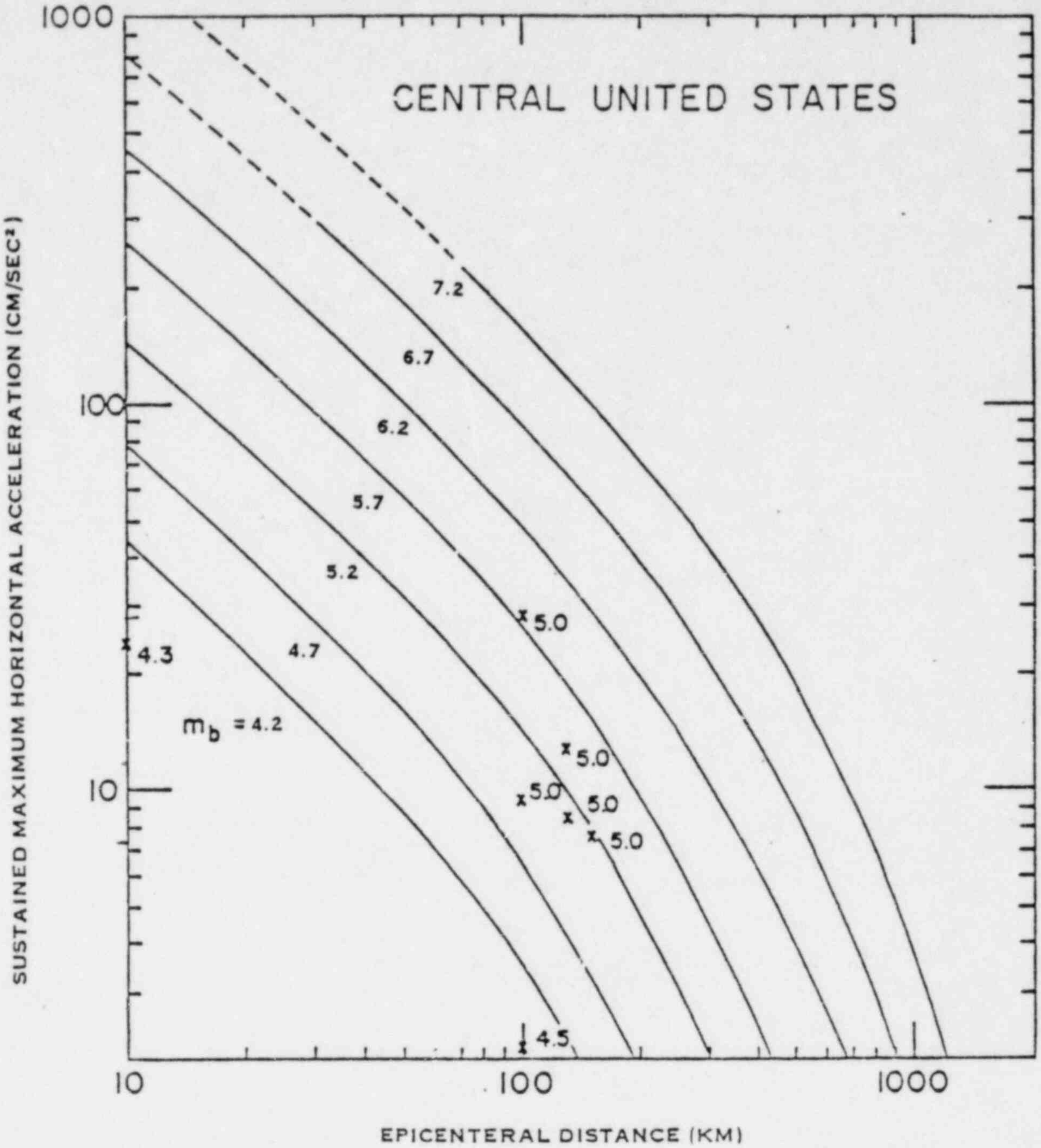
MODIFIED FROM BOLLINGER (1981)

CLINCH RIVER BREEDER REACTOR PROJECT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	EARTHQUAKE HYPOCENTERS PERPENDICULAR TO SEISMOGENIC ZONE JOB NO. MG1319 FIGURE 2-4



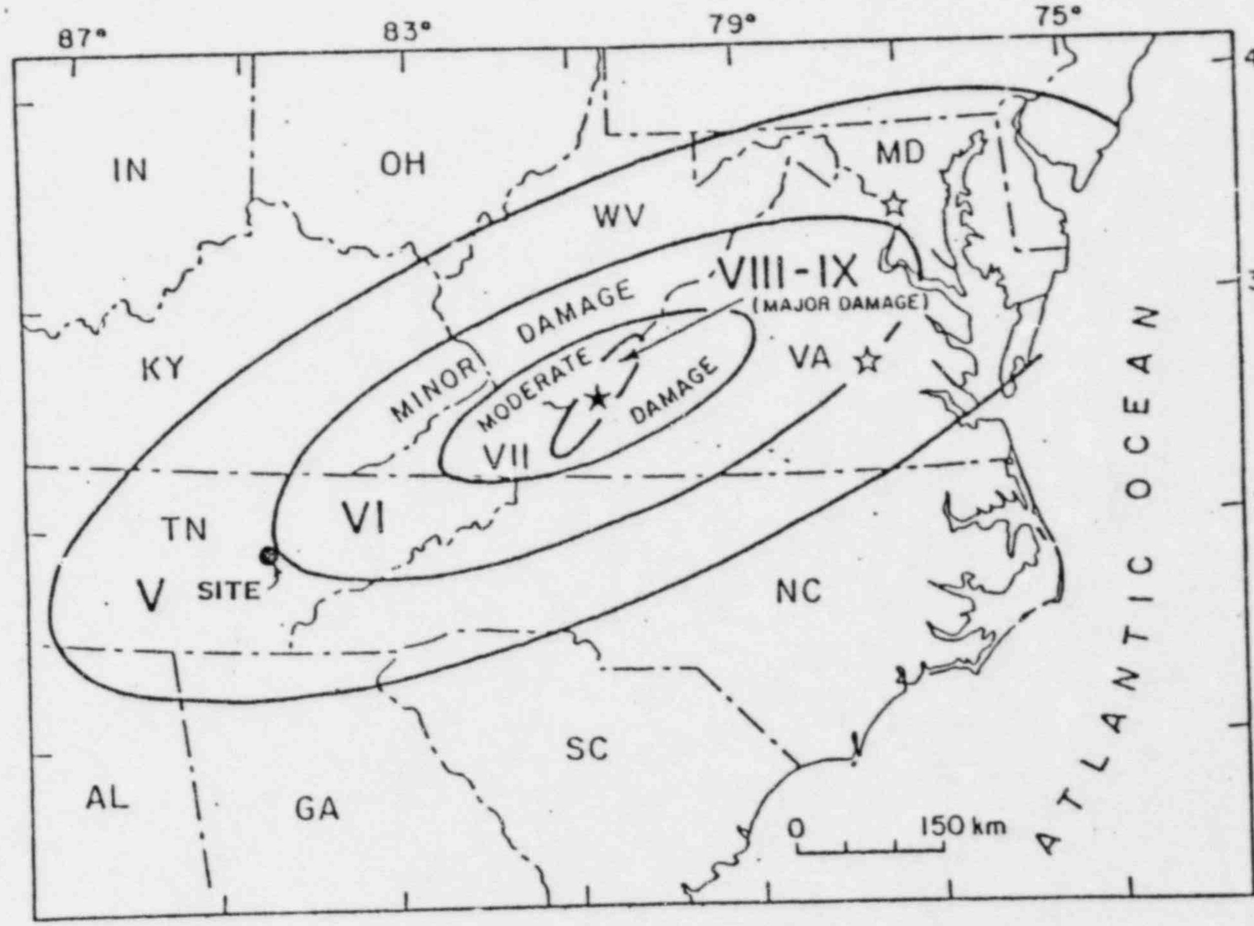
MODIFIED FROM BOLLINGER (1981)

CLINCH RIVER BREEDER REACTOR PROJECT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	FAULT PLANE AREAS INFERRED FROM HYPOCENTER LOCATION JOB NO. MG1319 FIGURE 2-5



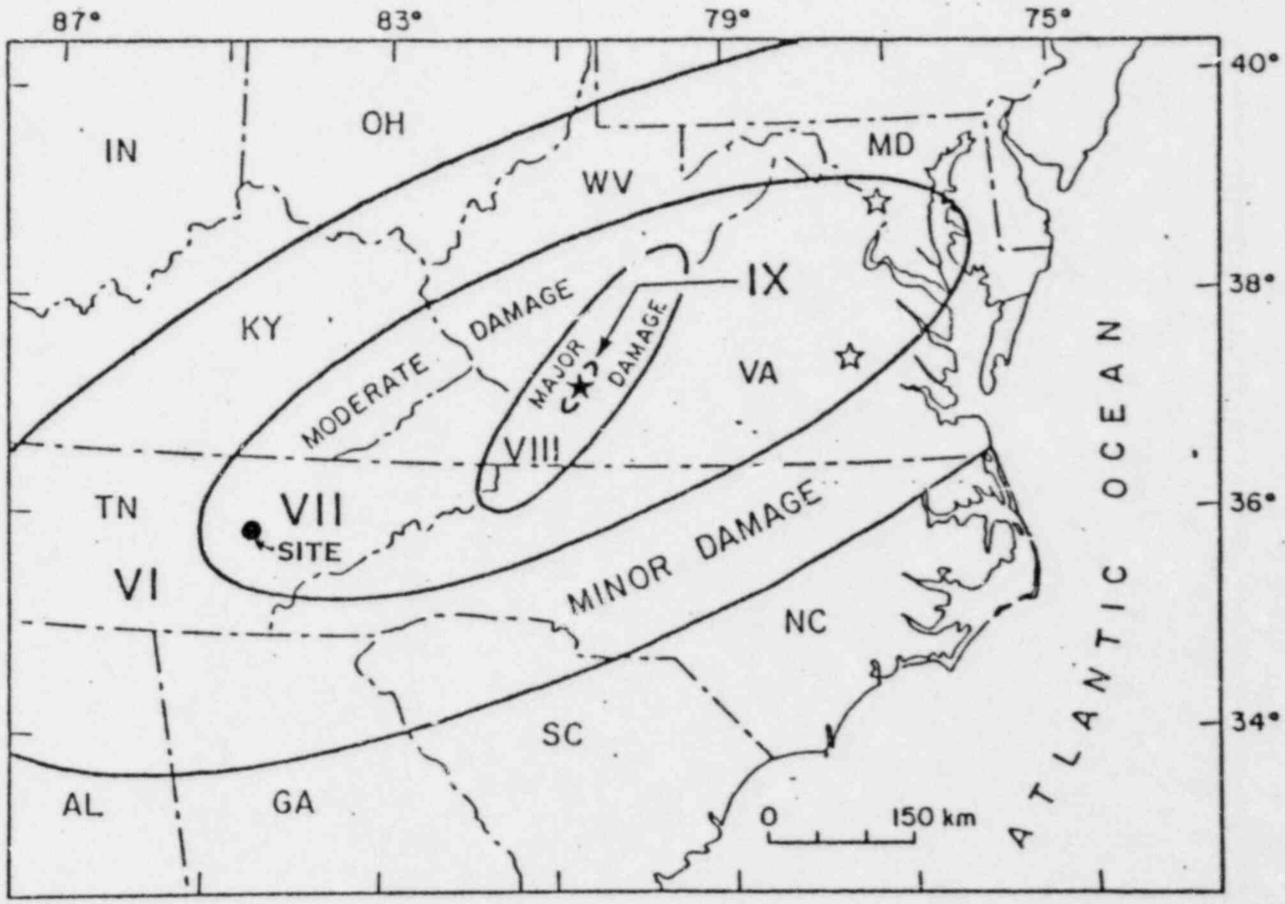
MODIFIED FROM NUTTLI (1979)

CLINCH RIVER BREEDER REACTOR PROJECT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	SUSTAINED MAXIMUM HORIZONTAL ACCELERATION VERSES EPICENTRAL DISTANCE FOR THE CENTRAL UNITED STATES JOB NO. MG1319 FIGURE 3-1



MODIFIED FROM BOLLINGER (1981)

CLINCH RIVER BREEDER REACTOR PROJECT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	HYPOTHETICAL ISOSEISMAL MAP FOR IX MM MAXIMUM EARTHQUAKE (50% FRACTILE) JOB NO. MG1319 FIGURE 3-2



MODIFIED FROM BOLLINGER (1981)

CLINCH RIVER BREEDER REACTOR PROJECT

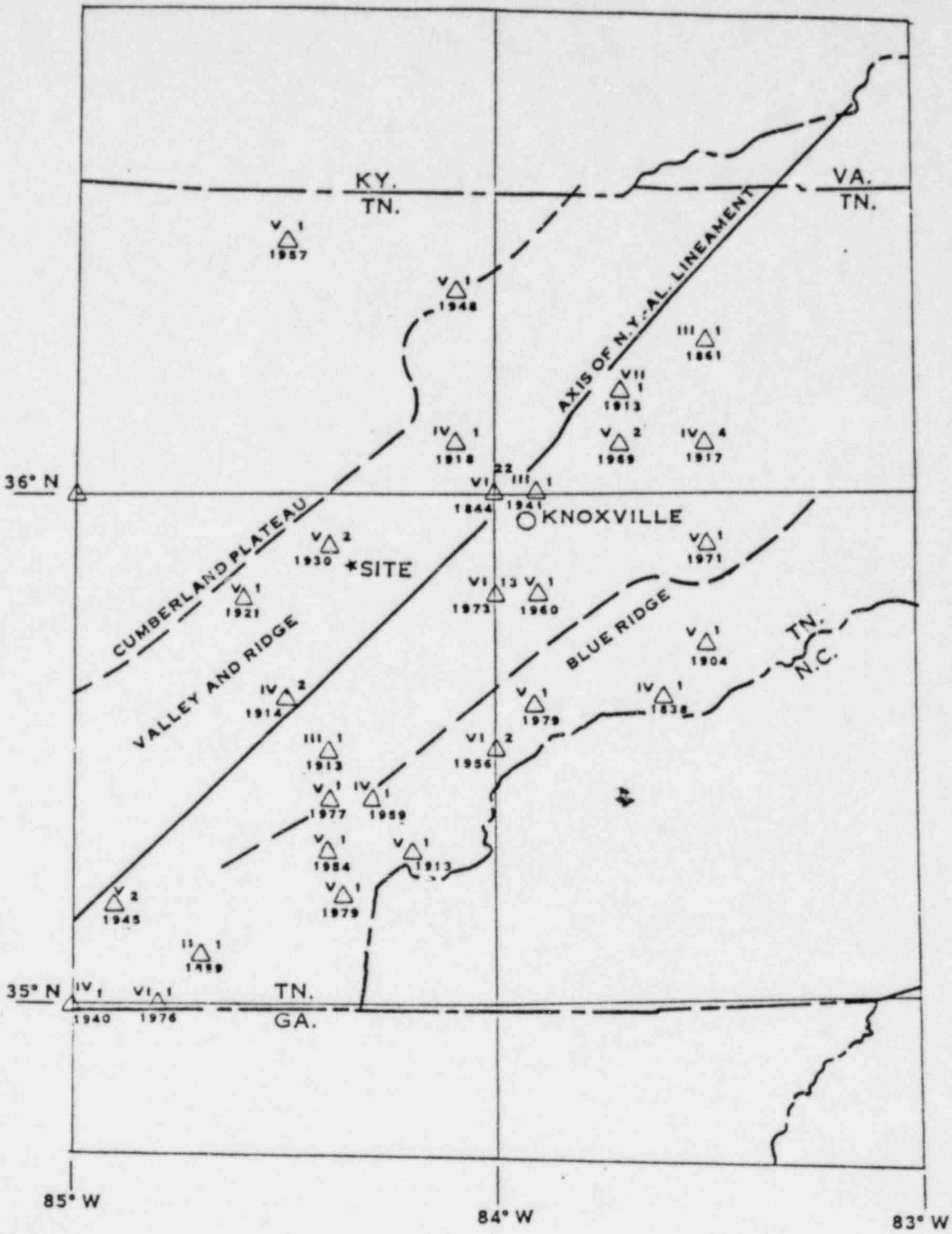
LAW ENGINEERING TESTING COMPANY

MARIETTA, GEORGIA

HYPOTHETICAL ISOSEISMAL MAP FOR IX MM MAXIMUM EARTHQUAKE (70% FRACTILE)

JOB NO. MG1319

FIGURE 3-3



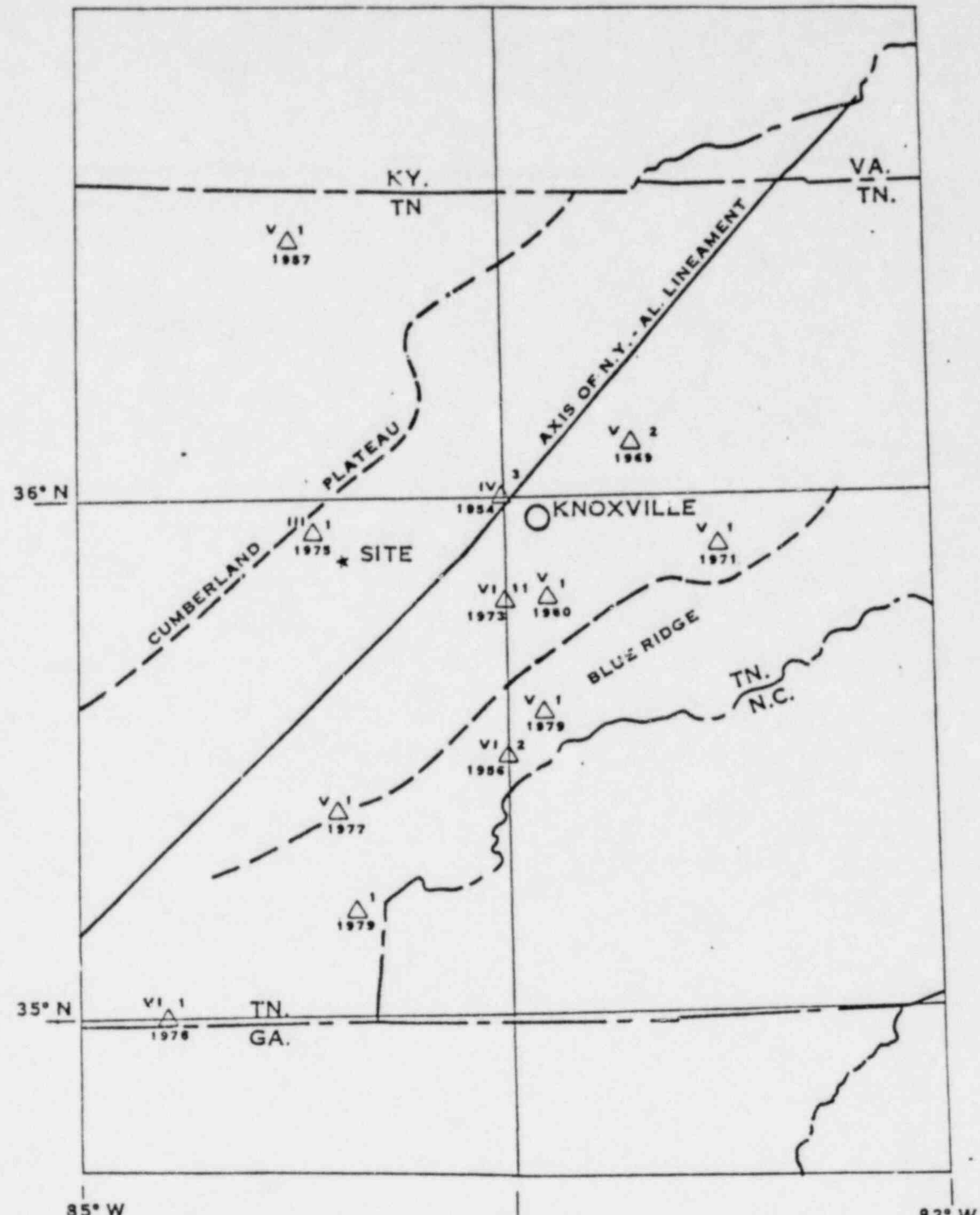
LEGEND

△ EPICENTRAL LOCATION

△² NUMBER OF EARTHQUAKES REPORTED AT GIVEN LOCATION

V△ 1969 MODIFIED MERCALLI EPICENTRAL INTENSITY AND DATE OF LARGEST EVENT AT GIVEN LOCATION

CLINCH RIVER BREEDER REACTOR PROJECT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	HISTORIC EARTHQUAKES IN EASTERN TENNESSEE JOB NO. MG1319 FIGURE 4-1



LEGEND

△ EPICENTRAL LOCATION

△² NUMBER OF EARTHQUAKES REPORTED AT GIVEN LOCATION

V △ 1969 MODIFIED MERCALLI EPICENTRAL INTENSITY AND DATE OF LARGEST EVENT AT GIVEN LOCATION

CLINCH RIVER BREEDER REACTOR PROJECT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	EARTHQUAKES IN EASTERN TENNESSEE WITH LOCATIONAL UNCERTAINTIES LESS THAN 0.5 DEGREE JOB NO.MG1319 FIGURE 4-2

YEAR/MO./DAY	TIME (EST)	LAT.	LONG.	Io/M	REF.
1969/7/13	16:51:09.4	36.1	83.7	V/4.1	16
1969/7/14	05:13:14.5	36.1	83.7	II	5
1969/7/14	06:15	36.0	84.0	III	8
1969/7/24	13:10	36.0	84.0	III	16
1971/7/12	21:03	36.0	84.0	V	17
1971/10/9	11:43:33.8	35.9	83.5	V/3.7	17
1973/10/30	17:58:39.0	35.75	84.00	V/3.4	18
1973/10/30	18:09	35.75	84.00		18
1973/11/30	02:48:41.2	35.80	83.96	VI/4.6	18
1973/11/30	03:51	35.80	83.96	II	18
1973/11/30	04:27	35.80	83.96		18
1973/12/13	10:	35.80	83.96	III	18
1973/12/14		35.80	83.96	III	18
1973/12/21	03:	35.80	83.96	III	18
1973/12/21	13:30	35.80	83.96	III	18
1975/5/2	11:22:58.7	35.92	84.45	III/2.6	19
1976/2/4	14:53:52.9	35.00	84.75	VI/3.0	20
1977/7/27	17:03:21.3	35.42	84.42	V/3.5	21
1979/8/13	00:18	35.21	84.35	V/3.7	22
1979/9/12	01:24	35.59	83.90	V/3.2	22
1980/6/25	12:02	35.78	84.05	V/3.3	23

TABLE 1 continued:

(Page 2 of 3)

YEAR/MO./DAY	TIME (EST)	LAT.	LONG.	Io/M	REF.
1918/6/21	20:00	36.1	84.1	IV	4
1920/12/24	02:30	36.0	85.0	V	5
1921/12/15	08:20	35.8	84.6	V	4
1938/3/31	05:10	35.6	83.6	IV	6
1940/10/19	00:55	35.0	85.0	IV	5
1941/3/4	01:15	36.0	83.9	III	5
1945/6/13	22:35	35.2	84.9	V	7
1946/4/7	00:	35.2	84.9	III	6
1947/6/6	07:55	36.0	84.0	III	6
1948/2/9	19:04	36.4	84.1	V	6
1950/6/18	23:19	35.8	84.0	IV	5
1953/11/10	09:45	36.0	84.0	IV	8
1953/12/5	08:45	36.0	84.0	IV	8
1954/1/14		36.0	84.0	IV	8
1954/1/22	20:	35.3	84.4	V	9
1955/1/12	01:25	35.8	84.0	IV	10
1955/1/25	14:34	36.0	84.0	IV	10
1956/9/7	8:36:01	35.5	84.0	VI	11
1956/9/7	8:49:29	35.6	84.0	V	11
1957/6/23	01:34:18	36.5	84.5	V	12
1957/11/7	12:15	36.0	84.0	IV	8
1959/6/12	20:	35.4	84.3	IV	13
1960/4/15	05:10:10	35.8	83.9	V	14
1964/7/28		36.0	84.0	III	8
1964/10/13	11:30	36.0	84.0	III	8
1966/10/24	01:00	35.8	84.0	IV	15

TABLE 1

HISTORIC EARTHQUAKES IN TENNESSEE BETWEEN 83°W AND 85°W LONGITUDE

YEAR/MO./DAY	TIME (EST)	LAT.	LONG.	Io/M	REF.
1777/11/16	02:	36.0	84.0	IV	1
1844/11/28	07:00	36.0	84.0	VI	2
1861/		36.3	83.5	III	3
1875/11/12	02:00	36.0	84.0	III	3
1877/5/25		36.0	84.0	III	3
1877/11/16	02:20	36.0	84.0	IV	3
1884/8/24	19:45	36.0	84.0	IV	3
1889/9/28		35.1	84.7	II	3
1904/3/4	19:30	35.7	83.5	V	2
1913/3/28	16:50	36.2	83.7	VII	2
1913/4/17	11:30	35.3	84.2	V	2
1913/5/2	01:00	35.5	84.4	III	4
1913/8/3	11:45	36.0	84.0	IV	4
1914/1/23	22:24	35.6	84.5	IV	4
1914/1/23	22:41	35.6	84.5	III	4
1917/1/26	07:15	36.1	83.5	III	4
1917/3/4	21:07	36.0	84.0	III	4
1917/3/25	16:15	36.1	83.5	III	4
1917/3/26	07:50	36.1	83.5	III	4
1917/3/27	15:00	36.1	83.5	IV	4

SEISMICITY REFERENCES

(Refer to Table 1)

1. Winkler, L., 1978, Early American earthquake history for nuclear reactor site selection, prepared for Nuclear Regulatory Commission, Contract NRC-04-78. 208,p. 1-61

2. Coffman, J. L. and Von Hake, C.A., 1973, Earthquake History of the United States, U.S. Dept. of Commerce, N.O.A.A., No. 41-1 (through 1970), p. 1-208.

3. Moneymaker, B.C., 1955, Earthquakes in Tennessee and nearby sections of neighboring states 1851 to 1900: Tennessee Academy of Science Journal, Vol.30, No.3, p. 222-233.

4. Moneymaker, B.C., 1957, Earthquakes in Tennessee and nearby sections of neighboring states 1901 to 1925: Tennessee Academy of Science Journal, Vol.32, No.2, p. 91-105.

5. McClain, W. C. and Meyers, O.M., 1970, Seismic history and seismicity of the southeastern region of the United States, Oak Ridge National Laboratory, Oak Ridge, Tenn., Union Carbide Corp., for the U.S. Atomic Energy Commission, p. 1-43.

6. Moneymaker, B.C., 1958, Earthquakes in Tennessee and nearby sections of neighboring states 1926 to 1950: Tennessee Academy of Science Journal, Vol.33, No. 3, p.224-239.

7. Bodle, R.R. and Murphy, L.M., 1947, United States Earthquakes 1945, U.S. Dept. Commerce, Coast and Geodetic Survey, Serial No. 599, p. 1-38.

8. Moneymaker, B.C., 1972, Earthquakes in Tennessee and nearby sections of neighboring states, 1951-1970, Tennessee Academy of Science Journal, Vol.47, No.4, p. 124-132.

9. Murphy, L.M., and Cloud, W. K., 1956, United States Earthquakes 1954, U.S. Dept of Commerce, Coast and Geodetic Survey, Serial No. 793, p. 1-110.

10. Murphy, L.M. and Cloud, W. K., 1957, United States Earthquakes 1955, U.S. Dept of Commerce, p. 1-83.

11. Brazee, R.J. and Cloud, W.K., 1958, United States Earthquakes 1956, U.S. Dept. of Commerce, p. 1-78.

12. Brazee, R.J. and Cloud, W.K., 1959, United States Earthquakes 1957, U.S. Dept of Commerce, p. 1-108.

13. Eppley, R.A. and Cloud, W.K., 1961, United States Earthquakes 1959, U.S. Dept. of Commerce, p. 1-115.

14. Talley, H.C. and Cloud, W.K., 1962, United States Earthquakes 1960, U.S. Dept of Commerce, p. 1-90.

15. Von Hake, C.A. and Cloud, W.K., 1968, United States Earthquakes 1966, U.S. Dept. of Commerce, p. 1-110.

16. Von Hake, C.A. and Cloud, W.K., 1971, United States Earthquakes 1969, U.S. Dept. of Commerce, p. 1-80.

17. Coffman, J.L. and Von Hake, C.A., 1973, United States Earthquakes 1971, U.S. Dept of Commerce, p. 1-174.

18. Coffman, J.L., Von Hake, C.A., Spence, W., Carver, D.L., Covington, P.A., Dunphy, C.J., Irby, W.L., Person, W.J. and Stover, C.W., 1975, United States Earthquakes 1973, U.S. Dept. of Commerce, U.S. Dept. of Interior, p. 1-112.

19. Person, W.J., Simon, R.B., and Stover, C.W., 1977, Earthquakes in the United States, April-June, 1975, U.S. Dept. of Interior, U.S. Geological Survey Circular 745-B, p. 1-27.

20. Simon, R.B., Stover, C.W., Person, W.J., and Minch, J.H., 1978, Earthquakes in the United States, January-March 1976, U.S. Department of Interior, U.S. Geological Survey Circular 766-A, p. 1-27.

21. Stover, C.W., Simon, R.B., and Person, W.J., 1979, Earthquakes in the United States, July-September, 1977. U.S. Geological Survey Circular 788-C, p. 1-26.

22. Minch, J.H., Stover, C.W., Person, W.J. and Smith, P.K., 1980, Earthquakes in the United States, July-September 1979. U.S. Geological Survey Circular 836-C, p. 1-39.

23. Bollinger, G.A., and Ellen Mathena, Seismicity of the Southeastern United States, Bulletins 1 through 7, April 1978 through May 1981. V.P.I.& S.U., Blacksburg, VA.

REFERENCES CITED

Bollinger, G.A., 1981, The Giles County, Virginia, seismic zone-configuration and hazard assessment: in Earthquakes and Earthquake Engineering in the Eastern United States, J.E. Beavers, ed., Vol.1, Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, p. 277-308.

Bollinger, G.A., Langer, C.J. and Harding, S.T., 1976, The Eastern Tennessee earthquake sequence of October through December, 1973, Bull. Seism. Soc. Am., Vol. 66, No.2, pp. 525-547.

Bollinger, G.A., and Wheeler, R.L., 1981; The Giles County, Virginia, seismogenic zone, unpublished draft manuscript to be published as a U.S. Geological Survey professional paper.

Bollinger, G.A., and Wheeler, R.L., 1980, The Giles County, Virginia, seismic network - monitoring results, 1978-1980, Earthquake Notes, Vol. 51, p.14.

Dewey, J. W. and Gordon, D., 1980, Instrumental seismicity of the eastern United States and adjacent Canada, Earthquake Notes, Vol. 51, p. 19.

Herrmann, R.B., 1979, Surface wave focal mechanisms for eastern North American earthquakes with tectonic implications, Journal of Geophysical Research, Vol.84, No. B7, p. 3543-3552.

King, E.R., and Isidore Zietz, 1978, The New York-Alabama lineament: geophysical evidence for a major crustal break in the basement beneath the Appalachian basin, Geology, Vol.6 No.5, pp. 312-318.

Langer, C. J., and Bollinger, G. A., 1971, Acoustical Phenomenon Associated with Virginia Earthquakes, G.S.A., Southeastern Section, 5th Annual Meeting, Abstract, 326 p.

Law Engineering Testing Company in conjunction with Burns and Roe, Inc., 1975, Report on Evaluation of Intensity of Giles County Virginia Earthquake of May 31, 1897.

Neumann, F., 1954, Earthquake Intensity and Related Ground Motion, University of Washington Press, Seattle, Washington.

Nuttli, O.W., 1979, The relation of sustained maximum ground acceleration and velocity to earthquake intensity and magnitude, Misc. paper S-73-1, State of the Art for Assessing Earthquake Hazards in the United States, Report No. 16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. 74p.

Nuttli, O.W., 1981, Telephone conversation with Law Engineering Testing Company.

Project Management Corporation, Preliminary Safety Analysis Report, Clinch River Breeder Reactor Plant

Singh, S.K., Bazan, E., and Esteva, L., 1980, Expected earthquake magnitude from a fault, Bull. Seism. Soc. Am., Vol.70, pp. 908-914.

Stover, C.W., Reagor, B.G. and Algermissen, S.T., 1979, Seismicity map of the state of Tennessee, U.S. Geological Survey, Misc. field studies map MF-1157.

Trifunac, M. D., and Brady, A. G., 1975, On the correlation of seismic intensity scales with the peaks of recorded strong ground motion, Bull. Seism. Soc. Am., Vol. 65, pp. 139-162.

Watkins, J.S., 1964, Regional geologic implications of the gravity and magnetic fields of a part of eastern Tennessee and southern Kentucky, U.S. Geological Survey Prof. Paper 516A, 17p.

Wyss, M., 1979, Estimating maximum expectable magnitude of earthquake from fault dimensions, Geology, Vol.7, p. 336-340.

Wyss, M., 1980, Comment and reply on estimating maximum expectable magnitudes of earthquakes from fault dimensions, Geology, Vol.8, No.4, pp. 162-164.

Question CS230.5

Reference 1 on page 2.5-21 and Reference 11 on page 2.5-23 are not to the right publications. Reference 129 is not in the reference list.

Response

The response to this question has been incorporated into revised PSAR Sections 2.5.2.1, 2.5.2.3 and References.

The Nuclear Island structures and the Emergency Cooling Tower will be founded on rock. The Category I Fuel Oil Storage Tanks will be supported on compacted Class 'A' structural backfill overlying competent siltstone. Consequently, both rock and overburden response to vibratory motions are a consideration in evaluating foundation bearing capability.

2.5.2.2 Nearby Tectonic Structures

A tectonic structure is a large scale dislocation or distortion within the earth's crust with its extent measured in miles. The tectonic structures in the Valley and Ridge consist of numerous Paleozoic thrust faults and folds (see Figure 2.5-2.) These structures were formed during the Allegheny orogeny at the end of the Paleozoic Era (Ref. 81, 101). The CRBRP site is situated between the traces of two inactive tectonic structures: the Copper Creek and Whiteoak Mountain thrust faults (see Figure 2.5-17). The inactive tectonic structures within the Valley and Ridge do not affect the determination of the Safe Shutdown Earthquake; however, the nearest two tectonic structures to the CRBRP site are discussed in Section 2.5.3 and summarized below.

2.5.2.2.1 <u>Copper Creek Fault</u>

The Copper Creek Fault is mapped approximately 100 miles in length and the CRBRP site is located near its mid-point. The shortest distance from the CRBRP Plant Island to the fault trace is about 3,000 feet south. In the site vicinity the fault strikes north 52 degrees east and dips southeast (away from the site) at an angle of about 25 degrees measured at the ground surface. Nearby borings indicate that the dip angle decreases with depth. In the site area, the Copper Creek Fault has thrust the Rome Formation over younger rocks of the Chickamauga Group for a horizontal distance estimated in miles. The stratigraphic displacement is approximately 7,200 feet (Ref. 54). About 65 miles southwest of the site, the fault becomes a complex zone and merges with the Whiteoak Mountain Fault.

The trace of Copper Creek Fault was identified at several outcrop locations in the vicinity of the site and in boring 43. Additional data on the Copper Creek Fault was obtained from two test wells, the Joy Test Well (Ref. 13) and B29 (Ref. 89), both located on the Oak Ridge Reservation about four miles east of the site.

The best exposure of the Copper Creek Fault near the site is at the I-40 road cut about two miles southwest of the site. The hanging wall is a dark gray dolomite of the Rome Formation, and the foot wall is a gray limestone of the Chickamauga Group. Except for minor undulations, the beds on both sides of the fault are undistrubed. The Rome beds strike north 55 degrees east, dip 35 degrees southeast, and the Chickamauga beds strike north 53 degrees east and dip 29 degrees southeast. The apparent dip of the fault trace is 20 degrees, which implies a 25 degree dip for the fault plane at this location.

Intensity estimates provide the basis for the epicentral locations of earthquakes prior to about 1960. Before 1800, much of the region was so sparsely populated that the epicentral locations were identified with the scattered towns, possibly tens of miles from the actual epicenters. Since then, the greater population density, better communications, and more seismograph stations have made it possible to locate areas of greatest intensity within a few miles. Within the past few years strong motion seismographs have been installed at several nuclear power plants being constructed in the general region.

Surface intensities at the site have not been directly observed. The intensities which occurred at the site have been estimated based on the epicentral intensity and distance from the CRBRP site (Ref.11).

The site area has experienced numerous light to moderate earthquakes. The maximum site intensity associated with these earthquakes is VI-VII MM. The site investigation has not produced any physical evidence which can be associated with any earthquakes.

2.5.2.4 Engineering Properties of Materials Underlying the Site

The engineering properties of materials underlying the site are discussed in section 2.5.4.2.

2.5.2.5 Earthquake History

Two historical earthquake listings are compiled. One listing, Table 2.5-2 includes historical earthquakes occurring within the region between 29.0°N - 42.0°N latitude and 69.0°W - 94.0°W longitude. This list contains events with epicentral intensities exceeding IV MM and/or assigned magnitudes greater than 3.0. The list also contains information on some significant early historical events for which neither magnitude nor intensity data are available.

A second listing, Table 2.5-3 contains all earthquakes reported to have occurred within a 50 mile radius of the CRBRP site, regardless of intensity or magnitude estimates.

(119) Meade, B. K. 1971 — Report of the Sub-Commission on recent Crustal Movements in North America, N.O.A.A., U.S. Dept. of Commerce.

(120) Murphy, L. 1973 — N.O.A.A. Personal telephone conversation with Law Engineering Testing Company.

(121) Nuttli, O. W. — Professor at Saint Louis University, Personal Communication to Law Engineering Testing Company.

(122) Seed, H. B. 1968 — (and Idriss, I. M.; Keifer, F. W.) Characteristics of Rock Motion During Earthquakes, Earthquake Engineering Research Center, Report No. EE-5C G8-5, College of Engineering University of California, Berkeley, California.

(123) Taber, S. 1914 — Seismic Activity in the Atlantic Coastal Plain Near Charleston, South Carolina; Bulletin, Seismological Society of America, Vol. 4, No. 3.

(124) Technical Information Division, U.S. Atomic Energy Commission 1967 — Summary of Current Seismic Design Practice for Nuclear Reactor Facilities; John A. Blume and Associates, Engineers, San Francisco, California, TID-25021.

(125) 1969 — Tectonic Map of North America; U.S.G.S. and the American Association of Petroleum Geologists.

(126) Tennessee Valley Authority — Relationships of Earthquakes and Geology in West Tennessee and Adjacent Areas.

(127) 1972 — Preliminary Information on Clinch River Site for LMFBR Demonstration Plant.

(128) U.S. Coast and Geodetic Survey — United States Earthquakes, 1928 - 1970.

(129) U.S. Coast and Geodetic Survey 1956 — Earthquake History of the United States.

(130) Gutenberg, B. 1942 — (and Richter, C. F.) Earthquake Magnitude, Intensity, Energy, and Acceleration, Bulletin Seismological Society of America, Vol. 32, No. 3.

(131) Gutenberg, B. 1956 — (and Richter, C. F.) Earthquake Magnitude, Intensity, Energy, and Acceleration (second paper), Bulletin Seismological Society of America, Vol. 46.

Question CS231.1

In addition to the work of Bollinger described in Question 230.4, update the PSAR to include a consideration of all pertinent geological and seismological research and other work that has been done since 1974, which is the latest geological reference cited. Considerable research in geology and seismology has been done since that time in the southeastern United States. Evaluate these studies as to their significance to the geologic and seismic safety of the CRBR site.

Response

Refer to the response to Question 230.1R (related to the Environmental Report) recently provided to NRC which includes the response to this question. The PSAR will be updated to conform with the response to Question 230.1R.

Question CS231.2

In Supplement 2, page 59, response to NRC Question 323.33 (2.5.3.7), you state that the stratigraphic and structural relationships in excavations for all Category I structures will be mapped concurrent with excavation. You further state that the AEC (NRC) will be kept fully informed on the progress of the excavation. It is our position that you notify Geosciences Branch in sufficient time (at least 1 week) after excavating and mapping, and prior to placing gunite, backfill, or concrete, so that a trip to the site can be arranged by a staff geologist if considered necessary. In addition to bedrock features the map should show the relationship of overlying soils, particularly the high terrace deposits, to structures in the rock. The geologic maps should be included in the FSAR.

Response

The response to this question has been incorporated into revised PSAR Section 2.5.4.5.1.3.

level will be blasted using pre-split blasting procedures. Berms will be provided at a predetermined vertical interval. It is expected that ripping may only be feasible for the highly weathered section.

Consideration will be given to removing the final 18 inches of rock by controlled means, e.g., air hammers, however, it is probable that if the final excavation lift is limited to 7 feet and careful control is exercised in blasting, the foundation grade will not be unduly disturbed or cracked from the blasting effect. This assumption will be checked in the field prior to deciding on the method for removal of the final layer of rock above foundation grade.

In order to prevent damage to freshly placed "green" concrete from blasting operations, the peak particle velocity on the foundation rock and overburden at the location of fresh concrete will be limited to the following:

Time after concrete Placement	Peak Particle Velocity
0-11 hours	0.10 in/sec.
11-24 hours	2.00 in/sec.

Unbolted side slopes in siltstone and the base of the excavation will be protected from deterioration and weathering caused by frost, ponding of water and construction activity by a layer of gunite prior to construction of the mat foundation.

An extensive inspection verification program will be established and implemented during construction, and will consist essentially of the following:

a. A qualified and experienced geologist will be on site immediately prior to the start of excavation and will monitor progress of the work until the base of the excavation has been prepared for the initial mat pour. He will report directly to the engineering and design organization and will be charged with the responsibility in the field of reviewing and commenting on the adequacy of the construction procedures proposed by the excavating contractor for ripping, blasting and removal of rock, inspecting exposed rock strata including side slopes and base of excavation and preparing a detailed geological map of the area. In addition to bedrock features, the map will include the relationship between overburden soils encountered in the excavation to structures in the rock. The map will be included in the FSAR.

b. A progress report will be submitted to the engineering and design organization on a weekly basis including photographs and detailed mapping of any significant geological features.

c. A consulting geotechnical review group consisting of specialists in rock mechanics and geology will inspect the excavation and report to the engineering and design organization on their findings at regular intervals, not exceeding one month.

d. If a geological discontinuity is noted, the engineering and design organization will be notified immediately and an inspection will be made by qualified personnel including members of the review board if considered necessary.

e. The site geologist will be assisted in his inspections if required by readily available air track drills which may be utilized for investigation purposes including geophysical logging of the holes and analysis of the data, and use of back-hoe or bulldozer with ripping capability. Zones of potentially high permeability may be checked by drilling from accessible berms constructed around the perimeter of the excavation.

f. The representivity of Boring 55, selected as the central boring in a test grouting program on the west side of the Nuclear Island, will be checked after excavation to confirm the homogeneity and satisfactory bearing capability of the foundation strata. This will be done by completing a series of airtrack holes supplemented by geophysical logging and additional core borings as required, extending through the Unit A Limestone. It is the consensus of opinion among the geotechnical consultants engaged in this project that the satisfactory bearing characteristics of the foundation strata will be confirmed. All borings will be gravity grouted on completion of the program.

g. Formal approval of the prepared base of the excavation will be required by the review board prior to proceeding with the pouring of the mat.

h. The NRC will be kept fully informed of the progress of the excavation. In addition, they will be notified at least one week in advance of placing gunite, backfill or concrete on the exposed rock surface to permit a trip to be made to the site by a staff geologist if considered necessary.

Question CS231.3

In response to NRC Questcn 230.2R during the environmental review, which addressed possible undetected cavities in Unit A limestone, you indicated that a test grouting program and a bedrock verification program will be conducted and will confirm the homogeneity of the Unit A limestone. Provide a description of the test grouting program and the verification program, including methods used and locations and depths of proposed borings.

Response

The verification program planned for the west side of the Nuclear Island as identified in the response to NRC Question 230.2R consists of a program of core borings and rotary percussion air borings. A total of 34 borings are planned to evaluate the potential for limestone solutioning in foundation substrata within the bearing zone of influence and immediately underlying Category I structures. The actual number of borings to be drilled will depend on the Engineer's evaluation of conditions encountered as the program proceeds. Boring locations are shown on Figure 231.3-1. All borings will be drilled to a depth of 100 feet into the Unit A limestone. Estimated total depths of proposed borings are outlined on Table CS231.3-1. Nine of the 34 borings will be rock core borings and the remaining 25 are to be drilled with compressed air and geophysically logged.

No test grouting program is planned in conjunction with the verification program. The test grouting program referred to in response to NRC Question 230.2R was completed during the initial site investigation work and results are presented in Appendix 2C of the PSAR. The results demonstrated the integrity and adequate bearing capability of the Unit A limestone in the area tested, which was representative of limestone most prone to solutioning. The intent of the currently planned verification program is to confirm the adequacy of the limestone over the full extent of Category I structures on the west side of the Nuclear Island.

The verification program will include the following features:

- The 9 rock core borings will be advanced using an NX core barrel and procedures required by the latest revision of ASTM D2113.

- The core driller will maintain a written log of conditions encountered such as water losses, soft zones, cavities, voids and total depth.

- The site geologist will prepare a written description of the rock core and record the percent recovery and the Rock Quality Designation (RQD). Final graphic boring logs will be prepared similar to those currently in the PSAR.

- Rotary percussion air borings will be 4" (minimum) in diameter.

- Upon completion of each core and percussion borng, a geophysical log will be made smilar to that shown on Fgure CS231.3-2. The following logs will be obtained: gamma ray, neutron, acoustic velocity, compensated density and caliper. These logs will be used to measure the strength of the foundation material and to identify the existence of cavities, clay seams, weathered zones and porous zones.

- Actual orientation of boreholes with depth will be determined using a deviation tool.

In addition to graphic borings logs, detailed geologic sections will be developed showing such features as existing topography, voids, cavities, water levels, rock classification, stratigraphic boundaries and key geophysical marker horizons. Analysis of these geologic sections will be made to determine the limits and soundness of the Unit A limestone and Upper Siltstone and groundwater conditions.

All data will be synthesized with existing PSAR data and figures and incorporated therein.

TABLE CS231.3-1

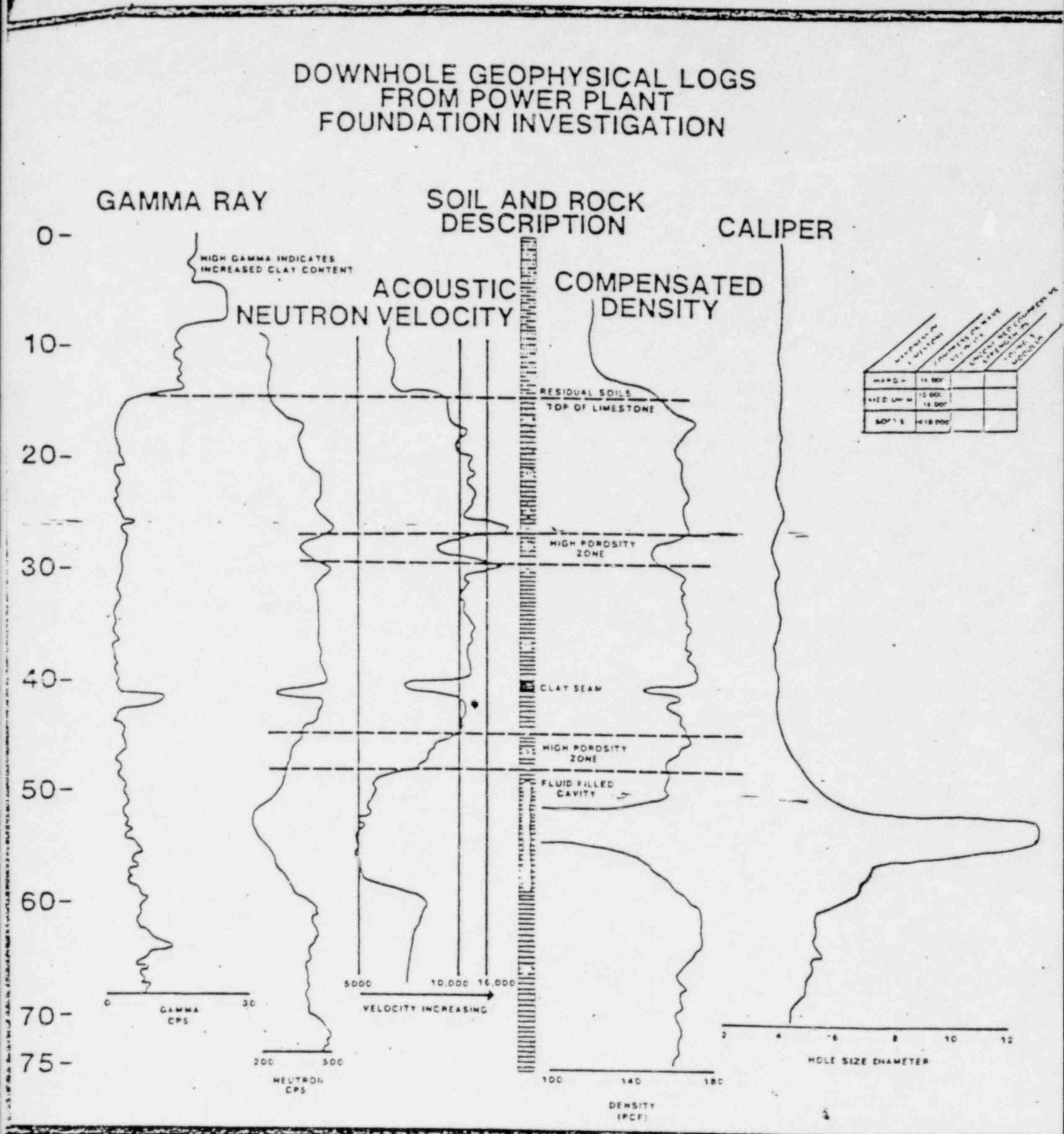
BORING TYPES AND ESTIMATED DEPTHS
VERIFICATION PROGRAM FOR THE WESTERN PORTION OF THE NUCLEAR ISLAND

BORING	BORING* TYPE	APPROX. SURFACE ELEVATION	ESTIMATED ELEV. OF TOP OF UNIT "A" LIMESTONE	ESTIMATED TERMINATION ELEVATION	DEPTH** OF BORING (FEET)
150	CB	773	695	595	180
151	CAB	773	695	595	180
152	CB	773	695	595	180
153	CAB	773	695	595	180
154	CB	773	695	595	180
155	CAB	773	695	595	180
156	CB	773	695	595	180
157	CAB	773	695	595	180
158	CB	773	695	595	180
159	CAB	773	695	595	180
160	CB	773	695	595	180
161	CAB	773	695	595	180
162	CB	773	695	595	180
163	CAB	774	665	565	210
164	CAB	774	665	565	210
165	CAB	774	665	565	210
166	CAB	774	665	565	210
167	CAB	774	665	565	210
168	CAB	774	665	565	210
169	CAB	774	665	565	210
170	CAB	780	630	530	250
171	CB	780	630	530	250
172	CAB	780	630	530	250
173	CAB	780	630	530	250
174	CAB	780	630	530	250
175	CB	780	630	530	250
176	CAB	780	630	530	250
177	CAB	776	710	610	165
178	CAB	776	710	610	165
179	CAB	776	710	610	165
180	CAB	776	710	610	165
181	CAB	776	710	610	165
182	CAB	776	710	610	165
183	CAB	776	710	610	165
				TOTAL	6,715

* CB = Core Boring, CAB = Compressed Air Boring (Rotary Percussion)
** Includes 10 feet contingency

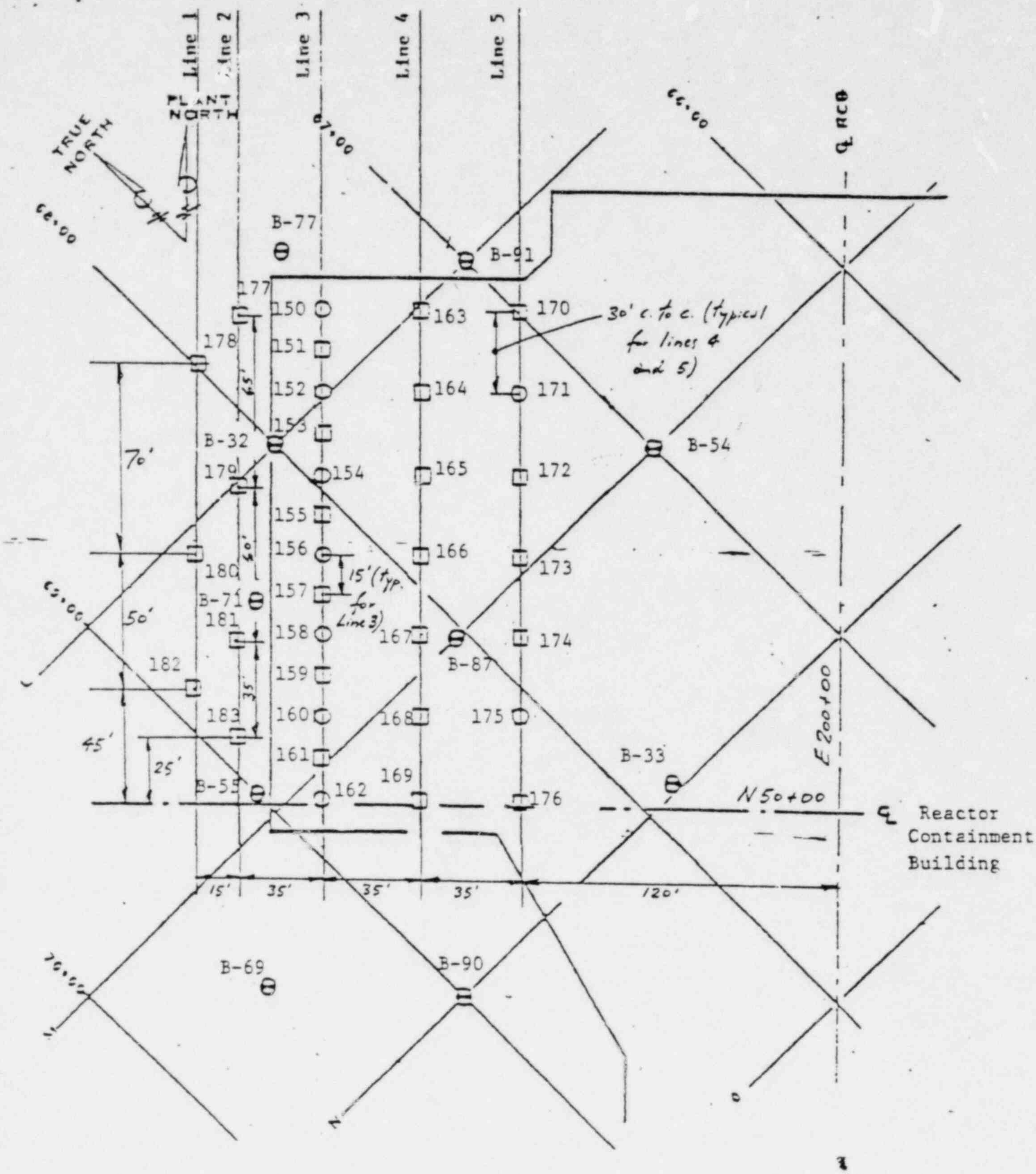
NOTES

1) Program may be modified as actual subsurface conditions are reported.
2) Estimates indicated above are preliminary. Actual footage will depend on elevation of siltstone/limestone contact recorded in borings.



TYPICAL GEOPHYSICAL LOG

Figure 6 231.3-2



⊖ Completed Core Borings

○ Proposed Core Borings

□ Proposed Air Track (Rotary Percussion) Borings

PROPOSED VERIFICATION PROGRAM BORINGS

Figure CS 231.3-1

Scale: 1" = 50'