UNCLASSIFIED FACSIMILE MESSAGE

DEPARTMENT OF ENERGY

OFFICE OF TECHNICAL SUPPORT, DP-45
DEFENSE PROGRAMS

DATE: 1/17/01

TO: Chris Steele LAAO

FROM: Jeff DP-45

COMMENTS: Chris - sorry its taken me so long on flooding USQ - 2000-2 takes a lot of my time away from fun stuff - I did discuss my thoughts with TCD and am writing a draft for your review - Jeff

NUMBER OF PAGES TO FOLLOW: 31

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DOE F 1325.8 (8-89) EFG (07-90)

United States Government

Department of Energy

memorandum

DATE: January 22, 1998

REPLY TO ATTN OF: Office of Nuclear Safety Policy and Standards:H. Chander:301-903-6681

SUBJECT: Newsletter (Interim Advisory on Straight Winds and Tornados)

TO: Distribution

DOE-STD-1020 "Natural Phenomena Hazards Design and Evaluation Criteria for DOE Facilities," was updated in early 1996 (Change Notice #1) and referenced ASCE 7-95 which was also approved for use in June 1996. ASCE 7-95 has several noteworthy changes from ASCE 7-93 and ASCE 7-88.

With the release of the latest version, ASCE 7-95, the description of the basic wind speeds was changed from "fastest mile" to "peak gust." The National Weather Service phased out the measurement of fastest-mile wind speeds and has redefined the basic wind speed as the peak gust that is associated with an averaging time of approximately three seconds. The basic methodology employed by ASCE 7-95 remains the same (refer to Attachment "B" for variations), but the coefficients and factors used to obtain pressure loading have changed to reflect the peak gust wind definition.

Table 3-2 of DOE-STD-1020 should not be used any longer for straight winds with the new provisions of ASCE 7-95. Attachment "A"gives the revised "peak gust" speeds for various DOE sites for different performance categories. Please note that it is no longer necessary to use "importance factor" of 1.07 previously given in Table 3-1, since this is now factored in Attachment "A". An attempt has been made in Attachment "A" to conform to basic concepts outlined in ASCE 7-95. The hurricane importance factor for sites within 100 miles of the coast has also been built into wind speeds in Attachment "A".

For sites where design for performance categories 3 and 4 is controlled by tornadoes, please continue to use the criteria in Table 3-1 and revised wind speeds in Attachment "A" until further notice. This subject is under active review and you will be advised of changes, if any. The Change Notice #2 to incorporate all these changes to DOE-STD-1020-94 will follow later.

The changes stated above will necessitate some minor editorial changes to Chapter 3 and Appendices D and E. These are being provided to you in Attachment "C".

If you have any questions, please call Harish Chander at (301) 903-6681, e-mail: harish.chander@eh.doe.gov.

Richard L. Black, Director
Office of Nuclear Safety
Policy and Standards

Attachments A, B & C

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Attachment A

Recommended Peak Gust Wind Speeds

[In miles per hour at 33 Ft. (10m) above ground

Current Performance Category	PC1	PC2[1]	PC3 Wind[1]	PC 3 Tornado[3][5]	PC4 Wind[1]	PC4 Tornado[3][5]
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-04	2.00E-06
Site						
Kansas City Plant, MO	90	96	–	162	–	219
Los Alamos National Laboratory, NM	90	96	117	–	135	–
Mound Laboratory, OH	90	96	–	154	–	208
Pantex Plant, TX	90	96	–	150	–	202
Rocky Flats Plant, CO	125	134	163	(4)	188	(4)
Sandia National Laboratories, NM	90	96	117	–	135	–
Sandia National Laboratories, CA	85	91	111	–	128	–
Argonne National Laboratory—East, IL	90	96	–	160	–	216
Argonne National Laboratory—West, ID	90	96	117	–	135	–
Brookhaven National Laboratory, NY[2]	125	138	178	(4)	219	(4)
Princeton Plasma Physics Laboratory, NJ[2]	110	122	156	(4)	193	(4)
Idaho National Engineering Laboratory, ID	90	96	117	–	135	–
Oak Ridge, X-10, K-25, and Y-12, TN	90	96	–	130	–	192
Paducah Gaseous Diffusion Plant, KY	90	96	–	162	–	219
Portsmouth Gaseous Diffusion Plant, OH	90	96	–	127	–	185
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	–	111	–	128
Stanford Linear Accelerator Center, CA	85	91	111	–	128	–
Savannah River Site, SC	100	107	–	155	–	212

Notes:

(1) Unless otherwise noted PC1 values are modified as follows:
- PC2 = PC1 x 1.07
- PC3 = PC1 x 1.30
- PC4 = PC1 x 1.50

(2)
- PC2 = PC1 x 1.105
- PC3 = PC1 x 1.42
- PC4 = PC1 x 1.75

(3) $V_t = (V_{fm} + 11.34)/0.958$

(4) 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 speed for the relevant performance category. APC need not be considered.

(5) Tornado speed includes rotational and translational effects.

ASCE 7-95 was a major revision to the wind loads section. The following changes occurred:

	ASCE 7-93	ASCE 7-95
Basic Wind Speed	Fastest-mile	3 sec gust
Importance Factor	$(IV)^2$	$I(V)^2$
		Thus $I(7\text{-}95) = I^2(7\text{-}93)$
Hurricanes	Treated with Variable I	Included in Basic Wind Speed Map
Classification	IV	I
	I	II → PC 1
	II	III
	III	IV → PC 2
Coefficients	—	Adjustments were made to be consistent with 3-sec gust windspeed
Formulas	—	Some refinements and additional features

Pressures on windward, leeward, side walls and roofs were computed by the ASCE 7-93 (7-88) and 7-95 procedures and compared. The pressures were computed for an enclosed rectangular building 50 ft. high, 100 ft. wide (across-wind direction) and 200 ft. long (along-wind direction). The facility was a PC 2 facility and Exposure C was used. The comparisons are shown in Table I.

Table 1. **Comparison of wall and roof pressures (psf) on 50' x 100' x 200' enclosed Performance Category (PC2) building for Exposure C**

Component	ASCE 7-93 (7-88)	ASCE 7-95
Top of windward wall	+ 15.71	+ 15.71
Side Walls	- 13.75	- 13.75
Leeward Walls	- 5.89	- 5.89
Roof	- 13.75 uniform	- 17.68 maxm
Internal Pressure	± 4.06	± 4.16

+ = Pressure
- = Suction

As can be seen from this comparison the pressures are essentially the same (for PC 2) with ASCE 7-95. ASCE 7-95 has a variable roof pressure distribution. The new roof pressure distribution is based on the latest research results. PC 3 & PC 4 comparisons will result in variations between two standards.

Chapter 3

Wind Design and Evaluation Criteria

3.1 Introduction

This chapter presents a uniform approach to wind load determination that is applicable to the design of new and evaluation of existing structures, systems and components (SSCs). As discussed in Appendix D.1, a uniform treatment of wind loads is recommended to accommodate straight, hurricane, and tornado winds. SSCs are first assigned to appropriate Performance Categories by application of DOE-STD-1021. Criteria are recommended such that the target performance goal for each category can be achieved. Procedures according to the wind load provisions of ASCE 7 (Ref. 3-1) are recommended for determining wind loads produced by straight, hurricane and tornado winds. The straight wind/tornado hazard models for DOE sites published in Reference 3-2 are used to establish site-specific criteria for 25 DOE sites. For other sites, the wind/tornado hazard data shall be determined in accordance with DOE-STD-1023.

The performance goals established for Performance Categories 1 and 2 are met by model codes or national standards (see discussion in Appendix B). These criteria do not account for the possibility of tornado winds because wind speeds associated with straight winds typically are greater than tornado winds at annual exceedance probabilities greater than approximately $1x10^{-4}$. Since model codes specify winds at probabilities greater than or equal to $1x10^{-2}$, tornado design criteria are specified only for SSCs in Performance Categories 3 and higher, where hazard exceedance probabilities are less than $1x10^{-2}$.

In determining wind design criteria for Performance Categories 3 and higher, the first step is to determine if tornadoes should be included in the criteria. The decision logically can be made on the basis of geographical location, using historical tornado occurrence records. However, since site specific hazard assessments are available for the DOE sites, a more quantitative approach can be taken. Details of the approach are presented in Appendix D. The annual exceedance probability at the intersection of the straight wind and tornado hazard curves is used to determine if tornadoes should be a part of the design criteria. If the exceedance probability at the intersection of the curves is greater than or equal to $2x10^{-5}$ then tornado design criteria are specified. By these criteria, tornado wind speeds are determined at $2x10^{-5}$ for PC-3 and $2x10^{-6}$ for PC-4. If the exceedance probability is less than $2x10^{-5}$ only the effects of straight winds or hurricanes need be considered. For straight winds and hurricanes, wind speeds are determined at $1x10^{-3}$ for PC-3 and $1x10^{-4}$ for PC-4.

3.2 Wind Design Criteria

The criteria presented herein meets or exceeds the target performance goals described in DOE 5480.28 for each Performance Category. SSCs in each category have a different role and represent different levels of hazard to people and the environment. In addition, the degree of wind hazard varies geographically. Facilities in the same Performance Category, but at different geographical locations, will have different wind speeds specified to achieve the same performance goal.

The minimum wind design criteria for each Performance Category are summarized in Table 3-1. The recommended basic wind speeds for straight wind, hurricanes and tornadoes are contained in Table 3-2 for laboratories, reservations, and production facilities. All wind speeds are 3 sec peak gust, which is consistent with the ASCE 7 approach. Importance factors as given in ASCE 7 should be used were applicable

Degrees of conservatism are introduced in the design process by means of load combinations. The combinations are given in the appropriate material-specified national consensus design standard, e.g. AISC Steel Construction Manual. Designers will need to exercise judgment in choosing the most appropriate combinations in some situations. Designs or evaluations shall be based on the load combination causing the most unfavorable effect. For PC-3 and 4 the load combination to be used should invoke either wind or tornado depending on which speed is specified in Table 3-2.

Most loads, other than dead loads, vary significantly with time. When these variable loads are combined with dead loads, their combined effect could be sufficient to reduce the risk of unsatisfactory performance to an acceptably low level. When more than one variable load is considered, it is unlikely that they will all attain their maximum value at the same time. Accordingly, some reduction in the total of the combined load effects is appropriate. This reduction is accomplished through load combination multiplication factors as given in the appropriate material-specific national consensus design standard.

Table 3-1 Summary Of Minimum Wind Design Criteria

	Performance Category	1	2	3	4
Wind	Hazard Annual Probability of Exceedance	$2x10^{-2}$	$1x10^{-2}$	$1x10^{-3}$	$1x10^{-4}$
Wind	Importance Factor	1.0	1.0	1.0	1.0
Wind	Missile Criteria	NA	NA	2x4 timber plank 15 lb @50 mph (horiz.); max. height 30 ft.	2x4 timber plank 15 lb @50 mph (horiz.); max. height 50 ft.
Tornado	Hazard Annual Probability of Exceedance	NA	NA	$2x10^{-5}$	$2x10^{-6}$
Tornado	Importance Factor	NA	NA	I = 1.0	I = 1.0
Tornado	APC	NA	NA	40 psf @ 20 psf/sec	125 psf @ 50 psf/sec
Tornado	Missile Criteria	NA	NA	2x4 timber plank 15 lb @100 mph (horiz.); max. height 150 ft.; 70 mph (vert.) 3 in. dia. std. steel pipe, 75 lb @ 50 mph (horiz.); max. height 75 ft, 35 mph (vert.)	2x4 timber plank 15 lb @150 mph (horiz.), max. height 200 ft.; 100 mph (vert.) 3 in. dia. std. steel pipe, 75 lb @ 75 mph (horiz.); max. height 100 ft, 50 mph (vert.) 3,000 lb automobile @ 25 mph, rolls and tumbles

Table 3-2 Recommended Basic Wind Speeds for DOE Sites, in miles per hour

Performance Category	Peak Gust Wind Speeds at 10m Height					
	1	2	3		4	
	Wind	Wind	Wind	Tornado(4)	Wind	Tornado(4)
DOE PROJECT SITES	$2x10^{-2}$	$1x10^{-2}$	$1x10^{-3}$	$2x10^{-5}$	$1x10^{-4}$	$2x10^{-6}$
Kansas City Plant, MO	90	96	–	162	–	219
Los Alamos National Laboratory, NM	90	96	117	–	135	–
Mound Laboratory, OH	90	96	–	154	–	208
Pantex Plant, TX	90	96	–	150	–	202
Rocky Flats Plant, CO	125	134	163	(3)	188	(3)
Sandia National Laboratories, NM	90	96	117	–	135	–
Sandia National Laboratories, CA	85	91	111	–	128	–
Argonne National Laboratory--East, IL	90(1)	96(1)	–	160	–	216
Argonne National Laboratory--West, ID	90(1)	96(1)	117	–	135	–
Brookhaven National Laboratory, NY	125(1)	138(1)	178	(3)	219	(3)
Princeton Plasma Physics Laboratory, NJ	110(1)	122(1)	156	(3)	193	(3)
Idaho National Engineering Laboratory	90(1)	96(1)	117	–	135	–
Oak Ridge, X-10, K-25, and Y-12, TN	90(1)	96(1)	–	130	–	192
Paducah Gaseous Diffusion Plant, KY	90(1)	96(1)	–	162	–	219
Portsmouth Gaseous Diffusion Plant, OH	90(1)	96(1)	–	127	–	185
Nevada Test Site, NV	90	96	117	–	135	–
Hanford Project Site, WA	85(1)	91(1)	111	–	128	–
Lawrence Berkeley Laboratory, CA	85	91	111	–	128	–
Lawrence Livermore National Lab., CA	85	91	111	–	128	–
LLNL, Site 300, CA	95	102	124	–	143	–
Energy Technology & Engineering Center, CA	85(1)	91(1)	–	111(2)	–	128
Stanford Linear Accelerator Center, CA	85	91	111	–	128	–
Savannah River Site, SC	100	107	–	155	–	212

NOTES:

(1) Minimum straight wind speed.

(2) Minimum tornado speed.

(3) Although straight winds govern, because the potential for a tornado strike is high, it is recommended that facilities be designed for tornado missiles using the missile speed for the relevant performance category. APC need not be considered.

(4) Tornado speed includes rotational and translational effects.

3.2.1 Performance Category 1

The performance goals for Performance Category 1 SSCs are consistent with objectives of ASCE 7 Building Class II, Ordinary Structures. Similar criteria in model building codes such as the current Uniform Building Code (Ref. 3-3) are also consistent with the performance goal and may be used as an alternative criteria. The wind-force resisting system of structures should not collapse under design load. Survival without collapse implies that occupants should be able to find an area of relative safety inside the structure during an extreme wind event. Breach of structure envelope is acceptable, since confinement is not essential. Flow of wind through the structure and water damage are acceptable. Severe loss, including total loss, is acceptable, so long as the structure does not collapse and occupants can find safe areas within the building.

In ASCE 7 Wind design criteria is based on an exceedance probability of $2x10^{-2}$ per year. The importance factor is 1.0.

Distinctions are made in ASCE 7 between buildings and other structures and between main wind-force resisting systems and components and cladding. In the case of components and cladding, a further distinction is made between buildings less than or equal to 60 ft and those greater than 60 ft in height.

Terrain surrounding SSCs should be classified as Exposure B, C, or D as defined in ASCE 7. Gust effect factors (G) and velocity pressure exposure coefficients (K) should be used according to the rules of the ASCE 7 procedures.

Wind pressures are calculated on walls and roofs of enclosed structures by using appropriate pressure coefficients specified in ASCE 7. Internal pressures on components and cladding develop as a result of unprotected openings, or openings created by wind forces or missiles. The worst cases of combined internal and external pressures should be considered in wind design as required by ASCE 7.

SSCs in Performance Category 1 may be designed by either allowable stress design (ASD) or strength design (SD). Load combinations shall be considered to determine the most unfavorable effect on the SSC being considered. When using ASD methods, customary allowable stresses appropriate for the material shall be used as given in the applicable material design standard (e.g. see Reference 3-4 for steel).

The SD method requires that the nominal strength provided be greater than or equal to the strength required to carry the factored loads. Appropriate material strength reduction factors should be applied to the nominal strength of the material being used. See Reference 3-5 for concrete or Reference 3-6 for steel for appropriate load combinations and strength reduction factors.

3.2.2 Performance Category 2

Performance Category 2 SSCs are equivalent to essential facilities (Class IV), as defined in ASCE 7 or model building codes. The structure shall not collapse at design wind speeds. Complete integrity of the structure envelope is not required because no significant quantities of toxic or radioactive materials are present. However, breach of the SSC containment is not acceptable if the presence of wind or water interferes with the SSCs function.

An annual wind speed exceedance probability of 1×10^{-2} is specified for this Performance Category. The importance factor is 1.0.

Once the design wind speeds are established and the importance factors applied, the determination of wind loads on Performance Category 2 SSCs is identical to that described for Performance Category 1 SSCs. ASD or SD methods may be used as appropriate for the material being used. The load combinations described for Performance Category 1 are the same for Performance Category 2.

3.2.3 Performance Category 3

The performance goal for Performance Category 3 SSCs requires more rigorous criteria than is provided by national standards or model building codes. In some geographic regions, tornadoes must be considered.

Straight Winds and Hurricanes

For those sites where tornadoes are not a viable threat, the recommended basic wind speed is based on an annual exceedance probability of $1x10^{-3}$. The importance factor is 1.0.

Once the design wind speeds are established and the importance factors applied, determination of Performance Category 3 wind loads is identical to Performance Category 1, except as noted below. SSCs in Performance Category 3 may be designed or evaluated by ASD or SD methods, as appropriate for the material used in construction. Because the hazard exceedance probability in Performance Category 3 contributes a larger percentage to the total probabilistic performance goal than in Performance Categories 1 or 2, less conservatism is needed in the Performance Category 3 design and evaluation criteria. This trend is different for seismic design as discussed in Chapter 2 and Appendix C. (See Appendix D for further explanation.) Thus, the load combinations given in the applicable material-specific national consensus design standard may be reduced by 10 percent. In combinations where gravity load reduces wind uplift, the reduction in conservatism is achieved by modifying only the gravity load factor.

When using ASD, allowable stresses shall be determined in accordance with applicable codes and standards (e.g. see Reference 3-4 for steel). Load combinations shall be evaluated to determine the most unfavorable effect of wind on the SSCs being considered. The SD load combinations shall be used along with nominal strength and strength reduction factors.

A minimum missile criteria is specified to account for objects or debris that could be picked up by straight winds, hurricanes or weak tornadoes. A 2x4 timber plank weighing 15 lbs is the specified missile. This missile represents a class of missiles transported by straight winds, hurricanes and weak tornadoes. Recommended impact speed is 50 mph at a maximum height of 30 ft above ground. The missile will break annealed glass; it will perforate sheet metal siding, wood siding up to 3/4-in. thick, or form board. The missile could pass through a window or weak exterior wall and cause personal injury or damage to interior contents of a building. The specified missile will not perforate unreinforced concrete masonry or brick veneer walls or other more substantial wall construction. See Table 3-3 for recommended wall barriers (Ref. 3-7).

Table 3-3 Recommended Straight Wind Missile Barriers for Performance Categories 3 and 4

Missile Criteria	Recommended Missile Barrier
2x4 timber plank 15 lb @ 50 mph (horiz.)	8-in. CMU wall with trussed horiz joint reinf @ 16 in. on center
max. height 30 ft. above ground Performance Category 3	Single wythe brick veneer with stud wall.
max. height 50 ft. above ground Performance Category 4	4-in. concrete slab with #3 rebar @ 6 in. on center each way in middle of slab

Tornadoes

For those sites requiring design for tornadoes, the criteria are based on site-specific studies, as presented in Reference 3-2. An annual exceedance probability of 1×10^{-3}, which is the same for straight wind, could be justified. As explained in Appendix D, a lower value is preferred because (1) the straight wind hazard curve gives wind speeds larger than the tornado hazard curve and (2) a lower hazard probability can be specified without placing undue hardship on the design. The basic tornado wind speed associated with an annual exceedance probability of 2×10^{-5} is recommended for Performance Category 3. Use importance factor of 1.0 for Performance Category 3.

The equations in ASCE 7 Table 6-1 should be used to obtain design wind pressures on SSCs. *Exposure Category C should always be used with tornado winds regardless of the actual terrain roughness.* Unconservative results will be obtained with exposure B. Tornadoes traveling over large bodies of water are waterspouts, which are less intense than land-based tornadoes. Thus, use of exposure category D also is not necessary. The velocity pressure exposure coefficient and gust effect factor are obtained from ASCE 7. External pressure coefficients are used to obtain tornado wind pressures on various surfaces of structures. Net pressure coefficients are applicable to systems and components. On structures, a distinction is made between main wind-force resisting systems and components and cladding.

If a structure is not intentionally sealed to maintain an internal negative pressure for confinement of hazardous materials, or, if openings greater than one square foot per 1000 cubic feet of volume are present, or, if openings of this size can be caused by missile perforation, then the effects of internal pressure should be considered according to the rules of ASCE 7. If a structure is sealed, then atmospheric pressure change (APC) associated with the tornado vortex should be considered instead of internal pressures (see Table 3-1 for APC values).

The maximum APC pressure occurs at the center of the tornado vortex where the wind speed is theoretically zero. A more severe loading condition occurs at the radius of maximum tornado wind speed, which is some distance from the vortex center. At the radius of maximum wind speed, the APC may be one-half its maximum value. Thus, a critical tornado load combination on a sealed building is one-half maximum APC pressure combined with maximum tornado wind pressure. A loading condition of APC alone can occur on the roof of a buried tank or sand filter, if the roof is exposed at the ground surface. APC pressure always acts outward. A rapid rate of pressure change, which can accompany a rapidly translating tornado, should be analyzed to assure that it does not damage safety-related ventilation systems. Procedures and computer codes are available for such analyses (Ref. 3-8).

When using ASD methods, allowable stresses appropriate for the materials shall be used. Since in this case, the hazard probability satisfies the performance goal, little or no additional conservatism is needed in the design. Thus, for ASD the tornado wind load combinations are modified to negate the effect of safety factors. For example, the combinations from ASCE 7 become:

(a) $0.63\ (D + W_t)$
(b) $0.62\ (D + L + L_r + W_t)$
(c) $0.62\ (D + L + L_r + W_t + T)$ (3-1)

Along with nominal material strength and strength reduction factors, the following SD load combinations for Performance Category 3 shall be considered:

(a) $D + W_t$
(b) $D + L + L_r + W_t$
(c) $D + L + L_r + W_t + T$ (3-2)

where:

W_t = tornado loading, including APC, as appropriate.

The notation and rationale for these load combinations are explained in Appendix D.

Careful attention should be paid to the details of construction. Continuous load paths shall be maintained; redundancy shall be built into load-carrying structural systems; ductility shall be provided in elements and connections to prevent sudden and catastrophic failures.

Two tornado missiles are specified as minimum criteria for this Performance Category. The 2x4-in. timber plank weighing 15 lbs is assumed to travel in a horizontal direction at speeds up to 100 mph. The horizontal speed is effective up to a height of 150 ft above ground level. If carried to great heights by the tornado winds, the timber plank can achieve a terminal vertical speed of 70 mph in falling to the ground. The horizontal and vertical speeds are assumed to be uncoupled and should not be combined. Table 3-4 describes wall and roof structures that will resist the postulated timber missile. A second missile to be considered is a 3-in. diameter standard steel pipe, which weighs 75 lbs. Design horizontal impact speed is 50 mph; terminal vertical speed is 35 mph. The horizontal speed of the steel pipe is effective up to a height of 75 ft above ground level. Table 3-4 summarizes certain barrier configurations that have been successfully tested to resist the pipe missile. Although wind pressure, APC and missile impact loads can occur simultaneously, the missile impact loads can be treated independently for design and evaluation purposes.

Table 3-4 Recommended Tornado Missile Barriers for Performance Category 3

Missile Criteria	Recommended Missile Barrier
Horizontal Component: 2x4 timber plank 15 lb @ 100 mph max. height 150 ft. above ground	8-in. CMU wall with one #4 rebar grouted in each vertical cell and trussed horiz joint reinf @ 16 in. on center
	Single wythe brick veneer attached to stud wall with metal ties
	4 in. concrete slab with #3 rebar @ 6 in. on center each way in middle of slab
Vertical Component: 2x4 timber plank 15 lb @ 70 mph	4 in. concrete slab with #3 rebar @ 6 in. on center each way in middle of slab
Horizontal Component: 3-in. diameter steel pipe 75 lb @ 50 mph max. height 75 ft. above ground	12-in. CMU wall with #4 rebar in each vertical cell and grouted; #4 rebar horizontal @ 8 in. on center
	Nominal 12-in. wall consisting of 8-in. CMU with #4 rebar in each vertical cell and grouted; #4 rebar horizontal @ 8 in. on center; single wythe brick masonry on outside face; horizontal ties @ 16 in. on center
	9.5- In. reinforced brick cavity wall with #4 rebar @ 8 in. on center each way in the cavity; cavity filled with 2500 psi concrete; horizontal ties @ 16 in. on center
	8-in. concrete slab with #4 rebar @ 8 in. on center each way placed 1.5 in. from each face
Vertical Component: 3-in. diameter steel pipe 75 lb @ 35 mph	6-in. concrete slab with #4 rebar @ 12 in. on center each way 1.5 in. from inside face

3.2.4 Performance Category 4

The performance goal for Performance Category 4 requires more conservative criteria than Performance Category 3. In some geographic regions, tornadoes must be considered.

Straight Winds and Hurricanes

For those sites where tornadoes are not a viable threat, the recommended basic wind speed is based on an annual exceedance probability of $1x10^{-4}$. The importance factor is 1.0.

Once the design wind speeds are established and the importance factors applied, determination of Performance Category 4 wind loads is identical to Performance Category 3, except as noted below. SSCs in category Performance Category 4 may be designed or evaluated by ASD or SD methods, as appropriate for the material being used in construction. As with Performance Category 3, the wind hazard exceedance probability contributes a larger percentage of the total probabilistic performance goal than Performance Categories 1 or 2. Less conservatism is needed in the design and evaluation procedure. The degree of conservatism for Performance Category 4 is the same as Performance Category 3. Thus, the load combinations for both the ASD and SD are the same for Performance Categories 3 and 4.

Although the design wind speeds in Performance Category 4 are larger than Performance Category 3, the same missiles are specified (Table 3-3), except the maximum height above ground is 50 ft instead of 30 ft for Performance Category 4.

Tornadoes

For those sites requiring design for tornadoes, the criteria are based on site-specific studies as presented in Reference 3-2. Again, as with Performance Category 3, an annual exceedance probability of $1x10^{-4}$ could be justified. However, for the same reasons given for Performance Category 3, a lower value is recommended. The basic tornado wind speed associated with an annual exceedance probability of $2x10^{-6}$ and an importance factor of 1.0 is recommended. Once the basic tornado wind speed is determined for the specified annual exceedance probability, the procedure is as described for Performance Category 3, except as noted below.

Three tornado missiles are specified for Performance Category 4: a timber plank, a steel pipe and an automobile. The 2x4 timber plank weighs 15 lbs and is assumed to travel in a horizontal direction at speeds up to 150 mph. The horizontal component of the timber missile is effective to a maximum height of 200 ft above ground level. If carried to a great height by the tornado winds, it could achieve a terminal vertical speed of 100 mph as it falls to the ground. The second missile is a 3-in. diameter standard steel pipe, which weighs 75 lbs. It can achieve a horizontal impact speed of 75 mph and a vertical speed of 50 mph. The horizontal speed could be effective up to a height of 100 ft above ground level. The horizontal and vertical speeds of the plank and pipe are uncoupled and should not be combined. The third missile is a 3000-lb automobile that is assumed to roll and tumble along the ground at speeds up to 25 mph. Table 3-5 lists wall barrier configurations that have been tested and successfully resisted the timber and pipe missile. Impact of the automobile can cause excessive structural response to SSCs. Impact analyses should be performed to determine specific effects. In structures, collapse of columns, walls or frames may lead to further progressive collapse. Procedures for structural response calculations for automobile impacts is given in References 3-9, 3-10 and 3-11. Although wind pressure, APC, and missile impact loads can occur simultaneously, the missile impact loads can be treated independently for design and evaluation purposes.

Table 3-5 Recommended Tornado Missile Barriers for Performance Category 4

Missile Criteria	Recommended Missile Barrier
Horizontal Component: 2x4 timber plank 15 lb @ 150 mph	6 in. concrete slab with #4 rebar @ 6 in. on center each way in middle of slab
max. height 200 ft. above ground	8-in. CMU wall with one #4 rebar grouted in each vertical cell and horiz trussed joint reinf @ 16 in. on center
Vertical Component: 2x4 timber plank 15 lb @ 100 mph	4 in. concrete slab with #3 rebar @ 6 in. on center each way in middle of slab
Horizontal Component: 3-in. diameter steel pipe 75 lb @ 75 mph max. height 100 ft. above ground	10-in. concrete slab with #4 rebar @ 12 in. on center each way placed 1.5 in. from each face
Vertical Component: 3-in. diameter steel pipe 75 lb @ 50 mph	8-in. concrete slab with #4 rebar @ 8 in. on center each way placed 1.5 in. from inside face

3.2.5 Design Guidelines

Reference 3-12 provides guidelines and details for achieving acceptable wind resistance of SSCs. Seven principles should be followed in developing a design that meets the performance goals:

(a) Provide a continuous and traceable load path from surface to foundation
(b) Account for all viable loads and load combinations
(c) Provide a redundant structure that can redistribute loads when one structural element is overloaded
(d) Provide ductile elements and connections that can undergo deformations without sudden and catastrophic collapse
(e) Provide missile resistant wall and roof elements
(f) Anchor mechanical equipment on roofs to resist specified wind and missile loads
(g) Minimize or eliminate the potential for windborne missiles

3.3 Evaluation of Existing SSCs

The objective of the evaluation process is to determine if an existing SSC meets the performance goals of a particular Performance Category.

The key to the evaluation of existing SSCs is to identify potential failure modes and to calculate the wind speed to cause the postulated failure. A critical failure mechanism could be the failure of the main wind-force resisting system of a structure or a breach of the structure envelope that allows release of toxic materials to the environment or results in wind and water damage to the building contents. The structural system of many old facilities (25 to 40 years old) have considerable reserve strength because of conservatism used in the design, which may have included a design to resist abnormal effects. However, the facility could still fail to meet performance goals if breach of the building envelope is not acceptable.

The weakest link in the load path of an SSC generally determines the adequacy or inadequacy of the performance of the SSC under wind load. Thus, evaluation of existing SSCs normally should focus on the strengths of connections and anchorages and the ability of the wind loads to find a continuous path to the foundation or support system.

Experience from windstorm damage investigations provide the best guidelines for anticipating the potential performance of existing SSCs under wind loads. Reference 3-13 provides a methodology for estimating the performance of existing SSCs. The approach is directed primarily to structures, but can be adapted to systems and components as well. The methodology described in Reference 3-13 involves two levels of evaluation. Level I is essentially a screening process and should normally be performed before proceeding to Level II, which is a detailed evaluation. The Level II process is described below. The steps include:

(a) Data collection
(b) Analysis of element failures
(c) Postulation of failure sequence
(d) Comparison of postulated performance with performance goals

3.3.1 Data Collection

Construction or fabrication drawings and specifications are needed to make an evaluation of potential performance in high winds. A site visit and walkdown is usually required to verify that the SSCs are built according to plans and specifications. Modifications not shown on the drawings or deteriorations should be noted.

Material properties are required for the analyses. Accurate determination of material properties may be the most challenging part of the evaluation process. Median values of material properties should be obtained. This will allow an estimate of the degree of conservatism in the design, if other than median values were used in the original design.

3.3.2 Analysis of Element Failures

After determining the as-is condition and the material properties, various element failures of the SSCs are postulated. Nominal strength to just resist the assumed element failure is calculated. Since the nominal strength is at least equal to the controlling load combination, the wind load to cause the postulated failure can be calculated. Knowing the wind load, the wind speed to produce the wind load is determined using the procedures of ASCE 7 and working backwards. Wind speeds to cause all plausible failure modes are calculated and tabulated. The weakest link is determined from the tabulation of element failures. These are then used in the next step to determine the failure sequence.

3.3.3 Postulation of Failure Sequence

Failure caused by wind is a progressive process, initiating with an element failure. Examples are failure of a roof to wall connection, inward or outward collapse of an overhead door, window glass broken by flying roof gravel. Once the initial element failure occurs at the lowest calculated wind speed, the next event in the failure sequence can be anticipated. For example, if a door fails, internal pressure inside the building will increase causing larger outward acting pressures on the roof. The higher pressures could then lead to roof uplift creating a hole in the roof itself. With the door opening and roof hole, wind could rapidly circulate through the structure causing collapse of partition walls, damage to ceilings or ventilation systems or transportation of small objects or debris in the form of windborne missiles. Each event in the sequence can be associated with a wind speed. All obvious damage sequences should be examined for progressive failure.

3.3.4 Comparison of Postulated Failures with Performance Goals

Once the postulated failure sequences are identified, the SSC performance is compared with the stated performance goals for the specified Performance Category. The general SSC evaluation procedures described in Apendix B(Figure B-2) are followed. If an SSC is able to survive wind speeds associated with the performance goal, the SSC meets the goal. If the performance criteria are not met, then the assumptions and methods of analyses can be modified to eliminate conservatism introduced in the evaluation methods. The acceptable hazard probability levels can be raised slightly, if the SSC comes close to meeting the performance goals. Otherwise, various means of retrofit should be examined. Several options are listed below, but the list is not exhaustive:

(a) Add x-bracing or shear walls to obtain additional lateral load resisting capacity

(b) Modify connections in steel, timber or prestressed concrete construction to permit them to transfer moment, thus increasing lateral load resistance in structural frames

(c) Brace a relatively weak structure against a more substantial one

(d) Install tension ties that run from roof to foundation to improve roof anchorage

(e) Provide x-bracing in the plane of a roof to improve diaphragm stiffness and thus achieve a better distribution of lateral load to rigid frames, braced frames or shear walls.

To prevent breach of structure envelope or to reduce the consequences of missile perforation, the following general suggestions are presented:

(a) Install additional fasteners to improve cladding anchorage
(b) Provide interior barriers around sensitive equipment or rooms containing hazardous materials
(c) Eliminate windows or cover them with missile-resistant grills
(d) Erect missile resistant barriers in front of doors and windows
(e) Replace ordinary overhead doors with heavy-duty ones that will resist the design wind loads and missile impacts. The door tracks must also be able to resist the wind loads.

Each SSC class will likely have special situations that need attention. Personnel who are selected to evaluate existing facilities should be knowledgable of the behavior of SSC classes subjected to extreme winds.

3.4 References

3-1. American Society of Civil Engineers (ASCE), **Minimum Design Loads for Buildings and Other Structures,** ASCE 7-95, New York, NY, 1995.

3-2. Coats, D.W. and R.C. Murray, **Natural Phenomena Hazards Modeling Project: Extreme Wind/Tornado Hazard Models for Department of Energy Sites,** UCRL-53526 Rev. 1, Lawrence Livermore National Laboratory, Livermore, California, 1985.

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3-5. American Concrete Institute, **Building Code Requirements for Reinforced Concrete, ACI 318-95**, Detroit, Michigan, 1995.

3-6. American Institute of Steel Construction, **Manual of Steel Construction, Load & Resistance Factor Design (LRFD)**, First Ed., Chicago, Illinois, 1986.

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3-12. McDonald, J.R., **Structural Details for Wind Design**, Lawrence Livermore National Laboratory, Report UCRL-21131, November 1988.

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Appendix D
Commentary on Wind Design and Evaluation Criteria

Key points in the approach employed for the design and evaluation of facilities for straight winds, hurricanes and tornadoes are discussed in this appendix.

D.1 Wind Design Criteria

Design goals are established for SSCs in Performance Categories 1 through 4. Design or evaluation of SSCs requires that the performance goals be met by selecting an appropriate hazard exceedance probability and utilizing sufficient conservatism in the methodologies and assumptions to assure the performance goals are met or exceeded.

A consensus standard, ANSI/ANS 2.3-1983 (Ref. D-1), which provides guidelines for estimating tornado and straight wind characteristics at nuclear power plant sites is an acceptable alternative approach to wind hazard assessment and design. However, the standard, which establishes tornado hazard probabilities at the 10^{-5}, 10^{-6}, and 10^{-7} levels on a regional basis, was not adopted by the Natural Phenomena Hazards Panel for the following reasons:

(a) The document is intended for siting of commercial nuclear power plants. Criteria are not necessarily appropriate for DOE SSCs.

(b) Site-specific hazard assessments were performed for each DOE site; it is not necessary nor desirable to use regional criteria

(c) Although published in 1983, the ANSI/ANS Standard is based on 15 year old technology

(d) Although ANSI/ANS Standard is a consensus document, it has not been approved by the U.S. Nuclear Regulatory Commission.

Instead of the ANSI/ANS Standard, a uniform approach to wind design is proposed herein, which is based on procedures of ASCE 7. The ASCE 7 document is widely accepted as the most technologically sound consensus wind load standard in the U.S.

The uniform approach to design for wind loads treats the types of windstorms (straight, hurricane and tornado) the same. Since ASCE 7 already treats straight winds and hurricanes the same, all that remains is to demonstrate the applicability of the approach to tornado resistant design. The procedure of ASCE 7 is applied for determining wind pressures on structures or net forces on systems and components. The additional effects of atmospheric pressure change (APC) and missile impact produced by tornadoes must also be considered at some sites.

The following argument is presented to justify the uniform approach to wind design. ASCE 7 addresses the physical characteristics of wind, including variation of wind speed with height and terrain roughness, effects of turbulence, and the variation of wind pressure over the surface of a building. Wind effects addressed in ASCE 7 can be detected and measured on wind tunnel models and on full-sized structures. Furthermore, evidence of the physical effects of wind found in wind tunnel and full-size measurements are also found in windstorm damage. The appearance of damage from straight, hurricane and tornado winds is very similar. The similarity suggests that wind pressure distribution on SSCs is generally independent of the type of storm. One cannot look at a collapsed windward wall, or an uplifted roof, or damage at an eave or roof corner or wall corner and determine the type of windstorm that caused the damage. Table D-1 lists specific examples where the appearance of damage from the three types of windstorms is identical. Many other examples could be given. The conclusion reached is that the proposed uniform approach is reasonable for estimating wind loads produced by straight winds, hurricanes and tornadoes.

D.2 Tornado Hazard Assessment

The traditional approach for establishing tornado criteria is to select extremely low exceedance probabilities. The precedence was established in specifying tornado criteria for the design of commercial nuclear power plants. An annual exceedance probability of $1x10^{-7}$ was adopted circa 1960 when very little was known about tornado effects from an engineering perspective. Much has been learned since 1960, which suggests that larger exceedance probabilities could be adopted. Some increase over the $1x10^{-7}$ is justified, especially for facilities that pose substantially smaller risks than commercial nuclear plants. However, two factors make it possible and desirable to use relatively low tornado hazard probabilities: 1) straight and hurricane winds control the criteria for probabilities down to about $1x10^{-4}$ and 2) additional construction costs to achieve low tornado probabilities are relatively small, when compared to earthquake design costs. For these reasons, the tornado hazard probabilities are set lower than straight winds and hurricanes. They also are set lower than earthquake and flood hazard probabilities.

Table D-1 Examples of Similar Damage from Straight Winds, Hurricanes, and Tornadoes

Type of Damage	Winds	Hurricanes	Tornadoes
Windward wall collapses inward	Mobile home, Big Spring, Texas 1973	A-frame, Hurricane Diana 1984	Metal building, Lubbock Texas 1970
Leeward wall or side wall collapses outward	Warehouse, Big Spring, Texas 1973	Commercial building, Hurricane Celia 1970	Warehouse, Lubbock, Texas 1970
Roof	Warehouse, Joplin, Missouri 1973	Motel, Hurricane Frederick 1979	School, Wichita Falls, Texas 1979
Eaves	Mobile home, Big Spring, Texas 1973	A-frame, Hurricane Diana 1984	Metal building, Lubbock, Texas 1970
Roof corners	Residence, Irvine, California 1977	Residence, Hurricane Frederick 1979	Apartment building, Omaha, Nebraska 1975
Wall corners	Metal building, Irvine, California 1977	Flagship Motel, Hurricane Alicia 1983	Manufacturing building, Wichita Falls, Texas 1979
Internal pressure	Not applicable	Two-story office building, Cyclone Tracey, Darwin, Australia 1974	High School, Xenia, Ohio 1974

A somewhat arbitrary, but quantitative approach is used to determine if a particular DOE site should be designed for tornadoes. Hazard assessments for both straight winds and tornadoes for each DOE site are presented in Reference D-2. The intersection of the straight wind and tornado hazard curves determines if tornadoes should be included in the design and evaluation criteria. If the exceedance probability at the intersection is greater than or equal to 2×10^{-5}, tornadoes are a viable threat at the site. If the exceedance probability is less than 2×10^{-5}, straight winds control the design or evaluation criteria. The concept is illustrated in Figure D-1. Straight wind and tornado hazard curves are shown for Oak Ridge National Laboratory (ORNL) and Stanford Linear Accelerator Center (SLAC). The SLAC curves intersect at an exceedance probability of approximately 2×10^{-7}, indicating that tornadoes are not a viable threat at the California site. On the other hand, the intersection of the ORNL curves is at 6×10^{-5} suggesting that tornadoes should be included in the design and evaluation criteria. Design wind speeds for the 25 DOE project sites were selected on this basis.

D.3 Load Combinations

The ratios of hazard probabilities to performance goal probabilities (risk reduction factor) for the Performance Categories in Table D-2 are an approximate measure of the conservatism required in the design to achieve the performance goal. The ratio is largest for

SSC Performance Categories 1 and 2, and is progressively smaller for Performance Categories 3 and 4 for winds and tornadoes. The trend is just the opposite from earthquake design. The reason for the decreasing trend in wind is because we use smaller hazard probabilities and thus need a lessor degree of conservatism in Performance Categories 3 and 4.

Conservatism can be achieved in design by specifying factors of safety for Allowable Stress Design (ASD) and load factors for Strength Design (SD). These factors for straight wind should be obtained from applicable material design standards. Consistent with the ratios in Table D-2, the loading combinations recommended for tornado design and evaluation of DOE SSCs are given in Table D-3.

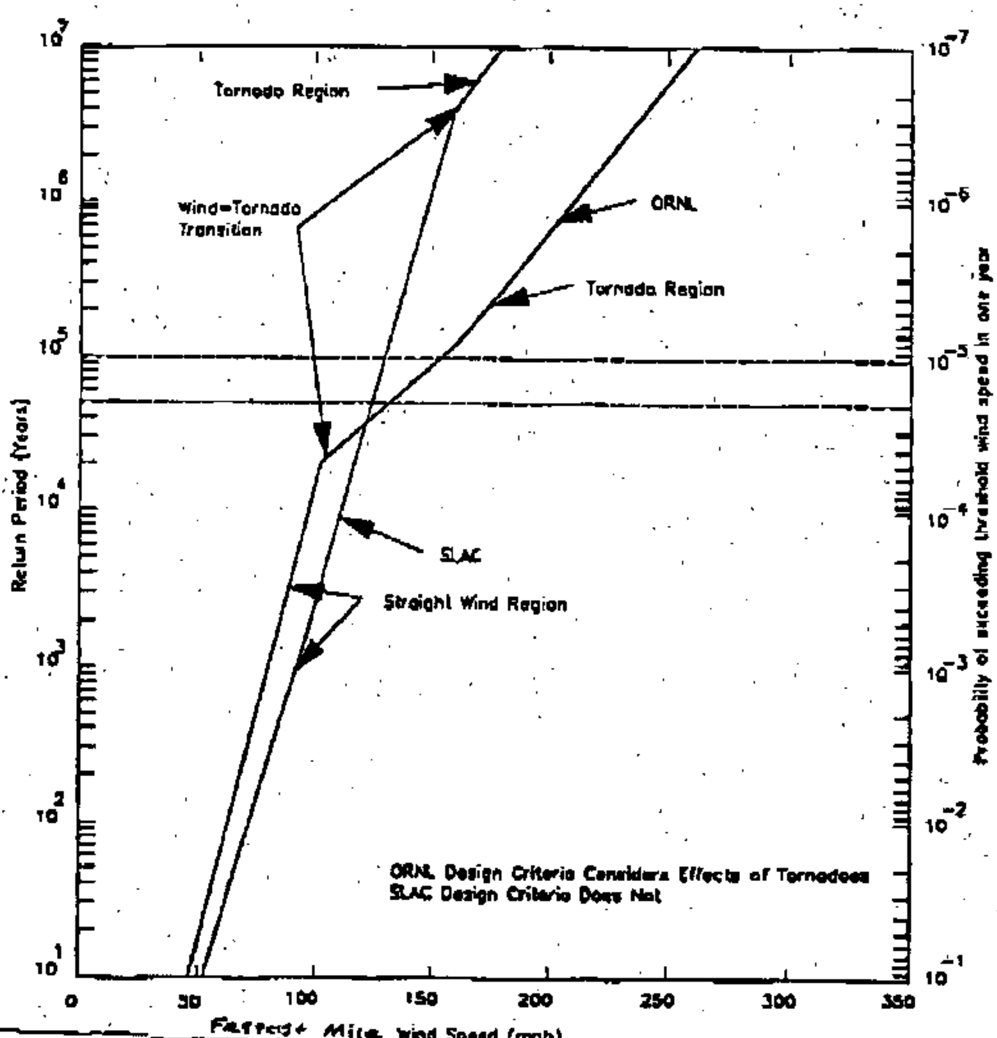

Figure D-1 Straight Wind and Tornado Regions of Wind Hazard Curves

Table D-2 Ratio of Hazard Probabilities to Performance Goal Probabilities

Performance Category	Performance Goals	Hazard Probability	Ratio of Hazard to Performance Probability
Straight Winds			
1	10^{-3}	2×10^{-2}	20
2	5×10^{-4}	10^{-2}	20
3	10^{-4}	10^{-3}	10
4	10^{-5}	10^{-4}	10
Tornadoes			
3	10^{-4}	2×10^{-5}	1/5
4	10^{-5}	2×10^{-6}	1/5

Table D-3 Recommended Tornado Load Combinations for Performance Categories 3 and 4

ASD	$\frac{1.0}{1.6}[D + W_t]$ $\frac{1.33}{1.6}[0.75(D + L + L_r + W_t)]$ $\frac{1.5}{1.6}[0.66(D + L + L_r + W_t + T)]$
SD	$D + W_t$ $D + L + L_r + W_t$ $D + L + L_r + W_t + T$

ASD = Allowable Strength Design
Use allowable stress appropriate for building material
SD = Strength Design
Use ϕ factors appropriate for building material
D = Dead load
L = Live load
L_r = Roof live load
W = Straight wind load
W_t = Tornado load, including APC if appropriate
T = Temperature load

The 1.6 denominator represents the factor of safety for material allowable stress, effectively removing this unneeded conservatism. The 1.33 and 1.5 factors negate the 0.75 and 0.66 factors permitted in ASD.

ASD is typically used for the design of steel, timber and masonry construction. Allowable stresses for the material and the type of loading (axial, shear, bending, etc.) are determined from applicable codes and specifications. The specified load combinations for ASD for Performance Categories 1 and 2 should be taken from the applicable material design standard (e.g. ACI or AISC) for straight winds. Load combinations for Performance Categories 3 and 4 can be less conservative than for Performance Categories 1 and 2. Because the ratio of hazard to performance probability is smaller by a factor of two, it is judged that the load combinations can be reduced by 10 percent. The load combinations for Performance Categories 3 and 4 for straight winds should reflect this reduction. The hazard to performance probabilities for tornadoes is more than satisfied by the hazard probability, as indicated by the ratio 1/5. The tornado load combinations for ASD Performance Categories 3 and 4 were somewhat arbitrarily chosen, based on engineering judgment.

Strength Design (SD) has been used for the design of reinforced concrete structures since about 1977 (Ref. D-4). Recently a strength design approach was introduced for steel construction which is called Load and Resistance Factor Design (LRFD) (Ref. D-5). Strength design concepts are currently being developed for use with timber and masonry construction. With SD, the nominal strength of the material is reduced to account for uncertainties in material and workmanship. The reduced material strengths must be greater than or equal to the factored loads in order to satisfy a postulated limit state. The required conservatism is reflected in the load factors for loads involving straight winds. In this case, the load factors for Performance Categories 3 and 4 are increased by ten percent. Load factors for Performance Categories 1 and 2 are recommended in References D-3, D-4 and D-5. Since the performance goals are satisfied by the tornado hazard probabilities, unit value of load factors can be used for SD. Unit values are justified in this case, because the material reduction factors account for uncertainties associated with materials. The load factors for tornadoes are consistent with recommendations for commercial nuclear power plants as given in ACI 349 (Ref. D-6) for concrete and ANSI/AISC N690-1984 (Ref. D-7) for steel.

D.4 Windborne Missiles

Windborne missile criteria specified herein are based on windstorm damage documentation and computer simulation of missiles observed in the field. Reference D-8 documents the occurrence of classes of missiles that are picked up and transported by straight winds and tornadoes. Computer simulation of tornado missiles is accomplished using a methodology developed at Texas Tech University. The method is similar to one published in Reference D-9.

The timber plank missile is typical of a class of missiles that are frequently found in the windstorm debris. The 2x4 timber plank weighing 15 lbs is typical of the debris from damaged or destroyed residences, office trailers and storage shacks. It can be carried to heights up to 200 ft in strong tornadoes. The 3-in. diameter standard steel pipe is typical of a class of missiles, which includes small diameter pipes, posts, light-weight rolled steel sections and bar joists. These objects are not likely to be carried to heights above 100 ft because of their larger weight to surface area ratio. Automobiles, storage tanks, trash dumpsters are rolled and tumbled by high winds and can cause collapse of walls, columns and frames. These heavy missiles are not picked up by winds consistent with the design criteria, they simply roll and tumble along the ground.

The missile wall and roof barriers recommended herein were all tested at the Tornado Missile Impact Facility at Texas Tech University. The impact tests are documented in Reference D-8. Structural response tests are not available for automobile impacts. Theoretical treatment of structural response calculations are given in References D-10, D-11, and D-12. Barriers that have not been tested such as grills, doors, wall cladding, tanks, mechanical ducts, etc should be tested in order to certify their performance.

Several empirical equations have been proposed for estimating the impact resistance if concrete and steel barriers. The equations were developed for use in the design of commercial nuclear power plants, and may not be applicable to the missile criteria specified herein. See Reference D-8 for a discussion of empirical missile impact equations.

D.5 References

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D-10. Kuilanoff, G. and Drake, R.M., **Design of DOE Facilities for Wind-Generated Missiles**, Proceedings of the Third DOE Natural Phenomena Hazards Mitigation Conference, St. Louis, MO, (October 15-18, 1991) published by Lawrence Livermore National Laboratory, Livermore, CA, 1991.

D-11. **Report of the ASCE Committee on Impactive and Impulsive Loads (Volume 5), Appendix C - Aircraft and Automobile Impact**, 2nd ASCE Conference on Civil Engineering in Nuclear Power, Knoxville, Tennessee, September 15-17, 1980.

D-12. **Structural Analysis and Design of Nuclear Plant Facilities**, Manuals and Reports on Engineering Practice - No. 58, American Society of Civil Engineers, 1980.

E.2 Effects of Wind

In this document high winds capable of damaging SSCs are classified as 1)straight winds, 2) hurricane winds or 3) tornado winds. Straight winds generally refer to winds in thunderstorm gust fronts or mesocyclones. Wind scirculating around high or low pressure systems (mesocyclones) are rotational in a global sense, but are considered straight winds in the context of this document. Tornadoes and hurricanes both have rotating winds. The diameter of the rotating winds in a small hurricane is considerably larger than the diameter of a very large tornado. However, most tornado wind diameters are large compared to the dimensions of typical buildings or structures.

Although the three types of wind are produced by distinctly different meteorological events, research has shown that their effects on SSCs are essentially the same. Wind effects from straight winds are studied in boundary layer wind tunnels. The results of wind tunnel studies are considered reliable because they have been verified by selected full-scale measurements (Reference E-1). Investigations of damage produced by straight winds also tend to support wind tunnel findings. Although the rotating nature of hurricane and tornado winds cannot be precisely duplicated in the wind tunnel, wind damage investi-gations suggest that the magnitudes and distribution of wind pressures on SSCs produced by hurricane and tornado winds are essentially identical to those produced by straight winds, if the relative wind direction is taken into account. Thus, the approach for deter-mining wind pressures on SSCs proposed in this document is considered to be independent of the type of windstorm.

Measurements of hurricane and straight wind speeds are obtained from anemometer readings. Wind speeds must be cited within a consistent frame of reference. In this document the frame of reference is "peak-gust" wind speed (speed of air passing an anemometer averaged over 3 sec) at 33 ft (10 meters) above ground in flat open terrain. Wind speeds measured relative to one frame of reference can be converted to another frame of reference through the use of wind speed profiles and relationships between averaging times (e.g., see Reference E-3).

Tornado wind speeds cannot be measured easily by conventional anemometers. Instead tornado wind speeds are estimated from appearance of damage in the storm path. The Fujita Scale (F-Scale) classification is generally accepted as the standard for estimating tornado wind speeds (Reference E-2). Table E-1 lists the wind speed ranges and describes the damage associated with each category. The wind speeds associated with the Fujita Scale are considered to be peak gusts (2-3 second averaging time). The tornado hazard assessments used in this document are based on F-Scale wind speeds at 33 ft (10 meters) above ground in flat open country.

Table E-1 F-Scale Classification of Tornadoes Based on Damage (Ref. E-2)

(F0)	LIGHT DAMAGE 40-72 mph (peak gust wind speed) Some damage to chimneys or TV antennae; breaks branches off trees; pushes over shallow rooted trees; old trees with hollow insides break or fall; sign boards damaged.
(F1)	MODERATE DAMAGE 73-112 mph (peak gust wind speed) 73 mph is the beginning of hurricane wind speed. Peels surface off roofs; windows broken; trailer houses pushed or overturned; trees on soft ground uprooted; some trees snapped; moving autos pushed off the road.
(F2)	CONSIDERABLE DAMAGE 113-157 mph (peak gust wind speed) Roof torn off frame houses leaving strong upright wall standing; weak structure or outbuildings demolished; trailer houses demolished; railroad boxcars pushed over; large trees snapped or uprooted; light-object missiles generated; cars blow off highway; block structures and walls badly damaged.
(F3)	SEVERE DAMAGE 158-206 mph (peak gust wind speed) Roofs and some walls torn off well-constructed frame houses; some rural buildings completely demolished or flattened; trains overturned; steel framed hanger-warehouse type structures torn; cars lifted off the ground and may roll some distance; most trees in a forest uprooted, snapped, or leveled; block structures often leveled.
(F4)	DEVASTATING DAMAGE 207-260 mph (peak gust wind speed) Well-constructed frame houses leveled, leaving piles of debris; structure with weak foundation lifted, torn, and blown off some distance; trees debarked by small flying debris; sand soil eroded and gravels fly in high winds; cars thrown some distances or rolled considerable distance finally to disintegrate; large missiles generated.
(F5)	INCREDIBLE DAMAGE 261-318 mph (peak gust wind speed) Strong frame houses lifted clear off foundation and carried considerable distance to disintegrate; steel-reinforced concrete structures badly damaged; automobile-sized missiles carried a distance of 100 yards or more; trees debarked completely; incredible phenomena can occur.

E.2.1 Wind Pressures

Wind pressures on structures (buildings) can be classified as external or internal. External pressures develop as air flows over and around enclosed structures. The air par-