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SITE CHARACTERISTICS

This Chapter provides information on the location of the WIPP facility and the site characteristics to support and clarify assumptions used in the hazards and accident analysis to identify and analyze potential external and natural phenomena accident initiators and accident consequences external to the facility. Included is information on: (1) site geography, (2) demographics, (3) nearby industrial, transportation, and military facilities, (4) meteorology, (5) demographics and land use, and (6) seismicity. Information relating to ecology, extractable resources, water and air quality, environmental radioactivity, surface and ground water hydrology, and geology, necessary to support the long-term performance assessment of the repository, may be found in the *Title 40 CFR 191 Compliance Certification Application for the Waste Isolation Pilot Plant*, DOE/CAO-1996-2184, October 1996.

2.1 Geography and Demography of the Area Around the WIPP Facility

2.1.1 WIPP Facility Location and Description

The Waste Isolation Pilot Plant (WIPP) Facility is located in Eddy County in southeastern New Mexico (Figure 2.1-1). The center of the WIPP facility is approximately 103°47'27" W longitude and 32°22'11" N latitude.

Prominent natural features within five miles (8.0 kilometers) of the center of the WIPP facility include Livingston Ridge and Nash Draw, which are located about five miles (8.0 kilometers) west. Livingston Ridge, the most prominent physiographic feature near the WIPP facility, is a northwest facing bluff (about 75 feet or 22.9 meters high) that marks the east edge of Nash Draw (a shallow drainage course about five miles [8.0 kilometers] wide).

Other prominent natural features are the Pecos River which is about 14 miles (22.5 kilometers) west at its nearest point, and the Guadalupe Mountains which includes the Carlsbad Caverns National Park at about 42 miles (67 kilometers) and the Guadalupe Mountains National Park which is about 65 miles (104.5 kilometers) west southwest. The nearest prominent man-made features are the city of Loving (with a 1990 population of 1243) which is 18 miles (29.0 kilometers) west southwest, and the city of Carlsbad (with a 1990 population of 24,896) which is 26 miles (41.8 kilometers) west.

2.1.1.1 WIPP Facility Area

The area of land that lies within the WIPP Site Boundary and committed to the WIPP facility is a square four miles (6.4 kilometers) on a side. It contains 10,240 acres or 4,146 hectares (16 mi^2 or 41.4 km^2) including Sections 15-22 and 27-34 in township T22S, R31E. The area containing the WIPP facility surface structures is surrounded with a chain link fence and covers about 35 acres or 14 hectares in Sections 20 and 21 of T22S, R31E. This fenced area is known as Property Protection Area. The location and orientation of the WIPP facility surface structures are shown in Figure 1.2-3. These structures include the Waste Handling Building (WHB) where radioactive waste is received and prepared for underground disposal, four shafts to the underground area, a Support Building containing laboratory and office facilities, showers, change rooms for underground workers, an Exhaust Filter Building (EFB), and a water supply system. Support structures outside of the chain link fence include sewage stabilization ponds, other auxiliary buildings, two mined-rock (salt) piles, and collection ponds for managing site runoff.

There are no industrial, commercial, institutional, recreational or residential structures within the WIPP Site Boundary and no through public highways, railways or waterways traverse the WIPP Site Boundary. Access to the WIPP facility is provided by two access roads that connect with U.S. Highway 62/180, 13 miles (21 km) to the north, and NM Highway 128 (Jal Highway), 4 miles (6.4 km) to the south. The north access road, which connects the site to U.S. Highway 62/180, is an access road built specifically for the DOE that will be used to transport TRU mixed waste from the highway to the site. The north access road is restricted for use by the personnel, agents and contractors of the DOE on official business related to the WIPP Project, or to personnel, permittees, licensees or lessees of the BLM. The south access road is county highway maintained by Eddy County and multiple-use access is allowed unless it is determined that access by industry or the general public represents a significant safety risk to WIPP personnel. There are four natural gas pipelines that traverse the vicinity of the WIPP facility. One pipeline that is within the WIPP Site Boundary is oriented northeast southwest and is about 1.2 miles (1.9 kilometers) north of the center of the WIPP surface structures at its closest point. This pipeline, along with other pipelines in the area of the WIPP facility, are discussed in Section 2.2.3.

The areas that have been designated as subdivisions within the WIPP Site Boundary are defined below and depicted in Figure 2.1-2.

The Property Protection Area is an area of approximately 35 acres or 14 hectares surrounded by a chain link fence. Most of the WIPP facility surface structures are located within this area. Except for the salt storage piles, and the wastewater stabilization ponds.

The Exclusive Use Area is an area of approximately 277 acres or 112 hectares surrounded by a barbed wire fence and posted no trespassing. Review of the WIPP Land Management Plan indicates that public access to the WIPP 16 section area up to the DOE "Exclusive Use Area" is allowed for grazing purposes and up to the DOE "Off-limits Area" for recreational purposes. Public access is controlled by the WIPP 24-hour security force, which regularly patrols the restricted access areas (Section 8.6).

The Off-limits Area (shown in Figure 2.1-2) is an area of approximately 1,421 acres or 575 hectares and is posted no trespassing. Access to this area will be restricted.

The WIPP Site Boundary encompasses an area of 10,240 acres or 4,146 hectares (16 sections). The DOE will not permit subsurface mining, drilling, or resource exploration unrelated to the WIPP Project within the WIPP Site Boundary during facility operation or after decommissioning. This prohibition precludes slant drilling under the WIPP facility from within or outside the WIPP facility, with the exception of existing rights under federal oil and gas leases No. NMNM 02953 and NMNM 02953C, which shall not be affected unless a determination is made to require the acquisition of such leases to comply with final disposal regulations or with the solid waste disposal act (42 U.S.C. 6901 et seq). [1]

Within the Property Protection Area, public access is restricted to employees and approved visitors. Within the Exclusive Use Area access is restricted to authorized personnel and vehicles. Mining and drilling for purposes other than those which support the WIPP project are prohibited within the 16-section (Land Withdrawal Act (LWA). In addition, small areas have been fenced to control access to material storage areas, borrow pits, the sewage stabilization ponds, and biological study plots.

A zone, provided between the mined area underground and the WIPP Site Boundary is a minimum of one mile (1.6 kilometers) wide. This thickness was specified based on recommendations made by Oak Ridge National Laboratory (ORNL). The ORNL recommendation of one to five miles (1.6 to 8.0 kilometers) for the size of the zone of intact salt was to preclude unacceptable penetration of the salt formation. The ORNL stated that the actual size of the zone must be based on site dependent factors including drilling operations, mining operations and salt dissolution rates. This was addressed in the Geological Characterization Report [2] where the authors state that the one mile (1.6 kilometers) thickness should provide more than 250,000 years of isolation using very conservative dissolution assumptions.

2.1.2 Exclusion Area Land Use and Control

2.1.2.1 Authority

The 10,240 acres (4,146 hectares) that lie within the WIPP Site Boundary are on federal land. During construction all the federal lands within the WIPP Site Boundary were managed in accordance with the terms of Public Land Order 6403 and a DOE/Bureau of Land Management (BLM) Memorandum of Understanding (MOU)[3] and the BLM Resource Management Plan.

During operations, the area within the WIPP Site Boundary will remain under federal control. This includes all facility areas described in Section 2.1.1.1

On October 30, 1992, the WIPP (LWA), Public Law 102-579 as amended by Public Law 104-201, was signed by President Bush transferring the land from the Department of the Interior (DOI) to the DOE. Consistent with the mission of the WIPP facility, lands within and around the WIPP Site Boundary are administered according to a multiple land use policy. Mining and Drilling for purposes other than those which support the WIPP project are prohibited within the 16-section LWA area subject such conditions and restrictions as may be necessary to permit the conduct of WIPP-related activities.[2]

2.1.2.1.1 Agricultural Uses

All the land within the WIPP Site Boundary up to the Exclusive Use Area has been leased for grazing, which is the only significant agricultural activity in the vicinity of the WIPP facility. The Smith Ranch, owned by Kenneth Smith, Inc. of Carlsbad, New Mexico, has lease rights to 2880 acres (1,166 hectares) within the northern portion of the WIPP Site Boundary. J. C. Mills of Abernathy, Texas, owner of the Mills Ranch, has lease rights to 7,360 acres (2,980 hectares) within the southern portion of the WIPP Site Boundary.

2.1.2.1.2 Water Use

There are no significant uses of surface or groundwater in the vicinity of the WIPP facility. Several windmills have been erected throughout the area to pump groundwater for livestock watering. Additionally, several ponds have been created to capture runoff for livestock.

2.1.2.1.3 Industrial and Commercial Facilities

There are no industrial surface facilities within a five-mile (8.0 kilometer) radius of the WIPP facility. Ranching is the only commercial operation within five miles of the facility, with the exception of oil and gas related activities. The five-mile (8.0 kilometer) radius encompasses grazing allotments of three separate ranches; however, only one ranch house is located in the area. It is about 3.5 miles (5.6 kilometers) from the center of the WIPP facility in the south southwest sector. There are four potash mines and two chemical processing plants (adjacent to the mines) between five and 10 miles (8.0 to 16.1 kilometers) of the WIPP facility.

References for Section 2.1

1 Public Law 102-579, 102nd Congress, Waste Isolation Pilot Plant Land Withdrawal Act, October 30, 1992 [as amended by Public Law 104-201].

2 SAND 78-1596, Geological Characterization Report for the WIPP Site, Southeastern New Mexico. Sandia National Laboratories, Albuquerque, NM, 1978.

3 Memorandum of Understanding, Bureau of Land Management and the Department of Energy, July 19, 1994.

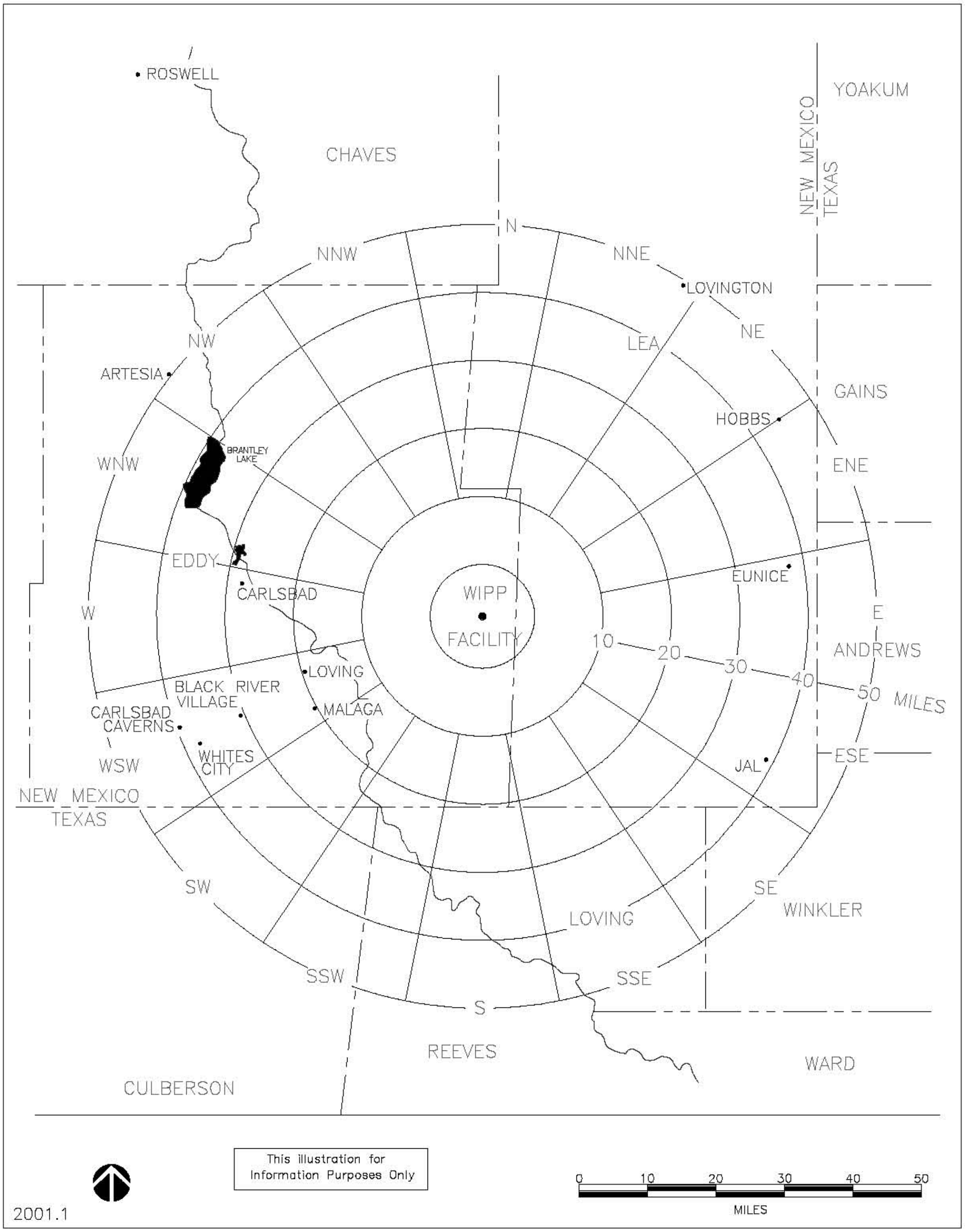

Figure 2.1-1, Region Surrounding the WIPP Facility

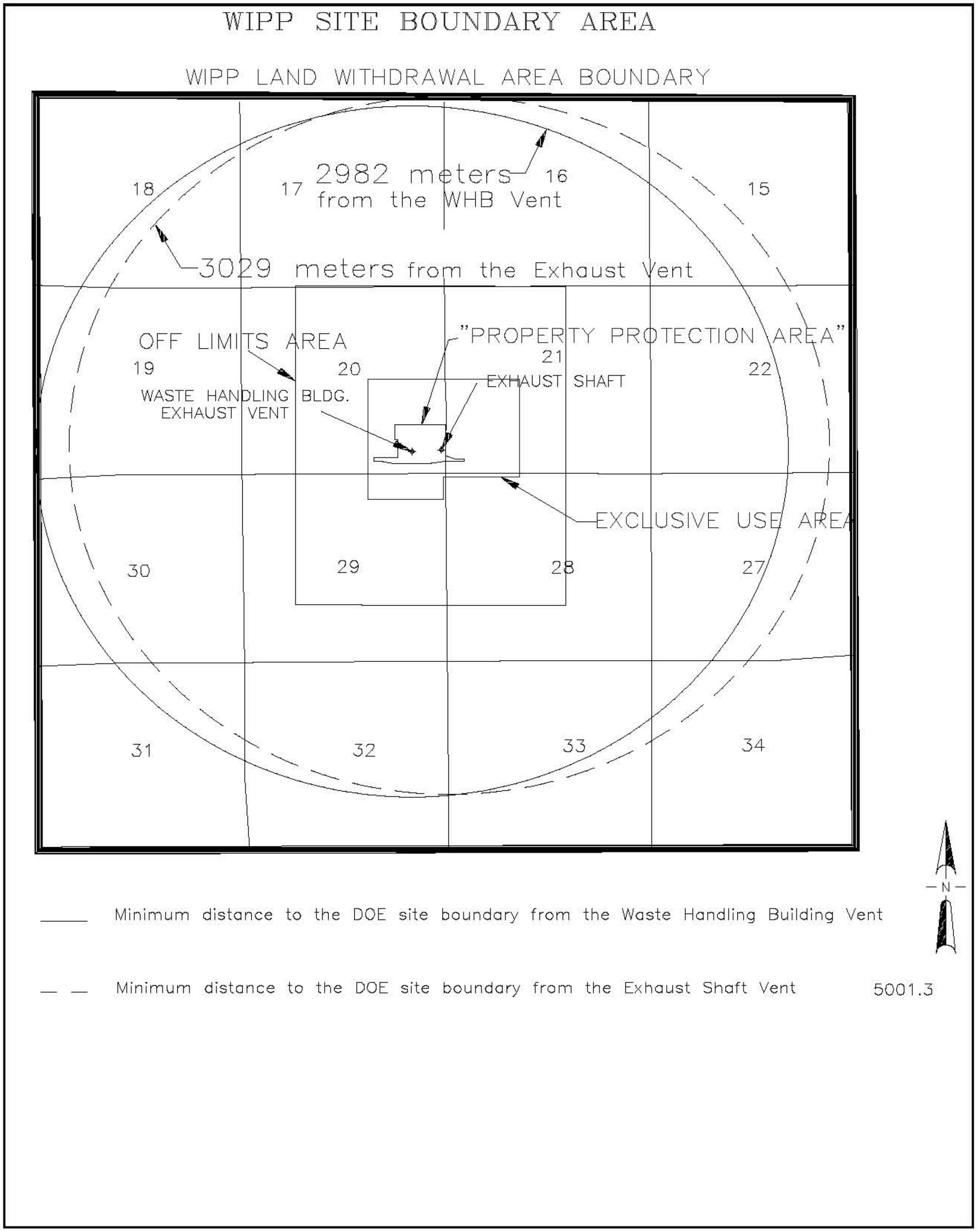

Figure 2.1-2, WIPP Facility Boundaries,

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2.2 Nearby Industrial, Transportation and Military Facilities

The extractive activities, transportation routes, and military operations that may have a potential affect on operations at the WIPP facility are discussed in this section.

2.2.1 Industrial and Commercial Facilities

There are some oil and gas related industrial facilities within a five-mile (8.0 kilometer) radius of the WIPP facility. The five-mile (8.0 kilometer) radius encompasses grazing allotments of three separate ranches; however, only one ranch house is located in the area. It is about 3.5 miles (5.6 kilometer) from the center of the WIPP facility in the south southwest sector. There are four potash mines and two chemical processing plants (adjacent to the mines) between five and 10 miles (8.0 and 16.1 kilometers) of the WIPP facility.

2.2.2 Extractive Activities

Within a five mile (8.0 kilometer) radius from the center of the WIPP Land Withdrawal Area (LWA), both oil and gas are extracted below the Salado formation. The majority of the newer wells produce oil and gas from the Brushy Canyon formation of the Delaware Mountain Group. Gas wells typically produce from the deeper Pennsylvanian-age formations (Atoka, Strawn, and Morrow formations). As of April 1995, there were 136 oil wells (some which produce both oil and gas), 21 gas wells, and 21 plugged wells within five miles (8.0 kilometers) of the Land Withdrawal Act (LWA) boundary (Figure 2.2-2a). The completion of these wells is stratigraphically below the repository horizon. There are likewise an additional 292 oil wells, 47 gas wells, and 83 plugged wells within ten miles of the LWA boundary (Figure 2.2-1). The plugged wells include both wells that are considered "dry holes" and wells that are no longer productive and have been permanently sealed.

Besides the oil and gas extractive activities, there are four active potash mines within ten miles (16.1 kilometers) of the WIPP LWA. Potash is extracted from the McNutt Potash member which is stratigraphically above the WIPP repository horizon.

2.2.3 Oil and Gas Pipelines

There are no crude oil pipelines within five miles (8.0 kilometers) of the WIPP facility. There are, however, 16 natural gas pipelines located within a five-mile (8.0 kilometer) radius of the WIPP facility. Many producing wells within the ten mile (16.1 kilometer) radius of the WIPP are connected to tank batteries by gathering systems of flexible, plastic tubing. These lines are typically buried at the time of installation; however, there are areas where these lines rest upon the surface of the ground. They carry a mixture of crude oil, natural gas, and produced waters. At the accumulation tanks, these fluids are separated, and the gas is then fed into pipelines. Thirteen of these pipelines have right-of-way lease permits issued by the U.S. Department of the Interior (DOI), Bureau of Land Management (BLM) for access to federal land, while four have permits issued by the State of New Mexico, State Land Office, for access to state lands. Two pipelines require both federal and state right-of-way lease permits. There is one pipeline located on federal land for which no right-of-way lease permit information is available.

The natural gas pipelines are owned and operated by three companies:

- El Paso Natural Gas Company, El Paso, Texas;

- Natural Gas Pipeline Company of America, Chicago, Illinois;
- Transwestern Pipeline Company, Roswell, New Mexico.

Figure 2.2-2a shows the location of each pipeline within five miles (8.0 kilometers) of the WIPP facility, along with pertinent information regarding each pipeline.

One major non-oil or gas pipeline lies within the WIPP Site Boundary. This is a 10 inch (25.4 centimeter) City of Carlsbad water pipeline that provides the WIPP facility with potable water.

2.2.4 Waterways

There are no navigable waterways within a five-mile (8.0 kilometer) radius of the WIPP facility. The nearest river is the Pecos River which is 12 miles (19.3 kilometers) west of the WIPP facility.

2.2.5 Military Facilities

There are no military facilities within a five-mile radius (8.0 kilometer) of the WIPP facility. Holloman Air Force Base is the nearest military facility to the WIPP Site and is located 138 miles (222.1 kilometers) to the northwest.

2.2.6 Airports and Aviation Routes

There are no airports within a ten-mile (16.1 kilometer) radius of the site. The nearest airstrip, 12 miles (19.3 kilometers) north of the WIPP facility, is privately operated by Transwestern Pipeline Company. The nearest commercial airport is Cavern City, 28 miles (45.1 kilometers) west of the WIPP facility near Carlsbad. Other airports in the area are Eunice (32 miles or 51.5 kilometers east), Carlsbad Caverns (42 miles or 67.6 kilometers southwest), Hobbs Airport (42 miles or 67.6 kilometers northeast), Jal (40 miles or 64.4 kilometers southeast), Lovington (50 miles or 80.5 kilometers northeast), and Artesia (51 miles or 82.1 kilometers northwest). The relationship of these airports to the WIPP facility is shown in Figure 2.2-3.

Portions of two federal airways are within five miles (8.0 kilometers) of the WIPP facility. Each airway is 10 miles (16.1 kilometers) wide. The centerline of low altitude airway V-102 is three miles (4.8 kilometers) northwest of the WIPP facility and high altitude airway J-15 is four miles (6.4 kilometers) northeast of the WIPP facility at their nearest points. These airways are shown in Figure 2.2-3. Traffic data for these airways are given in Table 2.2-1. The combined traffic on both routes is about 28 Instrument Flight Rule (IFR) flights per peak day. There are no approach or landing zones within five miles (8.0 kilometers) of the WIPP facility.

2.2.7 Land Transportation

2.2.7.1 Roads and Highways

Other than the highways that provide north or south access, only one other highway lies within a five-mile (8-kilometer) radius. This is New Mexico Highway 128, which is between four and five miles (6.4 to 8 kilometers) southwest of the WIPP facility (Figure 1.2-1). It connects the small community of Jal with NM 31, which leads into Loving and it provides access to Carlsbad. New Mexico Highway 128 is used by ranchers, school buses, potash miners, and by oil and gas company vehicles occasionally transporting drilling rigs (wide loads) to sites in the area. In 1985, it had an average daily traffic flow of about 400 vehicles. Several dirt roads in the area are maintained for ranching, pipeline maintenance, and access to drilling sites.

2.2.7.2 Railroads

Except for the rail spur that serves the WIPP facility, there are no railroad lines within the five-mile radius of the WIPP facility. Rail lines to International Minerals and Chemical Corp. Main Plant and Nash Draw operation, and the Mississippi Chemical Corp. Each plant, all potash mining operations, are located between six and 10 miles (9.7 to 16.1 kilometers) of the WIPP facility. All railroad lines within the general vicinity of the WIPP facility are used specifically to transport potash ore.

2.2.8 Projected Industrial Growth

While no industrial activity occurs within five miles (8 kilometers) of the WIPP facility, active potash mining is occurring. These ores are extracted from the Salado formation but are brought to the surface further than five miles (8 kilometers) from the WIPP. Other extractive activities are oil and gas production (as detailed in section 2.2.2). No extractive activity is allowed within the LWA with the exception of section 31 (the southwest corner section of the LWA). There is currently one gas well producing from that section below the 6000 foot (1828.8 meter) land withdrawal designation. This well was slant drilled from section 6 of Township 23 South. The other fifteen sections of the LWA are withdrawn to the center of the earth. Other permit applications for slant drilling into section 31 from outside sections have been denied by the BLM.

Four potash mining operations located around the WIPP facility were contacted concerning their anticipated growth. If these operations expand, there is a possibility that at least two new shafts will be sunk in the approximate two to five miles (3 to 8 km) radius. Plans for expansion are not firm because they are dictated in most cases by the market conditions for potash. Even if this expansion were to occur, it would not pose a safety risk for the WIPP facility since surface and underground operations would be restricted to areas outside the WIPP Site Boundary.

Except for the possible potash mining expansion discussed above, no significant increase in economic activity is forecast for the future within five miles (8 kilometers) of the WIPP facility.

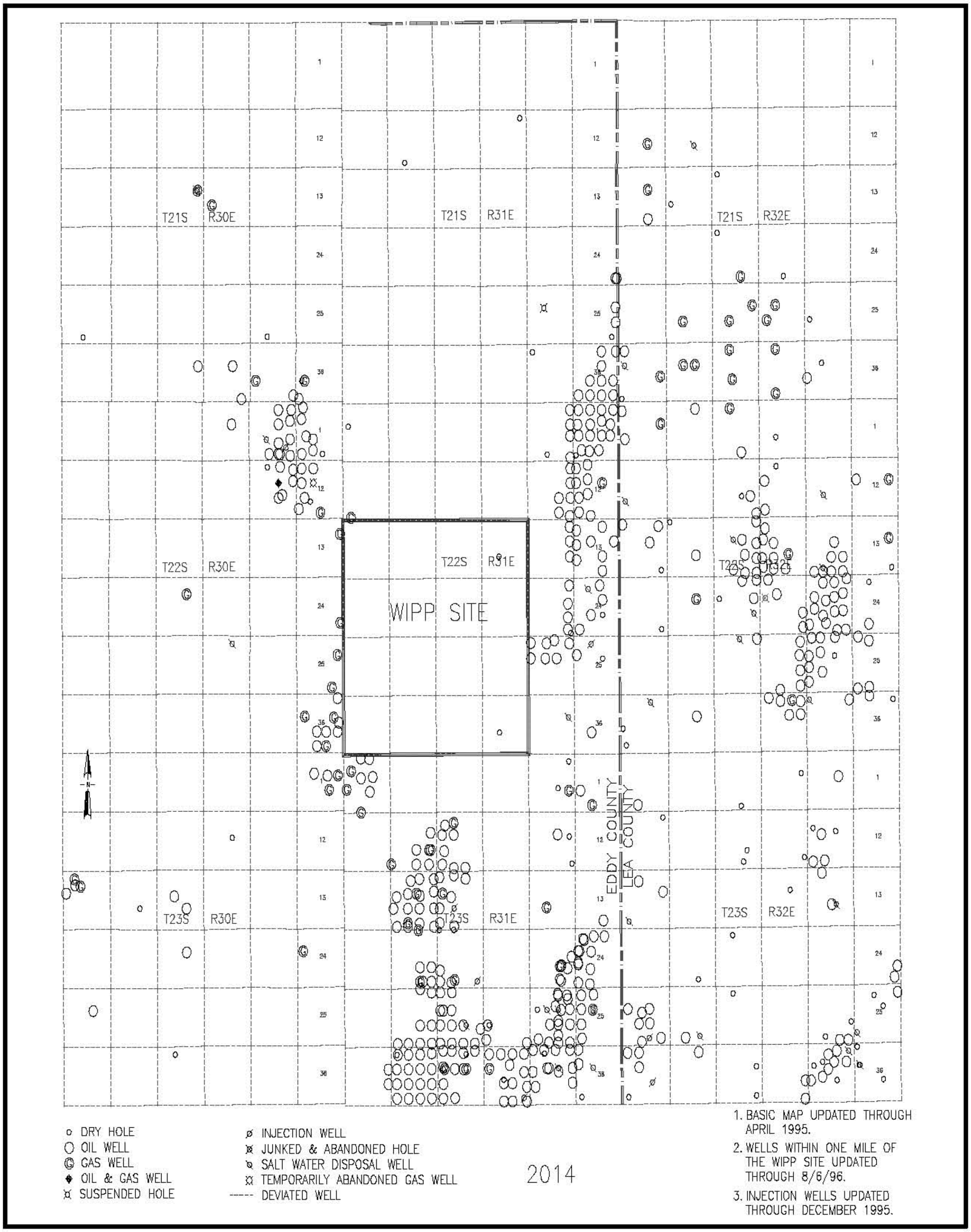

Figure 2.2-1, Natural Gas Wells, Oil Wells and Related Information Within a 10 Mile Radius

(1 kilometer = 0.62 miles)

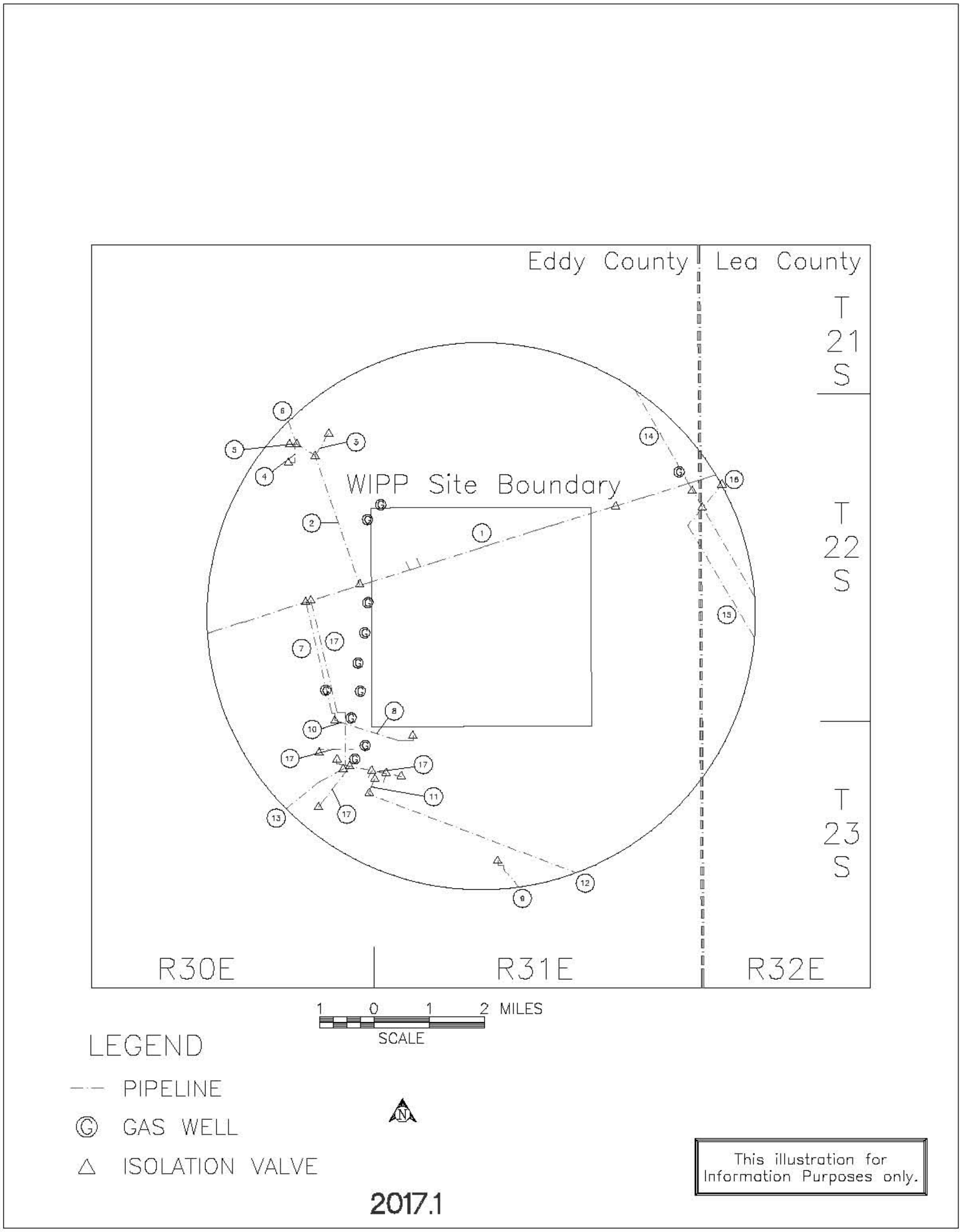

Figure 2.2-2a, 1995 Natural Gas Pipelines and Wells, 5 Mile Radius

(1 kilometer = 0.62 miles)

Figure 2.2-2b, Explanation to Figure 2.2-2a

1 El Paso Natural Gas Co., Eunice-Carlsbad Line (LC060762) 12.75" Dia Gas Line, Built 1945, Located 1.125 miles NNW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

2 El Paso Natural Gas Co., James “A” No. 1 (NM17321) 4.5"/8.625" Dia Gas Line, Built 1974, Located 2.375 miles WNW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

3 El Paso Natural Gas Co., Cabana No. 1 (NM18432) 4.5" Dia Gas Line, Built 1974, Located 4.25 miles NW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

4 El Paso Natural Gas Co., James “E” No. 1 (NM19974) 4.5" Dia Gas Line, Built 1974, Located 4.25 miles NW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

5 El Paso Natural Gas Co., El Paso “201" Spur Line (NM20125) 4.5" Dia Gas Line, Built 1974, Located 4.625 miles NW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

6 El Paso Natural Gas Co., James “C” No. 1 (RW18344) 6.625" Dia Gas Line, Built 1974, Located 4.625 miles NW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

7 El Paso Natural Gas Co., James Ranch Unit No. 1 (NM046228) (RW14190) 4.5" Dia Gas Line, Built 1958, Located 3.06125 miles WSW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

8 El Paso Natural Gas Co., James Ranch Unit No. 7 (NM26987) 4.5" Dia Gas Line, Built 1976, Located 2.625 miles SW of WIPP. Operating Pressure 721 PSIG, Burial Depth 24".

9 El Paso Natural Gas Co., Arco State No. 1 (RW17822) 6.625" Dia Gas Line, Built 1971, Located 4.625 miles S of WIPP. Operation Pressure 837, Burial Depth 24".

10 El Paso Natural Gas Co., Lateral EE-4 (NM16959/(RW18065) 4.5" Dia Gas Line, Built 1973, Located 3.125 miles SW of WIPP. Operating Pressure 1200 PSIG, Burial Depth 36".

11 Natural Gas Pipeline Co. Of America, Lateral EE-6 Built 1974, 4.5" Dia Gas Line, Built 1974, Located 3.2 miles SSW of WIPP. Operating Pressure 1200 PSIG, Burial Depth 36".

12 Natural Gas Pipeline Co. Of America, Lateral EE-3 (NM16029) 8.625" Dia Gas Line, Built 1972, Located 3.4 miles SSW of WIPP. Operating Pressure 1200 PSIG, Burial Depth 36".

13 Natural Gas Pipeline Co. Of America, Lateral EE-7 (NM22471) 4.5" Dia Gas Line, Built 1974, Located 4.7 miles SW of WIPP. Operating Pressure 1200 PSIG, Burial Depth 36".

14 Transwestern Pipeline Co., West Texas Lateral (NM070224) 24" Dia Gas Line, Built 1960, Located 4.5 miles ENE of WIPP. Operating Pressure 1200 PSIG, Burial Depth 30".

15 Transwestern Pipeline Co., West Texas Lateral (NM8722) 30" Dia Gas Line, Built 1969, Located 4.25 miles ENE of WIPP. Operating Pressure 930 PSIG, Burial Depth 30".

16 Transwestern Pipeline Co., Monument Lateral (NM073482) 10" Dia Gas Line, Built 1960, Located 4.5 miles ENE of WIPP. Operating Pressure 930 PSIG, Burial Depth 30".

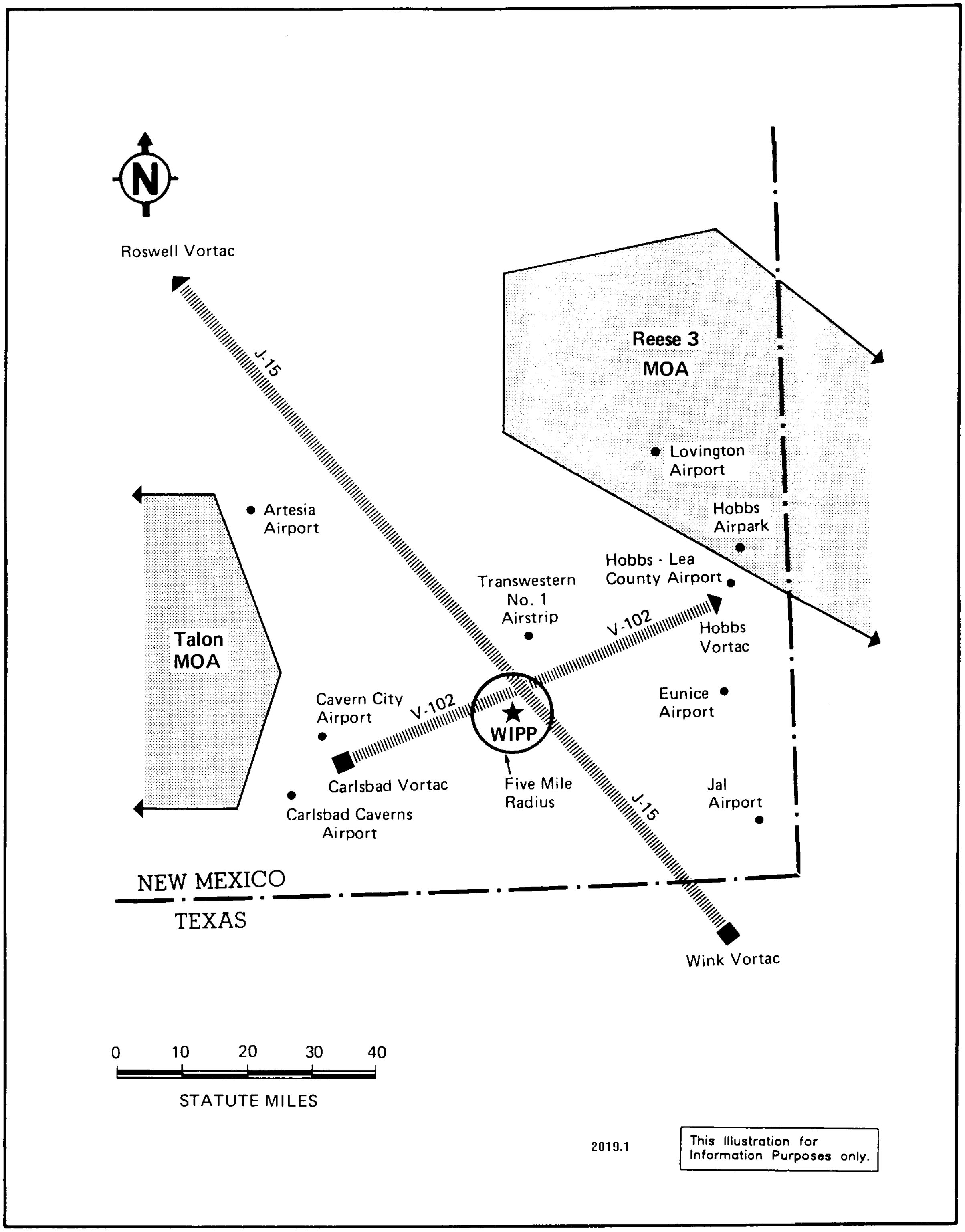

Figure 2.2-3, Airports and Aviation Routes Adjacent to the WIPP Facility

(1 kilometer = 0.62 miles)

Table 2.2-1, Aviation Routes Within 5 Miles (8 kilometers) of the WIPP Facility*

Name of Route	Altitude	Destination	Minimum Type	Origin and Flights/Day	Aircraft Flight Rule
FAA V-102	3,000 ft AGL	Carlsbad VORTAC Hobbs VORTAC	Commercial, military, and private	5**	IFR
FAA J-15	18,000 ft MSL	Wink VORTAC Roswell VORTAC	Commercial military, and private	23	IFR

*U.S. Department of Transportation, Federal Aviation Administration, Air Traffic Service, "En Route IFR Peak Day Charts, FY 1976."

**Flights per day on V-102 does not include aircraft operating under Visual Flight Rules.

NOTE: 1976 was the last year day charts were logged by FAA. Local airfield does not monitor this information.

2.3 Demographics and Land Use in the Carlsbad Resource Area

2.3.1 Demographics

The WIPP is located in the Southeastern part of Eddy County, near Lea County. The population density of Eddy County is 11.63 persons per square mile (4.49 persons /km^2); the Lea County population density is 12.69 persons per square mile (4.90 persons/km^2) (Census of Population).[1]

Demographics for the communities surrounding the WIPP site are listed below, by county.

EDDY COUNTY

Community	Population	Location Relative to the WIPP Site
Artesia	10,610	53 miles (85.3 kilometers) northwest
Carlsbad	24,896	26 miles (41.8 kilometers) west
Loving	1,243	18 miles (29.0 kilometers) west-southwest
Total Eddy County	48,605	

LEA COUNTY

Community	Population	Location, Relative to the WIPP Site
Eunice	2,731	40 miles (64.4 kilometers) east
Hobbs	29,115	40 miles (64.4 kilometers) east
Jal	2,153	45 miles (72.4 kilometers) southeast
Lovington	9,322	50 miles (80.5 kilometers) northeast
Total Lea County	55,765	

2.3.2 Land Use at the WIPP Site

At present, land within 10 miles (16 kilometers) of the site is used for potash-mining operations, active oil and gas wells, and grazing. This pattern is expected to change little in the future.

The *Waste Isolation Pilot Plant Land Withdrawal Act* (LWA) (Public Law 102-579 as amended by Public Law 104-201),[2] provides the DOE with lands for operation of the WIPP project. The law provides for the transfer of the WIPP site lands from the Department of the Interior (DOI) to the DOE and effectively withdraws the lands, subject to existing rights, from entry, sale, or disposition; appropriation under mining laws; and operation of the mineral and geothermal leasing laws. The LWA directed the Secretary of Energy to produce a management plan to provide for grazing, hunting and trapping, wild life habitat, the disposal of salt, and tailings and mining (PTB).[3]

There are no hydrocarbon production wells within the volumetric boundary defined by the LWA. One active well, referred to as James Ranch 13, was drilled in 1982 to tap gas resources beneath Section 31. This well was initiated in Section 6, outside the WIPP site boundary. The well enters Section 31 below a depth of 6,000 feet (1,829 meters) beneath ground level (PTB).[3]

Grazing leases have been issued for all land sections immediately surrounding the WIPP, with the exception of the 277 acre (112.1 hectare) Exclusive Use Area[5]. Grazing within the WIPP site lands operates within the authorization of the Taylor Grazing Act of 1934, the Federal Land Policy and Management Act (FLPMA), the Public Rangelands Improvement Act of 1978, and the Bankhead-Jones Farm Tenant Act of 1973. The responsibilities of the DOE include supervision of ancillary activities associated with grazing (e.g., wildlife access to livestock water development, assure water developments inside WIPP lands are configured according to the regulatory requirements, etc.) and ongoing coordination with respective allottees. Administration of grazing rights, including the collection of grazing fees, shall be in cooperation with the BLM in accordance with an existing Memorandum of Understanding (MOU) and the coinciding Statement of Work through guidance established in the East Roswell Grazing Environmental Impact Statement (DOE/WIPP 94-2033).[4] Portions of two grazing allotments administered by the BLM fall within the land withdrawal area: Livingston Ridge (No. 77027), and Antelope Ridge (No. 77032) (DOE/WIPP 93-004).[5]

2.3.2.1 Land Use in the Carlsbad Resource Area

Major land uses in the Carlsbad resource area include potash mining and oil and gas recovery (discussed previously), and ranching, farming, recreation, and tourism.

2.3.2.1.1 Ranching

There are 286 ranching units in the Carlsbad resource area (New Mexico Agricultural Statistics).[6] The approximate areas, in acres (1 hectare= 2.47 acre), are as follows:

County	Total	Federal	State	Deeded
Eddy	2,675,000	1,627,827	577,225	470,149
Lea	2,812,160	416,960	1,199,221	1,195,979

The number of livestock located on these ranching units will vary depending upon grazing conditions. However, the number of livestock (in head) for the Carlsbad resource area as reported in the 1993 *New Mexico Agricultural Statistics*[6] are:

County	Cattle	Dairy Herd	Sheep	Goats/ Horses/Pigs
Eddy	25,000	9,100	12,000	1,200
Lea	22,000	7,200	5,800	1,560

2.3.2.1.2 Farming

There are approximately 160,000 acres (64,750 hectare) of farmland in the Carlsbad resource area. The principal crops grown include cotton, alfalfa, and sorghum grains. There are also significant quantities of pecans grown in this area, and minor amounts of truck vegetables.

2.3.2.1.3 Recreation

Due to the topography, climatic conditions, and wildlife in the area of the WIPP site, an extensive (non-facility based) variety of recreational opportunities are available to include: hunting for both big and small game animals; camping; horseback riding; hiking; watching wildlife (e.g., bird watching); and sightseeing. The WIPP area contains significant biodiversity in addition to historic and prehistoric sites. These offer rewarding opportunities for scientific research and interpretive recreation.

2.3.2.1.4 Tourism

There are two national parks (Guadalupe Mountains and Carlsbad Caverns), a national forest (Lincoln), and two state parks (Living Desert Zoo and Gardens, and Brantley) located within or near the Carlsbad resource area. The Carlsbad Caverns National Park, which is 36 miles (58 kilometers) southeast of the WIPP site, has approximately 1 million visitors per year. There are three dams on the Pecos River that provide recreational activities during the summer months. The closest surface water to WIPP (the Pecos River) is located about 12 miles (19.3 kilometers) away.

References for Section 2.3

1 Census of Population, General Population Characteristics of New Mexico, Bureau of the Census. U.S. Department of Commerce, 1990

2 Public Law 102-579, Waste Isolation Pilot Plant Land Withdrawal Act, U.S. Congress, 1992 [as amended by Public Law 104-201].

3 WIPP-CAO-95-1014, Project Technical Baseline for Regulatory Compliance (PTB), United States Department of Energy, Carlsbad, N.M., Rev. 0, April 20, 1995.

4 DOE/WIPP 94-2033, Waste Isolation Pilot Plant Annual Site Environmental Report for Calendar Year 1993, September, 1994, Carlsbad, NM, 1994a.

5 DOE/WIPP 93-004, Waste Isolation Pilot Plant Land Management Plan, 1993b.

6 New Mexico Agricultural Statistics, U. S. Department of Agriculture, New Mexico Agricultural Statistics Service, Las Cruces, NM, 1993.

2.4 Meteorology

2.4.1 Recent Climatic Conditions

Current climatic conditions are provided to allow for the assessment of impacts of these factors on the disposal unit and the site. The WIPP facility does not rely on climatic conditions to control waste migration; however, meteorological information is used in the evaluation of the air pathway during operation of the facility.

2.4.1.1 General Climatic Conditions

The climate of the region is semiarid, with generally mild temperatures, low precipitation and humidity, and a high evaporation rate. Winds are mostly from the southeast and moderate. In late winter and spring, there are strong west winds and dust storms. During the winter, the weather is often dominated by a high-pressure system situated in the central portion of the western United States and a low-pressure system located in north-central Mexico. During the summer, the region is affected by a low-pressure system normally situated over Arizona.[1]

2.4.1.2 Regional Meteorological Conditions for Design and Operating Bases

2.4.1.2.1 Heavy Precipitation

The maximum 24-hour rainfall at Roswell was 5.65 inches (14.4 cm) in November 1901.[2] The maximum 24-hour snowfall in Roswell was 15.3 inches (38.9 cm) in December 1960. The greatest snowfall during a 1-month period was 23.3 inches (59.2 cm) in February 1905.[3]

2.4.1.2.2 Thunderstorms and Hail

The region has about 40 thunderstorm days annually. About 87.5% of these occur from May to September.[2] A thunderstorm day is recorded if thunder is heard; but, the thunderstorm record is not related to observations of rain or lightning and does not indicate the severity of storms in the region.

Hail usually occurs in April through June and is not likely to develop more than three times a year. During a 39-year period at Roswell, hail was observed 97 times (about 2.5 times a year), occurring nearly two thirds of the time between April and June.[4] For the 1° square (32° to 33° N by 103° to 104°W) surrounding the WIPP facility, hailstones 0.75 inches (1.9 cm) and larger were reported eight times from 1955 to 1967 (slightly less than once a year).

2.4.1.2.3 Tornadoes

For the period 1916-1958, 75 tornadoes were reported in New Mexico on 58 tornado days.[5] Data for 1953 through 1976 indicate a state wide total of 205 tornadoes on 152 tornado days,[6] or an average of 9 tornadoes a year on 6 tornado days. The greatest number of tornadoes in 1 year was 18 in 1972; the least was 0 in 1953. The average tornado density in New Mexico during this period was 0.7 per 1,000 mi^2 (2,590 km^2). Most tornadoes occur in May and June.[7] From 1955 through 1967, 15 tornadoes were reported within the 1° square containing the WIPP surface facility.[8]

H.C.S. Thom has developed a procedure for estimating the probability of a tornado striking a given point.[9] The method uses a mean tornado path length and width and a site specific frequency. Applying Thom's method to the WIPP facility yields a point probability of 0.00081 on an annual basis, or a recurrence interval of 1,235 years. An analysis by Fujita yields a point tornado recurrence interval of 2,832 years in the Pecos River Valley.[10]

According to Fujita, the WIPP design basis tornado with a million year return period has a maximum wind speed of 183 mi/h (294.6 km/hr), translational velocity of 41 mi/h (66 km/hr), a maximum rotational velocity radius of 325 ft (99.1 km), a pressure drop of 0.5 lb/in^2 (3.4 kPa), and a pressure drop rate of 0.09 lb/in^2/s (0.62 kPa/s).

2.4.1.2.4 Freezing Precipitation

The region of the WIPP facility has about 1 day of freezing rain or drizzle a year.[4] An ice accumulation of more than 0.25 inch (0.63 cm) has not been observed. Any ice accumulation that does occur is thin because of the scarcity of precipitation during the winter months and because daytime temperatures rise well above freezing.

2.4.1.2.5 Strong Winds

The maximum 1-min wind speeds recorded at Roswell are shown in Table 2.4-1. The fastest 1-min wind ever recorded at Roswell was 75 mi/h (120.7 km/h) from the west in April 1953.[11] Windstorms with speeds of 50 knots (93 km/hr) or more occurred ten times (during the period between 1955 and 1967) about one a year.[7] The mean recurrence interval for annual high winds at 30 ft (9.1 m) above the ground in south eastern New Mexico is shown in Table 2.4-2.[9,12] The 100-year recurrence 30-foot (9.1 m) level wind speed in southeastern New Mexico is 82 mi/h (132 km/hr). Based on a gust factor of 1.3,[13] the highest instantaneous gust expected once in 100 years at 30 ft (9.1 m) above grade is 107 mi/h (172.2 km/h). The vertical wind profile for two 100-year recurrence intervals has been estimated from the 30-foot (9.1 m) values using the 1/7 power law[16] and is presented in Table 2.4-2.

2.4.1.2.6 Restrictive Dispersion Conditions

Hosler[14] and Holzworth[15] analyze records from several National Weather Service stations with the objectives of characterizing atmospheric dispersion potential. Seasonal and annual frequencies of inversions based at or below 500 ft (152.4 m) for the WIPP facility region are shown in Table 2.5-3. Most of these inversions are diurnal (radiation-induced) and occur because the radiation cooling at the earth's surface is increased by conditions that frequently exist at the WIPP facility. The conditions are lack of moisture, clear skies and low air density. When these conditions exist in the early morning, radiation lost from the surface is not adequately absorbed and reradiated by upper level air to heat the air at the surface sufficiently. Consequently, the air at the surface quickly becomes cooler than the upper level air and the colder surface air becomes trapped.

Holzworth gives estimates of the average depth of vertical mixing, which indicates the thickness of the atmospheric layer available for the mixing and dispersion of effluents.[15] The seasonal afternoon mixing heights for the region (Table 2.4-4) range from 1,320 meters (4,329.6 ft) in winter to 3,050 meters (10,004 ft) in summer. Seasonal morning mixing heights in the region range from 300 meters (984 ft) in winter to 680 meters (2,230.4 ft) in summer.

2.4.1.2.7 Sandstorms

Blowing dust or sand may occur occasionally in the region due to the combination of strong winds, sparse vegetation and the semiarid climate. High winds associated with thunderstorms are frequently a source of localized blowing dust. Dust storms covering an extensive area are rare, and those that reduce visibility to less than 1 mi (1.6 km) occur only with the strongest pressure gradients such as those associated with intense extratropical cyclones which occasionally form in the region during winter and early spring. Winds of 50 to 60 mi/h (80.5 to 96.6 km/h) and higher may persist for several days if these pressure systems become stationary.[3] Ten windstorms of 58 mi/h (93.4 km/h) and greater were reported during 1955-1967 within the 1° square in which the WIPP facility is located.[7] Blowing dust or sand may reduce visibility to less than 5 mi (8.0 km) over an area of thousands of square miles. However, restrictions of less than 1 mi (1.6 km) are quite localized and depend on soil type, conditions, cultivation practices and vegetation in the immediate area.[3]

2.4.1.2.8 Snow

The 100-year recurrence maximum snowpack for the WIPP facility region is 10 lb/ft^2 (0.5 kPa).[12] The probable maximum winter precipitation (PMWP) in the WIPP facility region is taken to be the probable maximum 48-hour precipitation during the winter months of December through February. The PMWP for the WIPP facility is estimated to be 12.8 inches (32.5 cm) of rain (i.e., 66 lb/ft^2 or 3.2 kPa).[16,17] The snowload for the WIPP facility is calculated (ground level equivalent) to be 27 lb/ft^2 (1.3 kPa). Specific roof loads are estimated based on ANSI's methodology.[12]

2.4.2 Local Meteorology

2.4.2.1 Data Sources

On site meteorological data (hourly) are used to characterize the local meteorology of the WIPP facility.

2.4.2.2 Temperature Summary

Temperatures are moderate throughout the year, although seasonal changes are distinct. The mean annual temperature in southeastern New Mexico is 63°F (17.2°C). In the winter (December through February), night-time lows average near 23°F (-5°C), and average maxima are in the 50s. The lowest recorded temperature at the nearest Class-A weather station in Roswell was -29°F (-33.8°C) in February 1905. In the summer (June through August), the day-time temperature exceeds 90°F (32.2°C) approximately 75 percent of the time.[1] The National Weather Service documented a measurement of 122°F (50°C) at the WIPP site as the record high temperature for New Mexico. This measurement occurred on June 27, 1994. Table 2.4-5 shows the annual average, maximum, and minimum temperatures from 1990 through 1994.

2.4.2.3 Precipitation Summary

Precipitation is light and unevenly distributed throughout the year, averaging 13 inches (33 centimeters) for the past five years. Winter is the season of least precipitation, averaging less than 0.6 inches (1.5 centimeters) of rainfall per month. Snow averages about 5 inches (13 centimeters) per year at the site and seldom remains on the ground for more than a day at a time because of the typically above-freezing temperatures in the afternoon. Approximately half the annual precipitation comes from frequent thunderstorms in June through September. Rains are usually brief but occasionally intense when moisture from the Gulf of Mexico spreads over the region.[1] Monthly average, maximum, and minimum precipitations recorded at the WIPP site from 1990 through 1994 are summarized in Figure 2.4-1.

2.4.2.4 Wind Speed and Wind Direction Summary

The frequencies of wind speeds and directions are depicted by windroses in Figures 2.4-2 through 2.4-6 for the WIPP site, and Figures 2.4-7 through 2.4-11 for Carlsbad, New Mexico. In general, the predominant wind direction at the WIPP site is from the southeast, and the predominant wind directions in Carlsbad are from the south, southeast, and west.

2.4.2.5 Topography

The land surface in the vicinity of the WIPP facility is a semiarid, wind blown plain sloping gently to the west and southwest. Its surface is made somewhat hummocky by an abundance of sand ridges and dunes. The average slope within a 3-mile (4.8 km) radius is about 50 ft/mi (9.5 m/km) from the east to west.

A plot of terrain profiles from the center of the WIPP facility out to 5 miles (8.1 km) is presented in Figure 2.4-12 for each of the 16 direction sectors.

References for Section 2.4

1 DOE/EIS-0026, Final Environmental Impact Statement, Waste Isolation Pilot Plant, U.S. Department of Energy, Washington, DC, 1980.

2 Weather Bureau Technical Paper No. 2, Maximum Recorded U.S. Point Rainfall, (Rev.) U.S. Department of Commerce, 1963.

3 Climates of the States, Vol. 2 - Western States, Roswell, New Mexico, U.S. National Oceanic and Atmospheric Administration (NOAA), Water Information Center, Inc., Port Washington, NY, 1974.

4 Technical Report EP-83, Hail Size and Distribution, U.S. Army, Quartermaster Research and Engineering Center, 1958.

5 Technical Paper No. 20, Tornado Occurrences in the United States, U.S. Department of Commerce, 1960.

6 Climatological Data National Summary, National Oceanic and Atmospheric Administration (NOAA), 1976.

7 Technical Memorandum WBTM FCST 12, Severe Local Storm Occurrence, 1955-1957, Environmental Sciences and Services Administration (ESSA), U.S. Department of Commerce, Silver Spring, 1969.

8 WASH 1300, Technical Basis for Interim Regional Tornado Criteria, U.S. Atomic Energy Commission, Washington, DC.

9 Monthly Weather Review, Tornado Probabilities, November-December, 1963.

10 SMRP Research Paper No. 155, A Site-Specific Study of Wind and Tornado Probabilities at the WIPP Site in Southeast-New Mexico, Research Project, Department of Geophysical Sciences, University of Chicago, 1978.

11 Environmental Data Service, June 1968, Weather Atlas of the United States, (originally titled Climatic Atlas of the United States), reprinted in 1975 by Gale Research Co.

12 ANSI A58.1-1972, Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, Revision of A58.1-1955, American National Standards Institute, Inc., July 1972.

13 DGAF 140, Relations Between Gusts and Average Wind Speeds for Housing Load Determination, Daniel Guggenheim, Airship Institute, Cleveland, Ohio, 1946.

14 Monthly Weather Review, 89 (9), Low-Level Inversion Frequency in the Contiguous United States, 1961.

15 U.S. Environmental Protection Agency (EPA), Mixing Heights, Wind Speeds and Potential for Urban Air Pollution Throughout the Contiguous United States, Research Triangle Park, North Carolina, 1972.

16 Hydrometeorological Report No. 33, Seasonal Variations of the Probable Maximum Precipitation East of the 105th Meridian for Areas from 10 to 1,000 Square Miles and Durations of 6, 12, 24 and 48 Hours, Weather Bureau, 1956.

17 Housing and House Finance Agency, Snow Load Studies, Office of the Administrative Division of Housing Research, 1956.

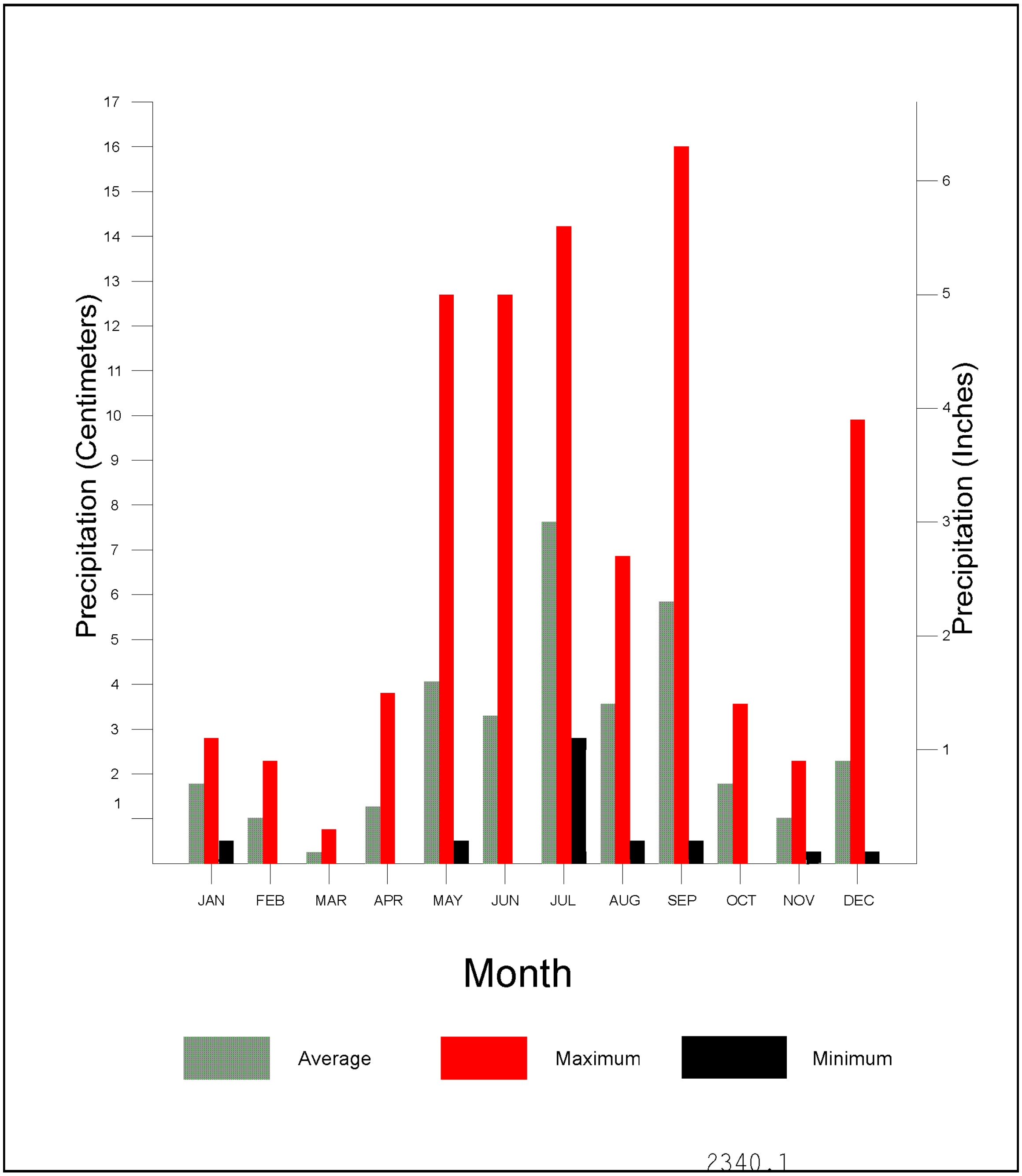

Figure 2.4-1, Monthly Precipitation for the WIPP Site from 1990 through 1994

Figure 2.4-2, 1990 Annual Windrose - WIPP Site (figure unavailable)

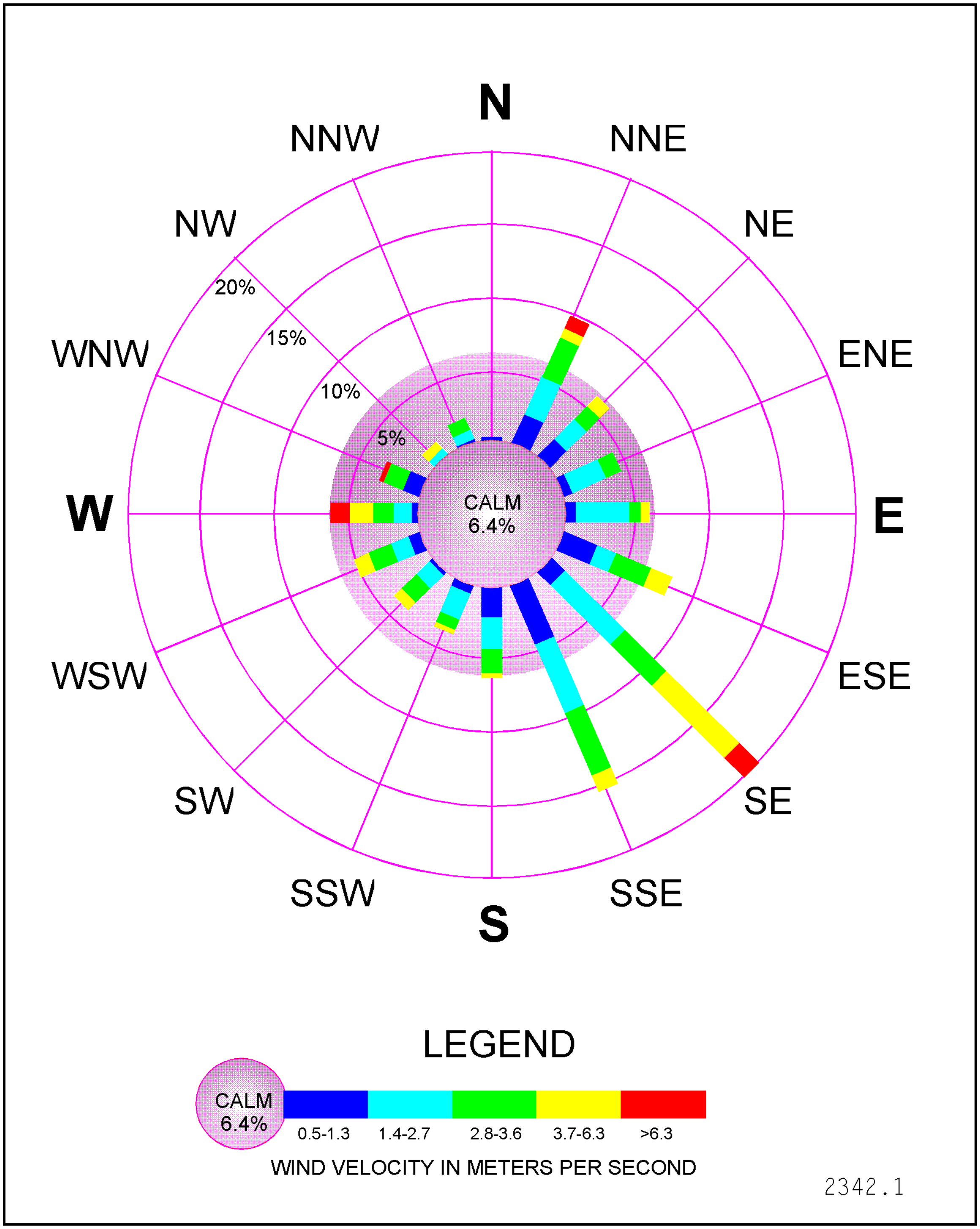

Figure 2.4-3, 1991 Annual Windrose - WIPP Site

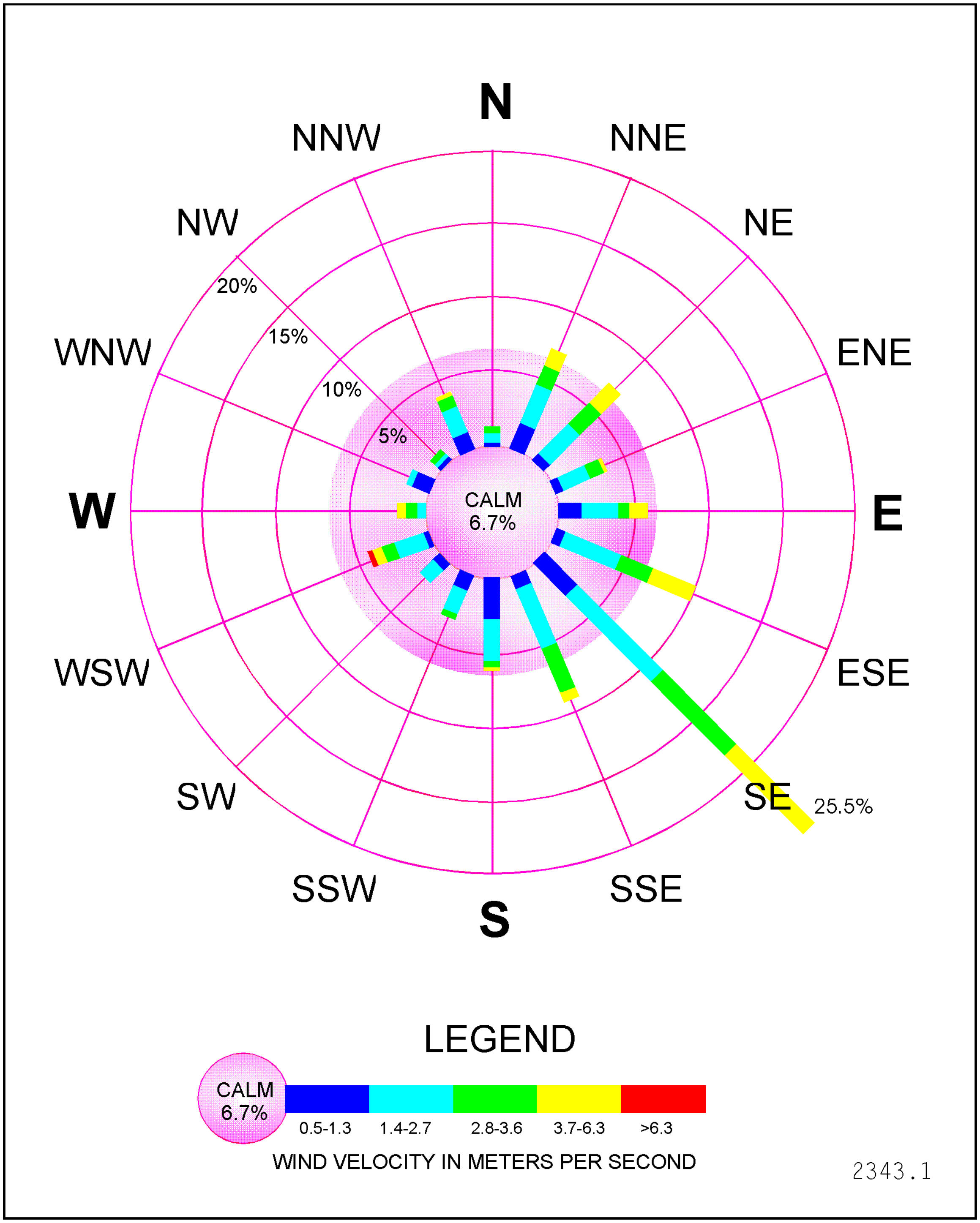

Figure 2.4-4, 1992 Annual Windrose - WIPP Site

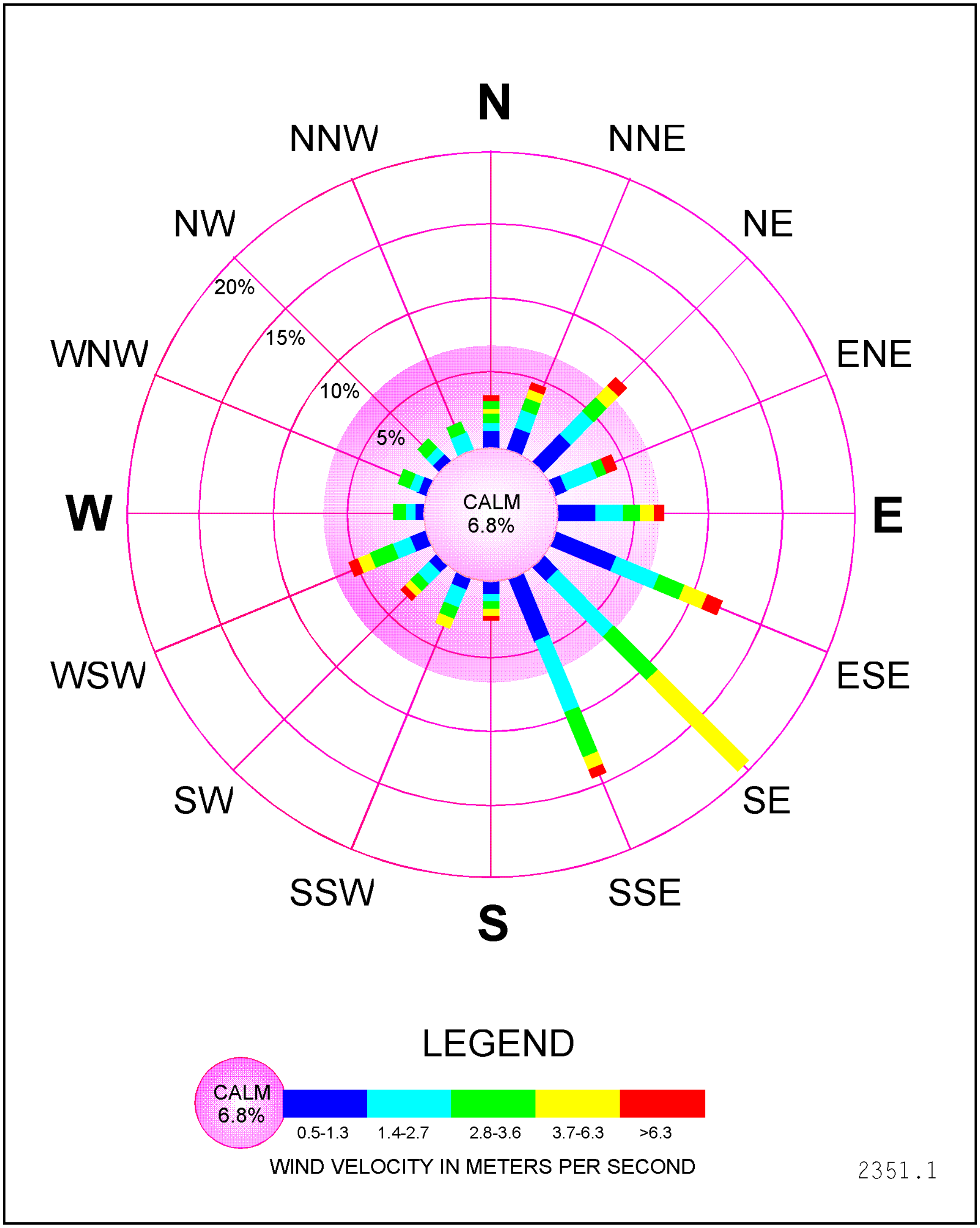

Figure 2.4-5, 1993 Annual Windrose - WIPP Site

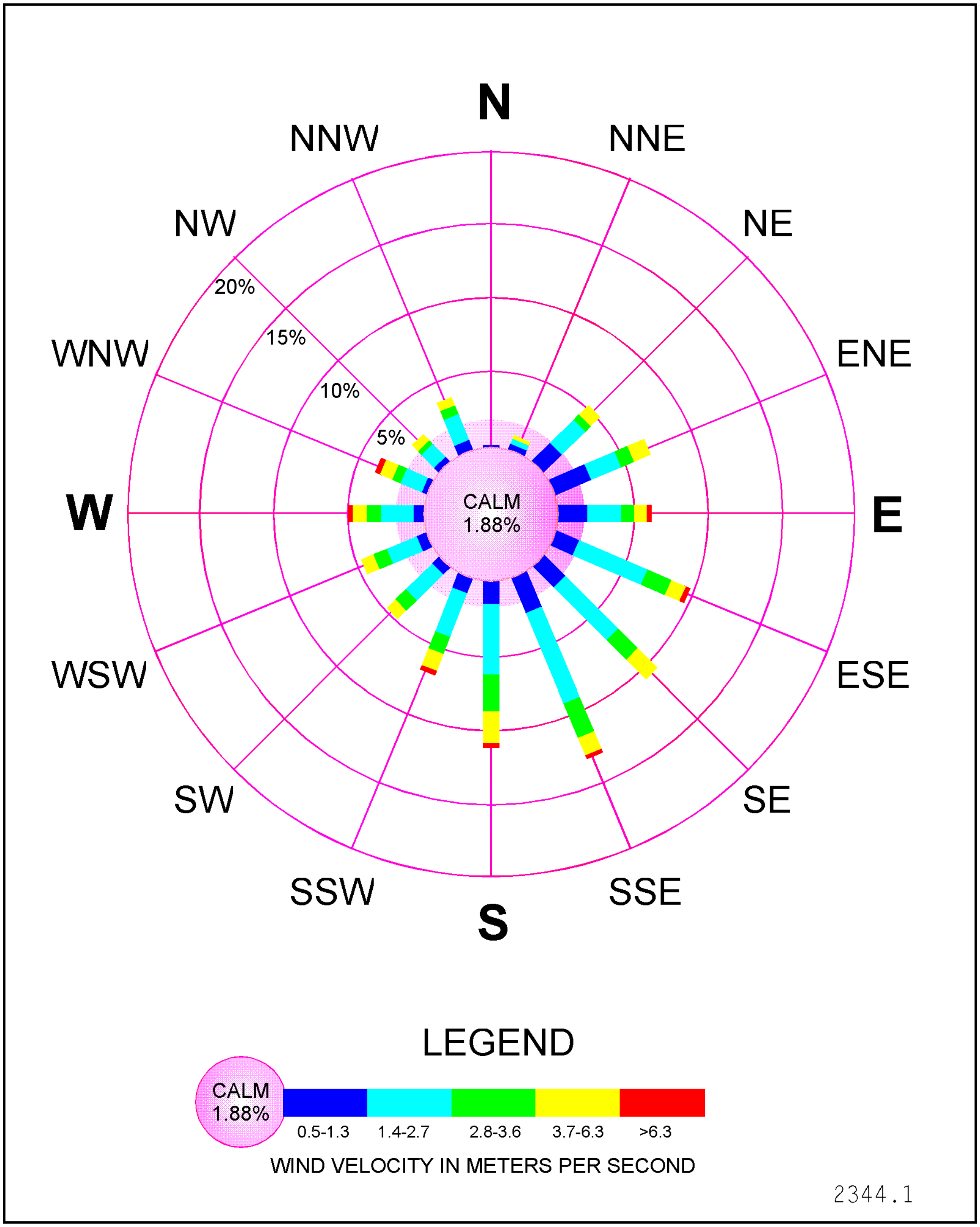

Figure 2.4-6, 1994 Annual Windrose - WIPP Site

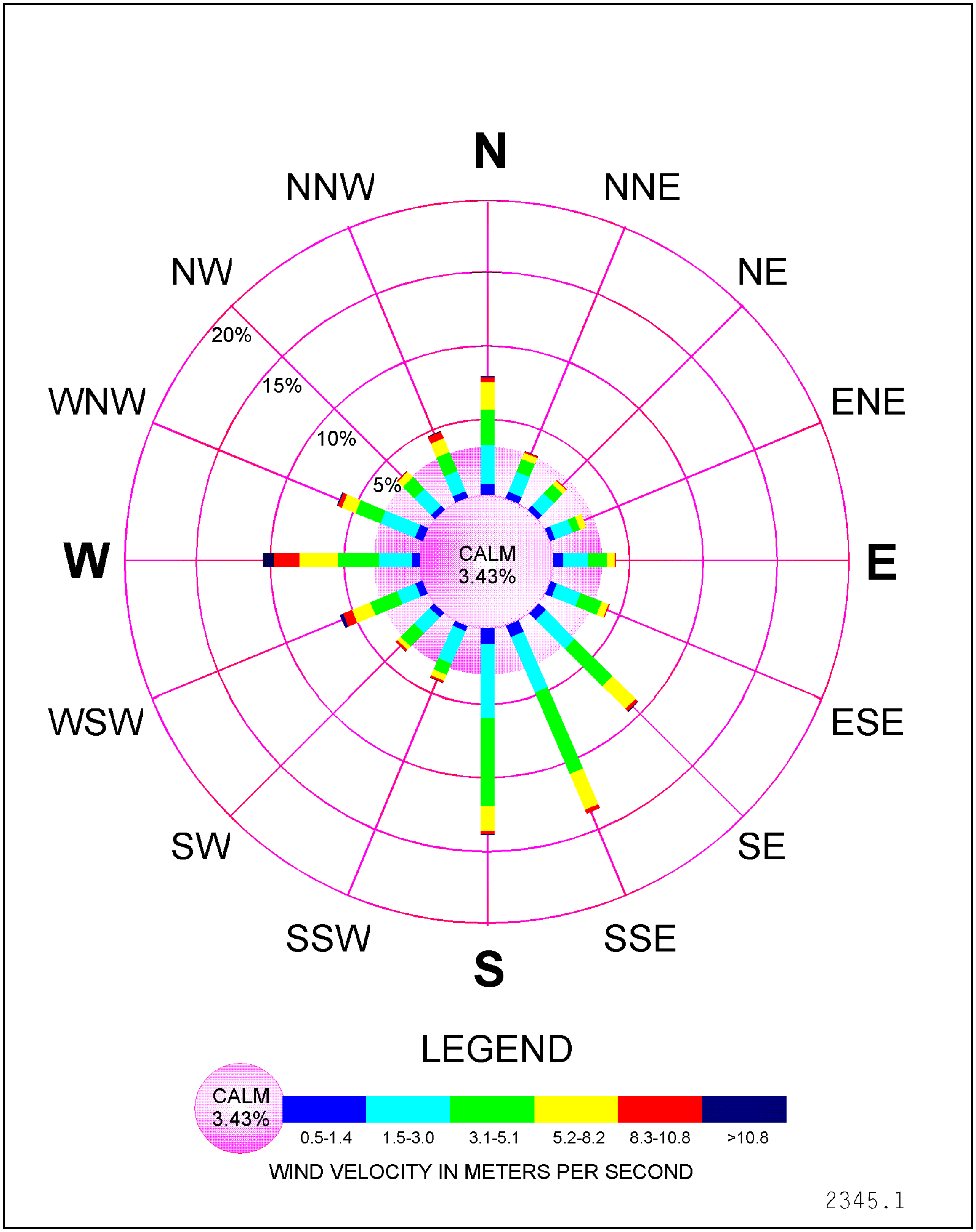

Figure 2.4-7, 1990 Annual Windrose - Carlsbad

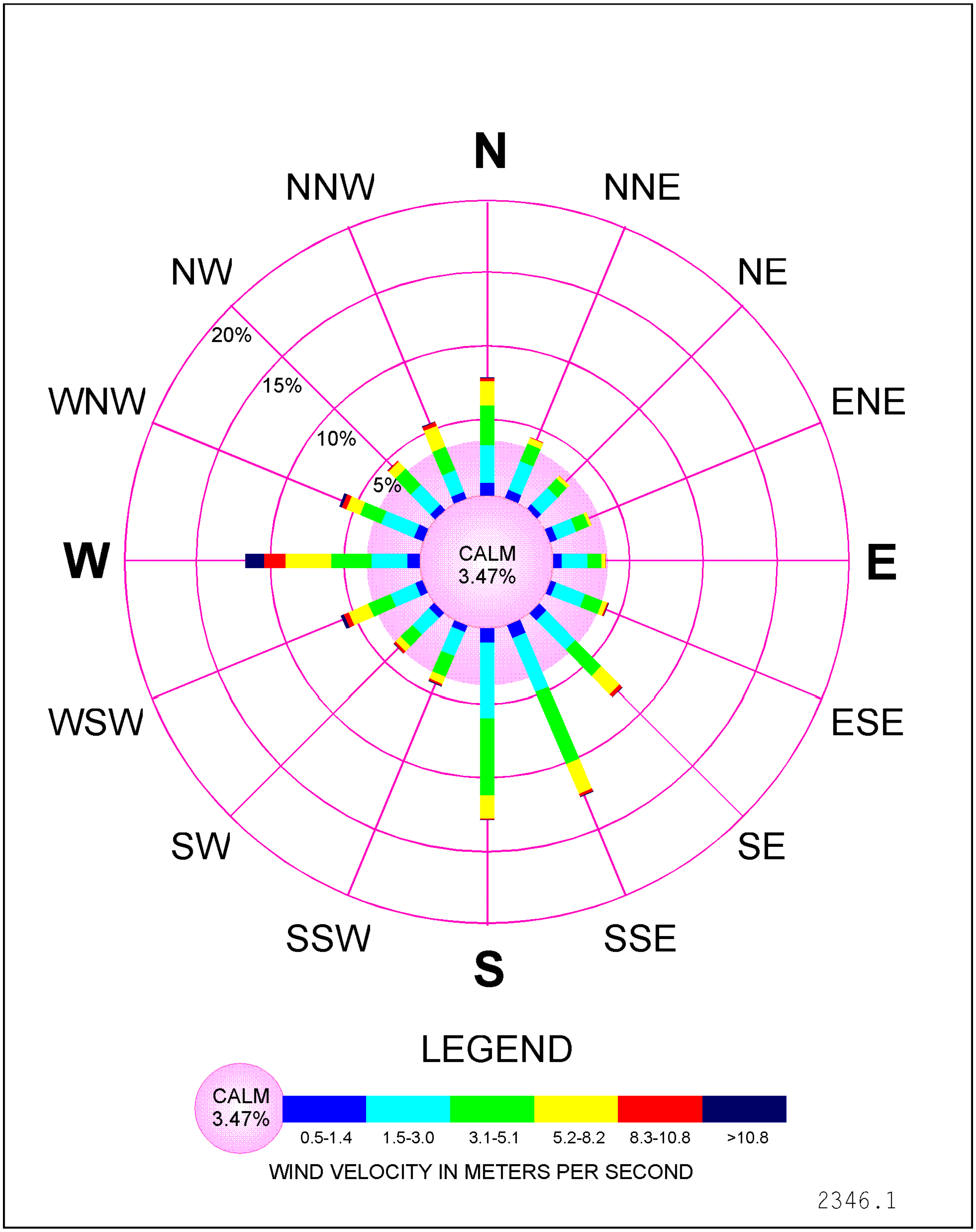

Figure 2.4-8, 1991 Annual Windrose - Carlsbad

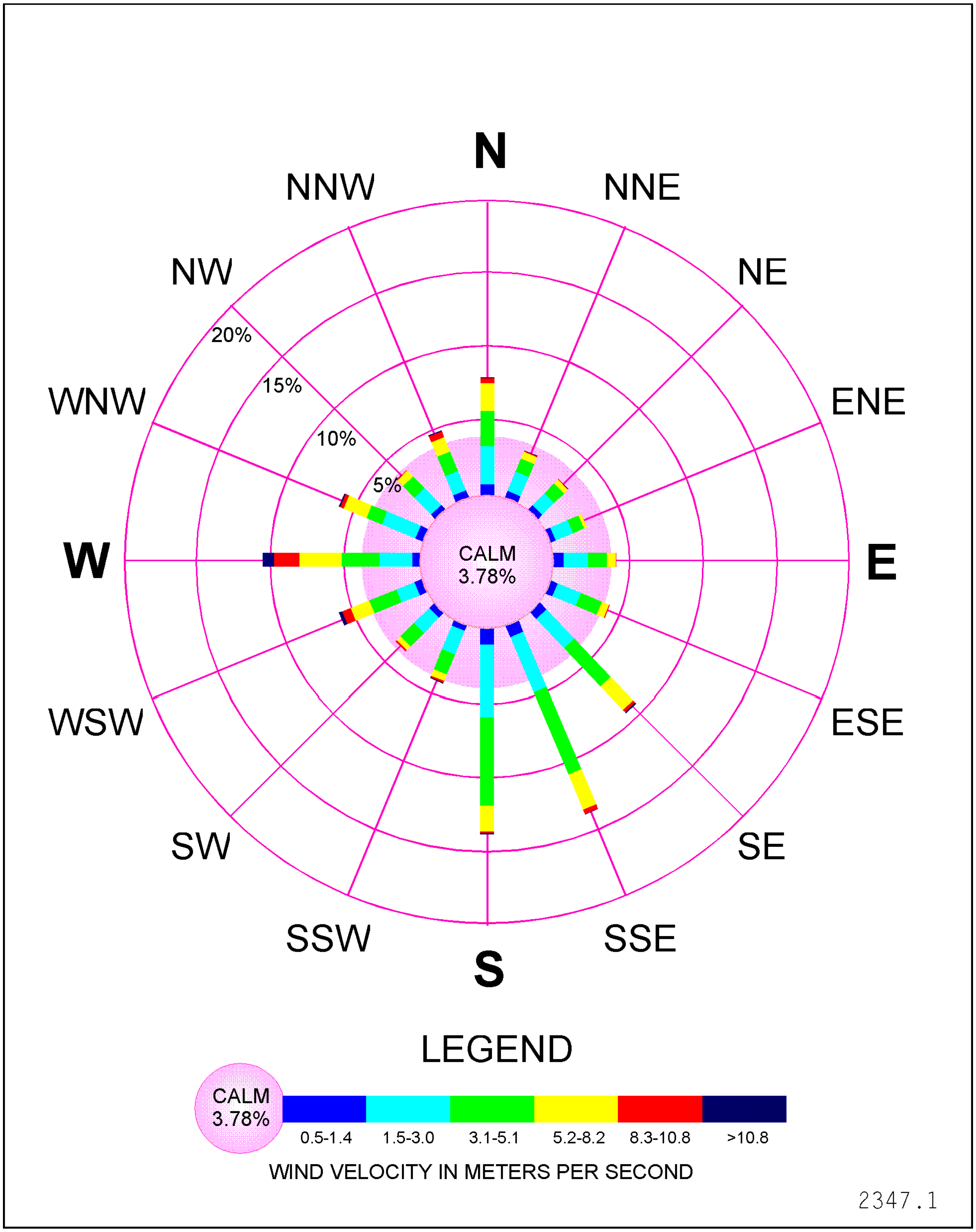

Figure 2.4-9, 1992 Annual Windrose - Carlsbad

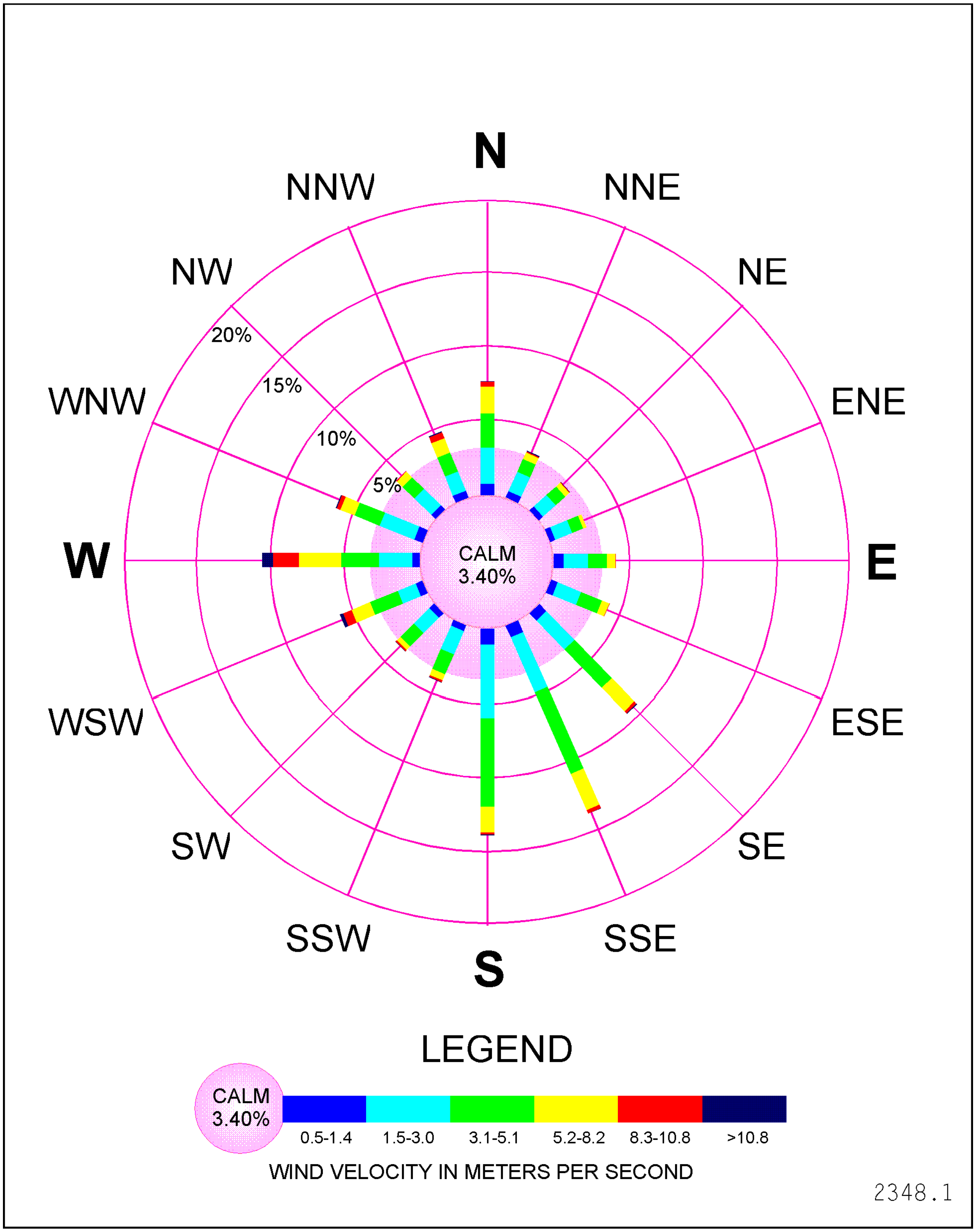

Figure 2.4-10, 1993 Annual Windrose - Carlsbad

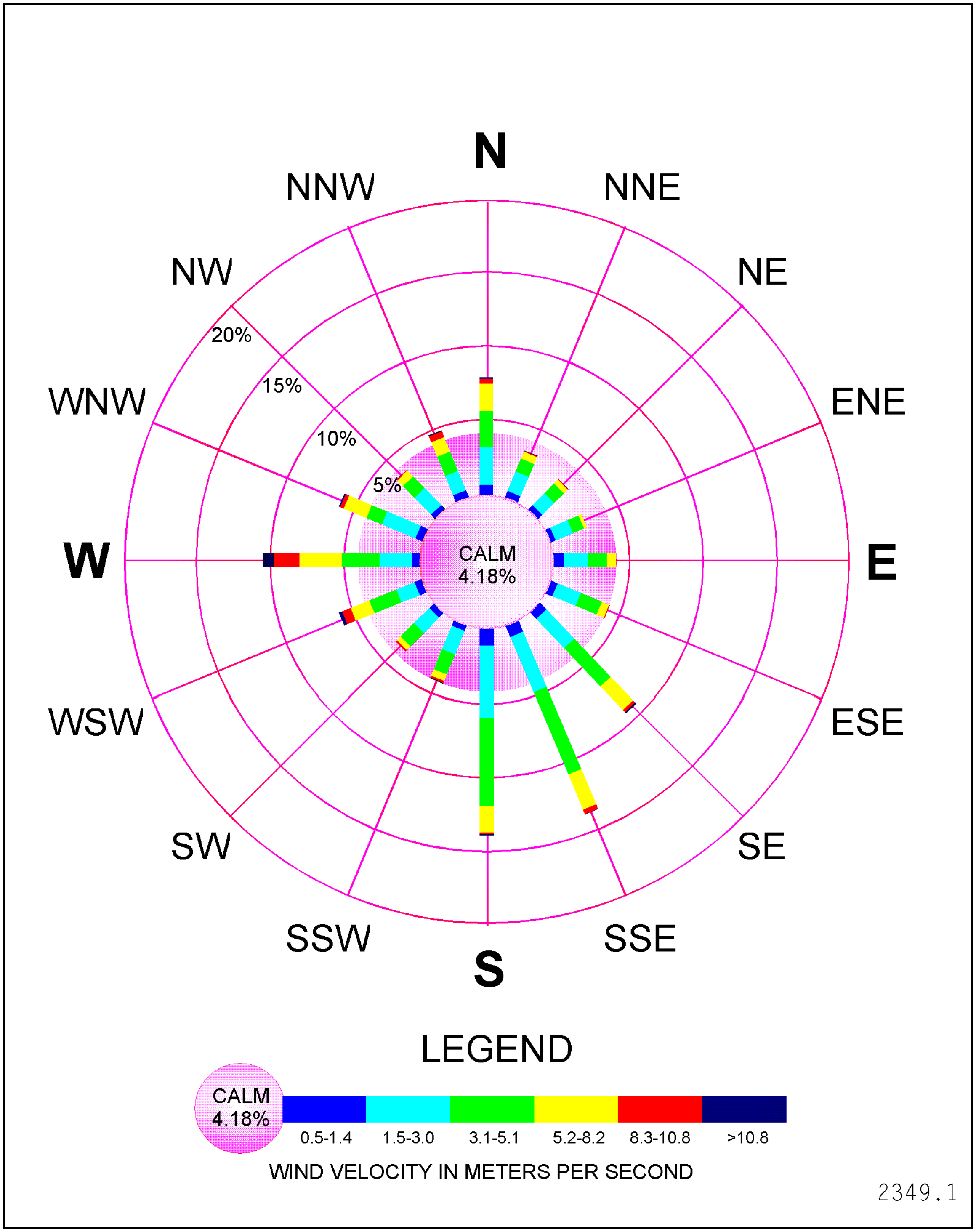

Figure 2.4-11, 1994 Annual Windrose - Carlsbad

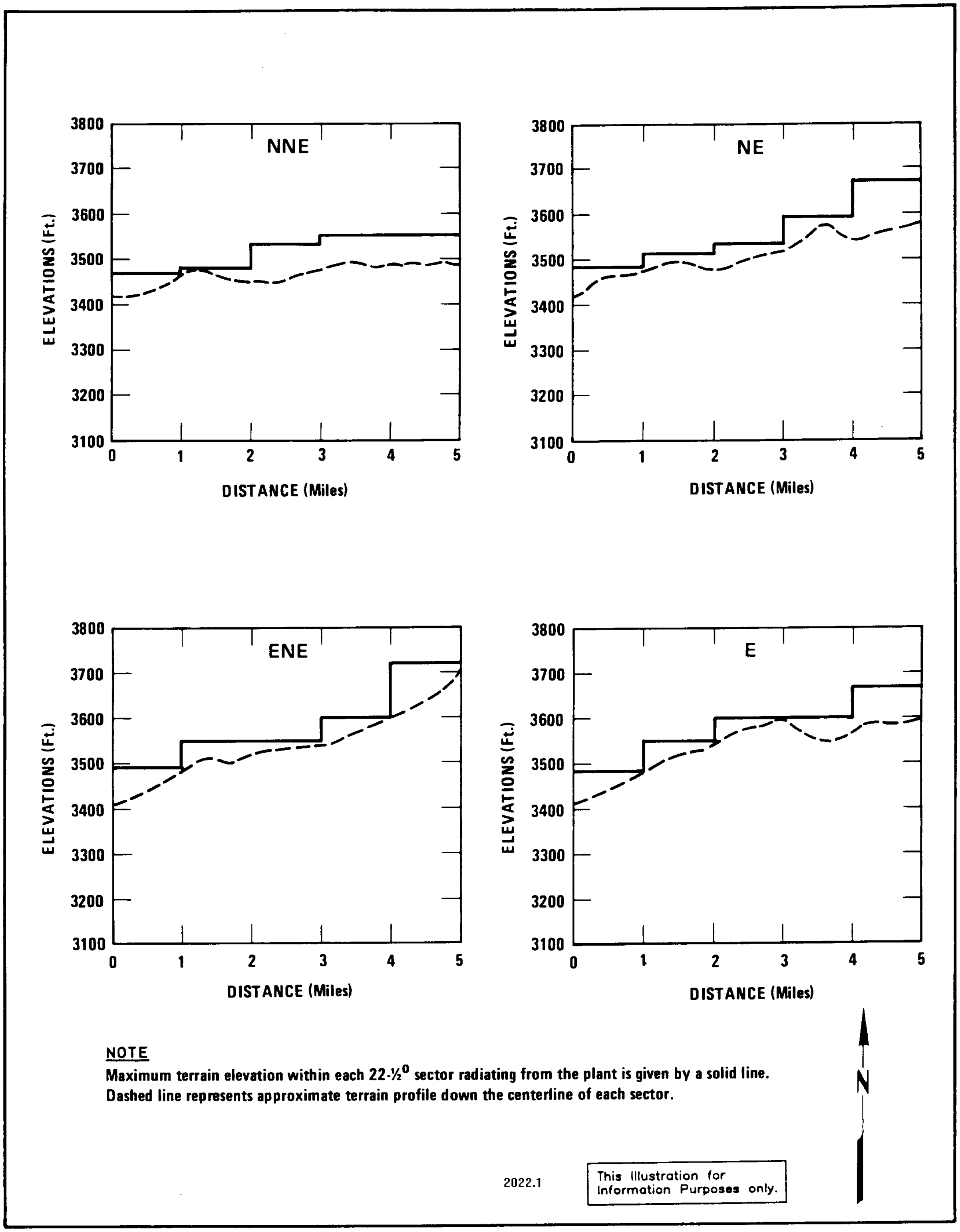

Figure 2.4-12A, Terrain Elevations Out to 5 Miles from Center of the WIPP Facility Sheet 1 of 4

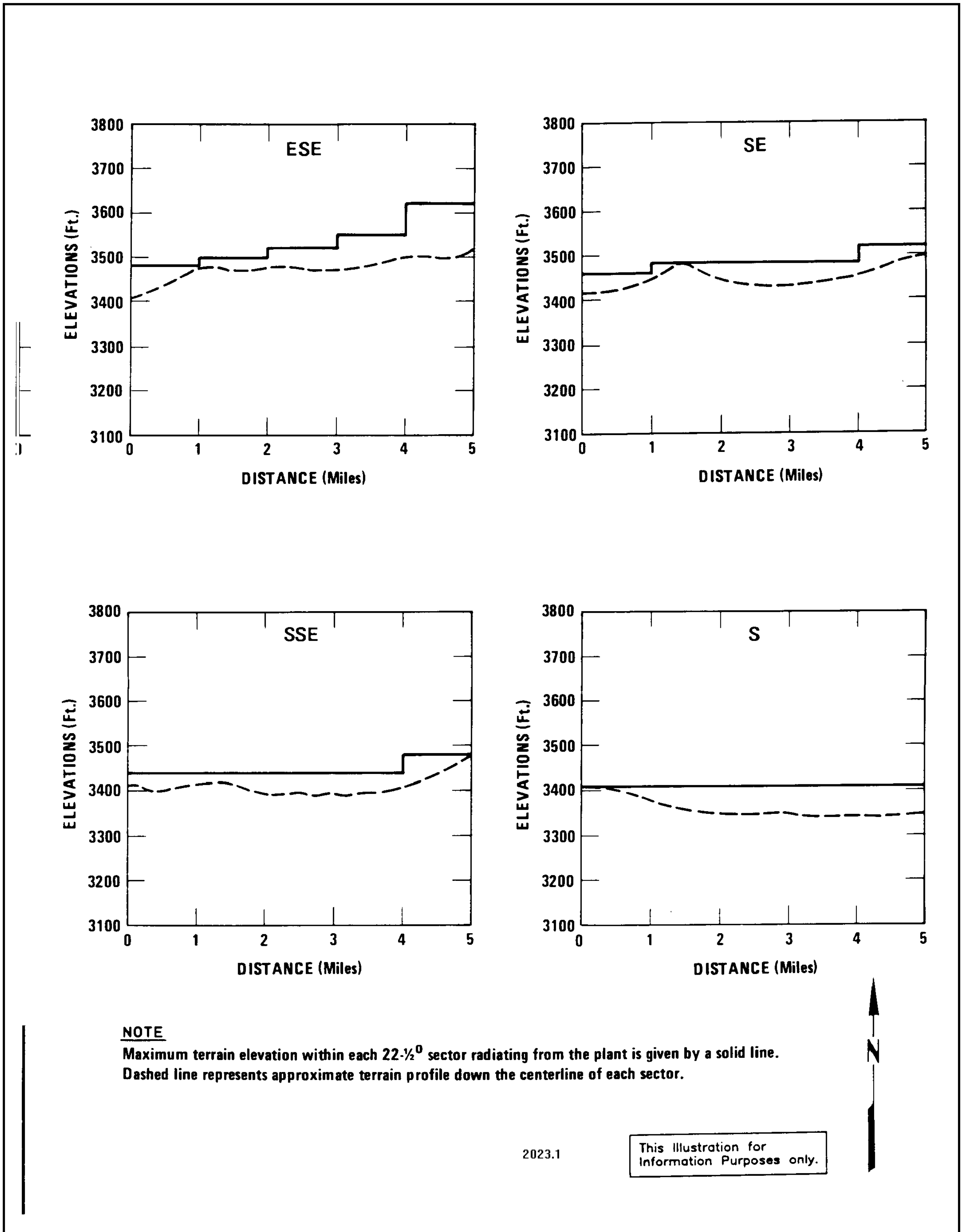

Figure 2.4-12B, Terrain Elevations Out to 5 Miles from Center of the WIPP Facility
Sheet 2 of 4

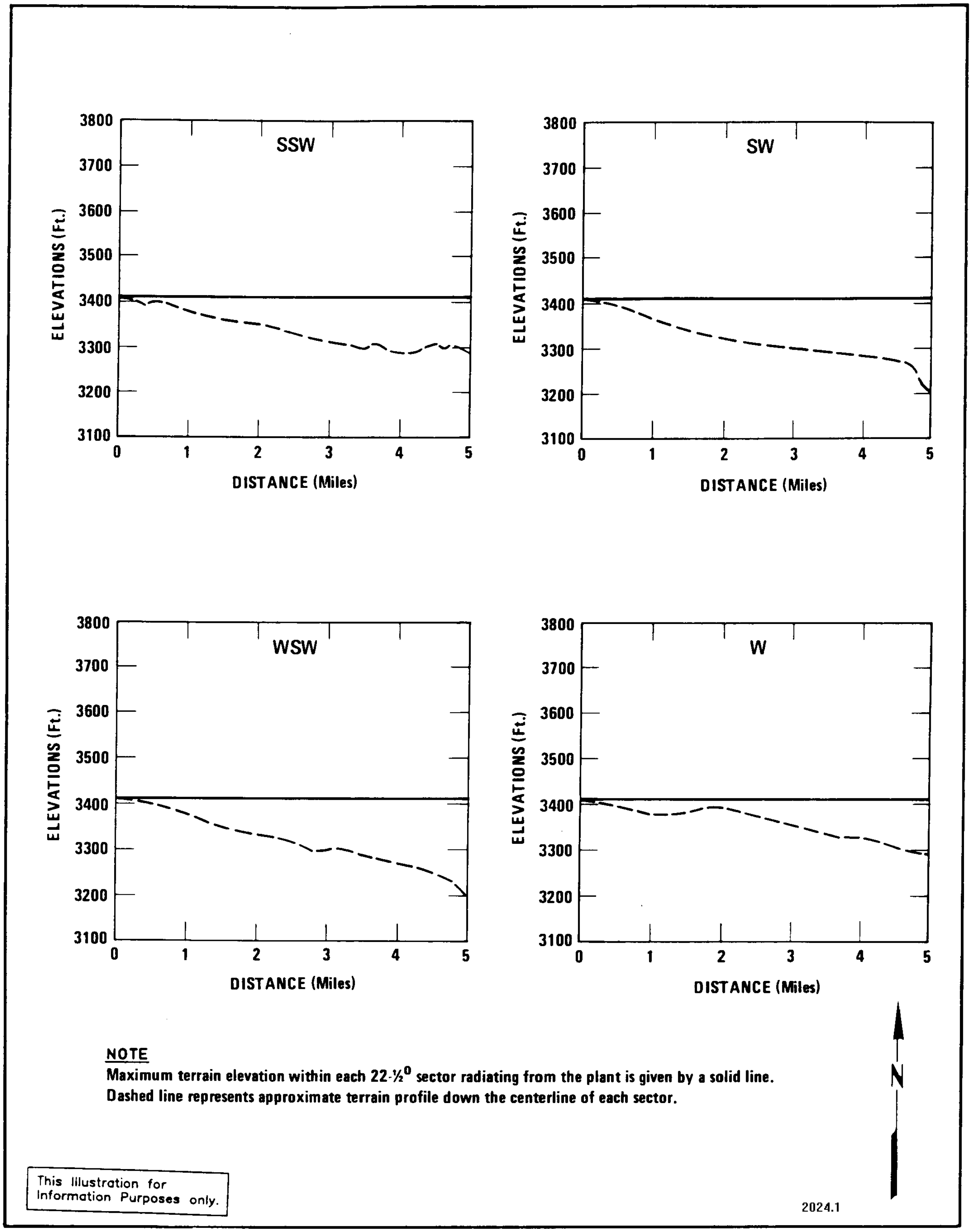

Figure 2.4-12C, Terrain Elevations Out to 5 Miles from Center of the WIPP Facility
Sheet 3 of 4

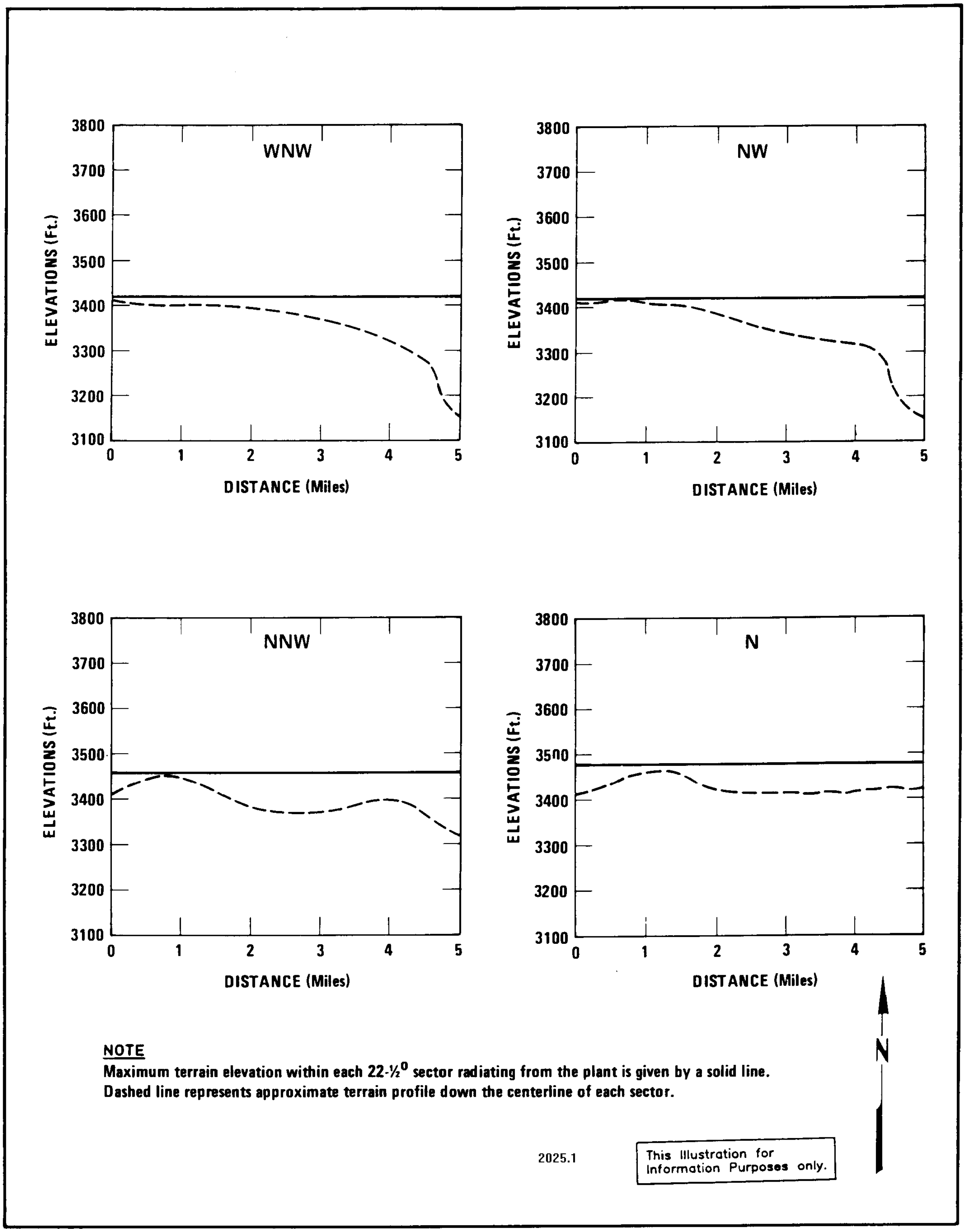

Figure 2.4-12D, Terrain Elevations Out to 5 Miles from Center of the WIPP Facility
Sheet 4 of 4

Table 2.4-1, Maximum Wind Speeds for Roswell, New Mexico*

Month	Max wind speed, mph	Month	Max wind speed, mph
January	67	July	66
February	70	August 72	
March	66	September	54
April	75	October	66
May	72	November	65**
June	73	December	72

*Climates of the States, Vol. 2 - Western States, Roswell, NM, U.S. National Oceanic and Atmospheric Administration (NOAA), Water Information Center, Inc., Asheville, NC, 1974, p. 804.Local Climatological Data, Annual Summary 1985, Roswell, NM, NOAA-ED.

**Occurred more than once.

Table 2.4-2, Recurrence Intervals for High Winds in Southeastern New Mexico*

	Speed, mph			
Recurrence, years	30'	50'	100'	150'
2	58	62	65	73
10	68	73	81	86
25	72	77	86	91
50	80	86	95	101
100	82	88	97	103

*O. G. Sutton, Micrometeorology (McGraw-Hill Book Co., Inc., New York, 1953), p. 238.

Table 2.4-3, Seasonal Frequencies of Inversions*

Season	Inversion frequency (% of total hours)	Maximum %**
Spring	32	65
Summer	25	68
Fall	35	72
Winter	46	78
Annual	35	70

*C. R. Hosler, "Low-Level Inversion Frequency in the Contiguous United States," Monthly Weather Review, 89 (9) (1961).

**Frequency of 24-hour periods with at least 1 hour of inversion based at or below 500 feet.

Table 2.4-4, Seasonal Values of Mean Mixing Heights*

Season	Mean afternoon mixing height, m	Mean morning mixing height, in.
Spring	2800	480
Summer	3050	680
Fall	2000	440
Winter	1320	300
Annual	2400	470

*G. C. Holzworth, Mixing Heights, Wind Speeds and Potential for Urban Air Pollution Throughout the Contiguous United States, U.S. Environmental Protection Agency (EPA), Research Triangle Park, NC (1972).

Table 2.4-5, Annual Average, Maximum, and Minimum Temperatures

Year	Annual Average Temperature (○C)	(○F)	Maximum Temperature (○C)	(○F)	Minimum Temperature (○C)	(○F)
1990	17.8	64.0	46.1	115.0	-13.9	7.0
1991	17.2	63.0	42.8	109.0	-7.8	18.0
1992	17.2	63.0	42.8	109.0	-10.0	14.0
1993	17.8	64.0	42.8	109.0	-18.9	-2.0
1994	17.8	64.0	50.0	122.0	-14.4	6.0
Average	17.6	63.6	44.9	112.8	-13.0	8.6

Source: WIPP Annual Site Environmental Report for Calendar Years 1990 through 1994 (Draft)

2.5 Vibratory Ground Motion

This section is directed towards establishing the seismic design basis for vibratory ground motion directly applicable to Design Class I and II confinement structures and components at the WIPP facility. The application of the results contained in this section to seismic design of plant facilities is discussed in Section 3.2.7. This presentation is aimed at conservatively estimating the Design Basis Earthquake (DBE) for the WIPP site facility.

The approach used in this analysis is to develop a probabilistic peak acceleration to be used in design. This peak acceleration is derived from a correlation between historical earthquake activity and various active geologic structures and tectonic provinces. These results are used to establish the site's DBE in Section 2.5.5.

2.5.1 Seismicity

In this section, data are presented for earthquakes within 180 miles (290 km) of the WIPP facility. This area is defined as the WIPP facility region for this discussion. The information for the WIPP facility region earthquakes before 1962 is based on chronicles of the effects of those tremors on people, structures and land forms (called macroseismic evidence). Virtually all information on earthquakes occurring after the beginning of 1962 in the WIPP facility region is derived from instrumental data recorded at various seismograph stations.

2.5.1.1 Pre-1962 Earthquake Data

Most earthquakes reported in New Mexico before 1962 occurred in the Rio Grande Valley area between Albuquerque and Socorro, a distance of more than 186 miles (300 km) from the WIPP site. About half of the earthquakes of Modified Mercalli Intensity (MMI) V or greater in New Mexico between 1868 and 1973 were in this region. In conformity with previous studies,[1,2,3] those events are not of immediate concern to this study. There has been one earthquake associated with moderate to considerable damage (intensity VIII) prior to 1962 within the WIPP facility region. The Valentine, Texas earthquake of 1931, occurred about 120 miles (193 km) south-southwest of the location of the WIPP facility. The area within 120 miles (193 km) of the WIPP facility has experienced only low-intensity earthquakes (intensity V or less).

Figure 2.5-1 shows locations of earthquakes occurring before 1962 within 186 miles (300 km of the WIPP site. These epicenters were assigned on the basis of macroseismic evidence and are also listed in Table 2.5-1. Supplemental descriptive material for most of those events is provided primarily by Sanford and Toppozada [1] and other sources.[4,7] All intensities listed in Table 2.5-1 are Modified Mercalli Intensities.[7] An abridged version of this scale is presented in Table 2.5-2.

The Valentine, Texas earthquake of August 16, 1931 was large enough to generate significant interest so that much more data are available for that event. A number of isoseismal maps were compiled soon after its occurrence. [5,7] Recently, Sanford and Toppozada assigned MMI on the basis of descriptions of the effects of this event and plotted the resulting isoseismal map reproduced in Figure 2.5-2. Several features of this plot are noteworthy. First, according to Figure 2.5-2, the intensity location of the WIPP facility from this earthquake was V. Second, isoseismal lines close to the zone of the highest intensity are elongated northwest-southeast conforming to the structural integrity of the region.

Two instrumental locations have been published for the Valentine, Texas earthquake. The United States Coast and Geodetic Survey (USCGS) places the epicenter at 29.9N and 104.2W with an origin time of 11:40:15 Greenwich Mean Time (GMT).[5] Byerly[9] made a detailed instrumental investigation of that earthquake and found the epicenter to be 30.9N and 104.2W with an origin time of 11:40:21 GMT. Byerly's[9] epicenter, 66 miles (106 km) north of the USCGS epicenter, is somewhat closer to the region of highest reported intensity and may for this reason be considered the more accurate of the two.[1] These two instrumental epicenters are plotted in Figure 2.5-2. Although neither of these instrumental locations is particularly close to Valentine, Texas, the USCGS and Byerly epicenters bracket the area of maximum reported intensity fairly well. For the purposes of Figure 2.5-1, Valentine, Texas has been adopted for the location of both the main earthquake and its aftershocks in agreement with Sanford and Toppozada.[1]

The area over which an earthquake is perceptible can be used to estimate its magnitude.[10,11] If a felt area of 4.5 x 10^5 mi^2 (1.2 x 10^6 km^2) is accepted as reported by the USCGS,[6] and a magnitude felt area formula for the central United States and Rocky Mountain region is used,[11] a magnitude of about 6.4 is calculated for the Valentine, Texas earthquake. This result is compatible with the maximum intensity reported for the shock[1] and is the same as the magnitude for this event calculated at Pasadena, California.[12]

2.5.1.2 Comprehensive Listing of Earthquakes From All Studies - January 1, 1962 through September 30, 1986

Presented in Table 2.5-3 is a listing of earthquake origin times, locations, and magnitudes, based on instrumental data gathered and analyzed by a number of different organizations. The listing is for earthquakes within the WIPP facility region for the 24 3/4 year interval from January 1, 1962 through September 30, 1986. The organization providing the earthquake parameters listed in the table is identified by an X in the appropriate column. Organizations providing data for the table were as follows:

- New Mexico Institute of Mining and Technology (NMT)
- U.S. Geological Survey (USGS)
- Los Alamos National Laboratory (LANL)
- Albuquerque Seismological Laboratory (ASL)
- University of Texas at Austin (UTA)
- University of Texas at El Paso (UTEP).

2.5.1.2.1 Magnitudes

Recent seismic events occurred at WIPP on January 2, 1992 and April 13, 1995. These events had magnitudes of 5.0 and 5.4 respectively. The January 2, 1992 Rattlesnake Canyon Earthquake had an epicenter located 37 miles (60 km) east southeast of the WIPP site. The Rattlesnake Canyon Earthquake and the April 13, 1995 earthquake had no effect on any of the structures at WIPP, as documented by post event inspections by the WIPP staff and the New Mexico Environment Department. These events were within the parameters used to develop the seismic risk assessment of the WIPP structures (Section 2.5.5). The Rattlesnake Canyon event likely was tectonic in origin based on a 7 +/- mile (12+/- km) depth. (Ref Part B Permit Application, Rev. 5, Appendix D6, Section D6-4 Seismicity)

Up to August 1981, NMT calculated magnitudes differently than other organizations. As a result, systematic differences in calculated magnitudes were observed. In Table 2.5-3, all magnitudes calculated by organizations other than NMT were modified by applying corrections. In all cases, these modifications reduced the reported magnitude by amounts ranging from 0.3 to 0.5.

After August 1981, NMT started using a magnitude scale based on the duration (t_D) of the recorded signal from onset of the P phase to when the trace amplitude approaches background noise. The equation used,

$$M_D = 2.79 \log t_D - 3.63$$

was derived by LANL researchers[21] and determined to be equivalent to the Richter local magnitude scale for earthquakes in northern New Mexico. Ake and Sanford[18] established that the LANL formula can be applied to earthquakes in central New Mexico which fall in the local magnitude range of 1.1 to 4.2. A careful study of the applicability of the formula to earthquakes in southeastern New Mexico and west Texas has not been made.

However, random comparisons between magnitudes calculated from the amplitude of S_g (Shear Wave) and duration of ground motion in the time period 1962 to 1974 indicate general consensus good agreement (within 0.3 magnitude units) between the two methods.

Most recurrence formulas in Section 2.5.4.2 are based on the earthquake data set included in Table 2.5-3, but at lower magnitudes. Therefore, the latest listing of events within the WIPP facility region does not require an upward revision in earthquake risk or the DBE.

2.5.1.2.2 Completeness of the Earthquake Data Set

From January 1, 1962 to April 5, 1974, events in the WIPP facility region were located by readings from stations generally several hundred miles from the epicenter. On April 5, 1974, a single station (CLN) was established near the center location of the WIPP facility which continued operation to September 1980. These stations are plotted in Figure 2.5-3. From November 1975 to late 1979, a seismograph array was in operation near Kermit, Texas. These are shown in Figure 2.5-4.

A small network of stations centered in the Davis Mountains of West Texas was operated by the UTA from July 1977 to July 1978. No stations were running near the location of the WIPP facility from shutdown of station CLN in September 1980 to startup of a three station network in August 1982. The WIPP seismograph network was not fully operational until March 1983.

The histograms in Figure 2.5-5 illustrate how the shifts in instrumentation affected the completeness of the earthquake data set presented in Table 2.5-3. The period from January 1, 1962 through September 30, 1986 was divided into eight time intervals of 1130 days, and the number of events greater than 3.0, 2.5, 2.0, and 1.5 were determined for each interval. The first four intervals (from January 1, 1962 through May 17, 1974) cover the period prior to installation of any stations at, or near the location of the WIPP facility. The fifth and sixth intervals (from May 18, 1974 through July 24, 1980) cover the period when station CLN, the Kermit array, and the UTA networks were in operation. Most of the seventh interval (from July 25, 1980 to August 28, 1983) covers the period between shutdown of station CLN and startup of the WIPP seismographic network. During the last interval (from August 29, 1983 through September 30, 1986) the WIPP array was fully operational.

The histogram in Figure 2.5-5 for events with M3.0 (upper left) suggests a complete data set of this magnitude level. The greatest number of events (6) occurred during the second interval (from February 4, 1965 through March 9, 1968), a period when no seismograph was operating within 135 miles (217 km) of the location of the WIPP facility except station FOTX during the first 67 days of the interval. (Station FOTX was located 72 miles (116 km) southeast of the WIPP facility). The least number of earthquakes occurred in the first, third, and eighth intervals. The WIPP seismographic network was fully operational during the eighth interval, but no seismic instrumentation within 135 miles (217 km) of the location of the WIPP facility existed during the first and third intervals except station FOTX (in operation the last 228 days of the first interval). Because the number of observed quakes with M3.0 does not correlate with the presence or absence of instrumentation at or near the WIPP facility, the data set is believed to be complete at that strength level. If the data set is complete, then the variations in activity observed in the histogram represent true temporal changes in the activity rate for earthquakes with M3.0.

In the lower two histograms of Figure 2.5-5, the period of maximum instrumentation is even more clearly defined by the increase in numbers of earthquakes during the fifth and sixth time intervals. In summary, the general shape of the histograms relative to temporal changes in instrumentation indicates the data set is probably complete above magnitude 2.7, and that it becomes progressively less complete at lower magnitudes.

2.5.1.2.3 Recurrence Interval Formulas

Many studies have demonstrated a linear relation between the logarithm of the cumulative number of earthquakes (N) and the magnitude (M), i.e.,

$$\log N = a - bM.$$

The values of the constants "a" and "b" are derived from existing earthquake data by plotting log N versus M and performing linear regression on those points that fall above the minimum magnitude where the data set is complete. The formulas obtained in this manner can be extrapolated to determine the recurrence interval for the maximum probable earthquake in the region. Section 2.5.4.2 describes in some detail how these relations can be used in establishing risk and ultimately the DBE.

Shown in Figures 2.5-6 and 2.5-7 is a log N versus M plot for the combined time periods from January 1, 1962 through September 30, 1986. Seismographs were not in operation near the WIPP facility from July 24, 1980 to August 29, 1983. Linear regression for data points greater than magnitude 1.9 yields the recurrence equation,

$$\log N = 4.05 - 1.01\ M.$$

The value of "b," 1.01, is three percent less than that obtained by Sanford et al. (1.04) using data for the 3 1/4 year period, April 1974 through June 1977. The "a" values cannot be compared because (1) the magnitudes in Table 2.5-3 are on the average approximately 0.4 less than those listed in Sanford et al.,[45] (2) the time period is approximately three times greater here than in Sanford et al,[3] and (3) the degree of activity at the M2.0 strength level was not as great in later periods as it was from April 1974 through June 1977 (see histograms in Figure 2.5-5).

2.5.1.2.4 Geographic Distribution of Earthquakes

Table 2.5-3 differs in another important way from earlier listings of earthquakes within 180 miles (290 km) of the WIPP facility. All but a few shocks in the table have epicenters determined by the algorithm HYPO 71 Revised,[19] rather than by the circle-arc method. The locations from the latter method were retained only when a satisfactory solution could not be obtained from HYPO 71.[19] Inclusion of crustal shear wave (Sg) arrival time readings in the HYPO 71[19] program probably makes it superior to the circle-arc method.

The accuracy of locations in Table 2.5-3 depends on many variables: the number, distance, and distribution of stations providing readings for the solution, and the quality of crustal compressional wave (Pg) and Sg phases picked. For the events that occurred within or near arrays of stations, primarily during the period April 1974 through September 1980, the accuracy of locations is reliable. However, for most of the earthquakes during the 24 3/4 year period, the locations depended on readings from stations several hundred kilometers away, falling in a narrow azimuthal range relative to the epicenter. The error in location under these circumstances can be considerable. However, even in the worst case (generally earthquakes in the far southern and southeastern regions of the study area) the locations are believed to be within ±16 miles (±25 km).

Figure 2.5-8 is a map showing all epicenters listed in Table 2.5-3. The distribution of earthquake activity in this figure is compatible with the boundaries of source regions discussed in Section 2.5.4.1. On the basis of the seismic activity, the eastern boundary of the Rio Grande rift source zone can be placed at the boundary proposed by Algermissen and Perkins[21] or at the alternate boundary proposed in Section 2.5.4.1. The later boundary is clearly less well-defined by seismic activity than the Algermissen and Perkins boundary.

All boundaries proposed for the Central Basin Platform (CBP) in Section 2.5.4.1 are generally compatible with the distribution of earthquake activity in Figure 2.5-8, but none are totally satisfactory. The earthquake epicenters in the vicinity of the CBP appear to require enlargement of the source zone to the southwest and contraction to the east and northeast. The nearest approach of CAP seismicity to the WIPP site appears to be east of boundaries proposed by Algermissen and Perkins[22] and those suggested by geologic and tectonic consideration.

Figure 2.5-9 is a map showing epicenters from Table 2.5-3 that fall in the time period April 5, 1974 through October 6, 1978. To some extent, the maps presented in Figures 2.5-8 and 2.5-9 distort the distribution of seismic activity. Detection of smaller quakes in the data set was variable in space and time as a result of changes in the numbers and distribution of seismograph stations. To avoid this problem, Figure 2.5-10 shows only epicenters for earthquakes with $M \geq 2.5$, a cut-off level only slightly below the magnitude at which the data set is believed complete.

The temporal variability of earthquake activity on the CAP and elsewhere within 180 miles (290 km) of the WIPP facility is illustrated in Figures 2.5-11 through 2.5-18. Plotted in these figures are epicenters for events with M2.5 which occurred in eight sequential time periods, each of 1130 days duration from January 1, 1962 to September 30, 1986.

2.5.2 Geologic Structures and Tectonic Activity

A study of the WIPP facility region suggests a fundamental geologic and tectonic separation into two significantly different subregions: (1) the Permian Basin and (2) the Basin and Range subregions. The geologic structures and tectonism of the Permian Basin are dominantly associated with large-scale basin, interbasin and basin margin subsidence or emergence that occurred during the Paleozoic era. Basin and Range structures and tectonism to the west are those associated with Basin and Range topography. The activity characteristic of this subregion began in middle to late Tertiary time and is probably still occurring to some extent.

The Permian Basin subregion is defined as that part of the Permian Basin within the site region. The WIPP facility is slightly more than 60 miles (97 km) from the western margin of the Permian Basin (Figure 2.5-19). The Permian Basin is a broad structural feature made up of a series of Paleozoic sedimentary basins whose last episodes of large-scale subsidence during late Permian time were associated with a thick accumulation of evaporites. This basin now exists as a subsurface structural feature extending roughly from the Amarillo uplift on the north to the Marathon thrust belt on the south and some 300 miles (483 km) eastward from the Diablo platform and Sacramento and Guadalupe Mountain areas into west-central Texas.[23]

The development of the Permian Basin began with the formation of a broad sag (named the Tobosa basin[24]) following deposition of lower Ordovician strata. Prior to the late Mississippian, several periods of minor folding, faulting and uplift with erosion occurred. Nevertheless, general structural stability prevailed.[50,51,52] Subsequently, tectonic activity accelerated in the area climaxing in late Pennsylvanian and was split into two rapidly subsiding basins (the Midland to the east and the Delaware to the west) by the medial Central Basin Platform.[25] Structural development of the Permian Basin within this framework continued until late Permian when broad-scale basement stabilization occurred concurrently with evaporite deposition.

Thus, the major tectonic elements of the Permian Basin were completely formed before the deposition of Permian salt-bearing rocks, and relative crustal stability of the region has been maintained since Permian time. Since then, the Permian Basin has been characterized throughout the Mesozoic and Cenozoic eras by erosional processes interrupted by only minor episodes of terrestrial and shallow water deposition. Regionally, the Permian Basin has been tilted and warped, but deep-seated faults since Permian time are rare except along the western margin of the basin outside the area of salt preservation. In areas where salt is near the surface, such as southeastern New Mexico, there are no indication of younger deep-seated faulting and only a few isolated igneous intrusives of post-Permian age.[25]

The Basin and Range subregion is defined as that part of the Basin and Range physiographic province within the site region. As shown in Figure 2.5-19, this subregion borders the western margin of the Permian Basin subregion to the west and southwest of the site. The Basin and Range subregion is characterized by fault block mountain ranges, many of which are bounded on the west by major high-angle normal fault systems. Uplift along these fault systems has resulted in gentle eastward tilting of the mountain blocks and the formation of intermontane or graben-like valleys. Major development of these characteristic structural features occurred from late Tertiary into early Pleistocene time.[50,51,52] Continued tectonism in the Basin and Range subregion is suggested by widely scattered Quaternary fault offsets on the order one to several meters. A number of fault offsets of this age along the western flanks of the Guadalupe, Delaware, Sacramento and San Andres mountains are described in the literature.[26,27,50,51,52] More recently, additional but similar fault systems have been found and described within the Basin and Range physiographic province in Trans-Pecos, Texas.[28]

The different physiographies of the two site subregions, as defined and briefly described above, are closely related to their distinctive geologic histories and structural configurations. This is suggested by Figure 2.5-20 which shows the boundary between the great Plains and Basin and Range physiographic provinces.[50,51,52] For this reason, Figure 2.5-19 is a good approximation to the boundary between the Permian Basin and Basin and Range subregions as suggested by the geologic evidence just outlined.

The results of a 1978 leveling survey between El Paso, Texas and Carlsbad, New Mexico,[29] are consistent with this geologically suggested regional separation. Comparison of this survey with previous leveling surveys along the same route carried out in 1934, 1943 and 1958, indicates that the Diablo Plateau region of Trans-Pecos, Texas (in the Basin and Range subregion as defined above) has been uplifted approximately 4 to 5 centimeters during this interval in archlike fashion in relation to the end points of the survey. Extending east from El Paso, the leveling route traverses Basin and Range subregion-type structures including the Hueco Basin, the Hueco Mountains, the Diablo Plateau, the Salt Basin and the Guadalupe Mountains before terminating on the High Plains in the Permian Basin subregion near Carlsbad. The observed relative uplift correlates well with the broad aspects of the tectonic evolution of the Diablo Plateau. The observed elevation changes are most easily attributed to deep-seated tectonic activity.[29]

The observed movements along the El Paso - Carlsbad line are not the largest in the area. Movements along the Roswell-Pecos line, which is entirely within and near the western margin of the Permian Basin subregion, are larger (Figure 5 of Reference 42). However, the movements on this route, which runs along a railroad near the Pecos River, are probably dominated by artificial water withdrawal.[46,47] Carlsbad appears to be relatively "inactive" with respect to Roswell, which is located well outside regions of known neotectonic activity.[29]

In summary, the WIPP facility region leveling data are consistent with the geologic evidence in that they suggest current tectonic activity in the Basin and Range subregion and current stability in the Permian Basin subregion. Because current tectonic activity implies crustal movement that in turn implies elastic strain accumulation and release, earthquakes are often considered a barometer of tectonic activity. The occurrence of more frequent and larger earthquakes is thus consistent with a higher level of tectonism.

Earthquakes occurring between 1923 and 1979 and between April 1974 and February 1979 are superimposed on the suggested site subregions in Figures 2.5-19 and 2.5-21, respectively. From Figure 2.5-19 it may be seen that most pre-instrumental and a substantial proportion of 1962 to 1977 instrumental earthquakes are located in the Basin and Range subregion. In the Permian Basin subregion, an important cluster of instrumental epicenters occurs on the Central Basin Platform, and a thin scattering of both instrumental and pre-instrumental events appears throughout the rest of this subregion. In the case of pre-instrumental events in the WIPP facility region, this distribution of shocks may be at least partly controlled by a population density that has always been greatest along the Rio Grande rift (within the Basin and Range subregion). A somewhat similar pattern appears in Figure 2.5-21, although in this figure (for which the smaller magnitude events on the Central Basin Platform have been made recordable by the inclusion of data from station CLN at the location of the WIPP facility) the recent predominance of the Central Basin Platform in terms of the total number of recorded events is apparent. The largest recorded earthquake in the Basin and Range subregion is the 1931 Valentine, Texas event whose magnitude is estimated to be about 6.4. The largest event on the Central Basin Platform is of magnitude 3 to 4 depending upon precisely how magnitudes of events in these areas are calculated. The largest event in the Permian Basin subregion but, not on or near the Central Basin Platform, was the 16 June 1978 event near Snyder, Texas, at the extreme eastern margin of the site region. This event was about 4.7 in magnitude.

Based on 11 years of instrumental data (1962 - 1972 inclusive), analysis of earthquakes throughout New Mexico of magnitude greater than or equal to 2.5 (which are believed to have been uniformly located during this interval) indicates a roughly comparable level of earthquake activity in the inactive and in the active physiographic provinces.[2,18] This result must further qualify the confidence with which the modest differences in historical seismicity levels (in terms of number of events) in the (inactive) Permian Basin and (active) Basin and Range subregions can be argued to be significant.

Thus, in light of geologic evidence and consistent recent leveling survey data, the Basin and Range subregion, as shown in Figures 2.5-19 or 2.5-21, exhibits a higher level of recent tectonism than the Permian Basin subregion. This is supported by the maximum magnitude earthquakes occurring in these subregions during historical time. The distribution of all known site region earthquakes shows that, with the exception of the Central Basin Platform area, the Permian Basin subregion has experienced marginally fewer events than the Basin and Range subregion. A significant cluster of small events is located along the Central Basin Platform.

2.5.3 Correlation of Earthquake Activity with Geologic Structures or Tectonic Provinces

The best available evidence does not suggest that recorded earthquakes have been well correlated with faults anywhere in the WIPP facility region. This is true for both the surface faults of the Basin and Range subregion (a number of which show evidence of Quaternary movement) and for the geologically older subsurface faults in the Permian Basin subregion.

Although no earthquakes in the WIPP facility region are known to be correlated to specific faults, a substantial cluster of seismic activity has occurred on and near the Central Basin Platform since about the mid-1960s. This suggests division of the Permian Basin subregion into a Central Basin Platform portion and a background portion. The seismicity pattern leading to this suggestion is made fairly explicit in Figures 2.5-19 and 2.5-21. There is no known evidence of any differences since late Permian time in the geologic histories of the Central Basin Platform and surrounding portions of the Permian Basin (Sections 2.5.2). In addition, there does not appear to be enough data at present to convincingly determine the direction of tectonic forces and the type of faulting on the Central Basin Platform;[4] therefore, this information could not be used to distinguish the Central Basin Platform.

First Shurbet,[13] and later Sanford and Toppozada[1] and Rogers and Malkiel[15] suggested that Central Basin platform earthquakes are not tectonic but are instead related to water injection and withdrawal for secondary recovery operations in oil fields in the Central Basin Platform area. Such a mechanism for the Central Basin Platform seismic activity could provide a reason why the Central Basin Platform is separable from the rest of the Permian Basin on the basis of seismicity data but not by using other common indicators of tectonic character. Both the spatial and temporal association of Central Basin Platform seismicity with secondary recovery projects at oil fields in the area are suggestive of some cause and effect relationship of this type.[15]

In summary, the best available evidence does not suggest that known earthquakes are well correlated with faults in the WIPP facility region. A substantial number of earthquakes have occurred on and near the Central Basin Platform since about the mid-1960s. The cause of the spatial coincidence of recent seismicity with this buried large-scale Paleozoic structure is not known. With this exception, WIPP facility region earthquakes may be correlated with two tectonic provinces for the purposes of this study. The first is a relatively inactive province made up of the eastern and northeastern two-thirds (approximately) of the WIPP facility region (and encompassing the WIPP facility). The other WIPP facility region tectonic province is a relatively inactive province made up of the rest of the WIPP facility region. A simple and reasonable model of these two general WIPP facility region tectonic provinces is furnished by the Permian Basin/Basin and Range subregion characterization of Section 2.5.2.

2.5.4 Probabilistic Earthquake Potential

In recent years, several procedures have been developed that allow formal determination to be made of earthquake probabilistic design parameters[30,31] and a number of studies have been performed incorporating these procedures[22,32,33] In typical seismic risk analyses of this kind, the region of study is divided into seismic source areas within which future events are considered equally likely to occur at any location. For each seismic source area, the rate of occurrence of event above a chosen threshold level is estimated using the observed frequency of historical events. The sizes of successive events in each source are assumed to be independent and exponentially distributed; the slope of the log number versus frequency relationship is estimated from the relative frequency of different sizes of events observed in the historical data. This slope, often termed the b value,[16] is determined either for each seismic source individually or for all sources in the region jointly. Finally, the maximum possible size of events for each source is determined, using judgment and the historical record.[37] Thus, all assumptions underlying a measure of earthquake risk potential derived from this type of analysis are explicit, and a wide range of assumptions may be employed in the analysis procedure.

In this section, the particular earthquake risk parameter calculated is peak acceleration expressed as a function of annual probability of being exceeded at the WIPP site. The particular analysis procedure applied to the calculation of this probabilistic peak acceleration is taken from a computer program written by McGuire.[33] In that program the seismic source zones are modeled geometrically as quadrilaterals of arbitrary shape. Contributions to site earthquake risk from individual source zones are integrated into the probability distribution of acceleration, and the average annual probability of exceedence then follows directly. The theory and mechanics of McGuire's computer program may be found in a number of papers,[30,34] so they are not outlined here.

In the analysis, input parameters at each stage of the development are taken from the best conservative estimates. Where more than one good estimate exists, alternative values are examined. The principal input parameters are: site region acceleration attenuation, source zone geometry, recurrence statistics, and maximum magnitudes. Based on theses parameters, several curves showing probabilistic peak acceleration are developed, and the conclusions that may be drawn from these curves are considered. The data treated in this way are used to arrive at a general statement of risk from vibratory ground motion at the site during its active phase of development and use.

2.5.4.1 Acceleration Attenuation

The first input parameters considered are those having to do with acceleration attenuation in the site region as a function of earthquake magnitude and hypocentral distance. The risk analysis used in this study employs an attenuation law of the form,

$$a = b_1 \exp(b_2 M_L) \text{ R-b}^3$$

where a is acceleration in cm/s^2, M_L is Richter local magnitude, and R is the distance in Kilometers. A number of relationships of the above from exist in the literature.[36,38] In all these studies, however, the constants $b_{1,}b_2$, and b_3 are found for data collected exclusively, or almost exclusively, west of the Rocky Mountains and are therefore perhaps not directly applicable at the WIPP facility region. Theoretical and empirical evidence indicates fundamental difference in acceleration attenuation between the western and central parts of the United States.[20,39,40]

The particular formula used in this study is based on a central United States model developed by Nuttli.[41,42] The formula coefficients $b_1 = 17$, $b_2 = 0.92$, and $b_3 = 1.0$ were selected as the best ones.

Curves using these coefficients are shown in Figure 2.5-23. This adopted attenuation law represents a conservative compromise between the estimated curves of various authors and the required form.[37,41,44]

Seismic Source Zones

Geologic, tectonic and seismic evidence indicates that three seismic source zones may be used to adequately characterize the region. These are well approximated by the Basin and Range subregion, the Permian Basin subregion exclusive of the Central Basin Platform, and the Central Basin Platform itself. The seismic source zones are outlined in Figures 2.5-19 and 2.5-21. However, specific boundaries are only intended to be simply defined approximations. For the purpose of earthquake risk analysis at the WIPP facility, some measure of the effect of the likely uncertainty in these source zone boundaries is desirable. Rather than allow the source zone boundaries to vary randomly by some amount, alternative boundaries are used based on an independent analysis of the WIPP facility region. These are taken from the study by Algermissen and Perkins of earthquake risks throughout the United States,[21] and were used in a previous analysis of WIPP site seismic risk by SNL.[15] A detailed discussion of how this characterization was developed and how it best fits recent estimates of site region seismic properties may be found in that reference.

Site region seismic source zones after Algermissen and Perkins are shown in Figure 2.5-23. Superposed on this figure are the earth-quake epicenters of Figure 2.5-1. It is clear from this superposition that the zonation presented generally conforms with historical seismicity. The source zonation of Figure 2.5-23 has no explicit analog to the Permian Basin subregion exclusive of the Central Basin Platform. This is considered part of the broad background region.

Another estimate of the appropriateness of the source zones as drawn in Figure 2.5-23 can be obtained from a consideration of Quaternary faulting. As shown in Figure 2.5-24, evidence of Quaternary fault offset is almost, but not quite completely, contained within the two western seismic source zones of Algermissen and Perkins. These two zones may be combined under the name "Rio Grande rift" since they include the parts of those provinces significant to the evaluation of probabilistic acceleration at the WIPP facility.

The general Algermissen and Perkins model, then, consists of three sources:

- The Rio Grande rift zone drawn by combining the western source zones as discussed above.

- The Central Basin Platform zone as shown in Figure 2.5-26.

- A WIPP site source zone centered at the site to model background seismicity in the High Plains. The manner in which the irregular Algermissen and Perkins source zones are adapted to the quadrilateral source zone configuration, which is required for the application of the seismic risk analysis method as discussed above, is straightforward (Figure 2.5-25).

For the purposes of this study, some minor modifications of the Algermissen and Perkins source zones were made. Geologic and tectonic evidence suggests that the physiographic boundary between the Basin and Range and Great Plains provinces provides a good and conservative approximation of the source zones as discussed in Sections 2.5.2 and 2.5.3. In addition, refined information from the Kermit array[15] indicates that the geometry used to model the limits of the Central Basin Platform source zone may be modified somewhat from the original preferred model for the WIPP site region seismic source zones in this study. This model is preferred because it is based more completely on consideration of geologic and tectonic information, as well as seismic data, and because it results in more conservative development of risks at the WIPP facility.

There is one purely geometrical issue to be resolved. It involves specifying a focal depth for events in each of the model source zones. There is little doubt that the focal depths of earthquakes in the WIPP facility region should be considered shallow. Early instrumental locations were achieved using an arc intersection method employing travel-time-distance curves calculated from a given crustal model, and the assumption of focal depths of five kilometers, 10 kilometers, or for later calculations, eight kilometers. Good epicentral locations could generally be obtained under these assumptions.

Within the range discussed, (that is, focal depths to 10 kilometers) the issue of selecting a proper depth for the probabilistic acceleration analysis at the WIPP site may be shown to be important only in the site source zone itself. For example, the difference in hypocentral distance (the distance to be used in the acceleration attenuation formula) for a closest approach event in the Central Basin Platform is only 1.05 kilometers in this depth range, assuming that the closest approach of this source zone is 35 kilometers as indicated by Figures 2.5-25 and 2.5-26. This is clearly the greatest difference of this kind outside the WIPP facility source zone. Within the WIPP facility source zone the selection of focal depth can be very important simply because the form of the attenuation law used asymptotically approaches infinite acceleration at very small distances. This is certainly not mechanically realistic and is not the intent of the empirical fitting process to an attenuation law of this form. A focal depth of five kilometers is used in all source zones of this study including that of the site. For smaller hypocentral distances, the form of the attenuation law adopted here severely exaggerates the importance of very small, very close shocks, in the estimation of probabilistic acceleration at the WIPP site (Figure 2.5-22).

2.5.4.2 Source Zone Recurrence Formulas and Maximum Magnitudes

The risk calculation procedure used in this study requires that earthquake recurrence rates for each seismic source zone be specified. This is done formally by computing the constants "a" and "b" in the equation,

$$\log N = a - b\,M$$

where N is the number of earthquakes of magnitude greater than or equal to M within a specified area occurring during a specified period.

For the WIPP facility region, three formulas of this type are needed—one for the active province west and southwest of the site (the Basin and Range subregion or Rio Grande rift source zone), another for the inactive province of the WIPP facility exclusive of the Central Basin Platform (the Permian Basin subregion or background source zone), and a final one for the Central Basin Platform. In practice, the difficulties in finding meaningful recurrence formulas for such small areas in a region of low historical earthquake activity are formidable.

Several estimates of recurrence rates in the WIPP facility region have been published.[1,14,21] For earthquakes within 180 miles (290 km) of the WIPP facility, exclusive of shocks from the Central Basin Platform and aftershocks of the 1931 Valentine, Texas earthquake, Sanford and Toppozada[1] find recurrence formulas of the form:

$$\log N_O = 1.65 - 0.6\,M_L$$

using instrumental data only, and

$$\log N_O = 1.27 - 0.6\,M_L$$

using both historical and instrumental data. In these and following recurrence formulas in this section, M_L is the Richter local magnitude and N_O is the number of earthquakes in the area of interest normalized to a time period of one year and an area of $3.6x10^4$ $miles^2$ (9.3 x 10^4 km^2).

Because the numbers of shocks used to establish the linear portions of these curves are very small (16 and 25, respectively), and the total time intervals over which data were collected are very short (11 and 50 years, respectively), an error in the slope (or b value) is quite possible. In fact, a certain dissatisfaction with these results on the part of Sanford and Toppozada[1] is indicated by their development of alternative curves defined to have a slope of 1.0 instead of 0.6. To the problems imposed by the spatially and temporally restricted data set available must be added the fundamental uncertainty associated with the definition of magnitude in the WIPP facility region. However, Sanford et al.[3] indicate that data collected since the Sanford and Toppozada[1] study of 1974 do not change any of the original conclusions regarding the magnitude, location, and recurrence intervals of major earthquakes within 180 miles of the WIPP facility.

Recent work[14] allows a preliminary treatment of the data. This work is based on 11 years of instrumental seismicity data which have been reinterpreted with respect to magnitude. In addition, recurrence formulas are computed for broad physiographic regions of New Mexico vastly increasing the data base. For example, Sanford et al.[14] find

$$\log N_O = 2.4 - 1.0\ M_L$$

for the High Plains physiographic province of the Permian Basin subregion or background source zone, and

$$\log N_O = 2.5 - 1.0\ M_L$$

for the Basin and Range - Rio Grande rift region. The b value in these equations is further substantiated by very recent work[44] in which all instrumental data on New Mexico earthquakes from 1962 through 1977 has been considered. The general criterion used in this earthquake risk analysis for the Rio Grande rift/Basin and Range subregion and Permian Basin/background source zones is the Sanford et al.[14] recurrence formula for the physiographic province. For this recurrence formula, an individual source zone occurs with the "a" value scaled to reflect area difference. The area of the High Plains province of interest for this analysis is approximately a 60 mile (97 km) radius [1.2 x 10^4 $miles^2$ (3.1 x 10^4 km^2)] surrounding the WIPP facility, but exclusive of part of the Central Basin Platform. Thus, the proper recurrence formula for site area background seismicity becomes,

$$\log N_O = 1.93 - M_L \text{Site source zone.}$$
(background)

Similarly, the part of the Southern Basin and Range - Rio Grande rift region of interest has been referred to in the above discussion as the Algermissen and Perkins[22] Rio Grande rift source zone and has an area of about 4.1 x 10^4 $miles^2$ (1.1 x 10^5 km^2). The proper recurrence formula for the Algermissen and Perkins Rio Grande rift source zone becomes,

$$\log N = 2.56 - 1.0\ M_L.$$

The Basin and Range subregion as shown in Figure 2.5-19 has an area of about 6.4 x 10^4 mi^2 (6.4 x 10^5 km^2). Thus, the proper recurrence formula for the Basin and Range Subregion becomes,

$$\log N = 2.75 - 1.0\ M_L.$$

This leaves only the Central Basin Platform, which is treated somewhat differently. Although the initial formulas[14] above were developed for areas near 7.2 x 10^4 miles^2 (1.9 x 10^5 km^2) (with some increased confidence in their validity because of the relatively large areas of data collection), this cannot be done for the Central Basin Platform source zone because it is unique and of very limited area. Therefore, it cannot be treated as a scaled-down version of some broader region. Although recent work using data from the Kermit array[15] is available for this source zone, the recurrence formulation of Sanford et al.[2] is used in this risk analysis primarily for consistency in approach. Based on the seismicity detected in the Central Basin Platform since the installation of station CLN in April 1974, the cumulative number of shocks versus magnitude may be expressed as,

$$\log N_O = 3.84 - 0.9\ M_L.$$

If the active portion of the Central Basin Platform is assumed to have an area of 2.9 x 10^3 miles^2 (7.5 x 10^3 km^2) during this period,[2] the proper recurrence relation for the Central Basin Platform source zone becomes,

$$\log N = 2.74 - 0.9\ M_L.$$

Because the Central Basin Platform seismicity is so really limited, this same recurrence formula is used for all alternative geometric characterizations. This has the effect of maintaining a constant activity rate for the Central Basin Platform as an entity.

These are the primary recurrence relationships used in the current risk analysis for the WIPP site. However, whereas magnitudes as used in the site region attenuation law above, or in consideration of maximum magnitude for a given source zone below, are by definition Richter local magnitudes, M_L, the earthquakes used to determine the recurrence formulas have measured magnitudes crucial to formula development. Some apparent disagreement exists in how site region magnitudes should be computed, with some suggestion [15] that the local magnitudes determined by Sanford et al.[2] may be, in some sense, too low. In order to test the effect of this possibility, an alternate set of recurrence formulas is derived by incrementing the M_L values in the above relationships by 0.5, in general agreement with the suggested relation between a "corrected" magnitude[15] and the local magnitude of Sanford et al.[2] The effect of this process is clearly to increase the activity rate of all source zones.

The four formulas now become:

$\log N = 2.43 - M_{CORR}$	Site source zone (background)
$\log N = 3.06 - M_{CORR}$	Algermissen & Perkins Rio Grande rift source zone
$\log N = 3.25 - M_{CORR}$	Basin & Range subregion
$\log N = 3.19 - 0.9\ M_{CORR}$	Central Basin Platform

The final parameter to be determined before WIPP facility risk may be computed is source zone maximum magnitude. A simple consideration of maximum historical magnitude within each of the three general source zones is not conservative. This is particularly true of the northern part of the Rio Grande rift source zone (Zone 43 of Algermissen and Perkins[22]) where a maximum historical intensity of only V is known. As discussed above, the fault scarps in these areas, particularly along the margins of the San Andres and Sacramento mountains, imply that major earthquakes have occurred in this region within the past 5 x 10^5 years. The length of the faulting in these two areas [about 36 to 60 miles

(58 to 97 km)] suggests the possibility of earthquakes comparable in strength to the Sonoran earthquake of 1887.[1]

That Sonoran earthquake (M - 7.8) produced 50 miles (80 km) of fault scarp with a maximum displacement of about 28 feet (8.5 m) extending southward from the U.S. - Mexico border at about 109W longitude. Sanford and Toppozada[1] assume that a similar future event is possible west of a line whose location is in good general agreement with the eastern boundary of either the Rio Grande rift zone as shown in Figure 2.5-25, or the Basin and Range subregion as shown in Figure 2.5-26. This eclipses the more southerly Valentine, Texas earthquake, whose magnitude was about 6.4. For this analysis, a maximum magnitude event of 7.8 is assumed possible anywhere within the Rio Grande rift/Basin and Range subregion source zone.

The selection of maximum magnitude events for the WIPP facility source zone and the Central Basin Platform source zone is more difficult. Algermissen and Perkin[21] assign a maximum historical intensity of VI to the Central Basin Platform. This is presumably the earthquake of August 14, 1966 which has been assigned this intensity in United States Earthquakes 1966.[45] On the basis of this intensity and the empirical relationship of Gutenberg and Richter,[43] a maximum magnitude event of 4.9 has been selected for the Central Basin Platform by Algermissen and Perkins as appropriate for their probabilistic acceleration analysis. The magnitude scale was designed to give some indication of the elastic energy released at the earthquake source, and in this context a 4.9 value is almost certainly an exaggeration of the energy really released during that particular earthquake. This conclusion is based on both macroseismic and instrumental evidence. In addition, several magnitudes have been published for this earthquake (USCGS-3.4; Sanford et al.[2] - 2.5) which are substantially lower than the 4.9 value used by Algermissen and Perkins. As discussed above, the maximum historical magnitude in the Central Basin Platform source zone is probably between 3.0 and 4.0, even after uncertainty in magnitude calculation methods is considered.

The features of this source zone that might bear on its possible maximum magnitude are the lack of recent geologic evidence of tectonism and the high activity rate that may or may not be directly associated with secondary oil recovery efforts. Sanford and Toppozada[1] conjecture that the maximum magnitude might be 6.0 for this source zone, and in this study of risks, their example is followed for one set of calculations. Because this value may be exceptionally conservative, an alternative maximum magnitude of 5.0 is also considered.

With regard to the WIPP facility zone, there is even less indication that significant magnitude events are reasonably likely. There is no Quaternary fault offset,[46] and seismic activity is low. However, recent studies[17] show that some level of background seismicity must currently be considered for the site area if conservatism is to be served. Apparently, an earthquake that current best evidence indicates was tectonic in origin, and with a magnitude of 3.6 has, occurred within the site source zone itself, within about 40 kilometers of the WIPP facility. In addition, the June 16, 1978 event with an approximate magnitude of 4.4 occurred within the Permian Basin subregion although near its extreme eastern margin. That event may have been induced by secondary oil recovery operations. Two maximum magnitudes are considered for the WIPP facility source zone in the risk analysis of this section: 4.5, that is, maximum historical event near the site of tectonic origin plus about one magnitude unit; and 5.5, the maximum event recorded anywhere within the Permian Basin subregion, plus about one magnitude unit.

2.5.4.3 Calculation of Risk Curves

Risk Curves for the WIPP facility calculated using the McGuire[35] formulation are presented in this section; first for individual model WIPP facility region source zones, and then for a few illustrative combinations of risks from all source zones in the WIPP facility region to form total WIPP facility risk curves. In particular, a set of curves is calculated for the WIPP facility source zone, another set for the Central Basin Platform and a third set for the Basin and Range or Rio Grande rift source zone to the west of the site. With a presentation of this type, the effect of earthquake source parameter variation may be explored source by source, and the inherent complexity of the broad spectrum parameter approach is thereby somewhat compartmentalized. The strength of the broad spectrum approach is that it allows an objective (although not precisely formulated) estimate of the uncertainty in risk values associated with given peak accelerations under the suite of possible geologic and seismic assumptions discussed above.

For the Basin and Range subregion or the Rio Grande rift source zone, two geometries (Figures 2.5-23 and 2.5-26) and two recurrence formulas (Section 2.5.4.2), but only one maximum magnitude are considered. Thus, a total of four risk curves, for this general source area to the west of the site, are presented in Figure 2.5-27. The specific parameters associated with each of the four curves are listed in Table 2.5-4.

In the case of the Central Basin Platform source zone, three geometries (Figures 2.5-23 and 2.5-26), two maximum magnitudes, and two recurrence formulas are considered, so that a total of 12 risk curves are implied. However, preliminary calculations for the Central Basin Platform source zone as suggested by recent seismicity (Central Basin Platform source zone is outlined by heavy dashed lines in Figure 2.5-26) show that risks from this particular model of the Central Basin Platform source zone geometry are generally less at low accelerations and much less at higher accelerations than those derived from the two alternative geometries for given maximum magnitude and recurrence formula conditions. For example, considering the case of a maximum Central Basin Platform source zone with a magnitude of 6.0 , and a recurrence formula of the form $\log N = 3.19\text{-}0.9\ M_{CORR}$ annual risks of $3.07\text{x}10^{-3}$, $6.80 \text{ x } 10^{-3}$, and $1.50\text{x}10^{-3}$ at the 1.3 ft/s^2 (40 cm/s^2) acceleration level and $5.89\text{x}10^{-4}$, $1.46\text{x}10^{-3}$ and $3.67\text{x}10^{-5}$ at about the 2 ft/s^2 (60 cm/s^2) acceleration level are computed at the site using the Algermissen and Perkins,[21] Central Basin Platform geology and recent Central Basin Platform seismicity suggested source geometries, respectively. Thus, the four risk curves for the seismically implied Central Basin Platform source geometry as shown in Figure 2.5-26, in association with the two maximum magnitudes and recurrence formulas for this source zone discussed above, cannot produce the most conservative estimation of risk at the WIPP facility. Because of the way risks from various source zones are combined to derive total risk curves, the do not lead to significantly lower estimates of total WIPP facility risks than those obtained using the Algermissen and Perkins geometry, given the particular form of the individual source zone risk curves in this study. Therefore, risk curves corresponding to the two alternative geometries are shown in Figure 2.5-28.

Finally, two maximum magnitudes and two recurrence formulas are considered for the background seismicity of the site source zone. The four risk curves thereby implied are shown in Figure 2.5-29. To aid in the task of keeping the assumptions underlying all these curves accessible, the parameters associated with each curve in Figures 2.5-27 through 2.5-29 are listed in Table 2.5-4.

The effects of varying the maximum magnitude within a given source zone are straightforward, although the details of these effects at the WIPP facility depend on the specific source-site geometric configuration. The general effect of increasing the maximum magnitude in any source zone is to increase the maximum acceleration at the WIPP facility attributable to that source zone, and to increase the WIPP facility risks from that source zone at all lower acceleration levels. In the case of the Central Basin Platform source zone, increasing the maximum source magnitude from 5.0 to 6.0 has the effect of increasing the WIPP facility risk from this source by a factor of 12.7 for the case of the Algermissen and Perkins[21] geometry, and about 18.5 for the geologically suggested source geometry at the 40 cm/s^2 acceleration level. This may be seen by comparing curves (1,2), (3,4), (5,6), and (7,8) of Figure 2.5-28. At low risk levels, the asymptotic approach of the lower maximum magnitude curves (the odd numbered curves of Figure 2.5-28) to an acceleration of just under 1.6 ft/s^2 (50 cm/s^2), and of the higher maximum magnitude (or even numbered) curves to an acceleration of about 3.94 ft/s^2 (120 cm/s^2), is clear. Very similar behavior is exhibited in Figure 2.5-29 for the background seismicity of the WIPP facility source zone. In this case, the ratio of site risks at the 1.3 ft/s^2 (40 cm/s^2) acceleration level due to curves generated using maximum magnitudes of 4.5 and 5.5 is 1.21, and somewhat over twice this at the 4.59 ft/s^2 (140 cm/s^2) level.

The effect of different recurrence formulas may be seen in any of Figures 2.5-27 through 2.5-29. As discussed above, the reason for considering different recurrence formulas is primarily to address the issue of uncertainty in the WIPP facility region magnitude determination, since the way in which magnitudes of recently recorded earthquakes are determined has a direct bearing on the form of the recurrence formulas derived for source zones in the WIPP facility region. In contrast, the maximum magnitudes specified for each of these source zones do not depend critically on calculated magnitudes, and therefore, are not dependent on the method of magnitude determination. For a given source zone geometry, maximum magnitude, and acceleration attenuation law, all risk curves approach the same maximum acceleration asymptote. The effect of any uncertainty in magnitude determination (acting through differences in recurrence formulas) is most noticeable at relatively higher risk levels. This may be seen by comparing curve pairs (1,2) or (3,4) in Figure 2.5-27, pairs (1,3), (2,4), (5,7) or (6,8) in Figure 2.5-28, or pairs (1,3) or (2,4) in Figure 2.5-29. For each of these risk curve pairs, the curves differ only in recurrence formula. The risk level at which convergence occurs for each of these pairs is clearly dependent on the risk level at which asymptotic behavior becomes evident under a given set of conditions. Convergence is not evident under the parameters used for the site source zone at the probabilities considered. For the two Central Basin Platform source zone geometries, convergence takes place at probabilities near 10^{-5} for a maximum source zone magnitude of 5.0, and at lower probabilities for the higher 6.0 maximum magnitude. This relatively simple behavior of curves from two different geometries occurs because the closest approach to the site is virtually identical for each of the two alternate Central Basin Platform source zones whose risk curves are platted in Figure 2.5-28. For earthquakes in the Basin and Range subregion or Rio Grande rift source zone, convergence is not evident at the lowest annual risk level calculated. For each of the cases discussed, different recurrence formulas lead to significantly different accelerations at risks lower than the convergence values. The final effect of parameter variation on the individual source zone risk curves has to do with the variation of the geometries of these zones. This effect is most easily seen in Figure 2.5-27 where effects of maximum magnitude variation do not occur. Curve pairs (1,3) and (2,4) in this figure differ only in source zone geometry characterization. The ratio of these curve pairs is not greatly dependent on risk level, being near 2.1, 3.4, and 2.6 for accelerations of 40, 80 and 3.94 ft/s^2 (120 cm/s^2), respectively. In both cases, risks from the Basin and Range subregion characterization are somewhat higher at a given acceleration level than those from the Rio Grande rift source zone of Algermissen and Perkins, because a slightly greater proportion of the Basin and Range subregion is closer to the WIPP facility, as may be seen by comparing Figures 2.5-25 and 2.5-26. For the Central Basin Platform source zone curve pairs (1,5), (2,6), (3,7), and (4,8) differ only by source geometry. The asymptotic convergence of these risk curve pairs closely approximates the behavior of convergence under recurrence formula variation discussed above, and at about the same risk levels for given maximum magnitude conditions. Again, variation is greatest at high risk levels. Ratios of risk levels for the curve pairs above are almost independent of the recurrence formula being 1.5 for curve pairs (1,5) and (3,7) and 2.2 for pairs (2,6) and (4,8) at the 1.3 ft/s^2 (40 cm/s^2) acceleration level.

In very general terms, increasing the maximum magnitude of any source zone using the recurrence formulas suggested by the magnitude calculation of Rogers and Malkiel,[15] or selecting the geology implied Central Basin Platform and Basin and Range subregion source zone geometries, has the effect of increasing site risk levels. Using these observations, several extreme WIPP facility risk curves are generated below.

Although much can be learned by considering each WIPP facility region source zone separately, several important issues cannot be addressed until total risk curves are generated combining the contributions from the individual source zones. The process is illustrated graphically in Figure 2.5-30. In this figure are shown the individual source zone curves for the Algermissen and Perkins[21] Central Basin Platform and Rio Grande rift zones (Figure 2.5-25) for maximum magnitudes of 6.0 and 7.8 respectively, and for the site source zone using a maximum magnitude of 5.5. In each case, the Sanford et al.[2] recurrence formulas are used. These are curve 2 of Figure 2.5-28, 1 of figure 2.5-27, and 2 of Figure 2.5-29. The total WIPP facility risk curve calculated by combining these three individual curves is shown as a solid light line in Figure 2.5-30. This particular total risk curve closely approximates the most conservative curve calculated in the WIPP Geological Characterization Report (Figure 5.3-6 of Reference 30, curve 4), except that a maximum WIPP facility source zone magnitude of 5.5 instead of 5.0 is used. One point is clear from Figure 2.5-31, under the assumptions used to calculate the source zone risks shown in this figure, the significance of the Rio Grande rift source zone to the total risk at the WIPP facility is relatively small at all acceleration levels. In fact, this is a general result for all combinations of source zone parameters considered. For the earthquake recurrence relationships considered for the various source zones, this will be true at lower acceleration levels no matter what assumptions are made about the maximum magnitudes in the WIPP facility and Central Basin Platform source zones. At higher acceleration levels, this will be true unless the lowest maximum magnitude proper for the WIPP facility source zone is lower than the 4.5 value considered here.

Note further that for the case considered in Figure 2.5-30, where 6.0 is the maximum magnitude event for the Central Basin Platform source zone, probabilities are largely controlled by earthquakes in this zone up to accelerations of around 0.04 g. For higher accelerations, the WIPP facility source zone is more important. The cross-over acceleration is clearly a function of the relative maximum magnitudes in the Central Basin Platform and WIPP facility source zones. For a lower maximum magnitude in the WIPP facility source zone relative to the Central Basin Platform source zone, the latter zone would be expected to dominate the WIPP facility total risk curve to higher acceleration levels. If the Central Basin Platform source zone maximum magnitude is lower relative to the WIPP facility source zone, its significance is totally eclipsed by the WIPP facility source zone at all acceleration levels. Perhaps the most obvious feature of the total risk curve of Figure 2.5-31 is its dominance by the WIPP facility source zone at higher accelerations. Consideration of different combinations of source zone parameters indicates that this feature of risk curves at the WIPP facility is universal for all cases derivable from the parameters considered. Therefore, if the probabilities at which these higher acceleration levels occur are thought to be of interest, it is the assumptions made about the immediate WIPP facility area that are most critical.

The question of total WIPP facility risk at a number of acceleration levels and under a number of assumptions about source zone parameters is addressed graphically in Figure 2.5-31, where several extreme cases are considered. Four curves in all are shown. Curves 1 and 2 both assume maximum source zone magnitudes of 7.8, 6.0, and 5.5 for the Basin and Range subregion (or Rio Grande rift), Central Basin Platform, and WIPP facility source zones, respectively, and recurrence formulas suggested by the Roger and Malkiel[15] magnitudes. That is, curve 1 of Figure 2.5-31 is the result of combining individual source zone risks at the WIPP facility represented by curve 4 of Figure 2.5-27, curve 8 of Figure 2.5-28, and curve 4 of Figure 2.5-29. Similarly, curve 2 of Figure 2.5-31 is the result of combining individual source zone risks at the site represented by curves 2 and 4 of Figures 2.5-27 through 2.5-29, respectively. The difference between curves 1 and 2 of Figure 2.5-31 is that curve 2 uses source zone geometries taken from Algermissen and Perkins,[21] while curve 1 uses the slightly more conservative alternate source zone geometries discussed in Section 2.5.4.2. Curves 3 and 4 of Figure 2.5-31 both assume smaller maximum source zone magnitudes of 7.8, 5.0, and 4.5 for source zones taken in the same order as above and recurrence formulas suggested by Sanford et al.[14] The individual risk curves used to generate these two total risk curves may be deduced from the above description and Table 2.5-4. The differences between curves 3 and 4 are precisely the geometric differences between curves 1 and 2.

It is clear from the four total site risk curves of Figure 2.5-31 that the geometric differences considered for the source zones do not introduce important differences in total WIPP facility risk at any acceleration level, although what small differences do exist are most evident at low accelerations. More importantly, for all parametric variations allowed in this study, extremum curves as shown in this figure imply accelerations associated with 10^{-3}/y risks ranging between about 1.31 and 2.46 ft/s^2 (40 and 75 cm/s^2), accelerations associated with 10^{-4}/y risks between 75 and 130 cm/s^2, and 10^{-5}/y risk accelerations between 4.27 and 8.04 ft/s^2 (130 and 245 cm/s^2).

2.5.5 Design Basis Earthquake

The stringent seismic criteria for nuclear power plants do not apply to the WIPP facility due to the unique character of the design and function of the facility. In particular, the terms "Operating Basis Earthquake" (OBE) and "Safe Shutdown Earthquake" (SSE) are not applied to the WIPP facility. Rather, the term "Design Basis Earthquake" (DBE) is used for the design of Class II and IIIA confinement structures and components (Section 3.2.7). As used here, the DBE is equivalent to the design earthquake used in Regulatory Guide 3.24 (U.S. Nuclear Regulatory Commission).[47] That is, in view of the limited consequences of seismic events in excess of those used as the basis for seismic design, the DBE is such that it produces ground motion at the WIPP facility with a recurrence interval of 1,000 years (Section 3.1.3). In practice the DBE is defined in terms of the 1,000-year acceleration and design response spectra.

The generation of curves expressing probability of occurrence or risk as a function of peak WIPP facility ground acceleration is discussed in detail in Section 2.5.4 for a number of possible characterizations of WIPP facility region source zones and source zone earthquake parameters. The most conservative (and the least conservative) risk curves are shown in Figure 2.5-31.

From this figure, the most conservative calculated estimate of the 1000 year acceleration at the WIPP facility is seen to be approximately 0.075g. The geologic and seismic assumptions leading to this 1000-year peak acceleration include the consideration of a Richter magnitude 5.5 earthquake at the site, a 6.0 magnitude earthquake on the Central Basin Platform, and a 7.8 magnitude earthquake in the Basin and Range subregion. These magnitudes correspond roughly to equivalent epicentral intensity events of VII, VIII and XI on the Modified Mercalli intensity scale.[8] These values, especially the first two, are considered quite conservative, and the other parameters used in the 0.075g derivation are also very conservatively chosen. For additional conservatism, a peak design acceleration of 0.1g is selected for the WIPP facility DBE. The design response spectra for vertical and horizontal motions are taken from Regulatory Guide 1.60 (U.S. Nuclear Regulatory Commission)[48] with the high frequency asymptote scaled to this 0.1g peak acceleration value. These response spectra are shown in Figures 3.2-2 and 3.2-3.

This DBE and the risk analysis that serves an important role in its definition are directly applicable to Design Class II and IIIA confinement structures and components at the WIPP Facility. Underground structures and components are Design Class IIIB and as such are not subject to DBE. Mine experience and studies on earthquake damage to underground facilities[49] show that tunnels, mines, wells, etc., are not damaged for sites having peak accelerations at the surface below 0.2g.

Design Class IIIB underground facilities do not require the consideration of seismic effects based on the above, and seismic load combinations with increased allowable stresses will not control the design.

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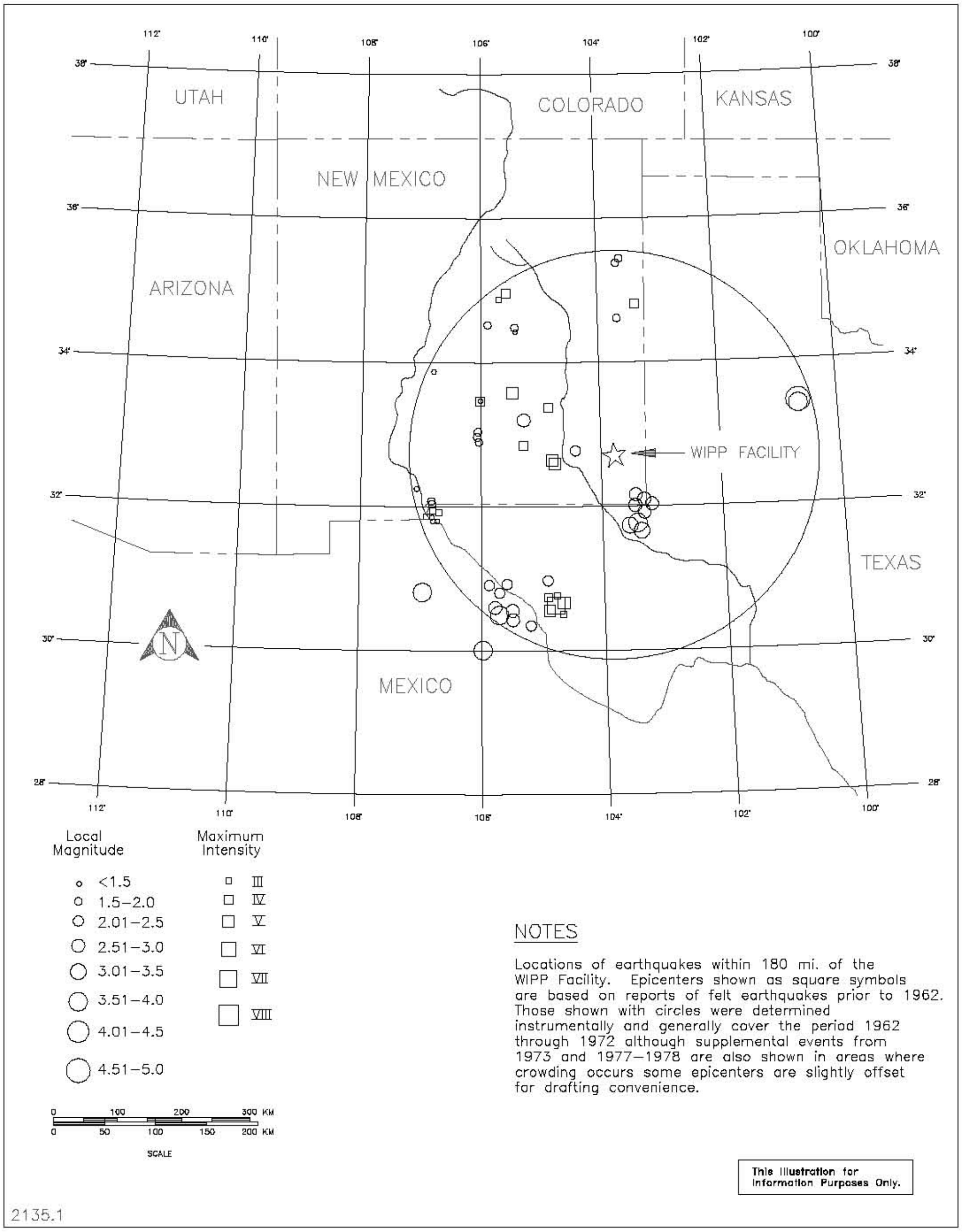

Figure 2.5-1, Earthquakes Located Using Macroseismic or Regional Seismographic Data 1923 - 1977

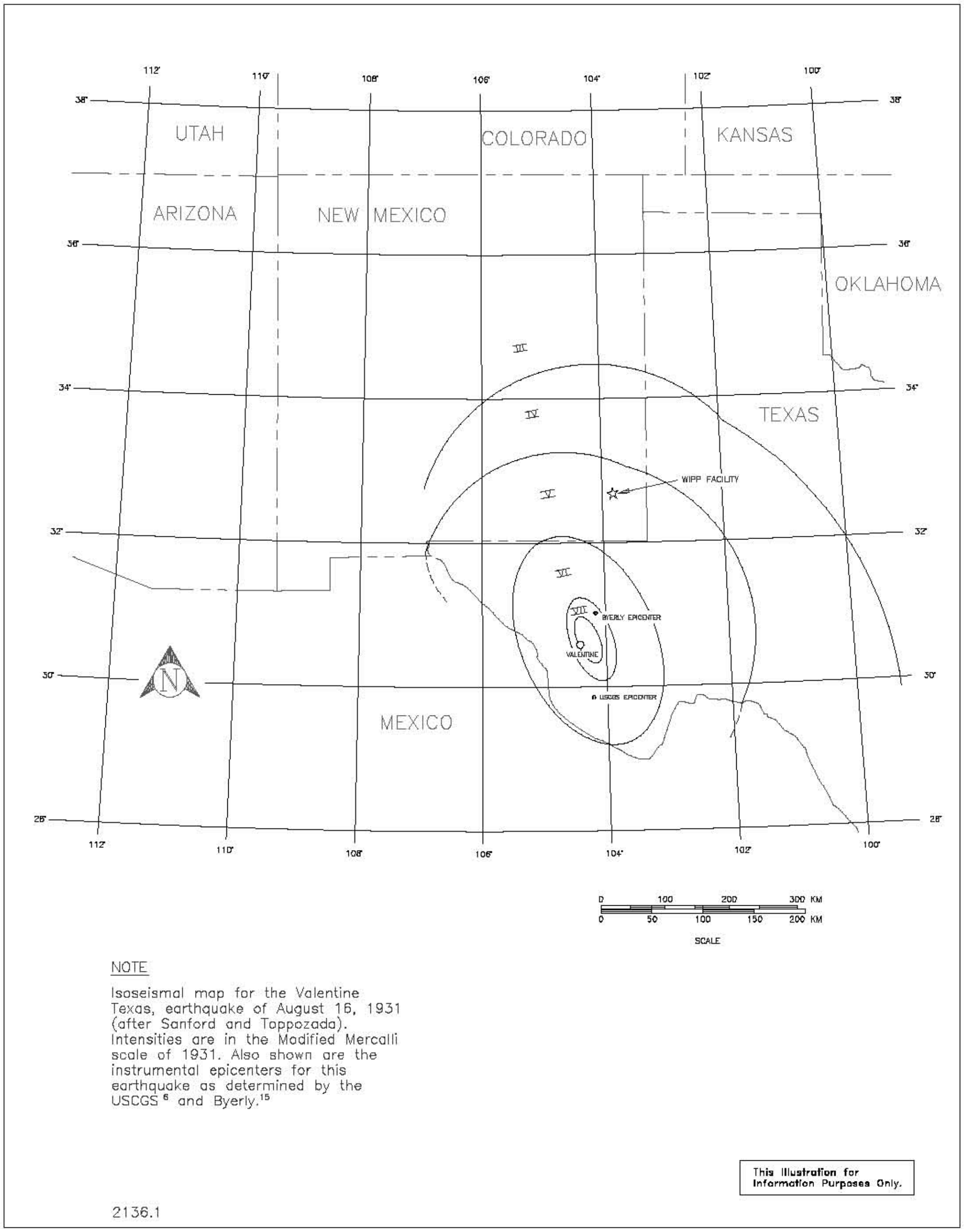

Figure 2.5-2, Valentine, Texas, Earthquake Isoseismals

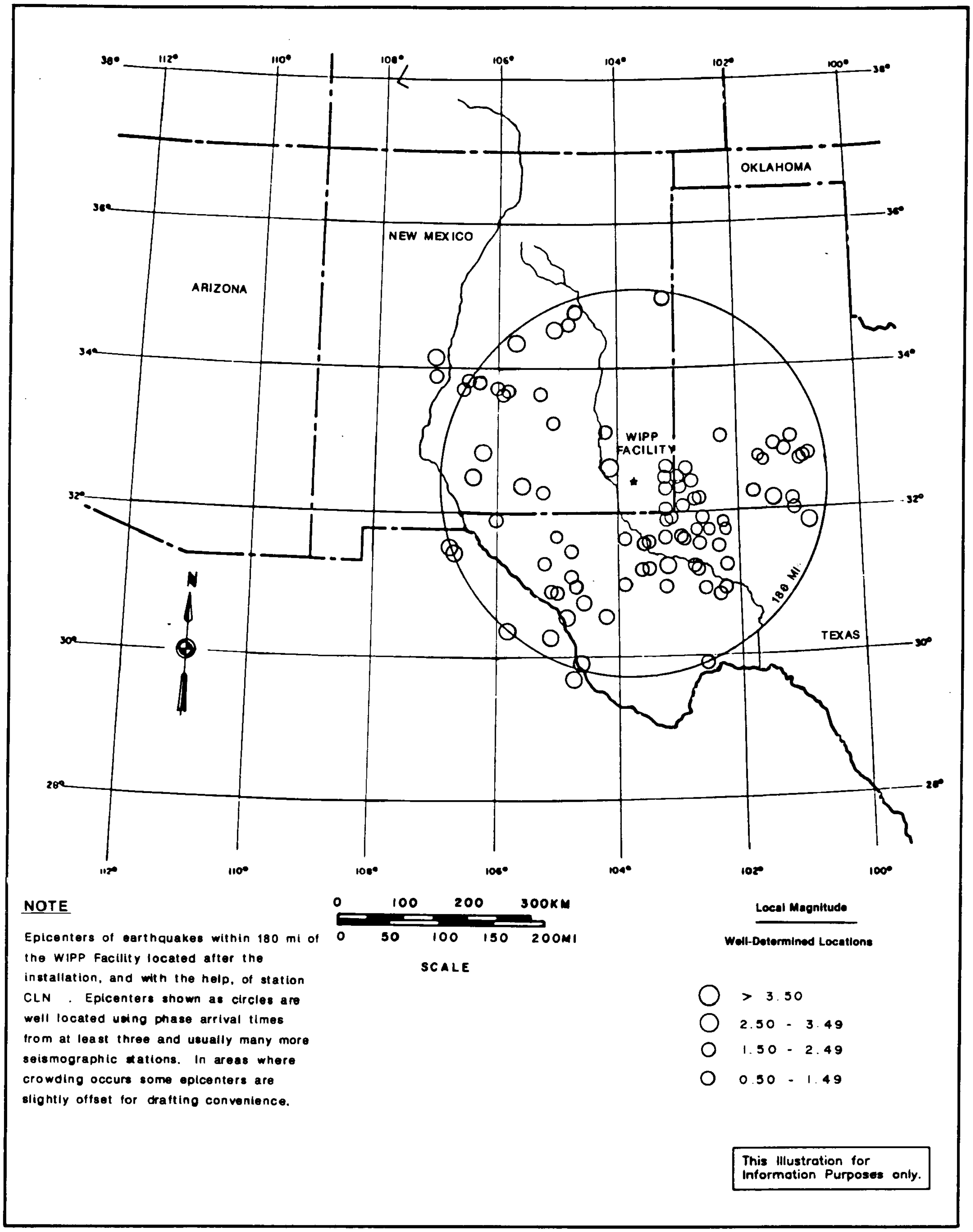

Figure 2.5-3, Earthquakes Located with the Help of Data from Station CLN(April 1974 - February 1979)

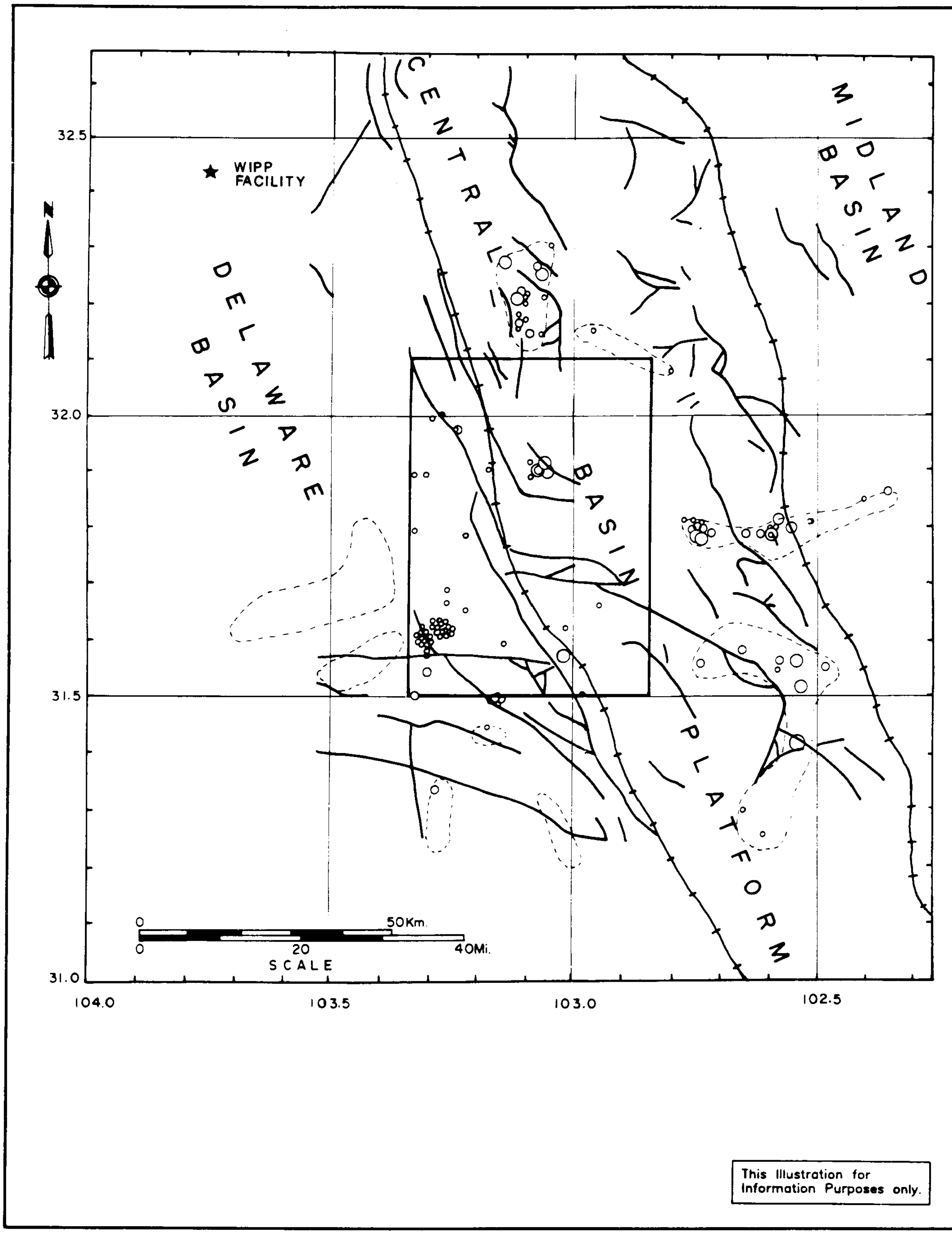

Figure 2.5-4a, Earthquakes Location Using Kermit Array Data November 1975 through July 1977

NOTE

Earthquakes located using the Kemit array network.[15]
All located events within the array (denoted by the small rectangular area in the map to the left and in the regional scale inset above) are shown, as well as those shocks on the array's periphery located by five or more array stations. The light dashed lines enclose peripheral epicenters whether or not they satisfy the five station criterion. Solid lines are pre-Permian faults, and the cross hatched lines the appro-ximate boundary of the Central Basin Platform, both after Rogers and Malkiel.[15] The regional location map below shows the total map area to the left as well as the Kermit array limits in a large scale context.

Magnitude (M_{LD})

- ∘ ≤ 2.35
- ○ 2.36–2.85
- ○ 2.86–3.35
- ◯ ≥ 3.36

2139.2

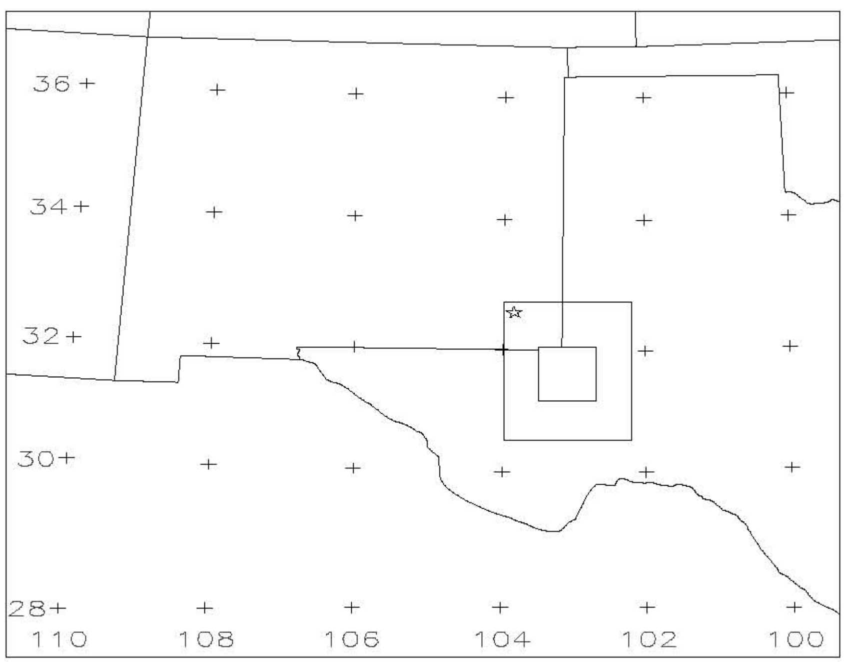

Figure 2.5-4b, Explanation to Figure 2.5-4a

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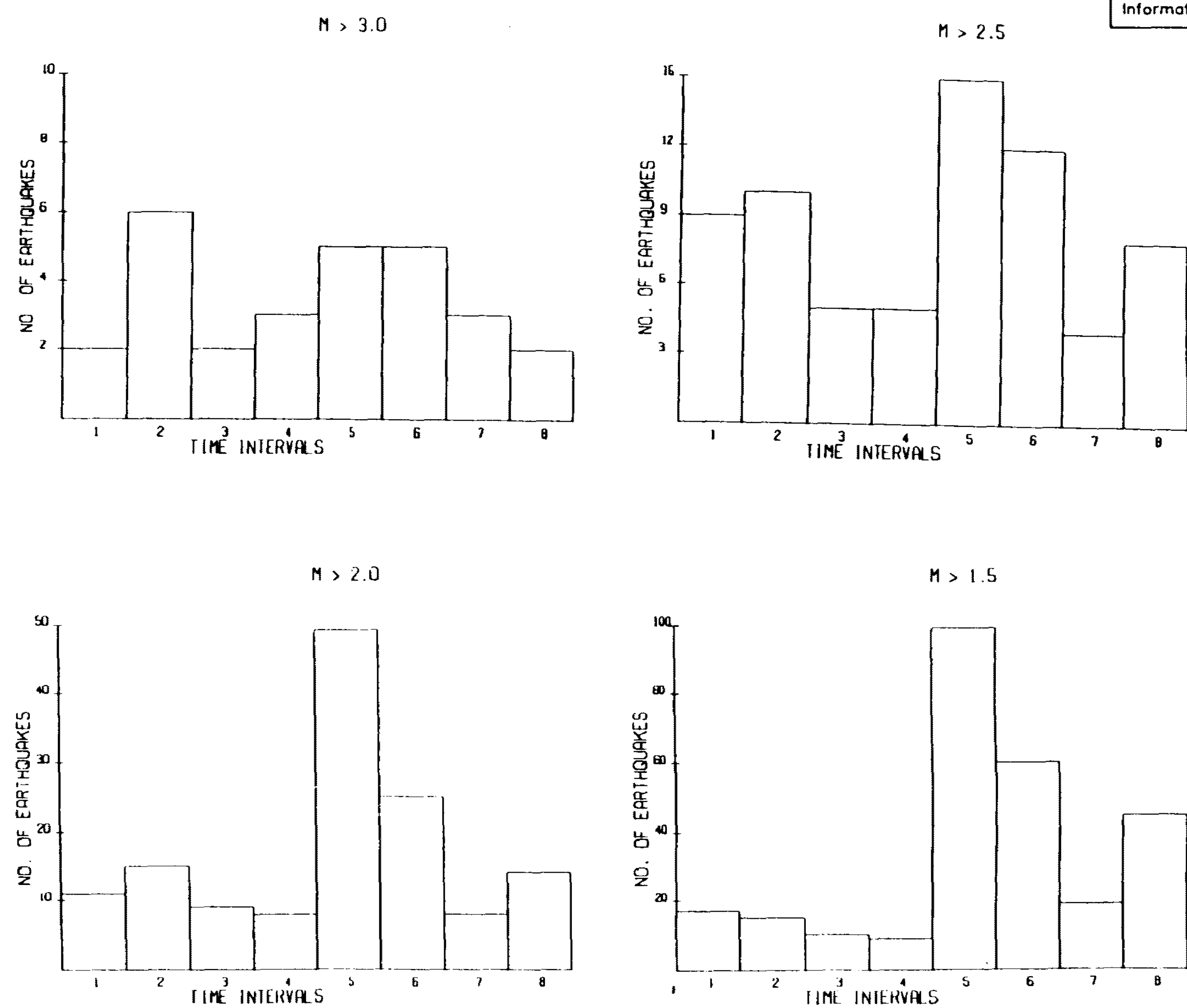


NOTE:

The 24 3/4 year period from 1 January 1962 through 30 September 1986 was divided into eight sequential intervals of 1130 days each. Shown in these four histograms are the numbers of events in each interval with M≥3.0, M≥2.5, M≥2.0 and M≥1.5.

Figure 2.5-5, Histograms of Number of Earthquakes: 1 January 1962 through 30 September 1986

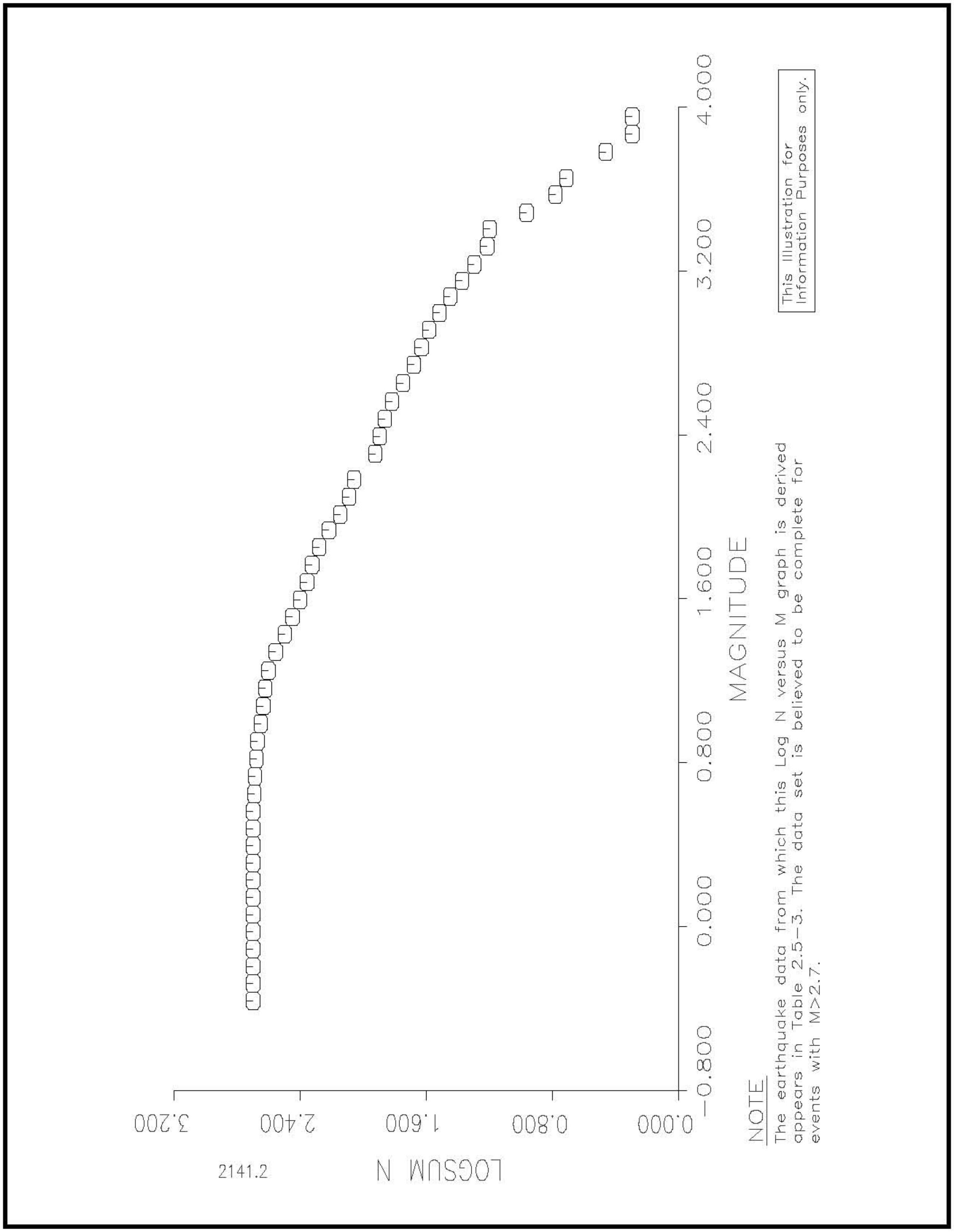


Figure 2.5-6, Earthquakes Recurrence Data (Log N versus M): 1 January 1962 through 30 September 1986

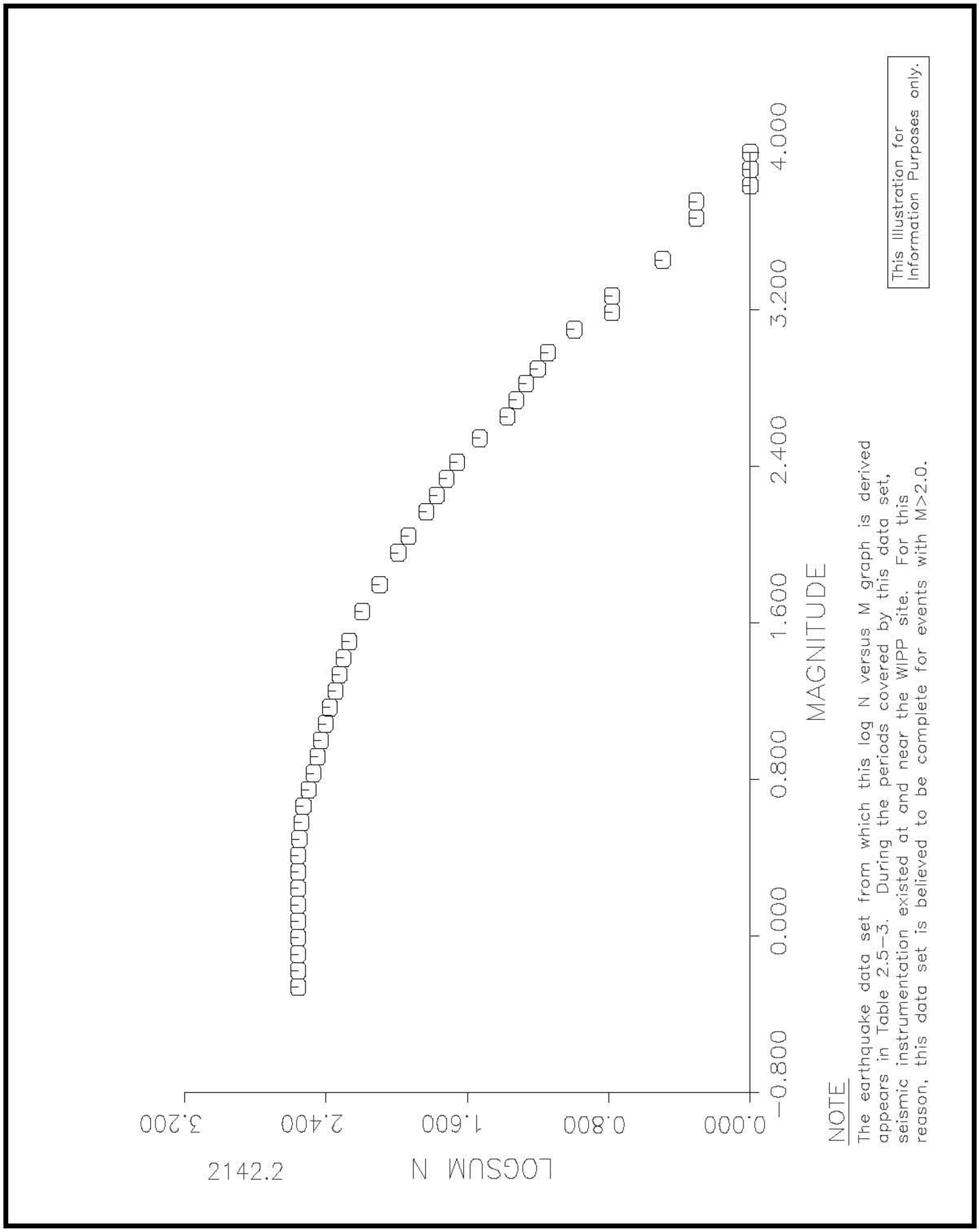


Figure 2.5-7, Earthquake Recurrence Data (Log N versus M): 18 May 1974 through 24 July 1980 and 29 August 1983 through 30 September 1986

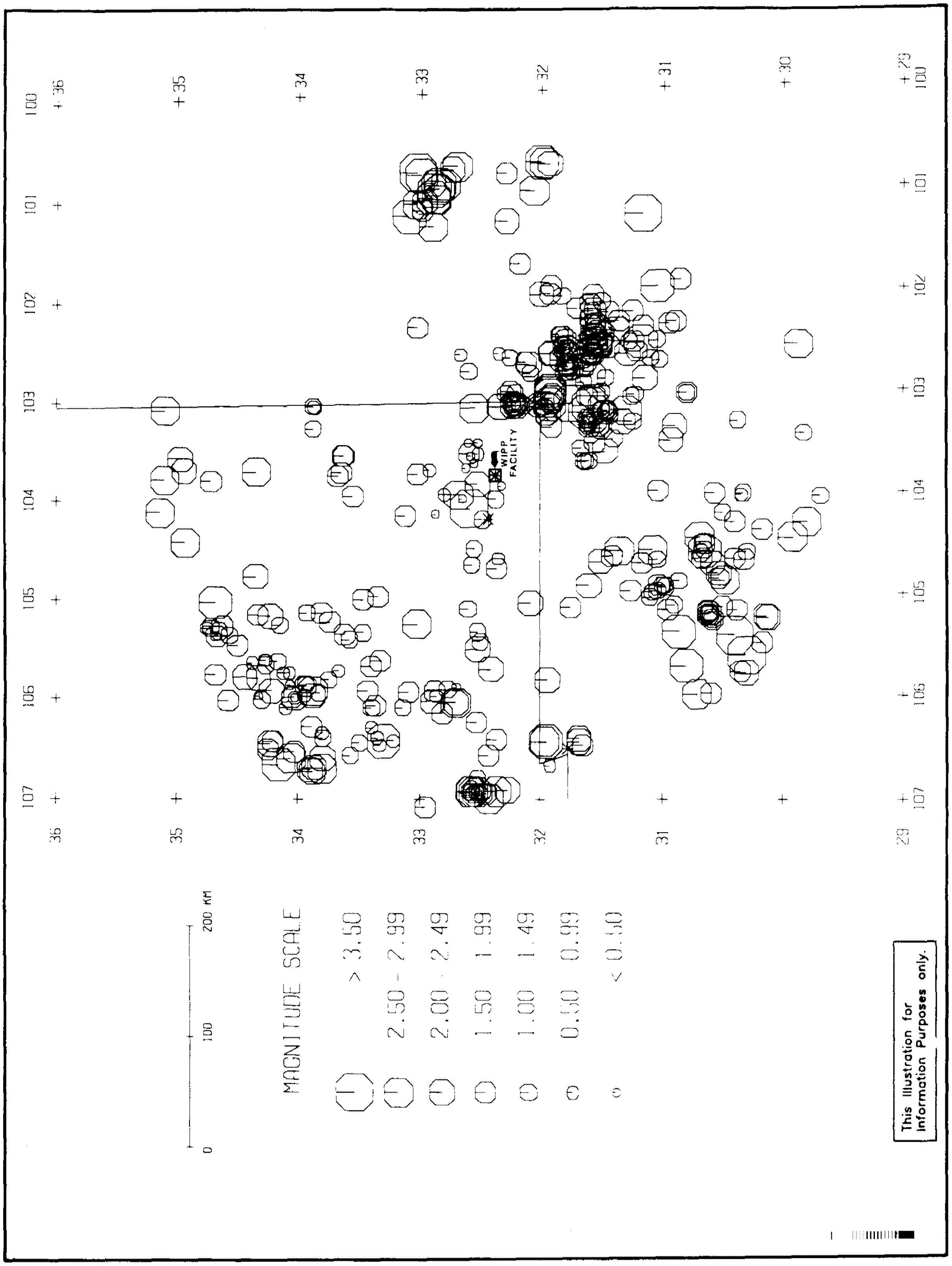


Figure 2.5-8, Epicenters for All Located Earthquakes: 1 January 1962 through 30 September 1986

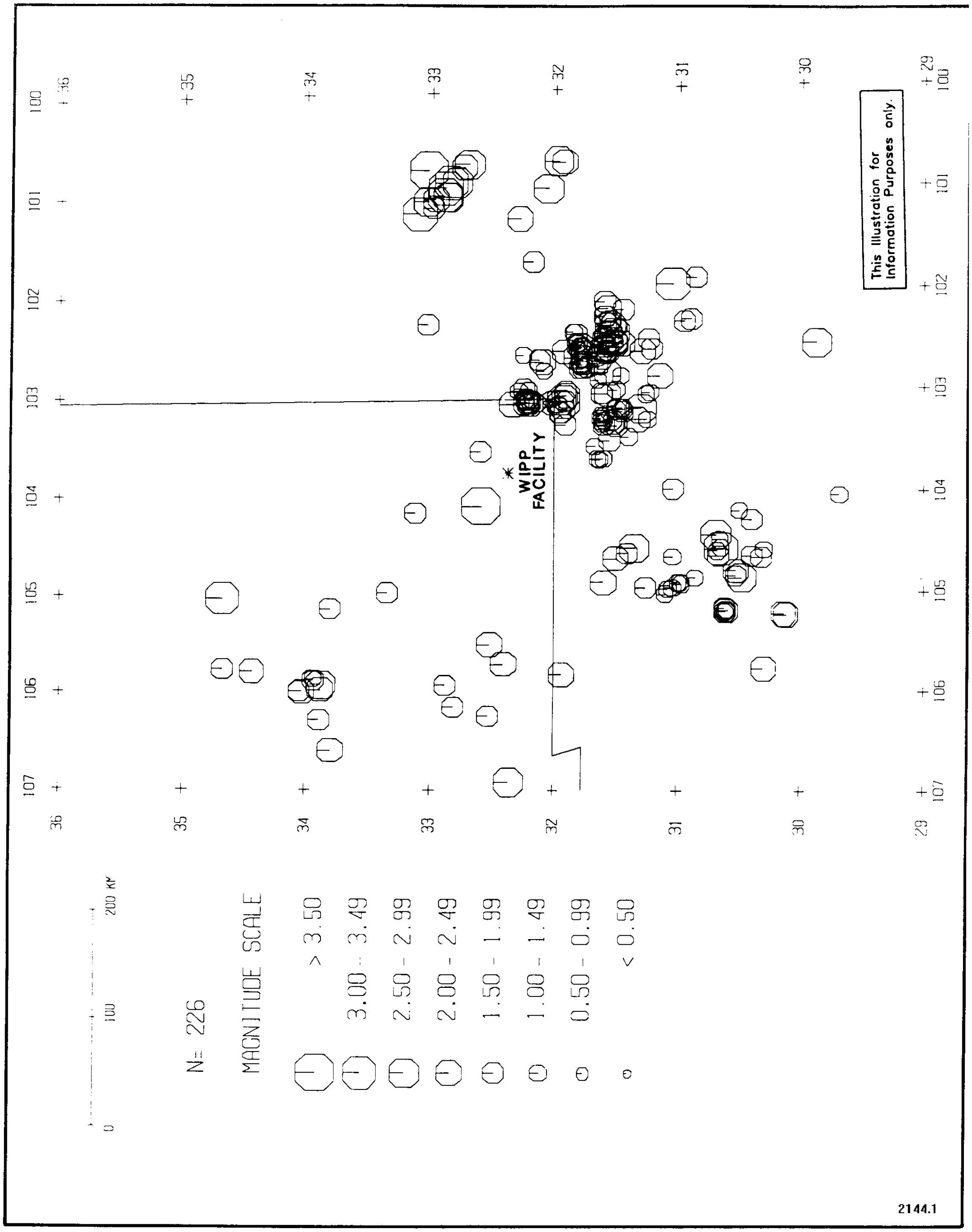


Figure 2.5-9, Epicenters for All Located Earthquakes: 5 April 1974 through 6 October 1978

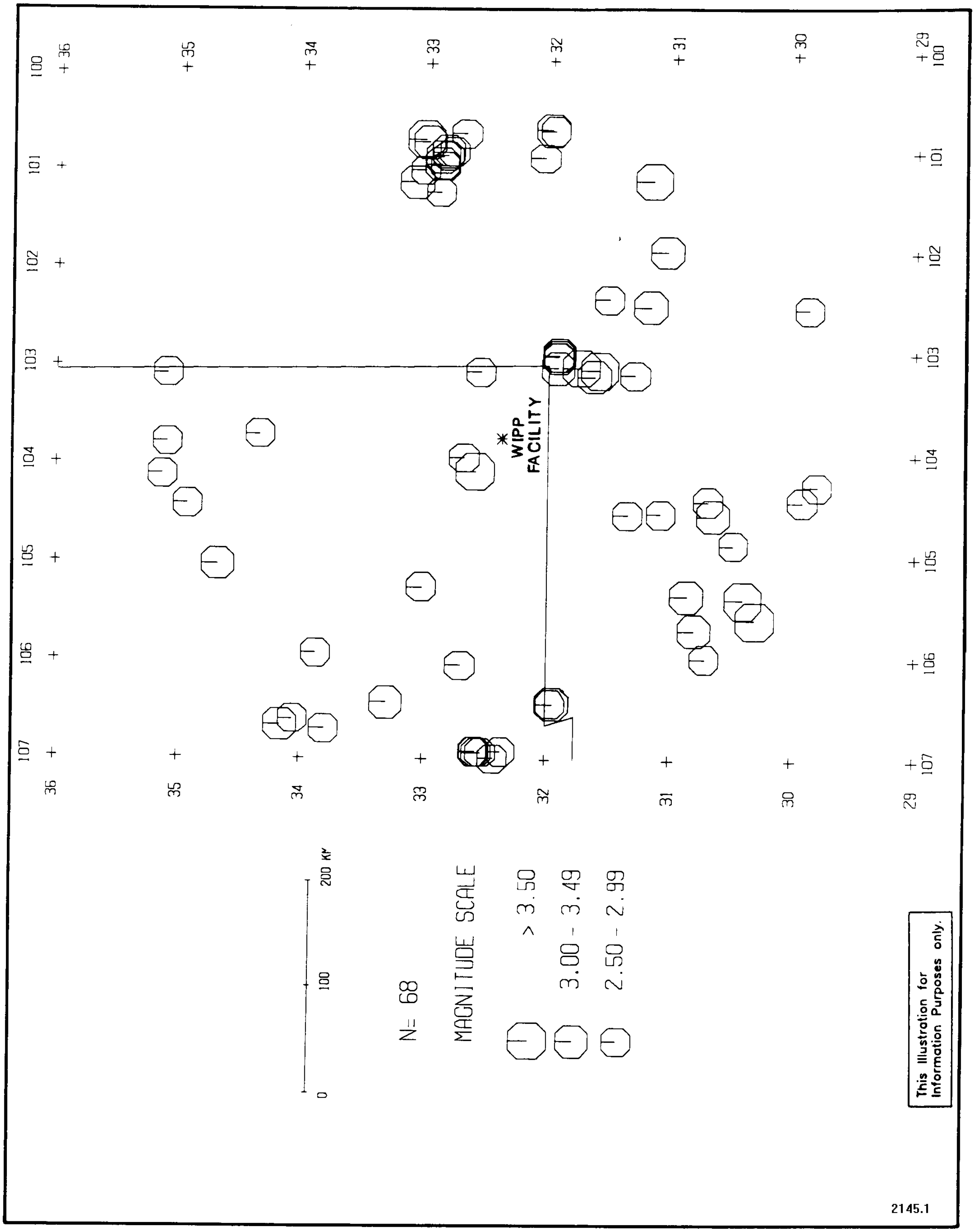


Figure 2.5-10, Epicenters for Located Earthquakes with M≥2.5: 1 January 1962 through 30 September 1986

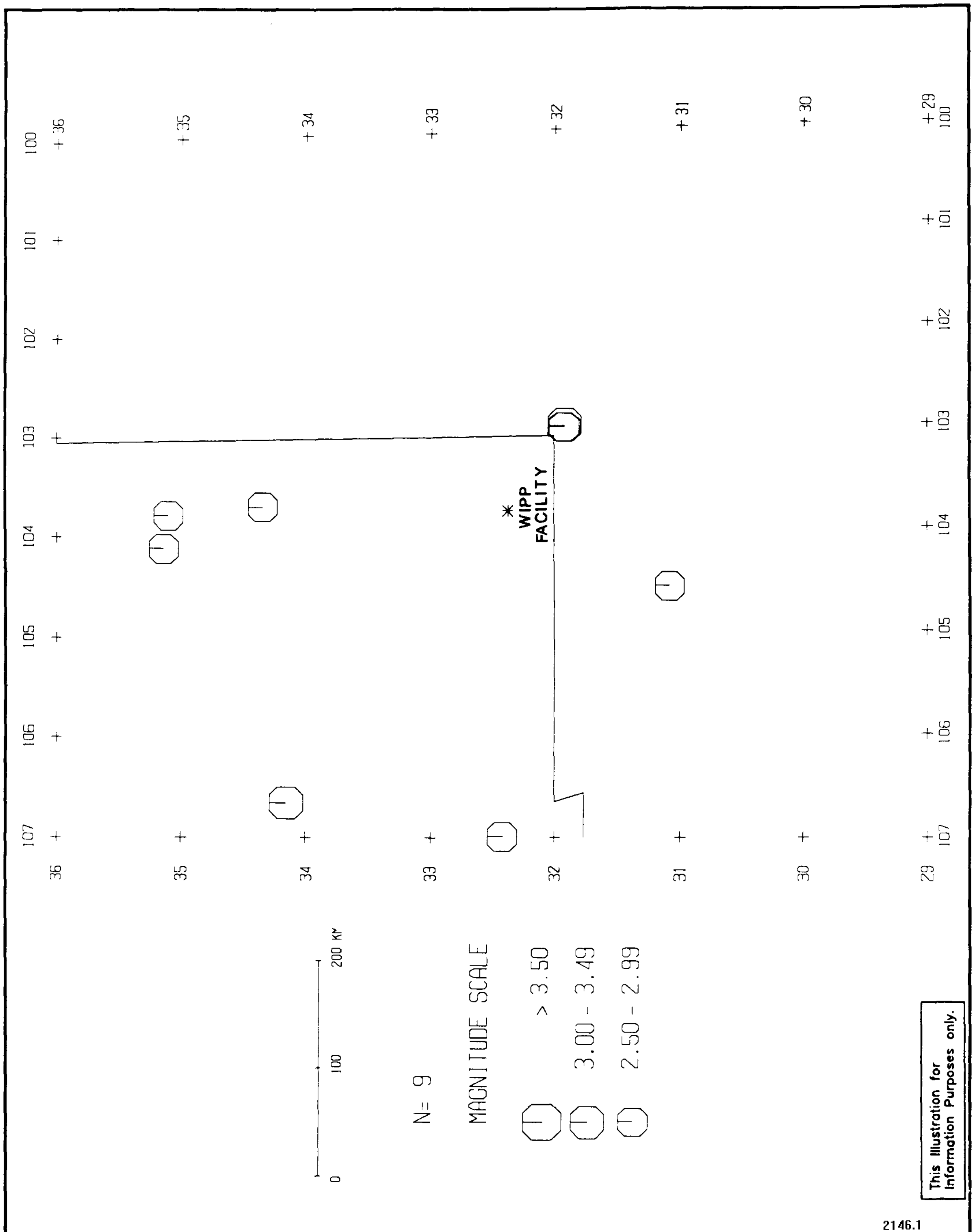


Figure 2.5-11, Epicenters for Located Earthquakes with M≥2.5: 1 January 1962 through 3 February 1965

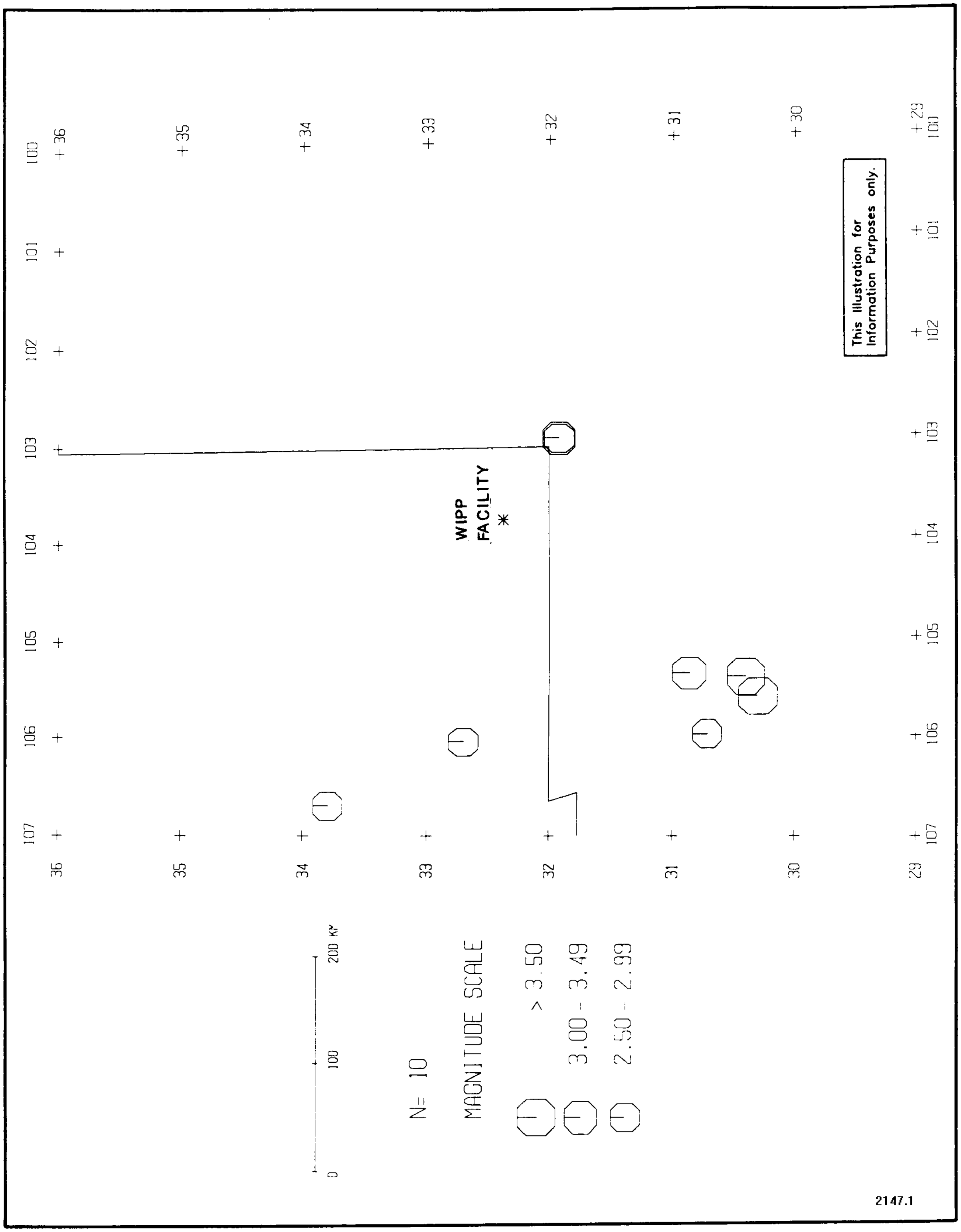


Figure 2.5-12, Epicenters for Located Earthquakes with M≥2.5: 4 February 1965 through 9 March 1968

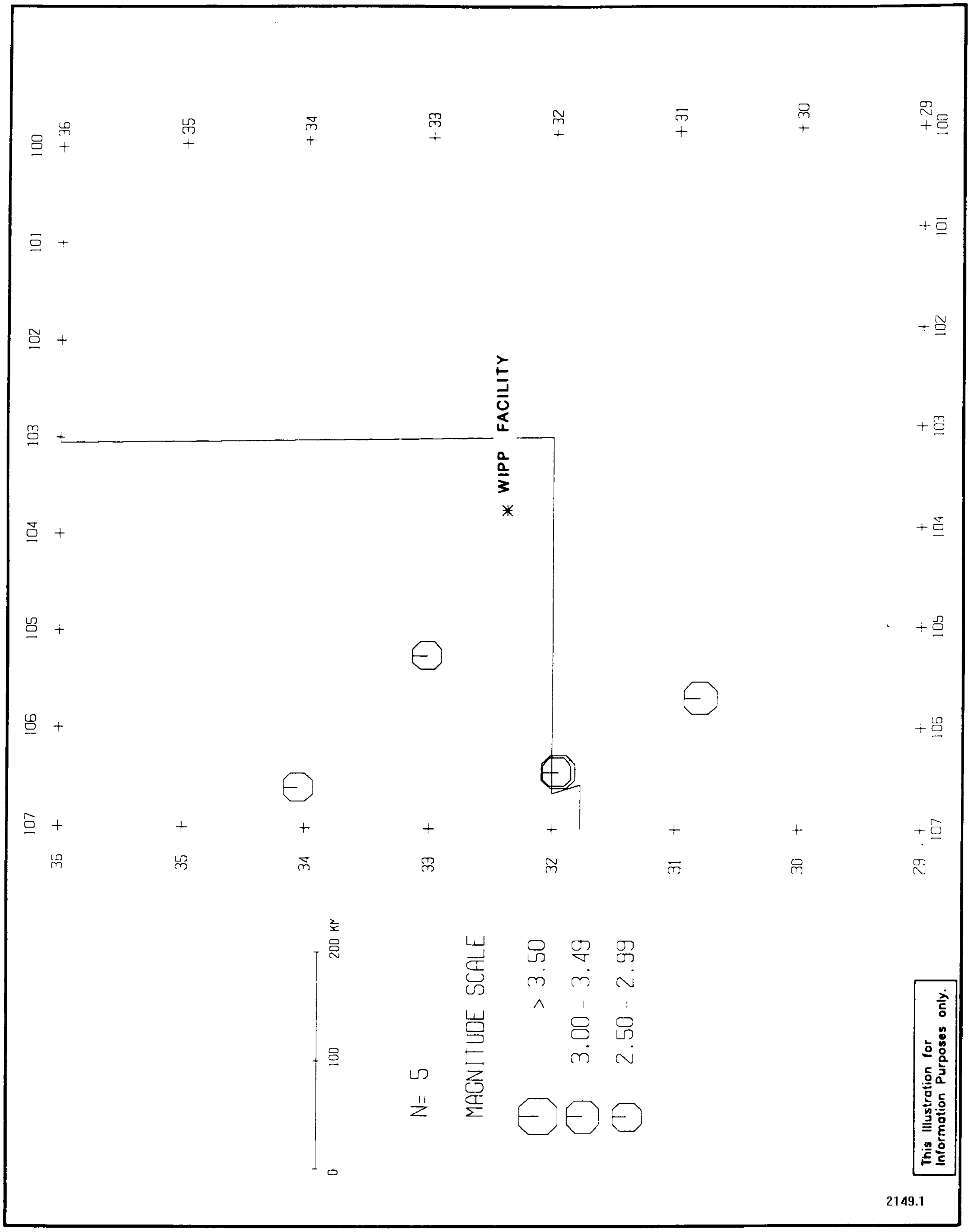


Figure 2.5-13, Epicenters for Located Earthquakes with M≥2.5: 10 March 1968 through 13 April 1971

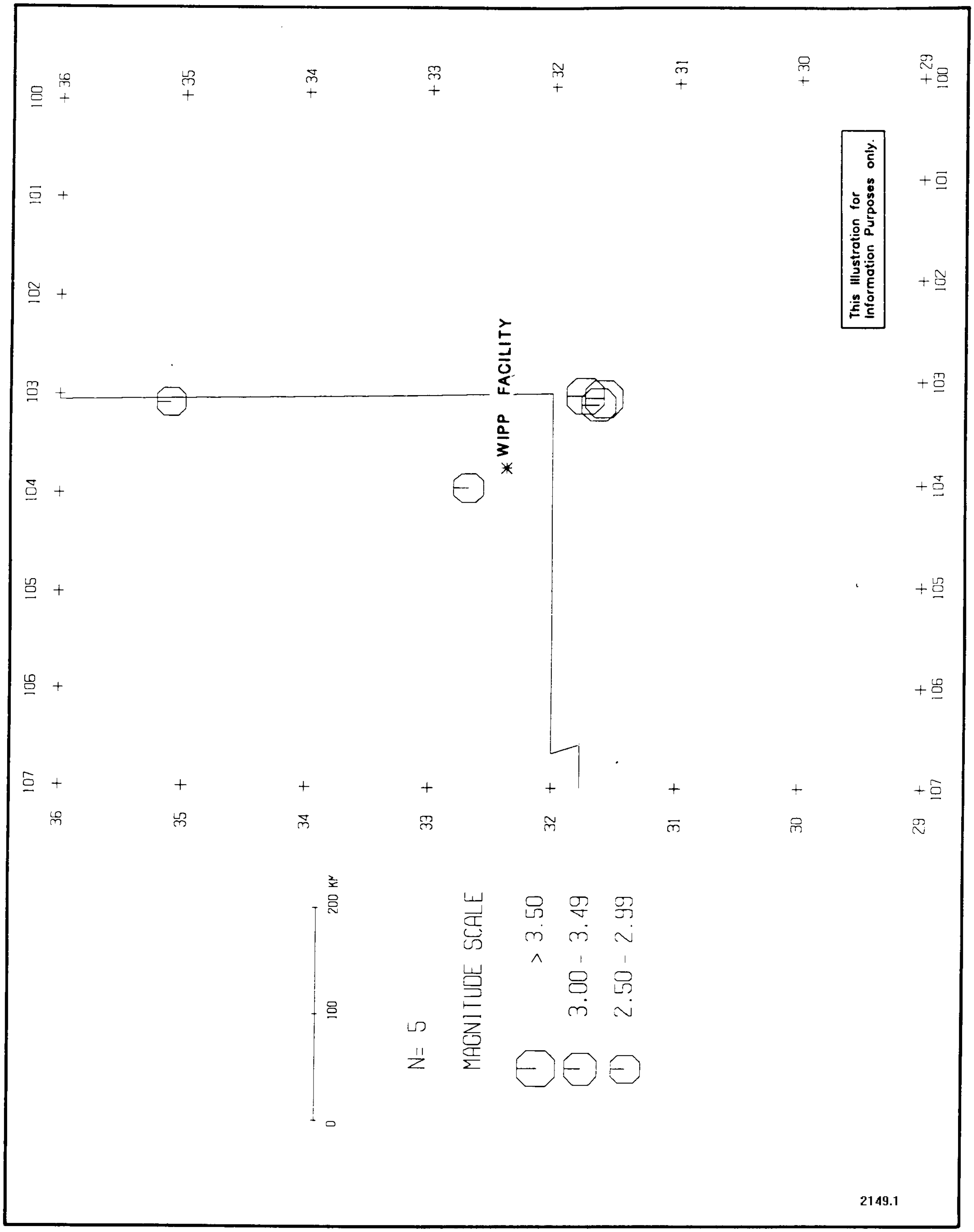


Figure 2.5-14, Epicenters for Located Earthquakes with M≥2.5: 14 April 1971 through 17 May 1974

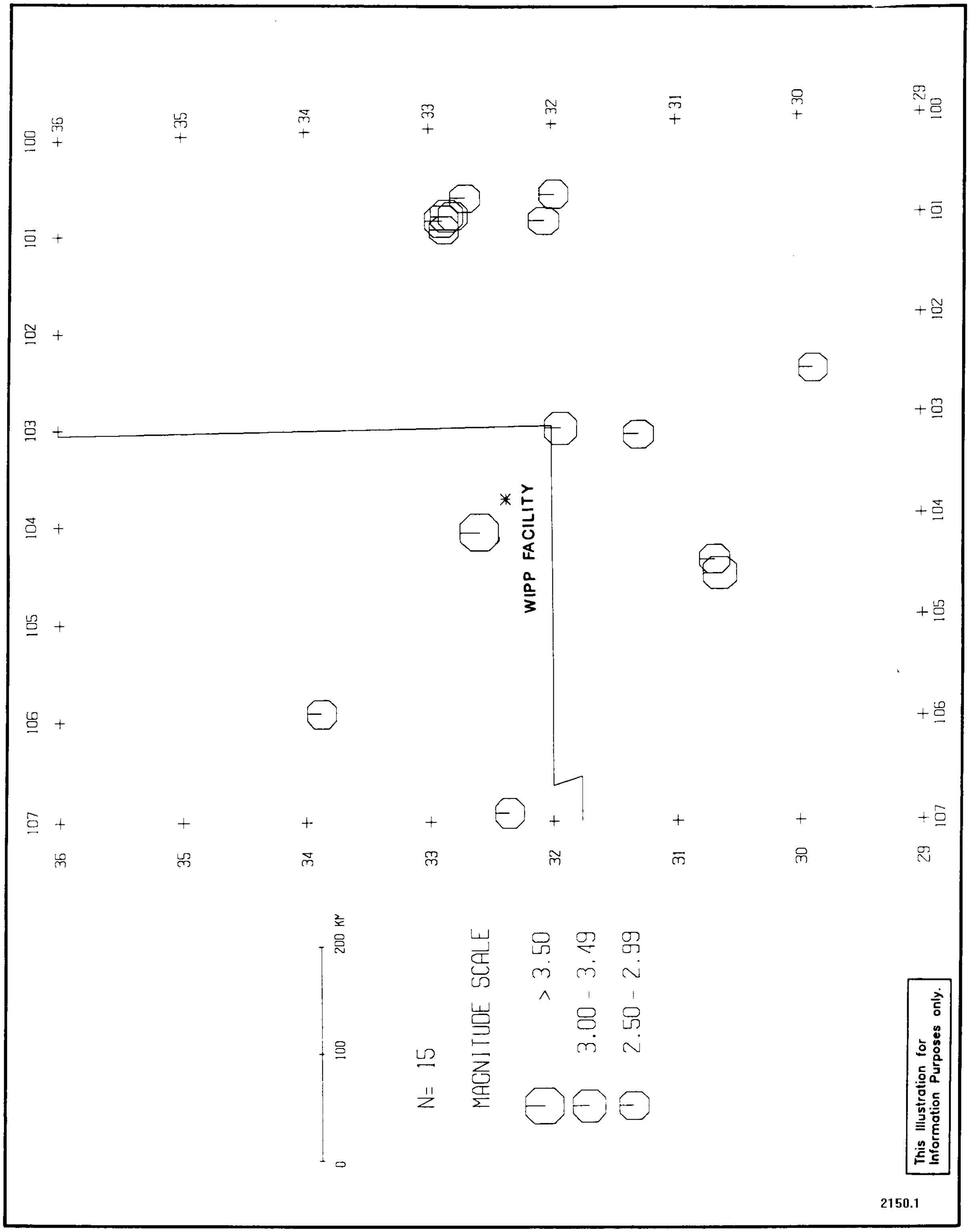


Figure 2.5-15, Epicenters for Located Earthquakes with M≥2.5: 18 May 1974 through June 21, 1977

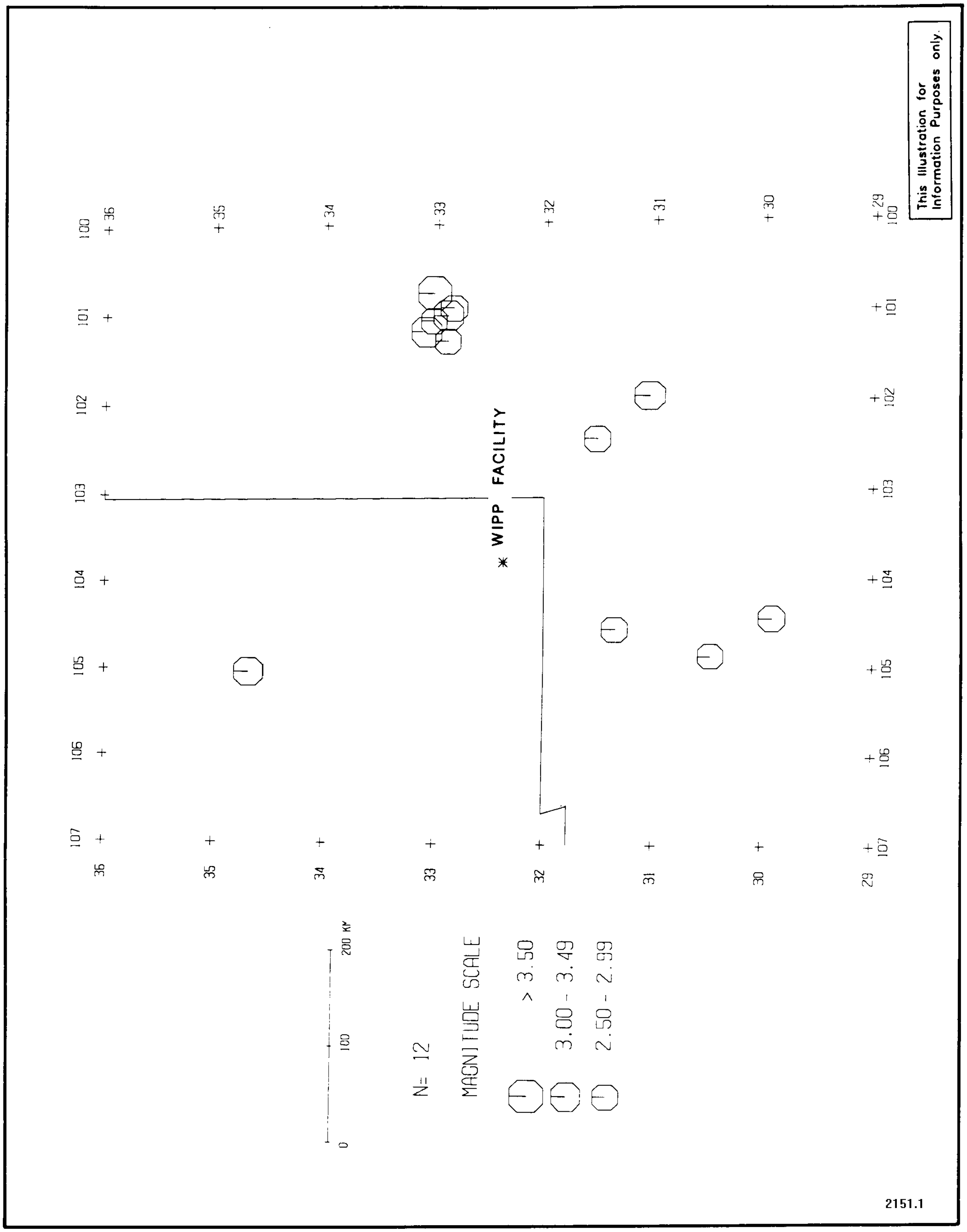


Figure 2.5-16, Epicenters for Located Earthquakes with M≥2.5: 22 June 1977 through 24 July 1980

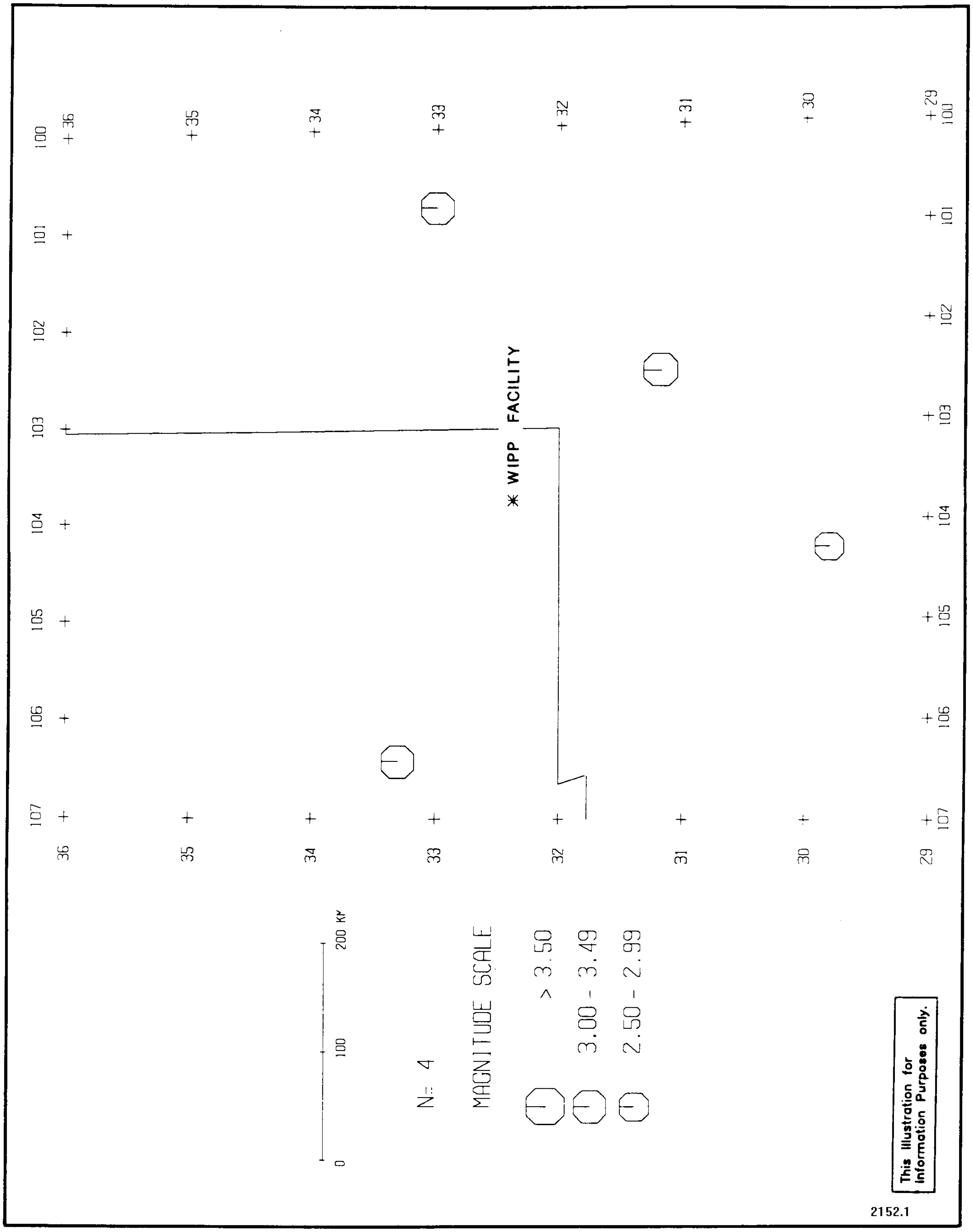


Figure 2.5-17, Epicenters for Located Earthquakes with M≥2.5: 25 July 1980 through 28 August 1983

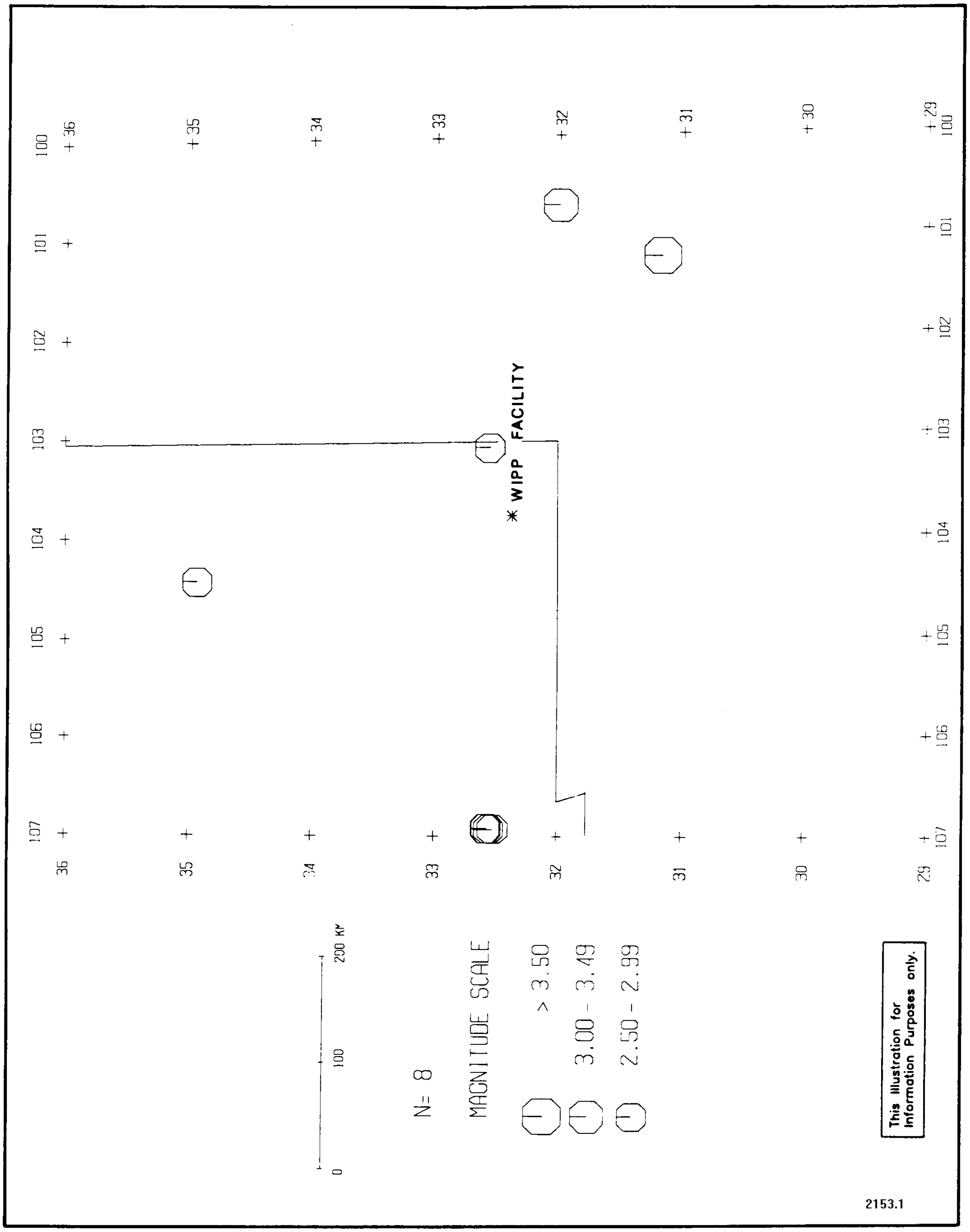


Figure 2.5-18, Epicenters for Located Earthquakes with M≥2.5: 29 August 1983 through 30 September 1986

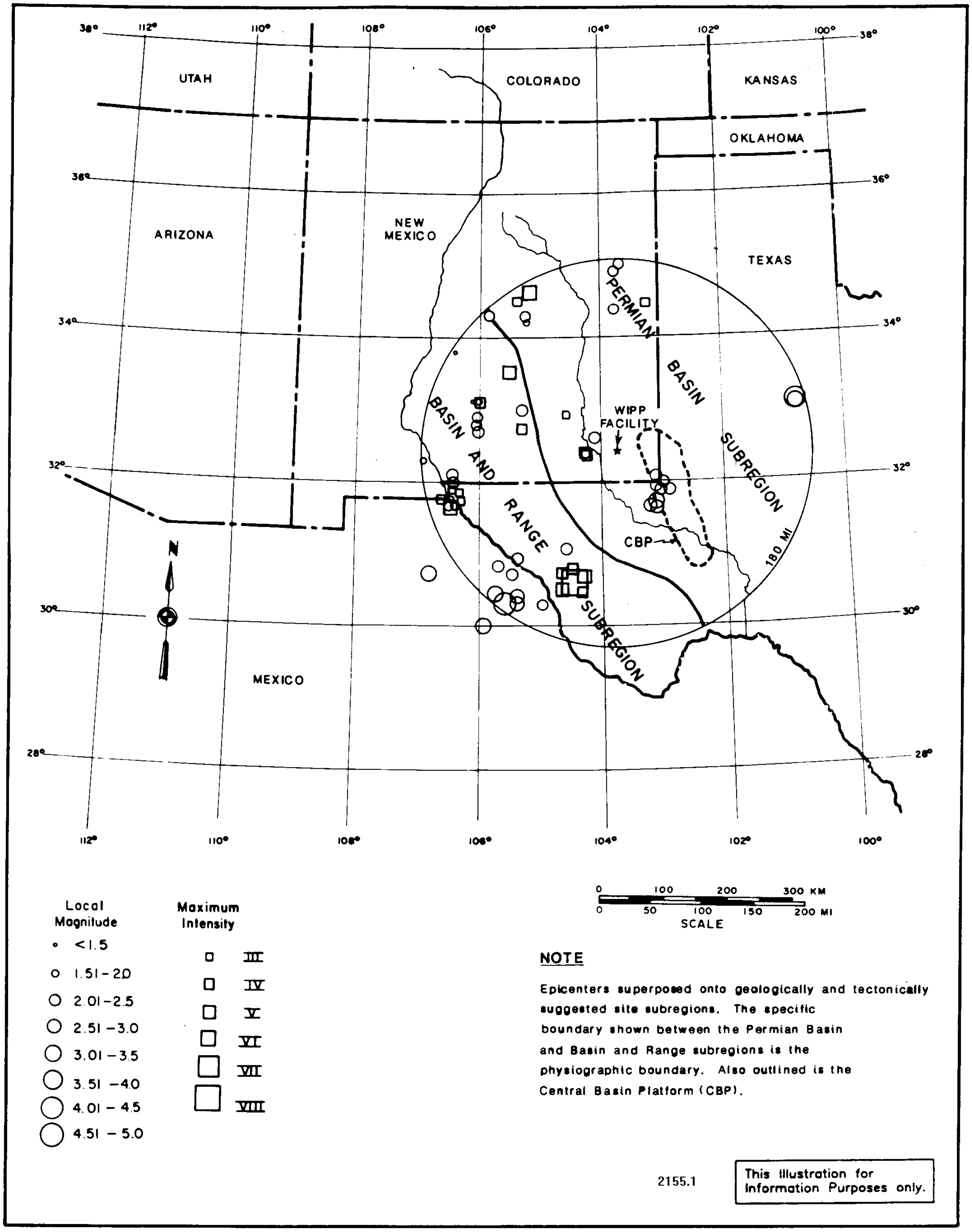


Figure 2.5-19, Earthquakes Located Using Macroseismic or Regional Seismographic Data 1923 - 1977 and Suggested Site Subregions

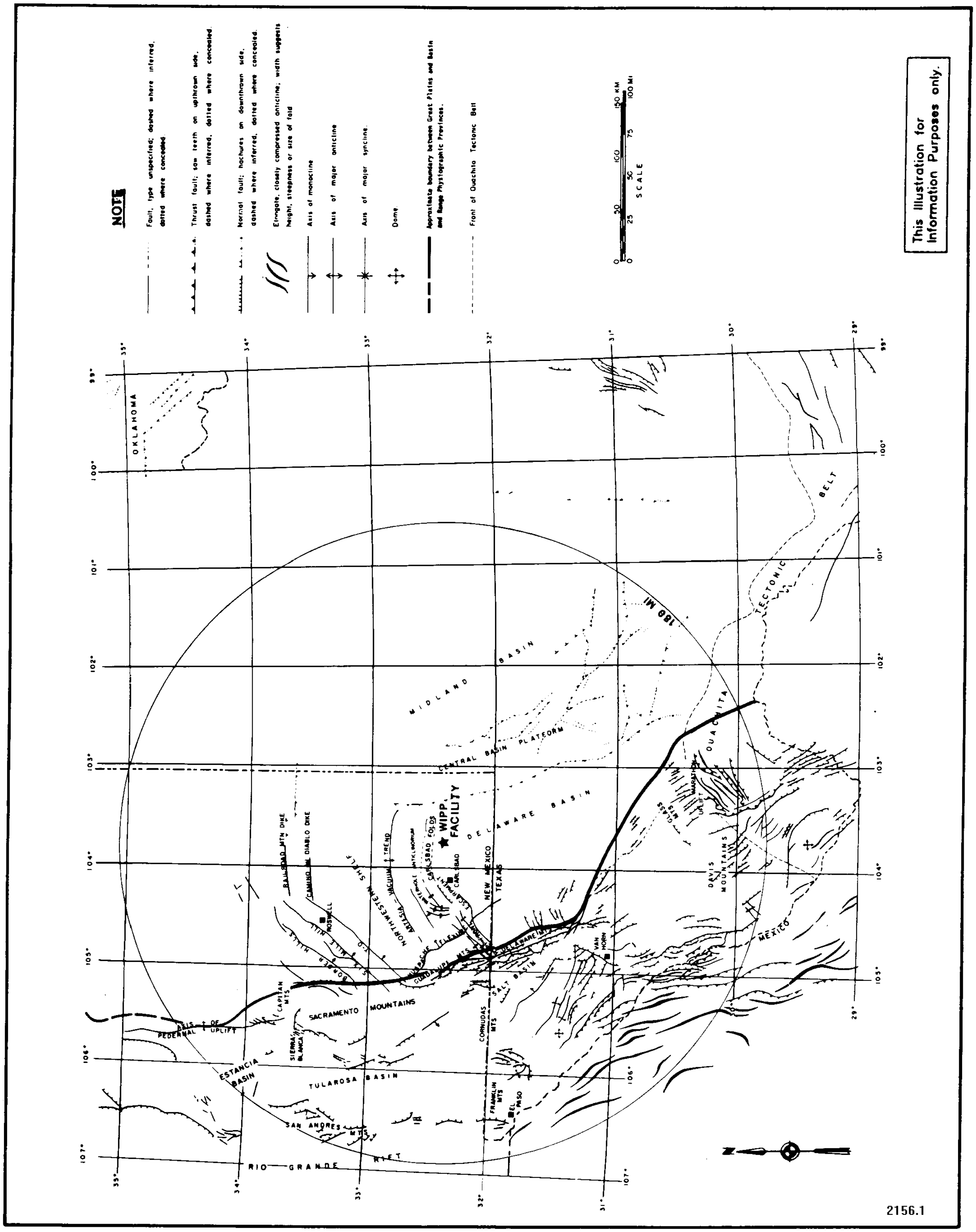


Figure 2.5-20, Site Region Structural Features and the Great Plains-Basin and Range Physiographic Boundary

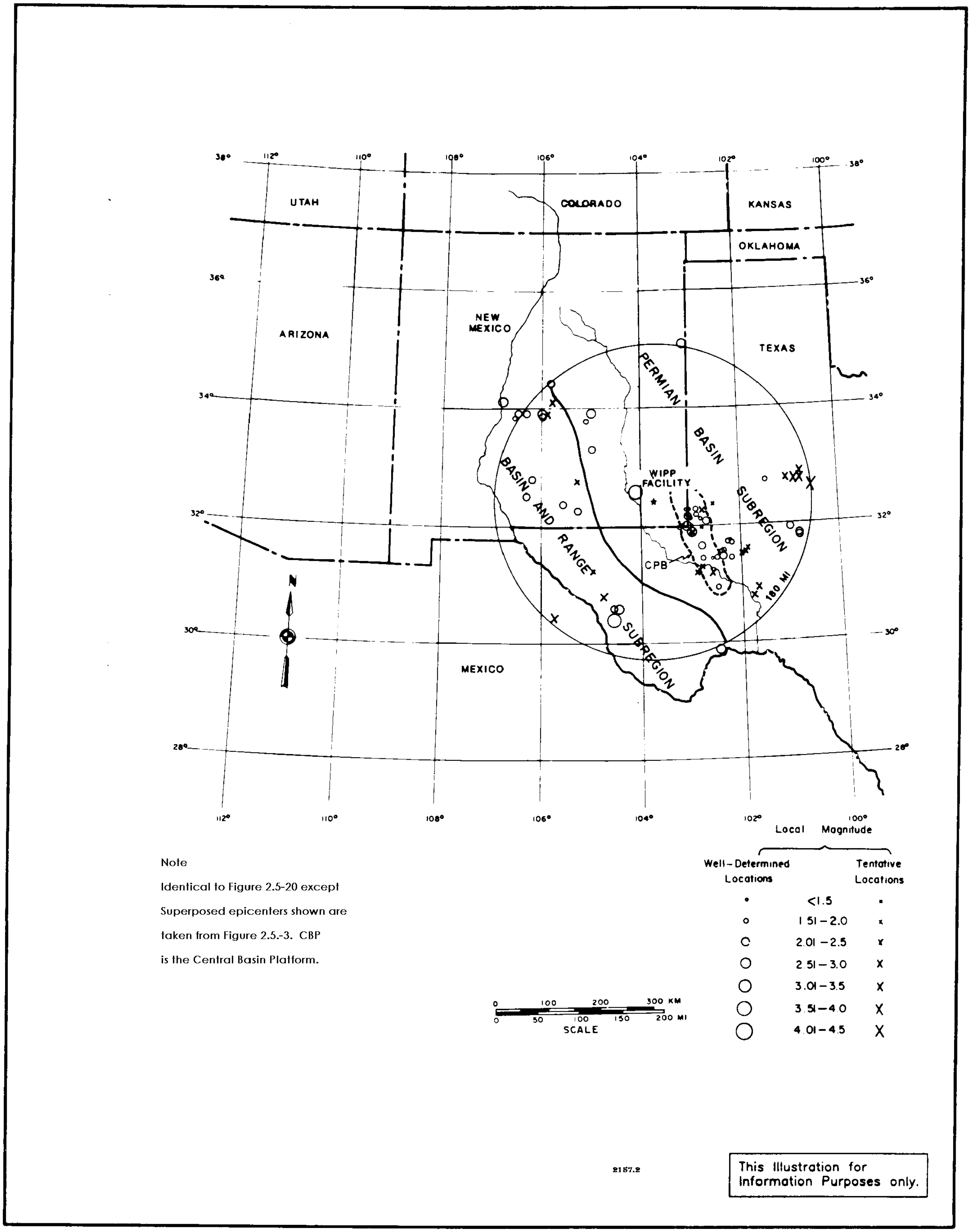
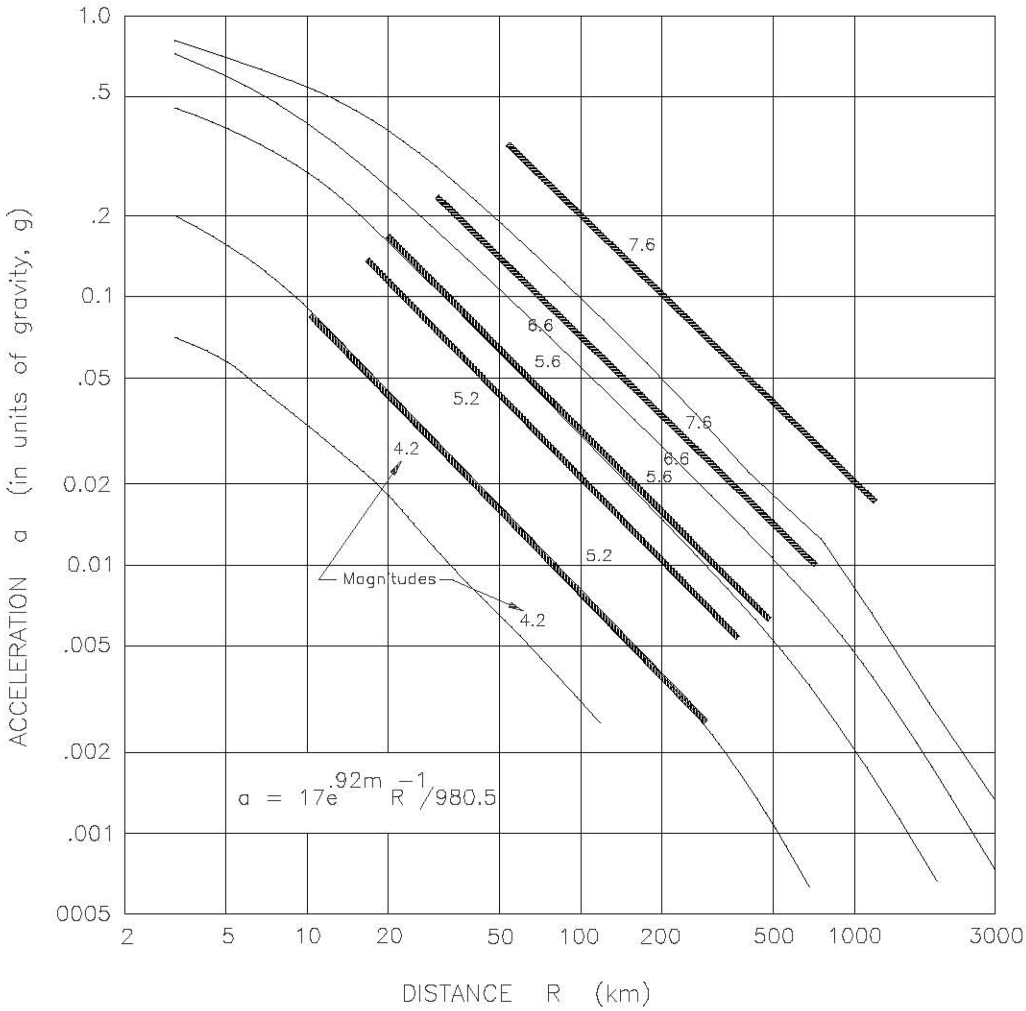


Figure 2.5-21, Earthquakes Located with the Help of Data from Station CLN and Suggested Site Subregions



NOTE

Comparison of acceleration attenuation curves for various magnitudes for areas of the United States east of 105°W longitude after Algermissen and Perkins[29] (light lines) with those used in the site hazard analysis of this report (heavy lines). The equation for the recommended attenuation curves is shown in the inset.

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Figure 2.5-22, Recommended Attenuation Curves

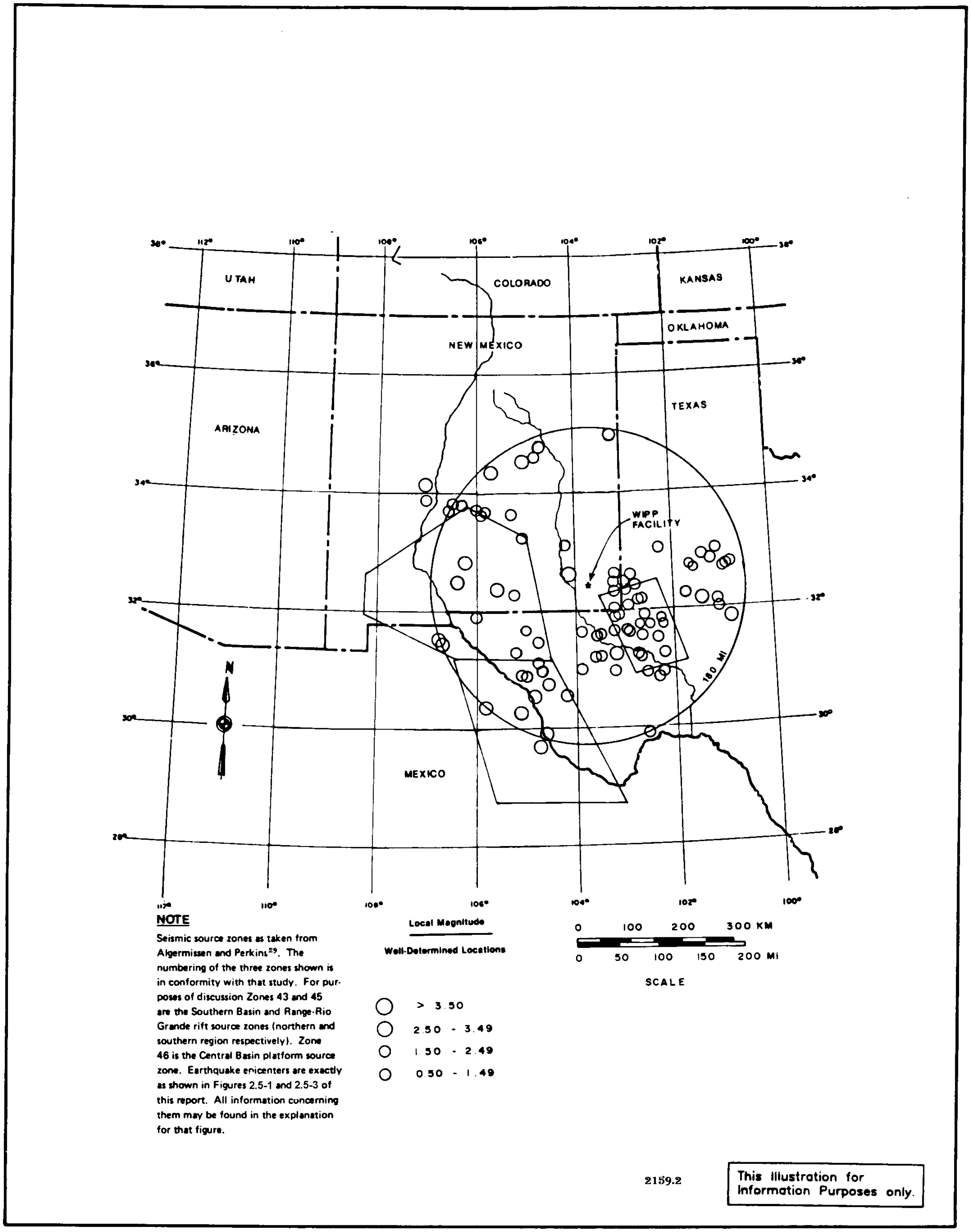

Figure 2.5-23, Algermissen and Perkins Seismic Source Zones

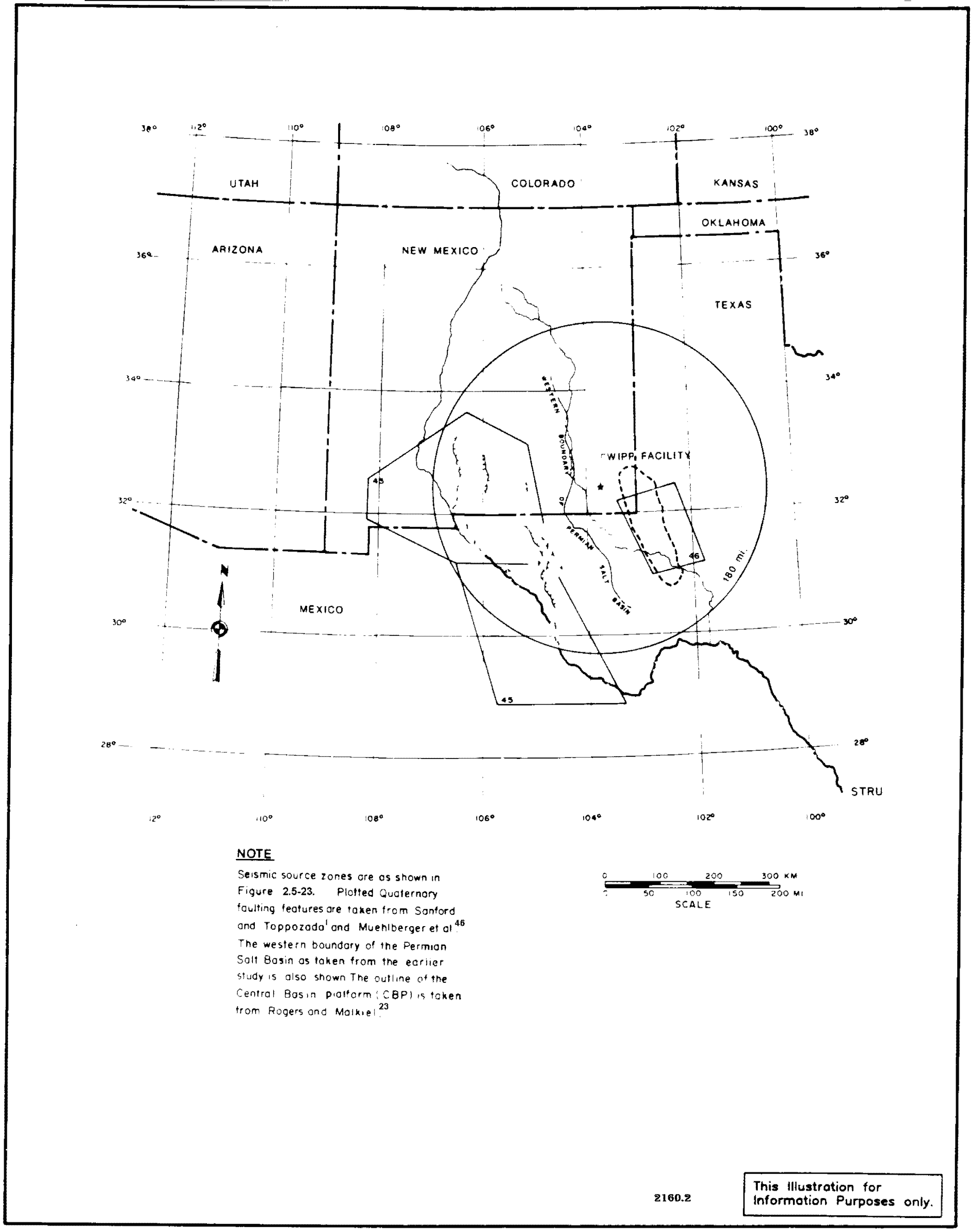

Figure 2.5-24, Structural Features in the WIPP Site Region

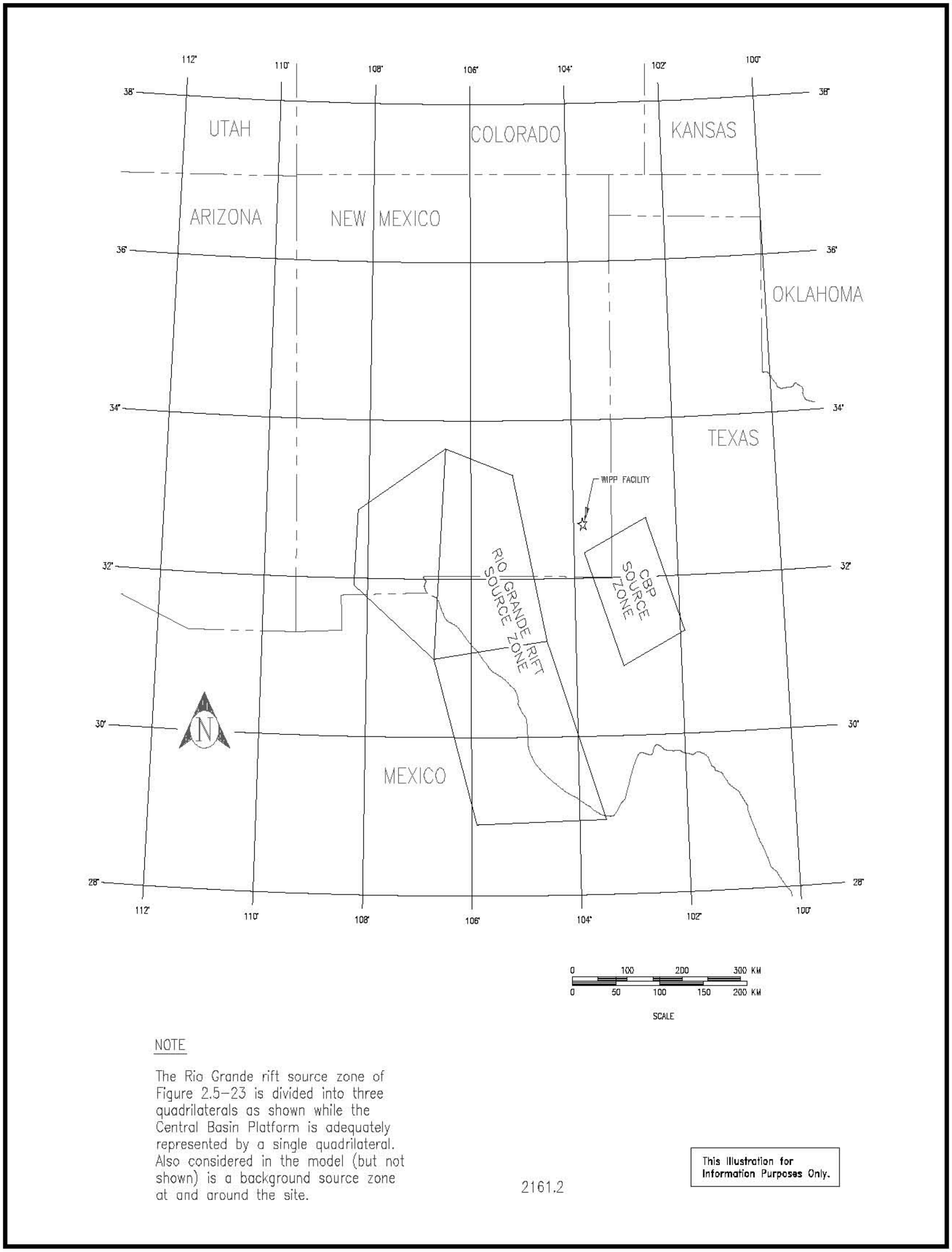

Figure 2.5-25, Quadrilateral Representation of Algermissen and Perkins Source Zones

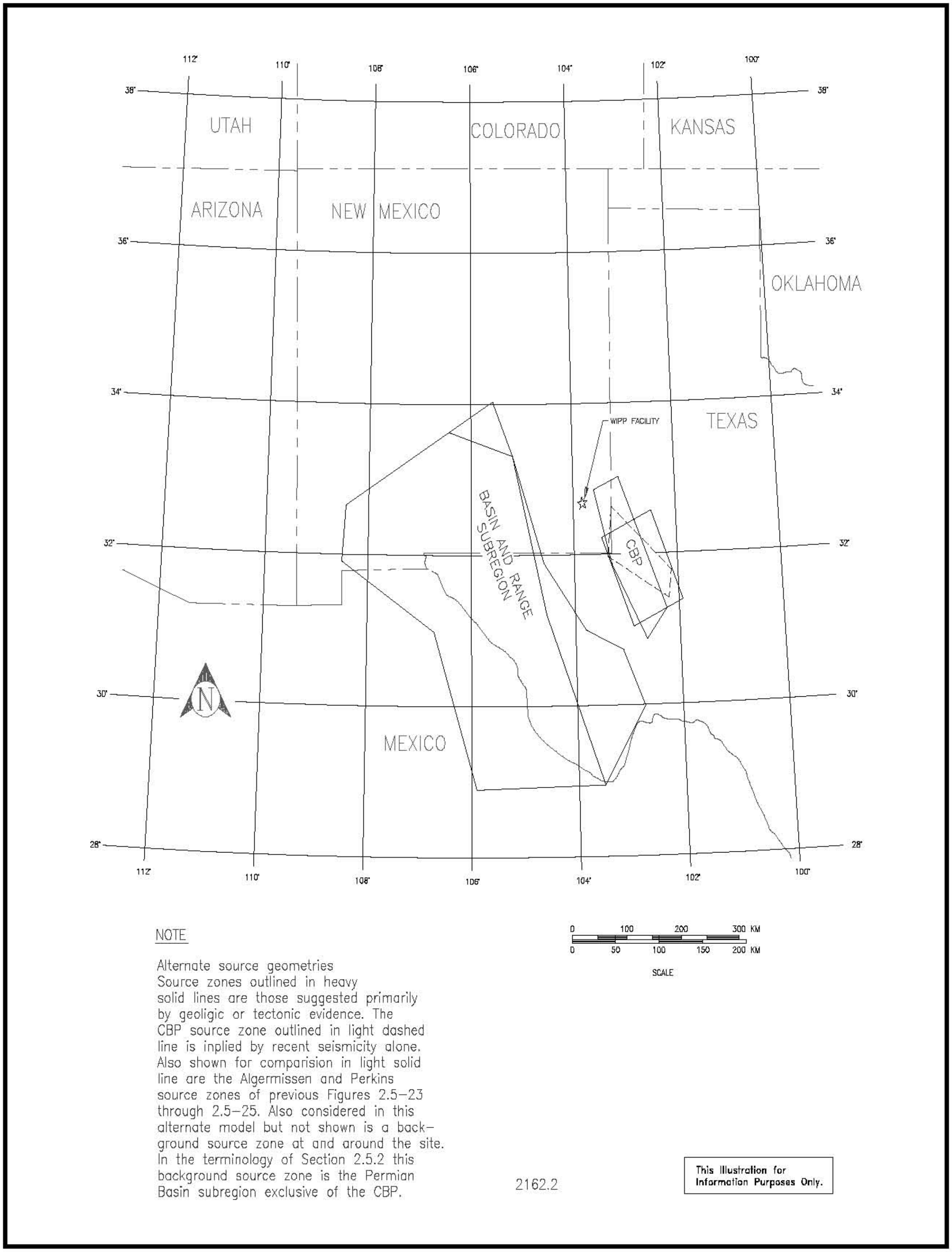

Figure 2.5-26, Alternate Source Geometries

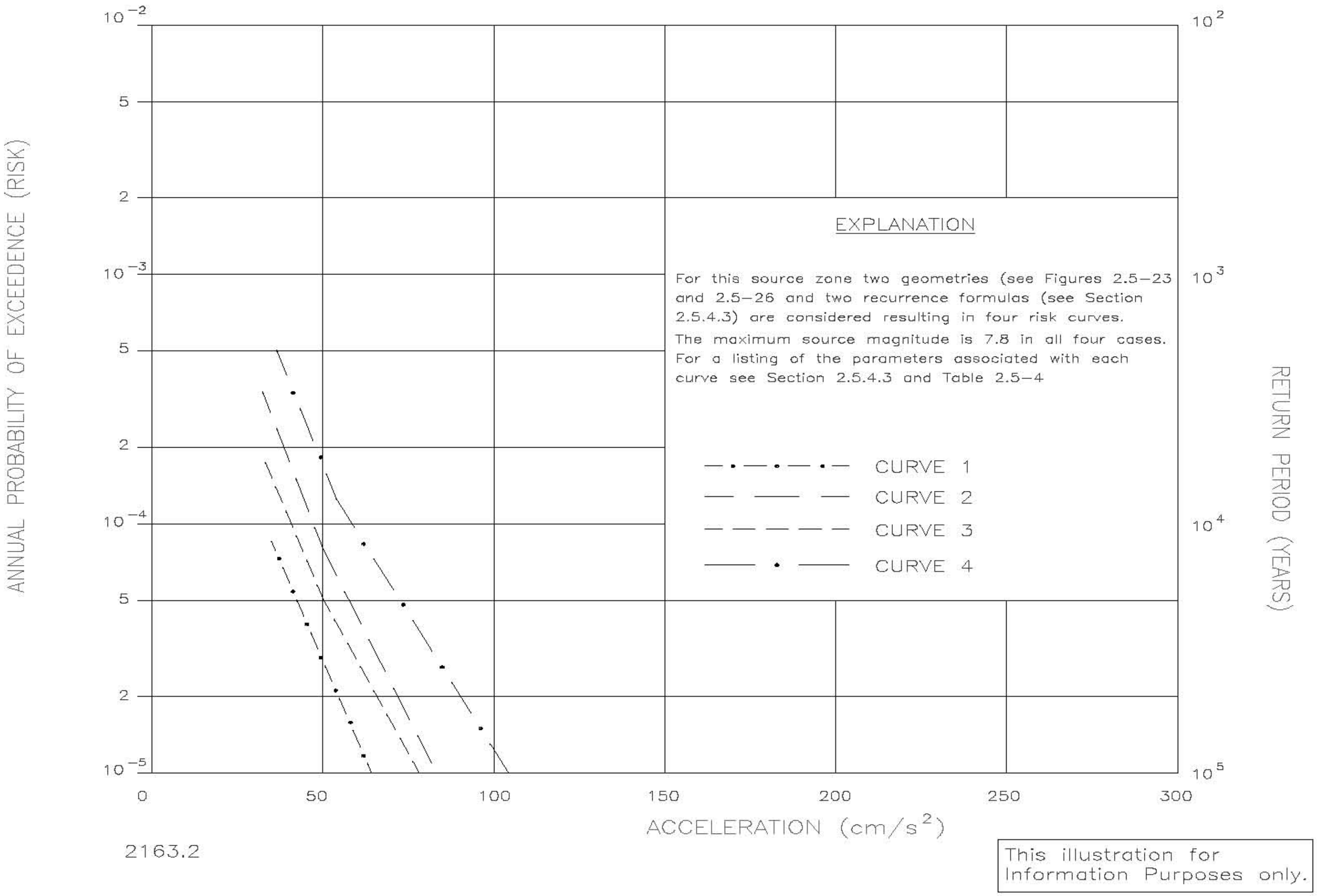

Figure 2.5-27, Risk Curves from Basin and Range or Rio Grande Rift Seismicity

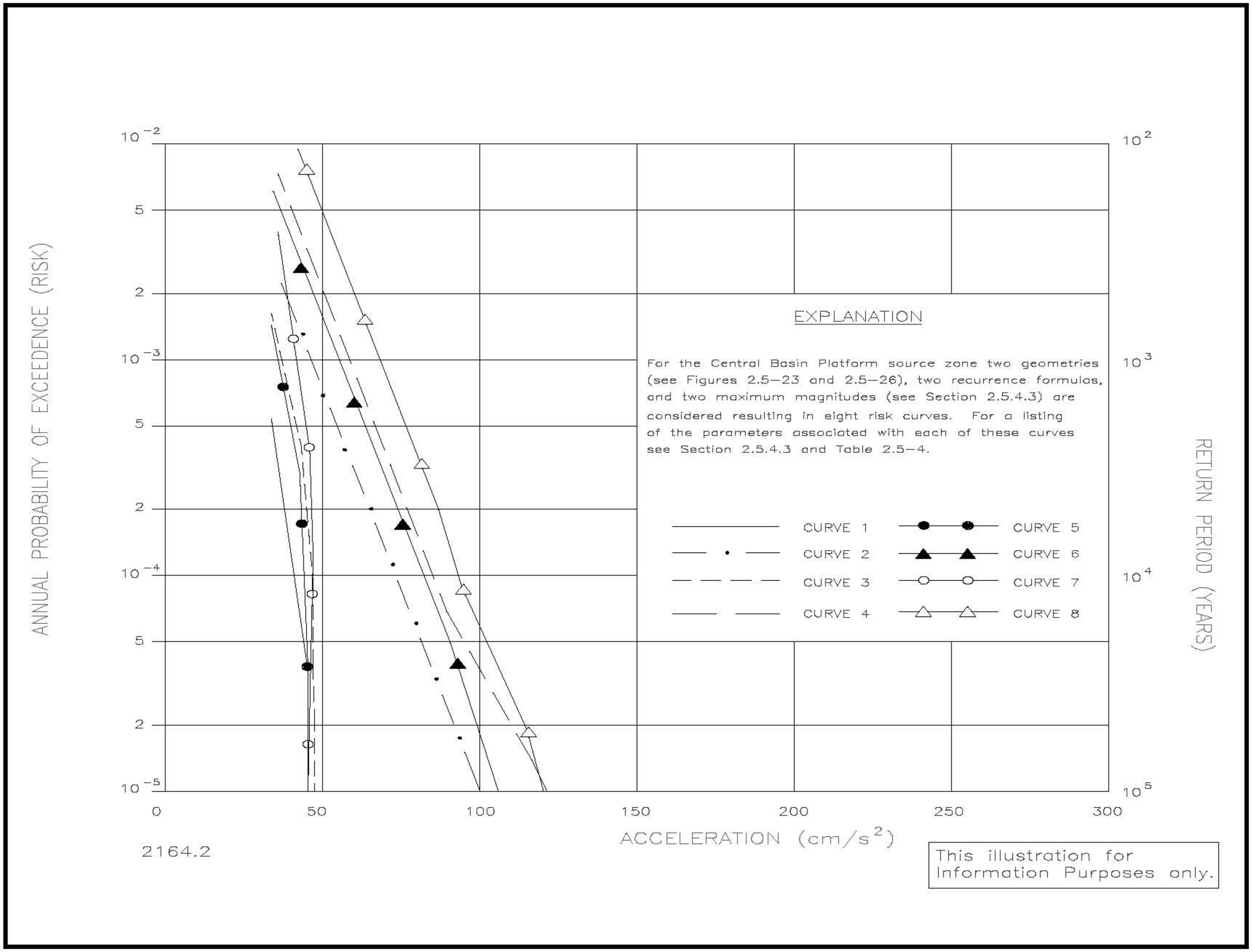

Figure 2.5-28, Risk Curves from Central Basin Platform Seismicity

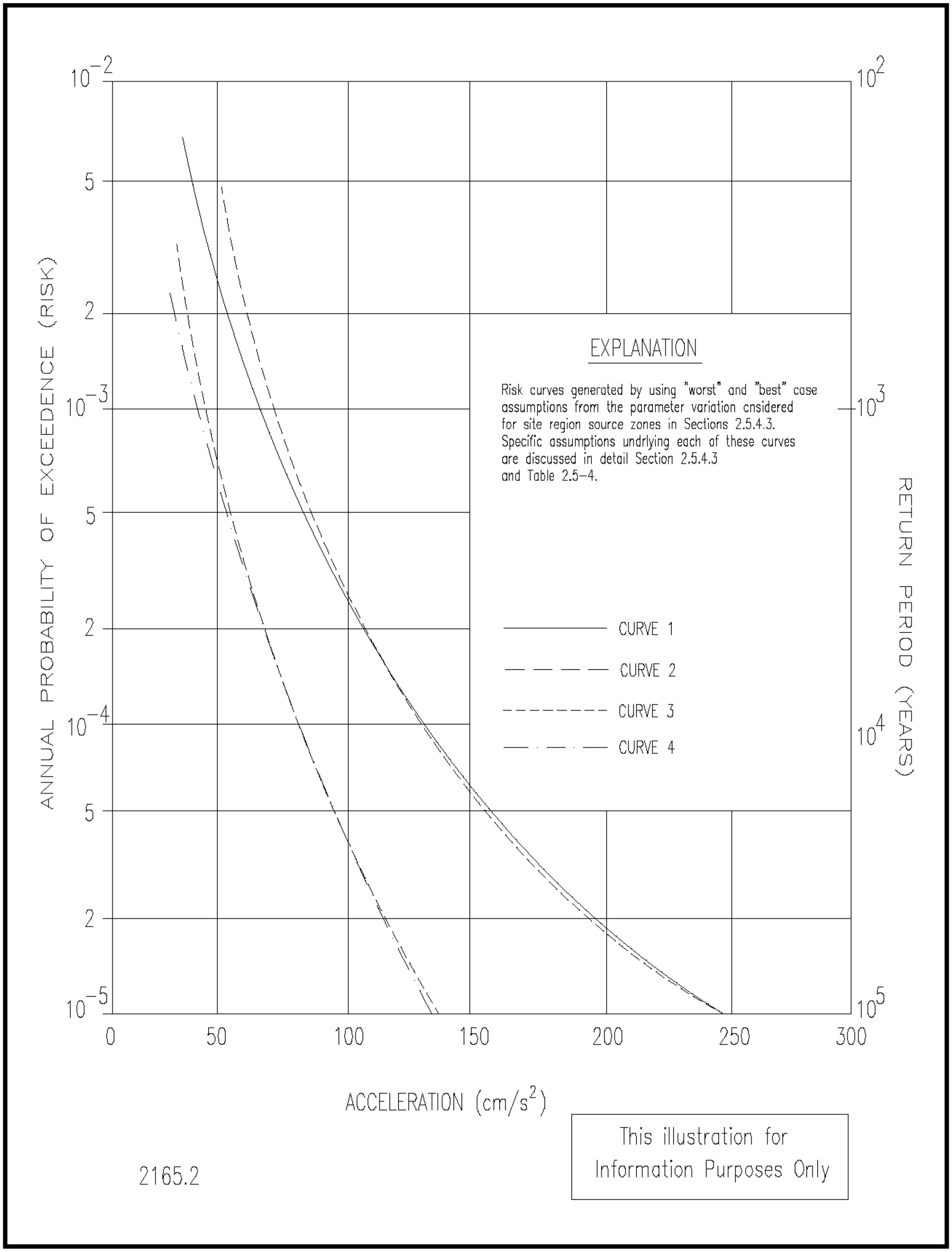

Figure 2.5-29, Risk Curves from WIPP Facility Source Zone Seismicity

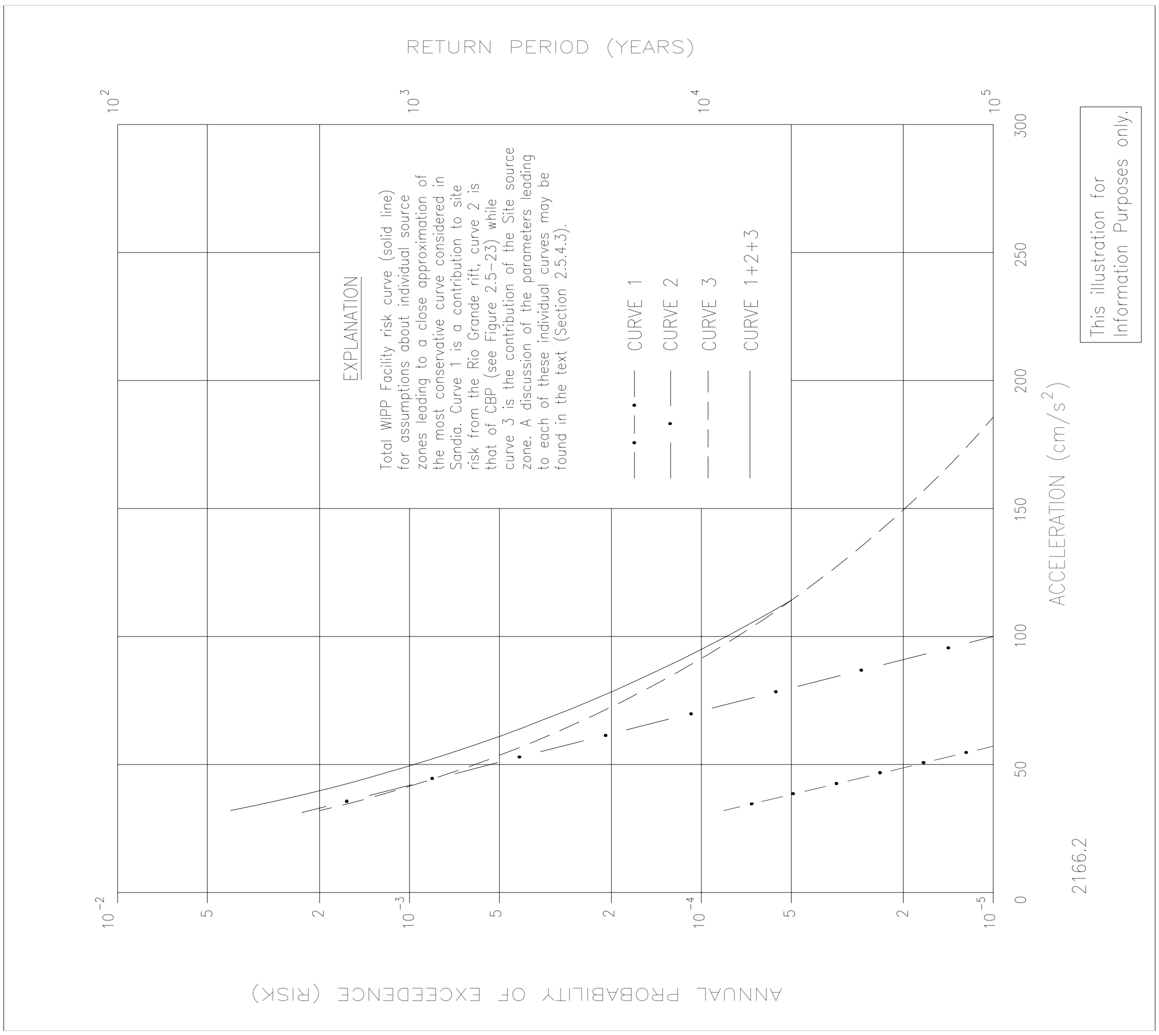

Figure 2.5-30, Generation of Total WIPP Facility Seismic Risk Curve Individual Source Risk Curves

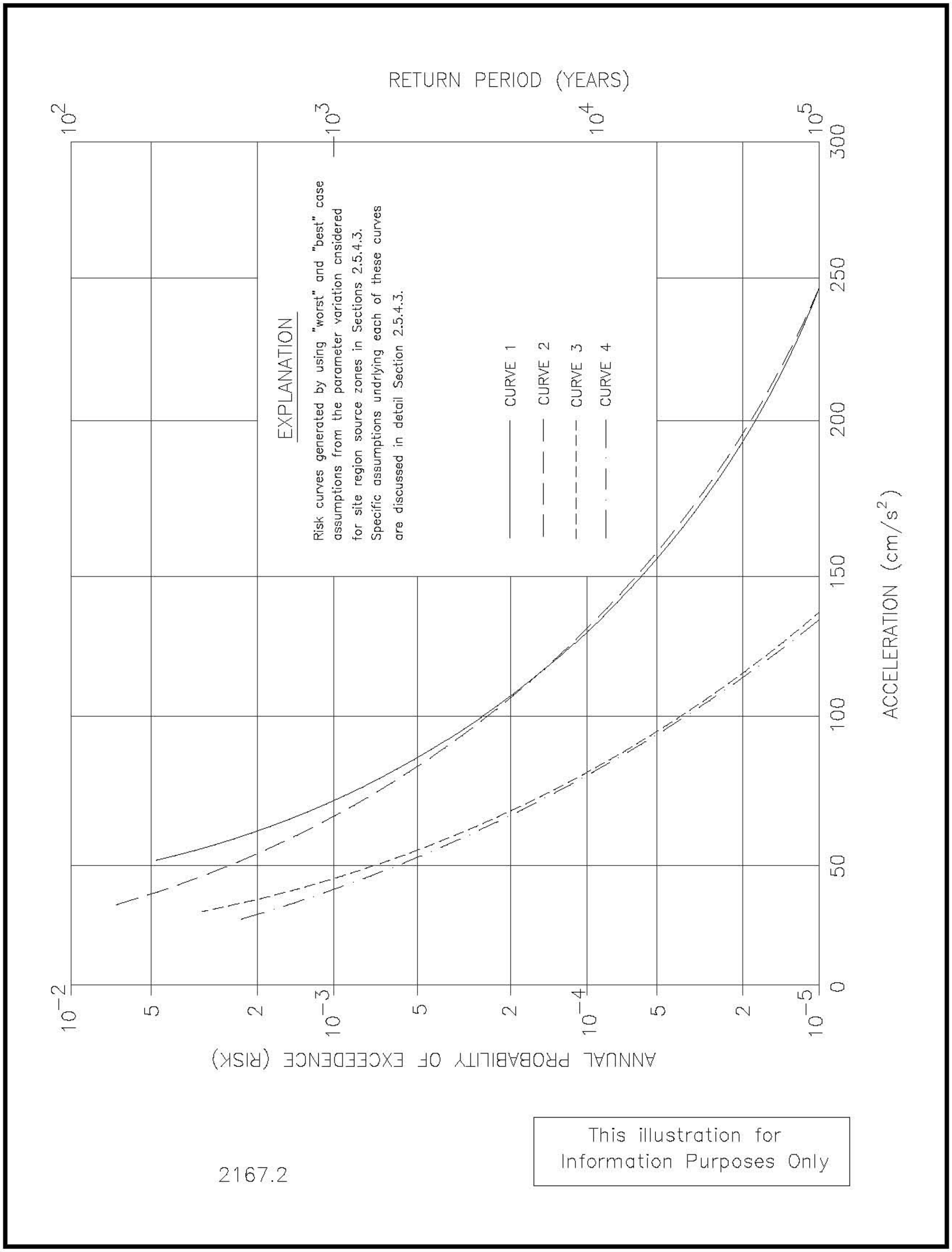

Figure 2.5-31, Total WIPP Facility Risk Curve Extrema

Table 2.5-1, Earthquakes Occurring Before 1962 and Centered Within 300 Km of the WIPP Facility*

Date Yr/Mo/Day	Origin Time, GMT	Location	Intensity	Distance
23/03/07	04:03	El Paso, Tex.	V	260
26/07/17	22:00	Hope and Lake Arthur, N.M.	III	90
30/10/04	03:25	34.5°N 105.4°W	(IV)	280
31/08/16	11:40	Valentine, Tex.	VIII	210
31/08/16	19:33	Valentine, Tex.	(V)	210
31/08/18	19:36	Valentine, Tex.	V	210
31/08/19	01:36	Valentine, Tex.	(V)	210
31/10/02	?	El Paso, Tex.	(III)	260
31/11/03	14:50	29.9°N 104.2°W	(V)	295
35/12/20	05:30	34.4°N 103.2°W	III-IV	230
36/01/08	06:46	Carlsbad, N.M.	(IV)	40
36/08/08	01:40	El Paso, Tex.	(III)	260
36/10/15	18:00	El Paso, Tex.	(III)	260
37/03/31	22:45	El Paso, Tex.	(IV)	260
37/09/30	06:15	Ft. Stanton, N.M.	(V)	200
43/12/27	04:00	Tularosa, N.M.	IV	220
49/02/02	23:00	Carlsbad, N.M.	(IV)	40
49/05/23	07:22	34.6°N 105.2°W	VI	280
52/05/22	04:20	Dog Canyon, N.M.	IV	158
55/01/27	00:37	Valentine, Tex.	IV	210

* A.R. Sandord and T.R. Toppozada, "Seismicity of Proposed Radio- active Waste Isolation Disposal Site in Southeastern New Mexico," New Mexico Bureau of Mines and Mineral Resources, Circ. 143, pp. 1-15 (1974).

Table 2.5-2, Modified Mercalli Intensity Scale of 1931*

(Abridged)

I. Not felt except by a very few under especially favorable circumstances. (I Rossi-Forel scale.)

II. Felt only by a few persons at rest, expecially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel scale.)

III. Felt quite noticeably indoors, expecially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel scale.)

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rock noticeably. (IV to V Rossi-Forel scale.)

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel scale.)

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel scale.)

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars. (VIII Rossi-Forel scale.)

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures.

Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars. (VIII+ to IX Rossi-Forel scale.)

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX Rossi-Forel scale.)

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel scale.)

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed, broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

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* H.O. Wood and F. Neumann, "Modified Mercalli Intensity Scale of 1931," Seismal. Soc. Am. Bull., 21, pp. 277-283 (1931).

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date	Origin Time	Epicenter		Located By						Mag.
Yr/Mo/Da	GMT	Lat. North	Long. West	NMT	USGS	LANL	ASL	UTA	UTEP	
62 03 03	18:16:48.1	33.80	106.40	X						1.2
62 03 06	09:59:09.7	31.08	104.55	X						2.9
62 03 22	04:23:53.4	34.25	106.51	X						1.7
62 04 09	23:42:58.0	34.21	106.44	X						1.8
62 09 01	16:15:07.9	34.16	106.66	X						3.0
63 02 22	07:02:08.1	32.42	106.99	X						2.5
63 02 22	08:53:18.1	32.45	106.94	X						1.5
63 03 08	06:16:40.0	32.95	107.08	X						1.6
63 06 02	05:07:34.6	34.23	106.46	X						2.0
63 12 19	16:47:28.4	35.14	104.13	X						2.9
63 12 30	08:48:14.6	34.03	106.54	X						1.7
64 02 11	09:24:31.0	34.35	103.73	X						2.5
64 03 03	01:26:26.6	34.97	103.59	X						2.2
64 06 18	20:20:18.5	33.14	106.10	X						1.2
64 06 19	05:28:38.8	33.09	105.95	X						1.7
64 11 08	09:26:00.5	31.93	102.98	X						2.9
64 11 21	11:21:23.8	31.92	102.98	X						2.6
65 02 03	11:32:34.4	35.10	103.80	X						2.9
65 02 03	19:59:32.4	31.92	102.96	X						3.2
65 05 27	18:50:53.9	33.88	106.73	X						2.0
65 05 27	18:58:40.9	33.90	106.71	X						2.0
65 05 29	13:01:08.2	33.87	106.69	X						2.0
65 07 28	03:52:07.4	33.80	106.70	X						2.6
65 08 30	05:17:29.8	31.92	102.98	X						2.7
66 08 14	15:25:47.1	31.92	102.98	X						3.1
66 08 17	18:47:21.0	30.71	105.98	X						2.9
66 08 19	04:15:44.6	30.30	105.60		X					4.8
66 08 19	08:38:21.9	30.30	105.60		X					3.8
66 09 17	21:30:13.0	34.94	103.71	X						2.2
66 11 26	20:05:41.0	30.86	105.36	X						3.0
66 11 28	02:20:57.3	30.40	105.40		X					3.5
66 12 05	10:10:37.8	30.40	105.40		X					3.5
67 09 29	03:52:48.0	32.27	106.91	X						2.0
68 03 09	21:54:25.7	32.70	106.05	X						2.9
68 03 23	11:53:38.7	32.70	106.05	X						2.2
68 05 02	02:56:43.8	33.02	105.27	X						2.6
68 08 22	02:22:25.5	34.33	105.80	X						2.0
69 05 12	08:26:18.5	31.95	106.44	X						3.2
69 05 12	08:49:16.3	31.96	106.44	X						2.5
69 06 01	17:18:24.2	34.23	105.18	X						2.0
69 06 08	11:36:01.9	34.23	105.18	X						2.4
69 10 19	11:51:34.4	30.80	105.70		X					3.4
71 01 27	07:56:28.3	34.06	106.60	X						2.6
71 03 25	02:43:02.4	34.58	106.03	X						1.7
71 07 30	01:45:50.3	31.74	103.09	X						3.7
71 07 31	14:53:48.0	31.59	103.12	X						3.6
71 09 24	01:01:54.0	31.63	103.18	X						3.0
72 02 27	15:50:03.9	32.89	106.04	X						2.2
72 07 26	04:35:43.9	32.68	103.98	X						2.9

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date Yr/Mo/Da	Origin Time GMT	Epicenter Lat. North	Epicenter Long. West	Located By NMT	USGS	LANL	ASL	UTA	UTEP	Mag.
72 12 09	05:58:38.9	31.68	106.44	X						2.2
72 12 10	14:37:50.2	31.68	106.41	X						2.2
72 12 10	14:58:02.5	31.65	106.48	X						1.9
74 02 02	20:39:22.6	35.10	103.10	X						2.9
74 07 31	17:34:48.5	33.12	104.18	X						1.8
74 08 17	07:35:17.3	30.30	105.77	X						2.4
74 08 26	07:33:21.5	34.44	105.79	X						2.3
74 09 26	23:44:08.5	32.81	106.16	X						1.9
74 10 02	02:40:20.0	31.98	100.71	X						2.6
74 10 27	16:18:53.9	30.53	104.79	X						2.2
74 11 01	10:45:49.6	33.80	106.60	X						2.0
74 11 12	02:31:59.0	32.06	100.98	X						2.5
74 11 12	02:35:34.2	32.13	102.67	X						1.8
74 11 12	07:14:27.7	31.93	100.72	X						2.2
74 11 21	16:22:58.6	32.53	106.25	X						1.9
74 11 21	18:59:05.8	32.10	102.69	X						2.3
74 11 22	08:54:00.1	32.99	101.14	X						1.9
74 11 22	14:11:13.2	33.81	105.15	X						1.5
74 11 28	03:35:20.5	32.59	104.12	X						3.7
75 01 30	16:00:39.9	31.15	102.85	X						2.1
75 04 08	15:29:42.4	32.18	101.70	X						1.6
75 04 20	16:59:56.4	31.29	102.60	X						2.0
75 07 25	08:11:40.0	29.88	102.54	X						2.8
75 08 01	07:27:41.2	30.65	104.57	X						3.2
75 08 03	03:26:53.1	31.04	103.97	X						1.9
75 10 10	11:16:55.5	33.35	104.99	X						1.9
76 01 10	01:49:58.5	31.74	102.75	X						1.9
76 01 15	20:43:57.6	30.95	102.31	X						1.8
76 01 19	04:03:31.4	31.95	103.10	X						2.4
76 01 21	23:11:17.2	30.90	102.29	X						1.7
76 01 22	07:21:57.7	31.92	103.05	X						2.0
76 01 25	04:48:27.3	31.93	103.09	X						3.1
76 01 28	07:37:54.7	32.29	101.27	X						2.1
76 02 04	16:15:30.0	31.67	103.54	X						1.3
76 02 14	05:35:22.1	31.61	102.47	X						1.6
76 02 19	08:23:58.4	31.60	103.66						X	1.2
76 02 19	08:45:31.5	31.63	103.67						X	1.2
76 02 19	09:23:36.6	31.65	103.66						X	1.0
76 03 05	02:58:18.0	31.92	102.59	X						2.1
76 03 20	12:42:20.4	31.26	104.95	X						1.8
76 03 20	16:15:58.1	32.20	103.10	X						1.7
76 03 27	22:25:21.9	32.21	103.10	X						1.7
76 04 01	14:40:27.7	33.94	105.88	X						1.8
76 04 01	14:46:58.2	33.88	105.98	X						2.2
76 04 01	14:51:16.5	33.94	105.87	X						1.3
76 04 03	20:40:51.4	31.30	103.17	X						2.5
76 04 06	18:09:00.3	33.88	105.93	X						2.6
76 04 12	08:02:34.9	32.25	103.11	X						1.5
76 04 18	03:48:18.5	32.88	105.94	X						1.6

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes

Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date	Origin Time	Epicenter		Located By						Mag.
Yr/Mo/Da	GMT	Lat. North	Long. West	NMT	USGS	LANL	ASL	UTA	UTEP	
76 04 21	08:40:07.5	32.23	103.06	X						1.8
76 04 30	19:28:34.8	31.96	103.20	X						1.5
76 04 30	19:51:12.5	31.91	103.32	X						1.5
76 05 01	11:13:40.1	32.34	103.11	X						2.3
76 05 03	06:52:59.3	32.52	105.52	X						2.0
76 05 03	08:00:38.9	32.03	103.14	X						1.3
76 05 03	11:27:39.3	32.03	103.06	X						1.2
76 05 06	17:18:24.0	31.95	103.20	X						1.8
76 05 06	17:28:45.1	31.90	103.17	X						1.1
76 05 08	11:46:40.8	31.97	103.12	X						1.0
76 05 11	23:04:40.2	32.25	102.96	X						1.9
76 05 21	13:17:27.8	32.41	105.72	X						2.0
76 06 14	23:29:59.5	31.59	102.59	X						1.7
76 06 15	02:19:56.3	31.55	102.29	X						1.7
76 06 15	08:50:20.6	31.56	102.42	X						2.2
76 07 28	12:21:50.6	33.03	102.30	X						1.9
76 08 05	18:53:09.2	31.57	103.02						X	2.2
76 08 06	21:12:38.6	31.78	102.59						X	1.8
76 08 10	09:03:14.3	31.83	102.42	X						1.7
76 08 10	09:12:28.6	31.77	102.61						X	1.3
76 08 10	10:15:18.7	31.79	102.54	X						2.0
76 08 15	19:12:04.3	30.14	105.22	X						2.2
76 08 25	01:21:23.5	31.65	102.88	X						1.1
76 08 25	01:27:47.5	31.57	102.42	X						2.0
76 08 26	15:22:18.1	31.79	102.57	X						1.6
76 08 29	19:49:24.4	30.12	105.23	X						2.1
76 08 30	11:51:24.8	31.57	102.58	X						1.8
76 08 30	13:07:47.5	33.89	106.29	X						1.6
76 08 31	12:46:22.2	31.57	102.81	X						2.0
76 09 03	21:00:24.7	31.55	103.48						X	1.7
76 09 05	10:39:43.4	32.26	102.62	X						1.1
76 09 05	16:10:27.7	31.61	103.31						X	1.4
76 09 10	19:18:43.4	31.91	103.09						X	1.5
76 09 17	02:47:46.5	32.20	103.10	X						2.2
76 09 17	03:56:29.5	31.46	102.52	X						2.3
76 09 19	10:23:23.3	32.14	103.10	X						1.2
76 09 19	10:40:48.0	30.69	104.43	X						2.7
76 10 14	11:02:59.0	32.29	102.98	X						1.2
76 10 22	05:06:11.1	31.57	102.17	X						2.0
76 10 23	12:51:35.8	31.59	102.32	X						1.5
76 10 25	00:27:04.8	31.83	102.65	X						2.1
76 10 25	10:52:27.3	31.85	102.40						X	1.3
76 10 26	10:44:44.1	31.33	103.28						X	2.0
76 11 03	23:24:06.4	30.86	101.88	X						1.8
76 12 12	23:00:14.2	31.52	102.50	X						2.4
76 12 12	23:25:57.6	31.57	102.61	X						1.5
76 12 15	08:51:45.1	31.64	102.75	X						1.1
76 12 18	18:27:45.7	31.62	103.02						X	1.5
76 12 19	21:26:15.8	31.78	102.56	X						1.8

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date	Origin Time	Epicenter		Located By						Mag.
Yr/Mo/Da	GMT	Lat. North	Long. West	NMT	USGS	LANL	ASL	UTA	UTEP	
76 12 19	23:54:23.3	32.22	103.09	X						1.5
76 12 19	23:56:47.4	32.23	103.10						X	2.1
76 12 23	08:36:58.0	34.68	105.77	X						1.9
77 01 04	18:31:37.6	32.36	106.92		X					2.7
77 01 04	23:41:58.0	34.03	106.00				X			2.4
77 01 05	12:19:02.0	34.05	106.00				X			1.7
77 01 08	20:20:27.2	31.50	102.98						X	1.1
77 01 29	09:40:40.1	30.53	104.84	X						1.9
77 02 04	07:48:16.2	30.67	104.64	X						1.7
77 02 10	01:22:50.8	32.21	103.07	X						1.1
77 02 18	14:10:36.5	32.24	103.07	X						1.2
77 03 01	11:50:45.9	31.25	103.28						X	1.2
77 03 05	22:56:14.6	31.47	102.84	X						1.4
77 03 12	00:05:23.8	31.62	103.29						X	1.1
77 03 14	10:10:25.6	32.97	101.06	X						2.4
77 03 20	07:54:08.4	32.23	103.07	X						1.6
77 03 23	11:02:51.8	31.81	102.51						X	1.1
77 03 29	00:35:34.7	31.60	103.28	X						1.0
77 04 03	12:39:57.4	31.26	103.03						X	1.1
77 04 03	13:48:09.2	31.49	103.17						X	1.6
77 04 03	14:24:07.3	31.45	103.20	X						1.5
77 04 04	00:44:05.3	31.48	103.17						X	1.6
77 04 04	01:47:50.4	31.44	103.18						X	1.3
77 04 04	04:35:56.8	31.50	103.17						X	1.3
77 04 04	04:47:30.4	31.46	103.18	X						1.3
77 04 04	05:01:29.8	31.23	103.01						X	1.3
77 04 07	05:45:40.3	32.23	103.07	X						1.9
77 04 07	18:56:55.1	31.53	103.29	X						1.4
77 04 12	23:18:26.7	31.22	102.58	X						1.7
77 04 16	06:44:22.2	31.61	103.22	X						0.8
77 04 17	21:47:09.9	31.55	102.30	X						1.3
77 04 18	18:08:24.1	31.60	103.28	X						1.4
77 04 22	22:56:34.8	32.21	102.97	X						1.0
77 04 25	10:12:51.4	32.09	102.78	X						1.4
77 04 26	09:03:07.3	31.90	103.03	X						2.1
77 04 28	12:54:38.2	31.81	102.53	X						0.9
77 04 28	12:55:40.1	31.80	102.53	X						2.2
77 04 28	15:22:36.8	31.78	102.53	X						1.3
77 04 29	03:09:41.3	31.81	102.58	X						1.3
77 05 01	21:33:58.7	31.45	103.16						X	1.1
77 06 07	23:01:20.9	32.85	100.90	X						3.2
77 06 08	00:51:26.0	32.70	100.72	X						2.6
77 06 08	13:29:12.0	32.89	100.95	X						3.0
77 06 08	13:39:25.	32.8	100.9	X						2.6
77 06 17	03:37:05.9	32.87	101.04	X						2.7
77 06 28	23:59:46.6	31.54	103.30						X	2.0
77 07 01	01:06:19.2	31.50	103.34						X	1.7
77 07 05	10:40:27.4	31.60	102.10	X						1.7
77 07 11	12:31:55.7	31.79	102.69	X						1.7

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date	Origin Time	Epicenter		Located By						Mag.
Yr/Mo/Da	GMT	Lat. North	Long. West	NMT	USGS	LANL	ASL	UTA	UTEP	
77 07 11	13:29:49.7	31.77	102.68	X						1.3
77 07 11	17:19:37.6	30.98	104.90					X		1.2
77 07 12	17:06:06.8	31.78	102.72	X						1.5
77 07 18	12:37:31.7	31.77	102.76	X						1.8
77 07 22	04:01:10.6	31.80	102.75	X						1.9
77 07 22	04:18:10.7	31.79	102.71	X						1.5
77 07 22	04:36:50.8	31.77	102.69	X						0.9
77 07 24	09:23:00.7	31.79	102.70	X						1.5
77 07 26	02:01:08.7	31.78	102.68	X						0.7
77 07 28	12:17:17.8	31.10	105.02					X		1.1
77 07 28	23:35:43.1	31.00	104.91					X		1.0
77 08 01	16:44:51.1	30.97	104.92					X		1.0
77 08 06	20:43:59.7	31.04	104.96					X		1.2
77 08 09	16:07:00.5	31.04	104.65					X		1.1
77 08 12	07:49:11.4	31.40	103.45						X	1.2
77 08 20	02:29:22.2	31.60	103.33						X	1.5
77 08 21	03:01:09.7	30.48	104.86	X						2.6
77 10 13	21:36:11.0	32.74	100.75	X						2.2
77 10 17	21:24:43.2	31.57	102.46						X	1.5
77 10 24	22:50:04.6	31.54	102.51						X	1.3
77 10 25	01:02:32.2	31.52	102.51						X	1.0
77 10 29	00:49:11.6	30.50	104.19					X		1.1
77 11 05	12:28:53.7	31.08	104.97					X		1.1
77 11 14	07:26:27.4	31.60	104.90	X						2.2
77 11 27	20:48:18.1	33.03	101.08	X						2.5
77 11 28	01:40:50.3	32.90	101.02	X						3.4
77 12 07	23:14:19.5	31.56	102.51						X	1.2
77 12 16	11:56:41.9	31.57	102.54	X						1.4
77 12 21	01:36:20.9	31.49	102.36	X						1.4
77 12 29	10:50:55.0	31.62	103.26						X	1.2
77 12 31	13:19:04.5	31.60	102.46						X	1.7
78 01 02	10:10:47.1	31.60	102.53						X	1.8
78 01 12	14:55:02.3	31.45	102.18	X						1.9
78 01 15	23:18:08.2	31.66	102.64	X						1.6
78 01 18	08:53:19.5	31.62	103.23	X						1.2
78 01 19	03:42:35.1	32.60	103.58	X						1.8
78 01 21	01:17:02.4	31.50	104.66					X		2.4
78 01 24	14:26:22.4	30.68	104.59					X		1.1
78 02 04	15:35:48.4	31.62	103.26						X	1.0
78 02 05	10:46:25.0	31.63	103.26						X	1.0
78 02 05	14:19:53.0	31.41	104.61	X						1.8
78 02 10	14:02:29.9	31.63	103.26						X	1.2
78 02 18	14:22:37.1	31.35	104.56	X						2.8
78 02 18	14:29:20.3	30.62	105.16					X		1.7
78 02 18	15:29:37.0	30.60	105.18					X		1.1
78 02 18	16:44:04.7	30.61	105.19					X		1.0
78 02 18	17:30:08.5	30.61	105.19					X		2.1
78 02 18	17:54:09.8	30.61	105.19					X		1.5
78 02 18	18:45:16.5	30.62	105.20					X		1.3

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date	Origin Time	Epicenter		Located By						Mag.
Yr/Mo/Da	GMT	Lat. North	Long. West	NMT	USGS	LANL	ASL	UTA	UTEP	
78 02 19	07:05:18.7	30.61	105.18					X		1.1
78 02 19	12:12:00.0	30.61	105.19					X		2.1
78 02 20	02:52:55.4	30.62	105.20					X		1.1
78 03 02	08:57:51.8	32.18	103.07	X						1.2
78 03 02	10:04:50.1	31.52	102.41	X						2.8
78 03 02	11:27:09.4	31.61	102.69						X	1.2
78 03 02	11:55:57.1	31.59	102.61						X	1.8
78 03 19	10:48:49.1	31.50	102.51	X						1.8
78 03 28	05:51:35.4	29.69	104.04					X		1.1
78 04 06	09:13:27.4	30.86	104.86					X		1.2
78 04 07	00:57:41.6	31.94	105.33	X						2.3
78 04 12	23:05:00.0	30.66	104.48					X		1.1
78 05 30	13:19:31.7	30.65	104.56					X		1.4
78 06 03	11:40:18.2	30.40	104.64					X		1.6
78 06 06	20:05:00.1	30.30	104.58					X		1.4
78 06 16	11:46:54.2	33.03	100.77		X					4.4
78 06 16	11:53:33.0	33.10	101.20					X		3.4
78 06 29	20:58:45.1	31.05	101.94	X						3.4
78 07 05	02:45:06.7	31.78	102.55	X						1.2
78 07 05	10:40:28.9	31.60	102.25	X						1.7
78 07 18	12:07:32.8	30.40	104.28	X						1.8
78 07 21	05:02:36.2	34.68	105.04	X						3.1
78 07 21	20:35:41.6	31.24	102.48	X						1.7
78 08 12	12:45:27.7	31.62	103.27	X						0.9
78 08 14	13:29:43.7	31.61	102.56	X						2.2
78 08 19	19:44:36.5	31.57	103.21	X						0.8
78 09 29	17:59:41.4	30.32	104.66				X			1.9
78 09 29	20:07:43.3	31.52	102.51	X						2.3
78 09 30	23:31:47.5	31.66	102.71	X						1.9
78 10 02	09:35:06.9	31.54	102.51	X						1.7
78 10 02	09:58:33.4	31.60	102.55	X						1.7
78 10 02	11:25:09.9	31.51	102.52	X						2.0
78 10 03	06:12:17.2	31.91	102.99	X						1.8
78 10 06	15:23:46.3	31.53	102.34	X						2.2
79 01 19	09:07:55.1	30.50	105.12					X		1.5
79 02 13	19:02:13.4	30.17	104.36					X		1.5
79 02 16	23:50:32.5	31.03	104.90					X		1.7
79 03 28	15:20:02.8	31.10	102.65	X						1.0
79 04 25	00:19:26.0	31.93	101.99	X						1.6
79 04 28	01:01:40.0	30.58	104.69	X						2.1
79 06 09	01:28:59.1	30.65	104.50					X		1.6
79 06 28	19:23:45.4	30.38	105.15					X		1.6
79 07 05	01:05:05.9	32.90	101.31	X						2.7
79 07 17	07:26:14.4	32.52	103.88	X						2.0
79 08 03	05:29:38.3	32.85	100.94	X						2.6
80 02 05	23:56:54.7	29.92	104.44						X	2.9
80 03 21	08:35:23.7	31.56	102.41	X						1.0
81 08 13	23:39:52.4	31.91	102.58	X						2.2
81 09 16	03:08:53.8	33.74	105.24	X						1.8

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date Yr/Mo/Da	Origin Time GMT	Epicenter Lat. North	Epicenter Long. West	Located By NMT	USGS	LANL	ASL	UTA	UTEP	Mag.
82 01 04	16:56:08.1	31.18	102.49							3.4
82 07 22	14:38:55.6	34.27	105.62	X						0.5
82 08 28	08:04:18.2	32.55	104.52	X						1.1
82 09 22	15:41:52.5	34.10	106.10	X						0.5
82 10 26	00:37:49.8	33.64	103.58	X						1.5
82 11 03	23:23:50.0	32.86	105.99	X						0.6
82 11 25	18:50:08.6	32.90	100.88	X						2.3
82 11 28	02:36:48.0	33.00	100.80					X		3.3
83 01 09	11:49:04.0	30.35	105.76	X						1.9
83 01 12	10:11:12.5	34.33	105.17	X						1.5
83 01 29	11:44:52.2	31.38	102.36	X						2.2
83 03 03	18:13:44.7	29.80	104.29	X						2.8
83 03 31	20:51:21.2	32.36	106.42	X						1.7
83 04 04	09:57:21.0	30.58	105.25	X						1.2
83 04 11	11:19:15.0	31.28	102.48	X						1.2
83 04 17	19:39:02.0	33.43	105.93	X						1.7
83 04 24	05:13:02.0	32.32	103.90	X						-1.5
83 04 30	07:34:18.8	33.30	106.43	X						3.4
83 05 14	01:35:00.0	31.92	106.67	X						0.8
83 05 17	01:40:20.0	31.47	103.57	X						2.0
83 05 20	03:44:29.0	31.50	102.08	X						1.2
83 06 03	20:31:21.0	29.83	103.42	X						1.1
83 06 05	06:17:22.0	32.52	105.35	X						1.3
83 06 18	23:52:22.0	31.05	102.47	X						1.1
83 06 21	23:01:13.0	33.63	103.58	X						1.6
83 07 06	22:17:02.0	30.38	103.28	X						1.2
83 07 09	04:31:19.0	30.33	104.00	X						1.0
83 07 09	17:06:02.0	30.35	104.02	X						0.7
83 07 13	20:38:00.0	32.87	104.17	X						0.2
83 07 21	15:35:26.0	30.95	105.15	X						1.6
83 08 02	08:16:11.0	32.58	103.60	X						0.0
83 08 02	09:23:17.0	32.55	103.67	X						0.0
83 08 04	00:50:31.0	32.60	105.12	X						1.3
83 08 14	13:35:59.0	33.47	105.35	X						1.1
83 08 19	03:17:02.0	31.92	101.92	X						1.5
83 08 19	03:31:07.0	31.58	102.17	X						1.3
83 08 23	15:05:02.0	30.58	105.25	X						1.9
83 08 26	04:56:40.0	31.37	102.28	X						1.9
83 08 30	21:16:01.0	32.35	104.62	X						0.9
83 08 31	11:10:07.0	32.52	103.58	X						0.6
83 08 31	22:25:58.0	31.80	102.45	X						1.9
83 09 06	11:12:48.0	33.75	105.82	X						1.0
83 09 29	07:44:11.0	34.93	104.43	X						2.7
83 09 30	11:42:35.0	30.57	104.00	X						1.6
83 11 09	00:12:49.0	32.67	102.58	X						0.9
83 11 12	03:11:18.0	32.60	102.75	X						1.3
83 11 16	21:01:50.0	32.52	103.47	X						-0.4
83 12 01	10:05:59.0	31.83	102.02	X						1.4
83 12 03	23:46:51.0	30.90	103.33	X						2.1

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date Yr/Mo/Da	Origin Time GMT	Epicenter Lat. North	Epicenter Long. West	Located By NMT	USGS	LANL	ASL	UTA	UTEP	Mag.
83 12 26	11:05:11.0	31.17	102.33	X						1.5
84 01 02	10:29:36.0	31.70	102.15	X						1.8
84 01 03	09:38:18.0	30.80	103.00	X						1.5
84 01 03	10:20:00.0	30.80	103.00	X						1.5
84 01 03	10:28:33.0	30.80	103.00	X						1.3
84 01 16	08:49:03.0	33.88	103.08	X						0.8
84 01 16	12:09:44.0	33.88	103.08	X						1.1
84 02 23	05:43:30.0	32.65	104.02	X						-0.7
84 03 02	09:08:56.0	30.90	105.10	X						1.4
84 03 12	12:37:10.0	32.62	103.72	X						0.2
84 03 23	01:37:36.0	32.30	100.80	X						1.5
84 03 24	22:58:00.0	34.75	105.30	X						0.5
84 04 17	16:16:46.0	32.43	106.57	X						1.5
84 05 12	17:29:55.0	34.17	105.63	X						1.1
84 05 21	20:25:26.0	32.37	104.03	X						1.2
84 05 26	00:57:16.0	32.60	103.47	X						-0.2
84 06 28	01:58:29.0	34.33	105.98	X						0.1
84 07 17	08:24:06.0	32.77	105.92	X						1.3
84 07 20	21:56:58.0	34.68	105.38	X						0.3
84 08 01	04:04:07.0	32.70	105.90	X						0.4
84 08 14	06:32:22.0	33.50	106.45	X						1.3
84 08 18	12:46:18.0	31.53	103.12	X						1.8
84 08 21	05:39:23.0	33.57	106.57	X						1.4
84 08 25	00:01:32.0	32.92	103.73	X						0.9
84 08 28	12:13:54.0	34.27	105.67	X						1.0
84 08 31	02:49:02.0	34.72	105.30	X						1.3
84 09 11	14:47:34.0	32.00	100.70	X						3.0
84 09 21	01:44:21.0	34.67	105.38	X						1.5
84 09 25	23:23:02.0	32.35	102.58	X						0.8
84 10 03	08:09:56.0	32.80	103.98	X						0.7
84 10 04	05:15:06.0	33.88	103.30	X						1.3
84 11 10	23:10:00.0	34.57	105.37	X						1.1
84 11 27	19:06:03.0	33.62	105.37	X						1.6
84 12 04	20:36:30.0	32.55	103.12	X						2.5
84 12 08	00:37:37.0	34.72	105.28	X						1.4
84 12 12	23:53:40.0	33.33	105.63	X						1.5
85 01 06	14:30:45.0	34.35	104.78	X						2.3
85 01 06	22:49:30.0	33.58	105.42	X						1.1
85 03 09	22:53:28.0	33.93	105.15	X						1.3
85 03 12	04:01:41.0	33.40	106.10	X						1.3
85 03 18	05:37:39.9	32.36	104.72	X						1.6
85 04 16	12:26:02.0	34.03	106.00	X						0.8
85 04 16	12:27:06.0	34.03	106.00	X						0.4
85 05 03	15:28:20.0	31.17	104.68	X						1.9
85 05 04	04:05:50.0	33.35	106.40	X						0.5
85 05 17	03:08:09.0	34.72	105.30	X						1.2
85 05 30	19:54:13.0	32.57	106.93	X						1.0
85 05 30	23:13:12.0	32.55	106.95	X						1.1
85 05 30	23:22:50.0	32.48	106.92	X						1.2

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date Yr/Mo/Da	Origin Time GMT	Epicenter Lat. North	Epicenter Long. West	Located By NMT	Located By USGS	Located By LANL	Located By ASL	Located By UTA	Located By UTEP	Mag.
85 06 02	13:54:54.0	31.25	102.18	X						1.6
85 06 04	23:06:49.0	34.65	105.33	X						1.4
85 06 05	10:36:01.0	32.57	106.92	X						2.9
85 06 05	11:15:09.0	32.58	106.92	X						1.2
85 06 05	11:47:30.0	32.52	106.80	X						1.1
85 06 10	04:53:03.0	33.83	105.95	X						1.0
85 06 10	21:23:24.0	34.22	105.93	X						2.0
85 06 12	01:58:31.0	34.72	103.82	X						1.8
85 07 28	16:45:53.0	34.07	105.87	X						0.4
85 08 02	01:39:57.0	32.48	104.23	X						1.4
85 08 04	13:57:27.0	33.40	106.30	X						0.9
85 08 12	19:55:12.0	34.30	106.02	X						1.2
85 08 27	04:58:59.0	33.37	106.08	X						1.8
85 09 05	06:56:49.0	33.65	103.75	X						1.8
85 09 05	17:57:52.0	32.55	106.95	X						1.4
85 09 06	05:22:03.0	32.52	106.90	X						0.9
85 09 06	05:22:46.0	32.55	106.93	X						2.6
85 09 09	08:57:58.0	33.95	105.98	X						0.5
85 09 18	14:49:39.0	30.93	103.47	X						2.0
85 09 19	00:37:48.0	32.57	106.90	X						1.0
85 09 22	22:59:30.0	32.57	106.93	X						1.2
85 09 23	01:35:07.0	32.57	106.93	X						1.1
85 09 25	02:13:22.0	33.33	106.47	X						0.8
85 09 25	19:23:22.0	32.52	106.93	X						2.5
85 09 25	20:35:07.0	32.52	106.93	X						0.8
85 09 25	23:01:38.0	32.52	106.93	X						1.1
85 09 26	01:04:23.0	32.52	106.93	X						0.6
85 10 23	02:28:29.0	33.22	106.43	X						0.6
85 11 13	06:17:58.0	32.02	103.12	X						1.8
85 11 13	08:47:19.0	33.67	105.73	X						0.6
85 11 13	23:07:58.0	33.80	106.35	X						0.9
85 11 28	19:39:05.0	31.57	102.02	X						1.8
86 01 15	21:01:41.0	34.50	105.47	X						1.8
86 01 28	03:52:37.0	34.15	105.27	X						1.2
86 01 30	19:07:18.0	33.55	103.98	X						1.9
86 01 30	22:26:37.0	31.17	101.23	X						3.5
86 02 07	12:36:09.0	32.50	105.45	X						1.4
86 03 11	05:57:07.0	32.08	105.07	X						2.0
86 03 21	00:36:13.0	33.40	105.68	X						1.6
86 03 26	05:19:08.0	34.62	105.28	X						1.5
86 04 05	13:41:48.0	34.07	105.75	X						0.9
86 04 17	21:04:30.0	32.58	106.92	X						2.7
86 04 29	23:14:03.0	31.03	102.67	X						1.2
86 04 30	01:28:02.0	31.03	102.67	X						1.1
86 05 11	10:35:44.0	30.60	105.97	X						1.9
86 05 18	14:06:43.0	34.38	105.65	X						0.8
86 05 28	22:15:24.0	31.75	105.12	X						1.6
86 06 07	02:29:50.0	30.17	105.48	X						1.9
86 06 19	05:06:08.0	32.50	106.95	X						1.4

Table 2.5-3, Instrumental Origin Times, Locations and Magnitudes of Earthquakes Within 180 Mi of the WIPP Facility January 1, 1962 Through September 30, 1986*

Date	Origin Time	Epicenter		Located By						Mag.
Yr/Mo/Da	GMT	Lat. North	Long. West	NMT	USGS	LANL	ASL	UTA	UTEP	
86 06 27	09:47:24.0	32.00	102.00	X						2.2
86 07 09	19:51:02.0	31.50	102.48	X						1.6
86 07 20	19:31:26.0	33.47	105.02	X						1.5
86 08 02	17:51:43.0	33.68	103.78	X						1.7
86 08 14	21:26:52.0	32.57	104.68	X						1.3
86 08 15	07:59:20.0	33.02	103.77	X						1.7
86 09 10	16:50:49.0	34.12	105.75	X						0.8

* REFERENCES 1, 2, 3, 19, 20

Table 2.5-4, Risk Curve Parameters

#	Figure	Curve	Source Zone	Recurrence Formula	M_{max}
1	2.5-27	1	Algermissen & Perkins* Rio Grande rift (see Figure 2.5-12)	$\log N = 2.56 - M_L$	7.8
2	2.5-27	2	Algermissen & Perkins* Rio Grande rift (see Figure 2.5-12)	$\log N = 3.06 - M_{CORR}$	7.8
3	2.5-27	3	Basin & Range subregion (Figure 2.5-15)	$\log N = 2.75 - M_L$	7.8
4	2.5-27	4	Basin & Range subregion (Figure 2.5-15)	$\log N = 3.25 - M_{CORR}$	7.8
5	2.5-28	1	Algermissen & Perkins* Cen. Basin Plat. (see Figure 2.5-12)	$\log N = 2.74 - 0.9M_L$	5.0
6	2.5-28	2	Algermissen & Perkins* Cen. Basin Plat. (see Figure 2.5-12)	$\log N = 2.74 - 0.9M_L$	6.0
7	2.5-28	3	Algermissen & Perkins* Cen. Basin Plat. (see Figure 2.5-12)	$\log N = 3.19 - 0.9 M_{CORR}$	5.0
8	2.5-28	4	Algermissen & Perkins* Cen. Basin Plat. (see Figure 2.5-12)	$\log N = 3.19 - 0.9 M_{CORR}$	6.0
9	2.5-28	5	Cen. Basin Plat. geometry suggested by geology (see Figure 2.5-15)	$\log N = 2.74 - 0.9 M_L$	5.0
10	2.5-28	6	Cen. Basin Plat. geometry suggested by geology (see Figure 2.5-15)	$\log N = 2.74 - 0.9 M_L$	6.0
11	2.5-28	7	Cen. Basin Plat. geometry suggested by geology (see Figure 2.5-15)	$\log N = 3.19 - 0.9 M_{CORR}$	5.0
12	2.5-28	8	Cen. Basin Plat. geometry suggested by geology (see Figure 2.5-15)	$\log N = 3.19 - 0.9 M_{CORR}$	6.0
13	2.5-29	1	WIPP Facility	$\log N = 1.93 - M_L$	4.5
14	2.5-29	2	WIPP Facility	$\log N = 1.93 - M_L$	5.5
15	2.5-29	3	WIPP Facility	$\log N = 2.43 - M_{CORR}$	4.5
16	2.5-29	4	WIPP Facility	$\log N = 2.43 - M_{CORR}$	5.5

* S. T. Algermissen and D. M. Perkins, "A Probabilistic Estimate of Maximum Ground Acceleration in the Contiguous United States," U.S. Geol. Surv. open-file Report 76-416, pp. 1-45, (1976).21