SUMMARY OF REVISED TORNADO, HURRICANE AND EXTREME STRAIGHT WIND CHARACTERISTICS AT NUCLEAR FACILITY SITES

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Categorization of Natural Hazard Phenomenon and Operational Load Combinations

Prior to the 1988 Uniform Building Code, UBC[1] natural hazard phenomenon (earthquake, wind, flooding and precipitation) and operational load combinations were divided into two categories:

NORMAL- Loads such as dead, live and design basis pressure.
Expected frequency: 1.0 per yr with a limiting acceptance criteria
Allowable stress design criteria: equal to one-half to two-thirds of specified minimum yield stress.

SEVERE - Natural hazard and operational transient loads.
Frequencies of occurrence: between 2x 10^{-2}/yr and 10^{-2}/yr in combination with normal loads
Acceptance criteria: in the form of allowable stress increase by factors of 1.2 to 1.33 or 0.72 to 0.88 times specified minimum yield stress.

Categorization (Cont.)

Third category: **EXTREME/ABNORMAL** added in 1988 to the UBC for earthquake loads (previously defined as a Severe Load at approximately 2×10^{-2}/yr frequency of exceedence) was increased to more than 2×10^{-3}/yr based on a conventional facility (Risk Category II) design life of 50 years.

Categorization (Cont.)

In the ASCE 7-10-2010 Standard wind loads were moved from the severe to the extreme/abnormal load categories by deleting the 1.6 load factor on wind load and increasing the wind velocity return period from 50 to 700 years for Risk Category 2 and 100 to 1700 years for Risk Categories III and IV.

The ASCE 7-10 Standard for loads on structures does not consider tornadoes as a design basis load.

Definition of Design Basis Tornado

In 1967 for large NPP a design basis tornado wind, pressure drop and windborne missile load was defined as a design basis. In the U.S. NRC Regulatory Guide 1.76 -1974 tornado design basis loads were defined at a 10^{-7}/yr frequency for design of NPP reactor safety related structures, systems and components. The acceptance criteria associated with a load combination including an allowable of specified minimum yield stress or its equivalent.

Measuring Tornado Wind Velocities

Historically, it has been very difficult to measure tornado wind velocities because under tornado loading the wind measuring devices are typically destroyed. Dr. T. Fujita in 1991[(2)] prepared a wind velocity damage scale adopted by the National Weather Service. In 2007 the National Weather Service modified the scale by defining an Enhanced Fujita Scale.[(3)] Both scales are shown in Table 1.

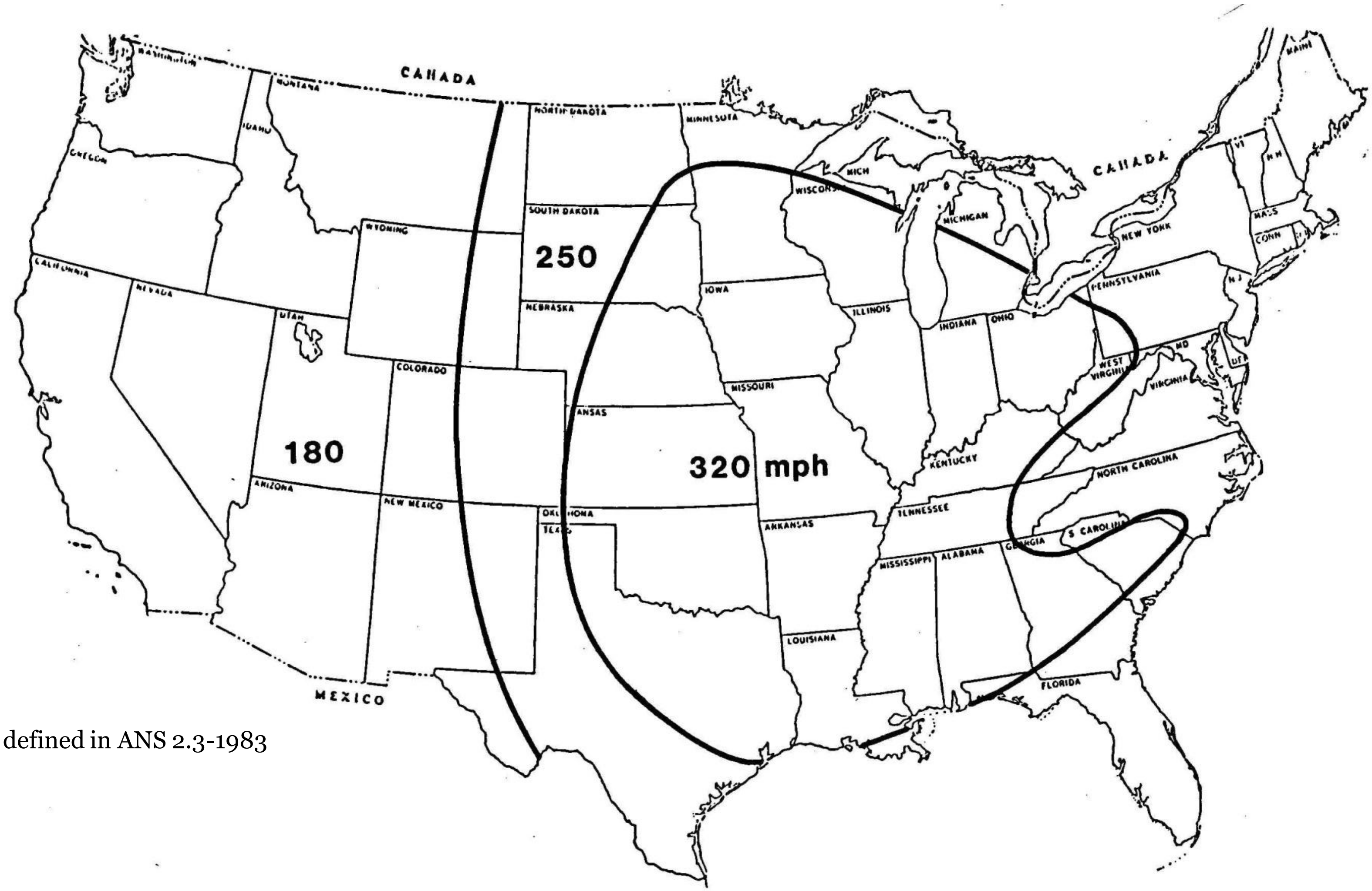
Table 1 Wind Speed Classification of Tornadoes by Fujita and Enhanced Fujita Damage Scales			
Original Fujita Wind Speed Scale	Enhanced Fujita Wind Speed Scale	Damage Potential	Effect Observed
F-0 (40-72 mph)	EF0 (65 to 85)	Light	Some damage to chimneys; branches broken off trees; shallow-rooted trees pushed over; sign boards damaged
F-1 (73-112 mph)	EF1 (86 to 110)	Moderate	Peel surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off roads
F-2 (113-157 mph)	EF2 (111 to 135)	Considerable	Roof torn off from homes; mobile homes demolished; boxcars pushed over; large trees snapped or uprooted, light-object missiles
F-3 (158-206 mph)	EF3 (136 to 165)	Severe	Roofs and some walls torn off well-constructed houses; trains overturned; most trees in forests uprooted; heavy cans lifted off ground and thrown
F-4 (207-260 mph)	EF4 (166 to 200)	Devastating	Well constructed houses leveled; structure with weak foundations blown off some distance; cars thrown and large missiles generated
F-5 (261-318 mph)	EF5 (>200)	Incredible	Strong frame houses lifted off foundations and carried considerable distance to disintegrate; automobile-sized missiles fly through air in excess of 100 m; trees debarked; incredible phenomena will occur
F-6 to F-12 (319-sonic velocity)		Currently believed nonexistent	

ANS Tornado Site Standard

The American Nuclear Society in 1983[4] published a tornado site standard that providing figures for:

- **tornado wind speeds**
- **pressure drop**
- **tornado missile wind speeds**

Geographical regional basis: between 10^{-5} to 10^{-7}/yr frequency for a 10^{-7}/yr frequency (See Fig. 1)



As defined in ANS 2.3-1983

Figure 1 Tornadic Wind Speeds Corresponding to a Probability of 10^7 Per Year (Gust Factor = 1.0)

DOE Publication of Performance Categories

In 1994 DOE published DOE Standard 1020 establishing the following frequencies

- Performance Category 3 structures, systems and components with a tornado frequency of $2x10^{-5}$/yr
- Performance Category 4 a frequency of 2×10^{-6}/yr as shown in Table 2.

This table was modified in the 2002 revision of the DOE 1020 Standard as shown in Table 3.

Table 2 Recommended Basic Wind Speeds
For DOE Sites, in miles per hour

Performance Category	Fastest-Mile Wind Speeds at 10m Height					
	1	2	3		4	
	Wind	Wind	Wind	Tornado[4]	Wind	Tornado[4]
DOE PROJECT SITES	2×10^{-2}	2×10^{-2}	1×10^{-3}	2×10^{-5}	1×10^{-4}	2×10^{-6}
Kansas City Plant, MO	72	72	--	144	--	198
Los Alamos National Laboratory, NM	77	77	93	--	107	--
Mound Laboratory, OH	73	73	--	136	--	188
Pantex Plant, TX	78	78	--	132	--	182
Rocky Flats Plant, CO	109	109	138	(3)	161	(3)
Sandia National Laboratories, NM	78	78	93	--	107	--
Sandia National Laboratories, CA	72	72	96	--	113	--
Pinellas Plant, FL	93	93	130	--	150	--
Argonne National Laboratory--East, IL	70(1)	70(1)	--	142	--	196
Argonne National Laboratory--West, ID	70(1)	70(1)	83	--	95	--
Brookhaven National Laboratory, NY	70(1)	70(1)	--	95(2)	--	145
Princeton Plasma Physics Laboratory, NJ	70(1)	70(1)	--	103	--	150
Idaho National Engineering Laboratory	70(1)	70(1)	84	--	95	--
Feed Materials Production Center, OH	70(1)	70(1)	--	139	--	192
Oak Ridge, X-10, K-25, and Y-12, TN	70(1)	70(1)	--	113	--	173
Paducah Gaseous Diffusion Plant, KY	70(1)	70(1)	--	144	--	198
Portsmouth Gaseous Diffusion Plant, OH	70(1)	70(1)	--	110	--	166
Nevada Test Site, NV	72	72	87	--	100	--
Hanford Project Site, WA	70(1)	70(1)	80(1)	--	90(1)	--
Lawrence Berkeley Laboratory, CA	72	72	95	--	111	--
Lawrence Livermore National Lab., CA	72	72	96	--	113	--
LLNL, Site 300, CA	80	80	104	--	125	--
Energy Technology & Engineering Center, CA	70(1)	70(1)	--	95(2)	--	111
Stanford Linear Accelerator Center, CA	72	72	95	--	112	--
Savannah River Site, SC	78	78	--	137	--	192

NOTES:

(1) Minimum straight wind speed.

(2) Minimum tornado speed.

(3) Although straight winds govern at Rocky Flats, because the potential for a tornado strike is high, it is recommended that facilities be designed for tornado missiles. APC need not be considered.

(4) Tornado speed includes rotational and translational effects

(5) Hurricane effects adjustments as per Table 3-1.

Table 3 Recommended Peak Gust Wind speeds for Straight Winds (for Category C Exposure) And Tornadoes in miles per hour at 33 Ft. (10,) Above Ground

Current Performance Category	PC1	PC2	PC3 Wind	PC3 Tornado(2)	PC4 Wind	PC4 Tornado(2)
Return period (yrs)	50	100	1000	50000	10000	500000
Annual Probability	2.00E-02	1.00E-02	1.00E-03	2.00E-05	1.00E-4	2.00E-06
Site						
Kansas City Plant, MO	90	96	-	(3)	-	(3)
Los Alamos National Laboratory, NM	90	96	117	-	135	-
Mound Laboratory, OH	90	96	-	(3)	-	(3)
Pantex Plant, TX	90	96	-	195	-	248
Rocky Flats Plant, CO	125	134	163	(1)	188	(1)
Sandia National Laboratories, NM	90	96	117	-	135	-
Sandia National Laboratories, CA	85	91	111	-	128	-
Argonne National Laboratories-East, IL	90	96	-	(3)	-	(3)
Argonne National Laboratories-West, ID	90	96	117	-	135	-
Brookhaven National Laboratory, NY	125	138	178	(1)	219	(1)
Princeton Plasma Physics Laboratory, NJ	110	122	156	(1)	193	(1)
Idaho National Engineering Laboratory , ID	90	96	117	-	135	-
Oak Ridge, X-10, K-25, and Y-12, TN	90	96	-	200	-	255
Paducah Gaseous Diffusion Plant, KY	90	96	-	(3)	-	(3)
Portsmouth Gaseous Diffusion Plant, OH	90	96	-	(3)	-	(3)
Nevada Test Site, NV	90	96	117	-	135	-
Hanford Project Site, WA	85	91	111	-	128	-
Lawrence Berkeley Laboratory, CA	85	91	111	-	128	-
Lawrence Livermore National Laboratory, CA	85	91	111	-	128	-
LLNL, Site 300, CA	95	102	124	-	143	-
Energy Technology & Engineering Center, CA	85	91	-	(3)	-	(3)
Stanford Linear Accelerator Center, CA	85	91	111		128	-
Savannah River Site, SC	100	107	-	169	-	213

1. Although straight wind speeds govern, because the potential for a tornado strike is high, it is recommended that facilities be designed for tornado missiles using the missile speeds for the relevant performance category. APC may not be considered.

2. Tornado speed includes rotational and translational effects

3. For non-NNSA sites tornado wind speeds need to be generated by sites from tornado hazard curves utilizing LLNL methodology (Reference 3-14).

Expansion of ANS 2.3

The ANS 2.3-2011 Standard[5] has been expanded from that published in 1983 to include:

- straight winds
- hurricane
- tornado missile parameters different than hurricane missile parameters

It also adopted the Enhanced Fujita wind velocity damage scale of 2007 (See Table 1) significantly reducing wind velocities and associated pressure drop and missile velocities as a function of frequency previously defined in the ANS 2.3-1983 Standard based on the original Fujita damage scale. For example, at the 10^{-7}/yr frequency for geographical Region 1 (See Fig. 1) the tornado wind speed has been reduced to 230 from 320 mph.

Note: this wind speed was somewhat less than the 360 mph wind velocity defined at the time in R.G. 1.76.[6] In 2007 the U.S. NRC revised its R.G. 1.76 to a Region I wind speed of 230 mph.

Definition of Wind Velocities

There were also changes in the way wind velocities were defined. The Fujita Scale defined wind speeds as fastest one quarter mile wind speeds while the Enhanced Fujita Scale defined wind speeds as 3 second gusts. As a practical matter for tornado wind speeds above 120 mph the difference between the two wind speeds definitions are minor.

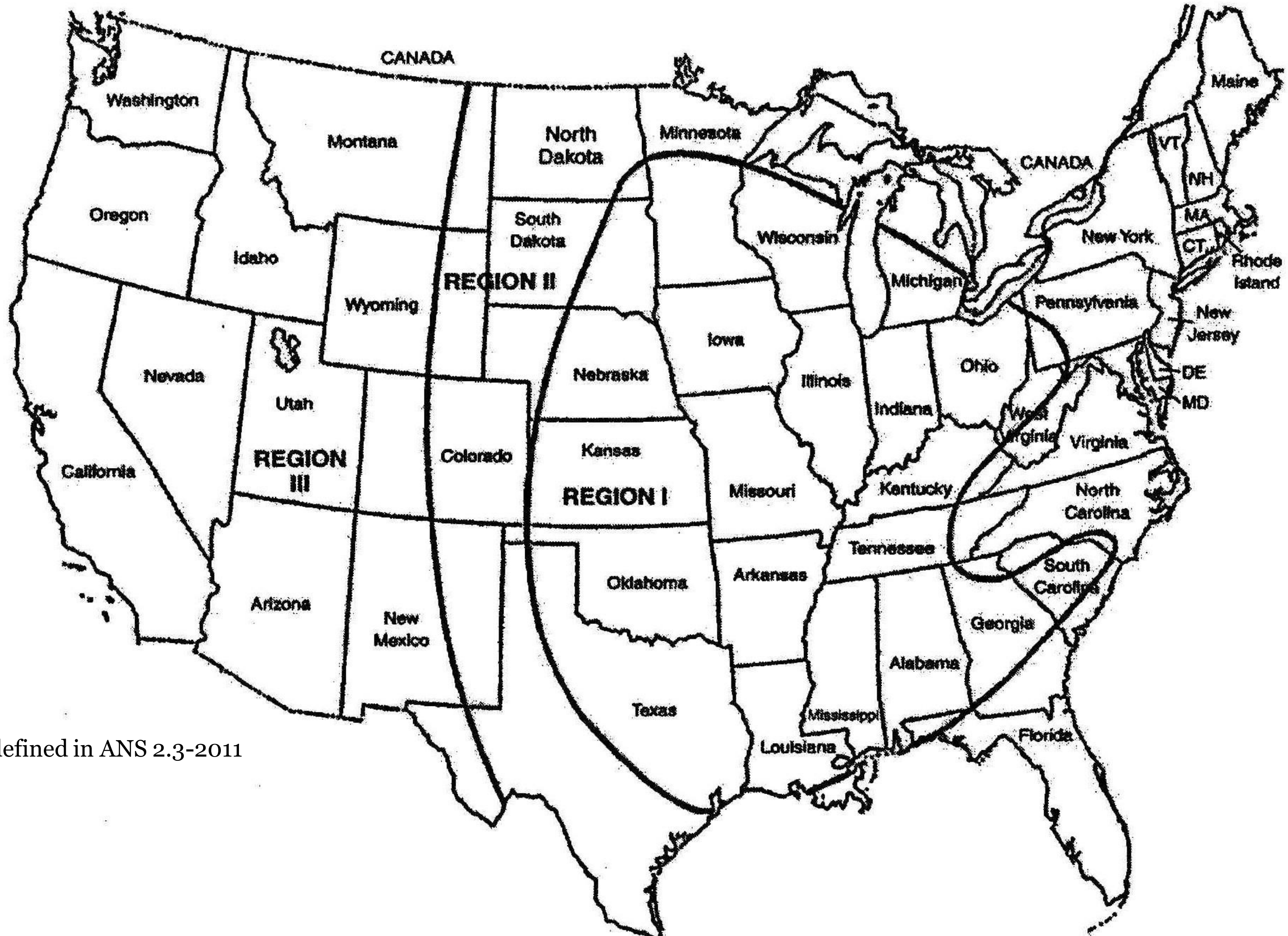
Modification of Geographical Regions

In ANS 2.3-2011 Standard 3 geographical regions (See Fig 1) were modified and expanded to include:

- **extreme (i.e. straight winds), and**
- **rare (i.e. (hurricane and tornado) events (See Fig. 2).**

Resultant wind speed in the three U.S. geographical regions as a function of mean return period (reciprocal of frequency), are shown in Figs. 3 to 5. The data used to generate the curves in these Figures 5 is contained in Table 4 where tornado parameters are based on a tornado probability study NUREG/CR-4461, Rev. 2.[7]

Similar study relative to geographical tornado data was prepared by Lawrence Livermore National Laboratory in 2000[8] that came up with slightly more conservative probability based wind speed estimates.



As defined in ANS 2.3-2011

Figure 2 – Regionalization of Extreme and Rare Wind Speeds

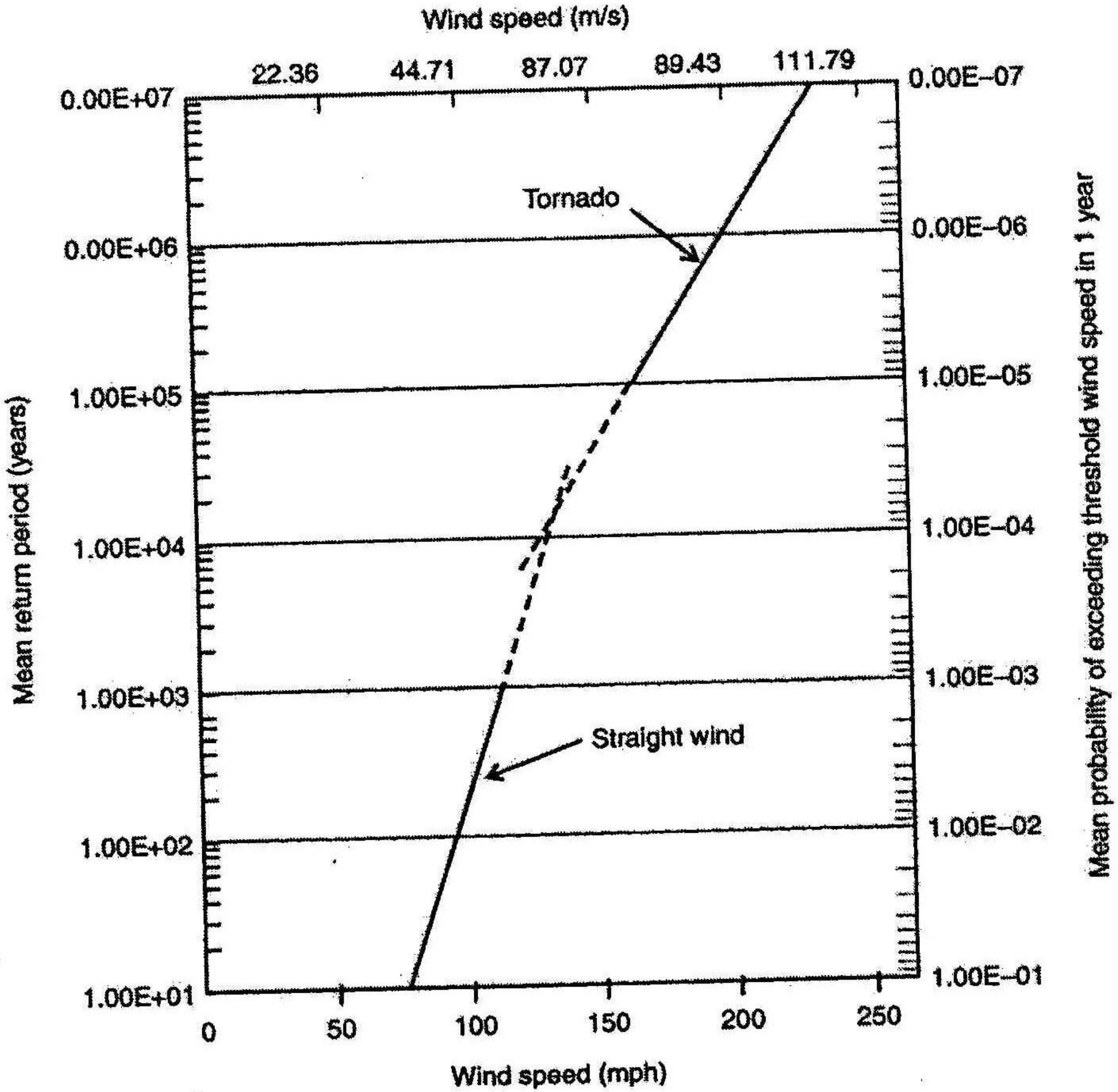


Figure 3 – Wind Speeds at a Region I Wind Hazard Site

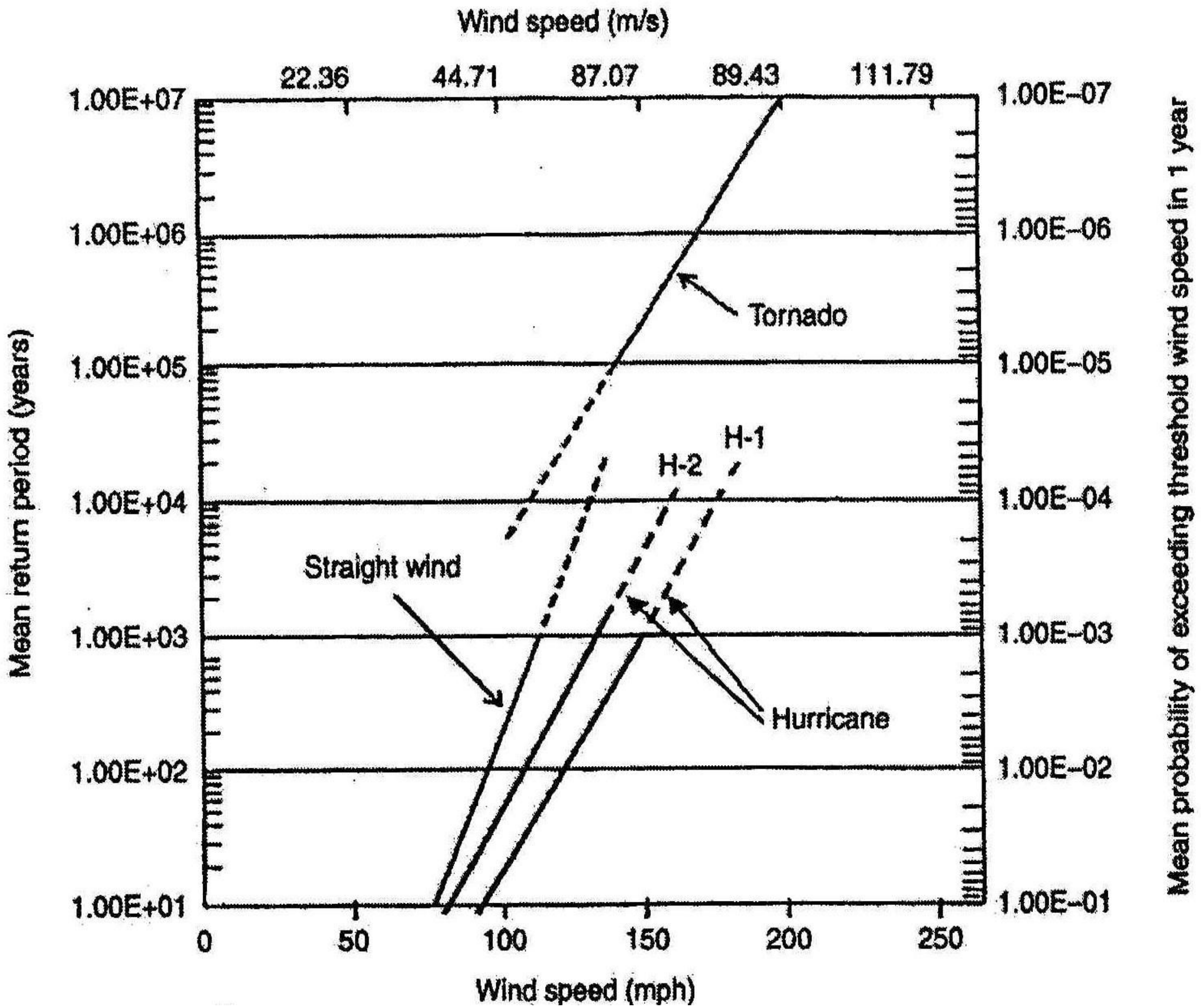


Figure 4 – Wind Speeds at a Region II Wind Hazard Site

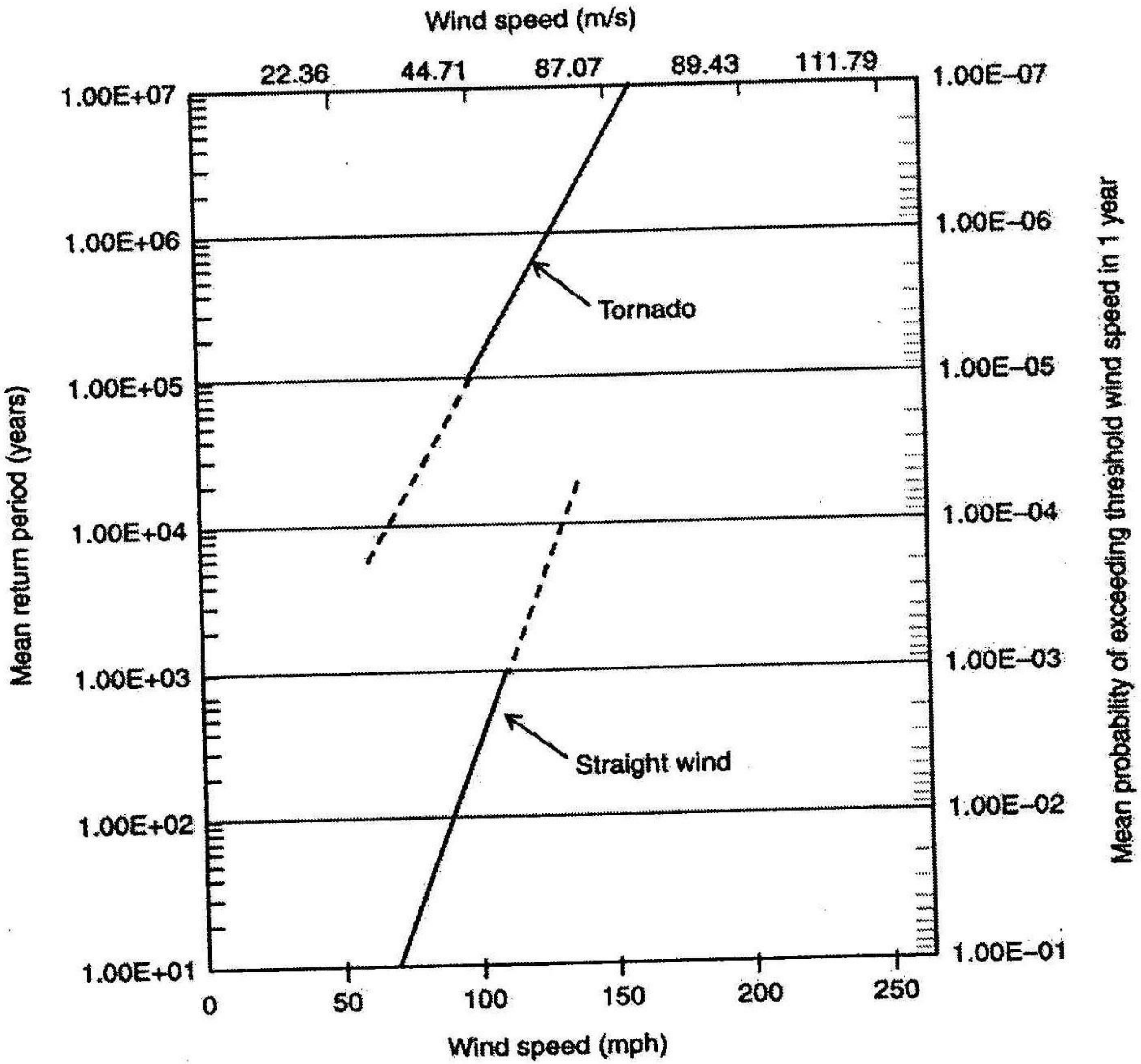


Figure 5 – Wind Speeds at a Region III Wind Hazard Site

Table 4 Data Used to Generate mean Return period and Probabilities of Exceedence Curves

Region I data				
Straight line wind			Tornado	
Mean return period (years)	1) 2)	Miles per hour	Mean return period (years)[3]	Miles per hour
1.00E+04[4]	1.52 × 90 =	137	1.00E+07 =	230
1.00E+03	1.30 × 90 =	118	1.00E+06 =	200
5.00E+02	1.23 × 90 =	111	1.00E+05 =	170
2.00E+02	1.14 × 90 =	103		
1.00E+02	1.07 × 90 =	96		
5.00E+01	1.00 × 90 =	90		
1.00E+01	0.84 × 90 =	76		

Table 4 (Cont.)

Region II data									
Straight line wind			Tornado		Hurricane				
Mean return period (years)	1) 2)	Miles per hour	Mean return period (years)[3]	Miles per hour	Mean return period (years)	H-2	Miles per hour	H-1	Miles per hour
1.00E+04	1.52 × 90 =	137	1.00E+07 =	200	1.00E+04	1.15 × 137 =	158	1.3 × 137 =	178
1.00E+03	1.30 × 90 =	118	1.00E+06 =	170	1.00E+03	1.15 × 118 =	136	1.3 × 118 =	153
5.00E+02	1.23 × 90 =	111	1.00E+05 =	140	1.00E+02	1.15 × 96 =	111	1.3 × 90 =	125
2.00E+02	1.14 × 90 =	103							
1.00E+02	1.07 × 90 =	96							
5.00E+01	1.00 × 90 =	90							
1.00E+01	0.84 × 90 =	76							
(Continued)									

Table 4 (Cont.)

Region III data				
Straight line wind			Tornado	
Mean return period (years)	1) 5)	Miles per hour	Mean return period (years)[3]	Miles per hour
1.00E+04	1.52 × 85 =	129	1.00E+07 =	160
1.00E+03	1.30 × 85 =	111	1.00E+06 =	130
5.00E+02	1.23 × 85 =	105	1.00E+05 =	100
2.00E+02	1.14 × 85 =	97		
1.00E+02	1.07 × 85 =	91		
5.00E+01	1.00 × 85 =	85		
1.00E+01	0.84 × 85 =	71		

1)The slope of the straight wind hazard as a function of mean return period is taken from Table C6-7 of the commentary to ASCE/SEI 7-05 [14].

2)Multiplication factor applied to a 90 mph straight line wind 50-year mean return period from Table C6-7 of the commentary to ASCE/SEI 7-05 [14].

3)Tornado wind data from NUREG/CR-4461, Rev. 2, Table 8-1 [12]; summary of data used to plot wind speed in Figs. 2, 3, and 4.

4)Read as 1.00×10^{04}.

5)Multiplication factor applied to an 85 mph straight line wind 50-year mean return period from Table C6-7 of the commentary to ASCE/SEI 7-05 [14].

Wind Velocity Data

The wind velocity data for hurricane and straight winds are taken from an extension of the return period given in the commentary for wind loads in ASCE 7-95.[9] It should be noted the draft revision to DOE Std. 1020 has changed the return period (frequency) from that prescribed in the current version of DOE Standard 1020-2002 and also makes specific reference to the use of the ANS 2.3-2011 Standard as shown in Table 5.

Table 5 Mean Return Periods For Design Basis wind Speeds for WDC-3, WDC-4 and WDC-5 SSCs from Draft DOE Std. 1020-XX

		Design basis Mean Return Period Years		
Current 1020 Std. Performance Categories	WDC **	Extreme Straight-Line Wind	Hurricane *	Tornado **
PC-3	WDC-3	2,500	2,500	50,000
PC-4	WDC-4	5,000	5,000	125,000
--	WDC-5	10,000	10,000,000	10,000,000

* For hurricane-prone areas (i.e. near the Gulf of Mexico and Atlantic Coast) only

** Tornado wind hazards need not be considered if the straight-line wind speeds are greater than tornado wind speeds at the design basis return periods tabulated above, see ANSI/ANS-2.3-2011, "Standard for Estimating Tornado, Hurricane, and Extreme Straight-line wind Characteristics at Nuclear Facility Sites," for additional information.

ANS 2.3-2011 Guidance

The ANS 2.3-2011 Standard also provides guidance for:

- **tornado and hurricane design basis missile as a function of wind speed, and**
- **type of wind loading (see Table 6).**

Hurricane basis missiles generally considered to travel at a greater velocity due to the gradual wind velocity gradient as a function of the distance from the center of rotation in a hurricane as compared to a tornado.

Table 6 Standard Design Missile Spectrum for Tornado and Hurricane-Type Winds

		Missile Horizontal Velocity Coefficient 1), 2)	
Missile 3)	**Horizontal wind velocity range greater than V or V_h**	**Tornado (V) coefficient, k_1**	**Hurricane (V_h) coefficient, k_1**
	Weight 4000 lb (1810 kg) 2)		
Impact type: automobile, 20.0-ft² (2.0-mi²) contact area	250 mph (400 kmph)	0.4	0.7
	200 mph (325 kmph)	0.4	0.6
	150 mph (245 kmph)	0.3	0.6
	100 mph (160 kmph)	0.3	0.5
	Weight 287 lb (130 kg) 1)		
Penetrating-type, Schedule 40 pipe, 6.0-in. (150-mm) diameter, 15-ft (4.58-m) length	250 mph (400 kmph)	0.4	0.5
	200 mph (325 kmph)	0.4	0.5
	150 mph (245 kmph)	0.4	0.5
	100 mph (160 kmph)	0.4	0.5
	Weight 0.147 lb (0.0669 kg) 1)		
Solid steel sphere, structural opening 1.0-in. (25-mm)-diameter	250 mph (400 kmph)	0.1	0.5
	200 mph (325 kmph)	0.1	0.4
	150 mph (245 kmph)	0.1	0.4
	100 mph (160 kmph)	0.0	0.3

* ft^2 = square feet; mi^2 = square miles; mph = miles per hour; kmph = kilometers per hour; k_1 = missile velocity coefficient as shown in note 2).

1) Vertical velocity taken as 0.67 of horizontal velocity.

2) Missile velocity = $k_1(V \text{ or } V_h)$.

3) Automobile missile impact limited to elevation ≤30 ft (9.14 m) above plant grade.

Definition of Loads

- ASCE 7-2005 Standard defined straight wind and hurricane wind loads area as a severe load with a 50 or 100 year return period depending on the code Importance Factor and wind load defined for design multiplied by a 1.6 load factor.
- In the 2010 ASCE Standard defined straight wind and hurricane design basis 3 second gust wind based on U.S. geographic location with a 700 year return period for ASCE 7-10 Risk Category II as shown in Figure 6 and 1700 year return period as shown in Figure 7 for Categories III and IV.
- The wind load was redefined from a severe to an extreme/abnormal load category with its design basis load factor changed to 1.0 from 1.6.

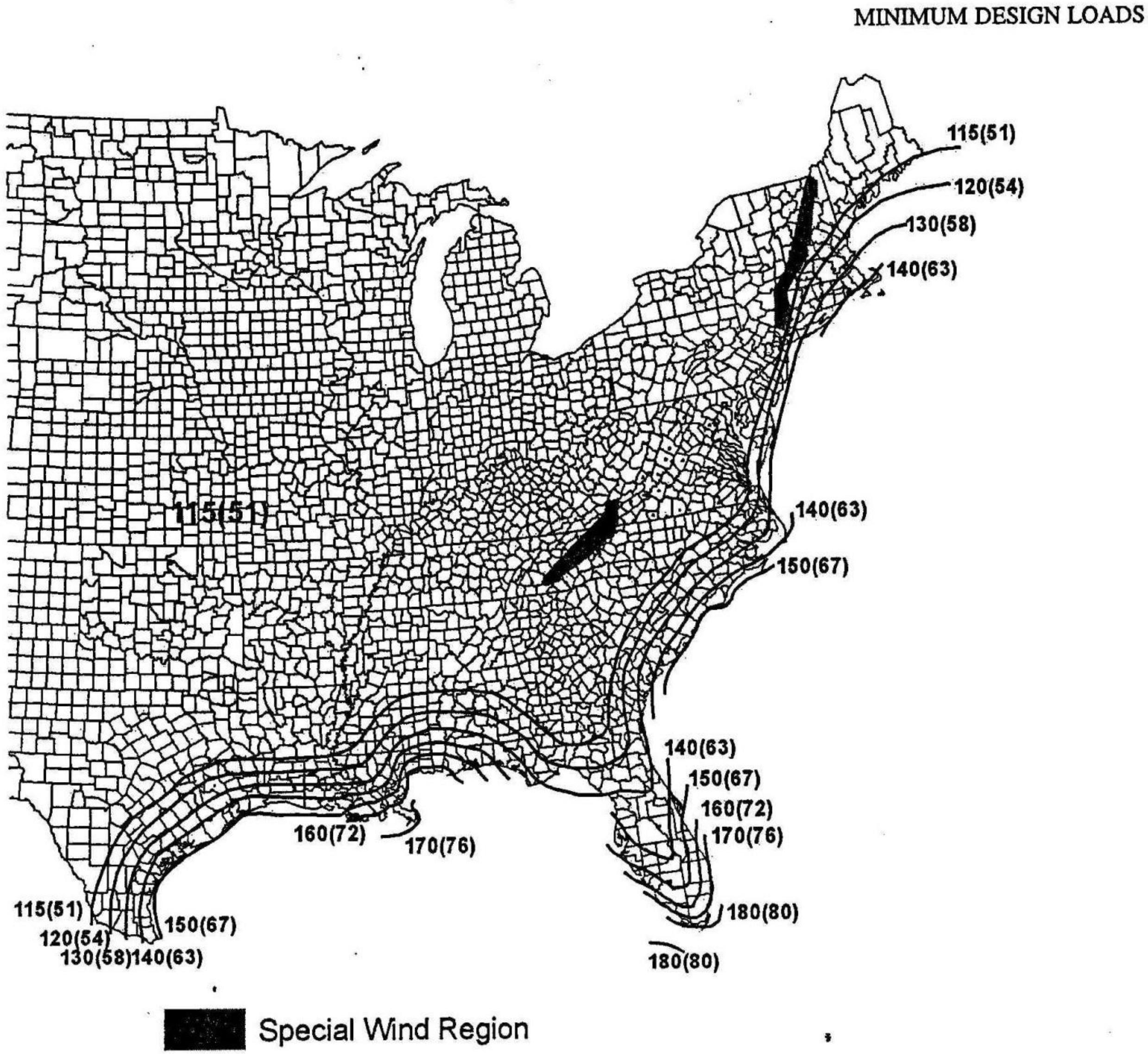


Figure 6 – U.S. Design Basic Wind Speeds for ASCE 7-10 Occupancy Category II Structures

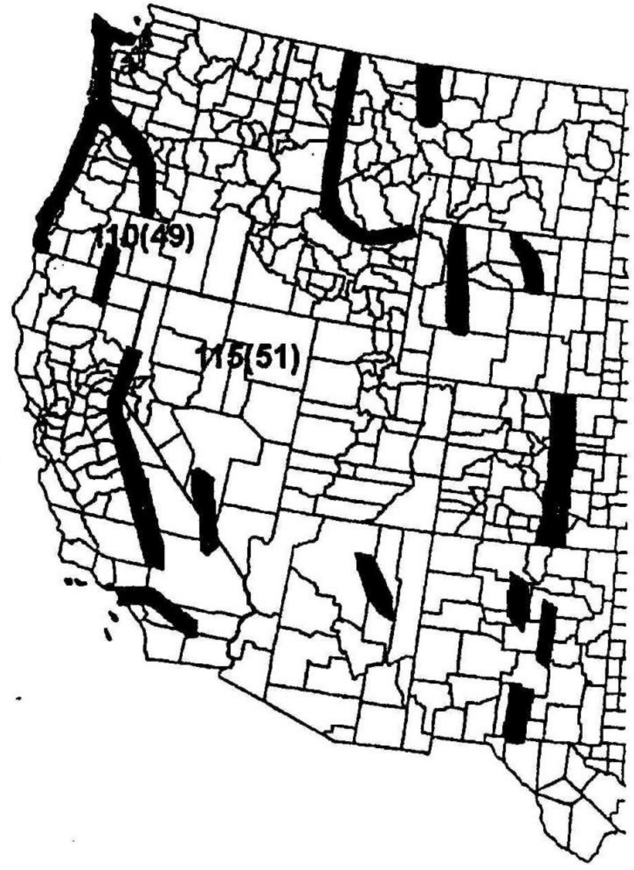


Figure 6 – Cont.

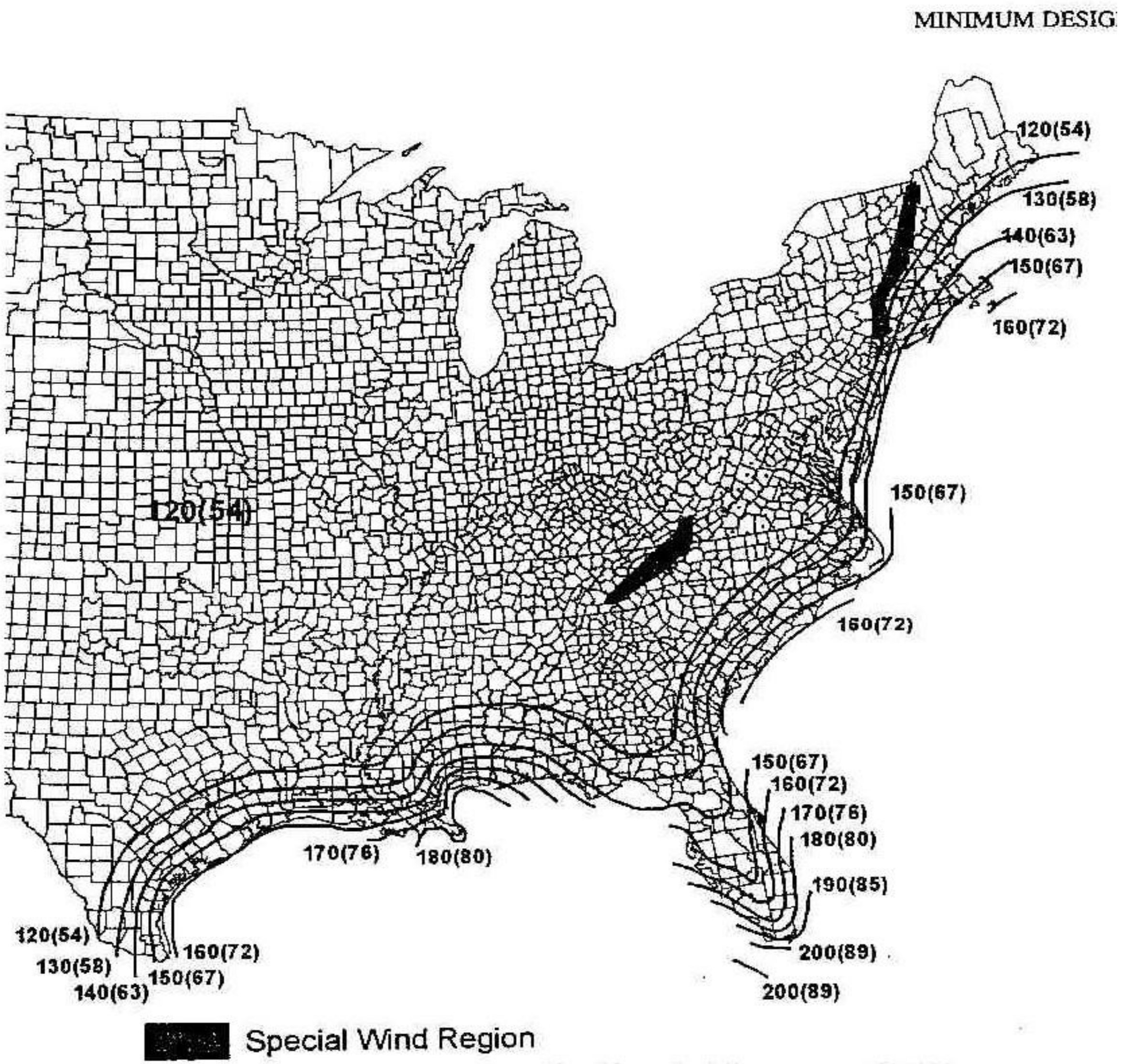


Figure 7 Design Basis Wind Speed for ASCE 7-10 Risk Categories III and IV Structures

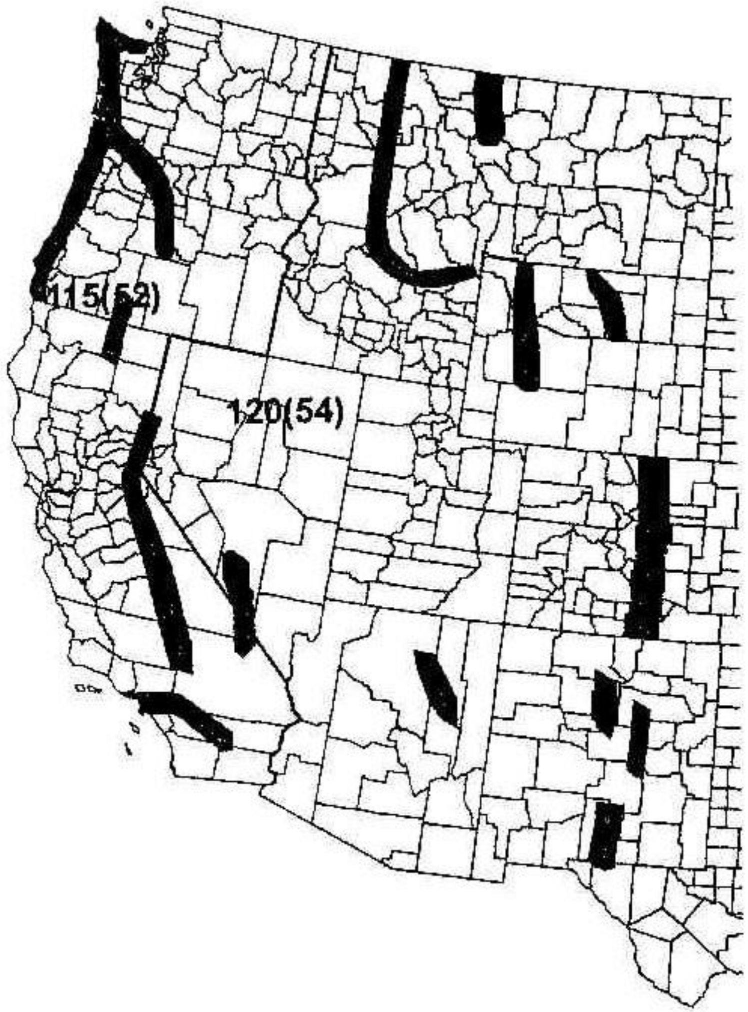


Figure 7 Cont.

Wind Velocities

Note: wind velocities are assumed to change for every doubling of return period:

- **factor of 1.07 for wind velocity, and**
- **factor of 1.15 for wind load**

At this time neither the ACI-349 nor AISC N-690 Standards have caught up with the basic change in the ASCE defined loading. As a result, the existing ACI and AISC-06 Standards should continue to use the ASCE 7-05 Standard wind load definition until they are modified to be in agreement with the changes in the ASCE 7-10 Standard.

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