Design-Basis Tornado Characteristics

The original version of Regulatory Guide 1.76 characterized tornadoes in each geographical region by (1) maximum wind speed, (2) translational speed, (3) maximum rotational speed, (4) radius of maximum rotational speed, (5) pressure drop, and (6) rate of pressure drop. Because the model used in this regulatory guide is based on a single Rankine combined vortex, the same parameters apply. If a tornado model with suction vortices were used, additional parameters would be necessary. Table 1 summarizes the design-basis tornado characteristics used in this regulatory guide.

Table 1. Design-Basis Tornado Characteristics

Region	Maximum wind speed m/s (mph)	Translational speed m/s (mph)	Maximum rotational speed m/s (mph)	Radius of maximum rotational speed m (ft)	Pressure drop mb (psi)	Rate of pressure drop mb/s (psi/s)
I	103 (230)	21 (46)	82 (184)	45.7 (150)	83 (1.2)	37 (0.5)
II	89 (200)	18 (40)	72 (160)	45.7 (150)	63 (0.9)	25 (0.4)
III	72 (160)	14 (32)	57 (128)	45.7 (150)	40 (0.6)	13 (0.2)

Tornado-Generated Missile Characteristics

To ensure the safety of nuclear power plants in the event of a tornado strike, NRC regulations require that nuclear power plant designs consider the impact of tornado-generated missiles (i.e., objects moving under the action of aerodynamic forces induced by the tornado wind), in addition to the direct action of the tornado wind and the moving ambient pressure field. Wind velocities in excess of 34 m/s (75 mph) are capable of generating missiles from objects lying within the path of the tornado wind and from the debris of nearby damaged structures.

The two basic approaches used to characterize tornado-generated missiles are (1) a standard spectrum of tornado missiles, and (2) a probabilistic assessment of the tornado hazard. No definitive guidance has been developed for use in characterizing site-dependent tornado-generated missiles by hazard probability methods. The damage to safety-related structures by tornado or other wind-generated missiles implies the occurrence of a sequence of random events. That event sequence typically includes a wind-based occurrence in the plant vicinity in excess of 34 m/s (75 mph), existence and availability of missiles in the area, injection of missiles into the wind field, suspension and flight of those missiles, impact of the missiles with safety-related structures, and resulting damage to critical equipment. Given defense-in-depth considerations, the uncertainties in these events preclude the use of a probabilistic assessment as the sole basis for assessing how well the plant is protected against tornado missile damage.

Protection from a spectrum of missiles (ranging from a massive missile that deforms on impact to a rigid penetrating missile) provides assurance that the necessary structures, systems, and components will be available to mitigate the potential effects of a tornado on plant safety. Given that the design-basis tornado wind speed has a very low frequency, to be credible, the representative missiles must be common items around the plant site and must have a reasonable probability of becoming airborne within the tornado wind field.

To evaluate the resistance of barriers to penetration and gross failure, the tornado missile speeds must also be defined. Simiu and Scanlan (Ref. 8) estimate tornado-generated missile speeds for nuclear plant design purposes. They assumed that missiles start their motion from a point located on the tornado translation axis, at a distance downward of the tornado center equal to the radius of the maximum circumferential wind speeds. In addition, they assumed that the speed with which a missile hits a target is equal to the maximum speed (V^{max}) that the same missile would attain if its trajectory were unobstructed by the presence of any obstacle.

The tornado wind field model used to calculate the maximum missile velocities differs somewhat from the tornado wind field model used in the above discussion of tornado characteristics to obtain the tornado pressure drop and maximum time rate of change of the pressure. Chapter 16 of Reference 8 provides the tornado wind field model (which includes a radial component for the tornado wind speed) and the equations of motion used for the maximum missile velocities. The NRC staff developed a computer program to calculate the maximum horizontal missile speeds by solving these equations.

Design-Basis Tornado Missile Spectrum

In accordance with 10 CFR 50.34, “Contents of Applications; Technical Information,” GDC 2, and GDC 4 structures, systems, and components that are important to safety must be designed to withstand the effects of natural phenomena without losing the capability to perform their safety function. Tornado missiles are among the most extreme effects of credible natural phenomena at nuclear power plant sites. The selected design-basis missiles for nuclear power plants include at least (1) a massive high-kinetic-energy missile that deforms on impact, (2) a rigid missile that tests penetration resistence, and (3) a small rigid missile of a size sufficient to pass through any opening in protective barriers. The NRC staff considers a 6-inch (15.24-centimeter) Schedule 40 steel pipe and an automobile to be acceptable as the penetrating and massive missiles, respectively, for use in the design of nuclear power plants. Automobiles are common objects near the plant site, and ample evidence supports their potential to be lifted in a tornado wind field. Schedule 40 pipe is also common around plant sites. However, such pipe is intended to represent a rigid component of a larger missile (e.g., building debris or an automobile) that may be lifted in the tornado wind field. Thus, the staff used the maximum speed calculated for the automobile missile for the penetrating missile as well, rather than the speed calculated for a pipe. To test the configuration of openings in the protective barriers, the missile spectrum also includes a 1-inch (2.54-centimeter) solid steel sphere as a small rigid missile. Simiu and Scanlan (Ref. 8) describe the methods that form the bases for the characteristics of these missiles. Table 2 summarizes the design-basis tornado missile spectrum and maximum horizontal speeds.

Table 2. Design-Basis Tornado Missile Spectrum and Maximum Horizontal Speeds

Missile Type		**Schedule 40 Pipe**	**Automobile**	**Solid Steel Sphere**
Dimensions		0.168 m dia × 4.58 m long (6.625 in. dia × 15 ft long)	Region I and II 5 m × 2 m × 1.3 m (16.4 ft x 6.6 ft x 4.3 ft)	2.54 cm dia (1 in. dia)
			Region III 4.5 m x 1.7 m x 1.5 m (14.9 ft x 5.6 ft x 4.9 ft)	
Mass		130 kg (287 lb)	Region I and II 1810 kg (4000 lb)	0.0669 kg (0.147 lb)
			Region III 1178 kg (2595 lb)	
C_DA/m		0.0043 m^2/kg (0.0212 ft^2/lb)	Region I and II 0.0070 m^2/kg (0.0343 ft^2/lb)	0.0034 m^2/kg (0.0166 ft^2/lb)
			Region III 0.0095 m^2/kg (0.0464 ft^2/lb)	
V_{Mh}^{max}	**Region I**	41 m/s (135 ft/s)	41 m/s (135 ft/s)	8 m/s (26 ft/s)
	Region II	34 m/s (112 ft/s)	34 m/s (112 ft/s)	7 m/s (23 ft/s)
	Region III	24 m/s (79 ft/s)	24 m/s (79 ft/s)	6 m/s (20 ft/s)

The NRC considers the missiles listed in Table 2 to be capable of striking in all directions with horizontal velocities of V_{Mh}^{max} and vertical velocities equal to 67 percent of V_{Mh}^{max}. Barrier design should be evaluated assuming a normal impact to the surface for the Schedule 40 pipe and automobile missiles. The automobile missile is considered to impact at all altitudes less than 30 feet (9.14 meters) above all grade levels within 0.5 mile (0.8 kilometer) of the plant structures. Table 2 includes a different size and weight automobile for Region III than for Regions I and II. The heavier automobile used in the calculations for Regions I and II will have a lower kinetic energy in Region III. This effect is a consequence of the low maximum horizontal speed V_{Mh}^{max} of the heavier automobile in the Region III tornado wind field.