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INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) is required by Paragraph 100.10(c) of 10 CFR Part 100, "Reactor Site Criteria," to consider a variety of physical characteristics, including meteorological conditions, in determining site suitability for nuclear power plants. Regulatory Guide 1.76 (USAEC 1974) describes design basis tornadoes that are acceptable to the Regulatory staff. The technical basis for Regulatory Guide 1.76 is contained in Technical Basis For Interim Regional Criteria (Markee, Beckerly and Sanders 1974), which is commonly referred to as WASH-1300.

WASH-1300 summarizes published information on tornado frequency of occurrence and dimensions through 1973. It also contains estimates of tornado strike probabilities and wind speeds at the 10^{-7} yr^{-1} probability of occurrence for the contiguous United States. Procedures for estimating strike probabilities and wind speeds outlined in WASH-1300 have been implemented in the TORNADO computer code (Schreck and Sandusky 1982), which is used by the regulatory staff.

The information summarized in WASH-1300 came from several data bases of varying extent. For example, tornado frequencies for the contiguous United States were based on data for the periods 1953-1962 (Thom 1963) and 1955-1967 (Pautz 1969); and the tornado path length and area data were derived from 1937-1962 Iowa tornadoes (Thom 1963), 1953-1962 Kansas tornadoes (Thom 1963), and 1965, 1967, and 1969 tornadoes (Fujita 1970a).

Since publication of Regulatory Guide 1.76 and WASH-1300, the tornado data base has improved significantly. As interest in tornado hazard assessment has increased, more complete information on tornado characteristics has been recorded, techniques for estimating tornado intensity have been refined, and inconsistencies between data bases have been resolved (e.g., McDonald 1983; Grazulis 1984; and Schaefer, Kelly and Abbey 1985). Using some of the more recent data, the American Nuclear Society and the American National Standards Institute have proposed a "Standard for Tornado and Extreme Wind Characteristics at Nuclear Power Sites," ANSI/ANS-2.3-1983 (ANS 1983). This proposed standard presents design wind speeds for tornadoes for much of the contiguous United States that are lower than the design speeds suggested in Regulatory Guide 1.76. As a result of the improved data base and the proposed industry standard, the NRC staff, through a technical assistance contract, initiated an update of WASH-1300 as a first step in reevaluating its guidance on design basis tornadoes for nuclear power plants.

This report presents a climatological summarization of the characteristics of tornadoes reported in the contiguous United States in the 30 years from January 1, 1954, through December 31, 1983. The year 1954 was selected as the beginning of the period for summarization of tornado characteristics because it is the first year in which both the number of

smaller than the means of the distributions. The mean tornado area is particularly important because it is used to determine tornado strike probabilities.

The true mean tornado dimensions can only be estimated from observed tornado tracks. Using arithmetic averages of the dimensions reported for the tornadoes in an area tends to underestimate the true mean tornado dimensions because small tornadoes are more likely than large ones, and the distribution of the measured tornado dimensions may not accurately reflect the true distributions. However, as the number of reported tornadoes in an area increases, the accuracies of arithmetic averages improve as estimators of mean dimensions.

Underestimating mean tornado areas results in underestimating strike probabilities and wind speeds. Consequently, another statistic is frequently used to estimate the true mean area. That statistic is the expected value of the area. Arithmetic averages make no use of information about the distributions of dimensions; expected values include information about the distributions. For skewed distributions, like the distributions of tornado dimensions, the expected value is a better estimate of the true mean than the arithmetic average if the exact forms of the distributions are known.

The expected value of a random variable x (the x can be any tornado characteristic), denoted by E[x], is mathematically defined as

$$E[x] = \int_{-\infty}^{\infty} x\, f(x)\, dx \qquad (1)$$

where f(x) is the probability density function for x. If the form of the frequency distribution is known, both E[x] and the arithmetic average of a finite set of values of x approach the mean as the number of values in the set increases, but E[x] should approach the mean faster. If, however, the form of the distribution is unknown and an incorrect form is assumed, E[x] will not approach the true mean.

WASH-1300, Regulatory Guide 1.76, and the TORNADO computer code (Schreck and Sandusky 1982) assume that tornado areas have a log-normal distribution. This practice is consistent with the suggestion of Thom (1963) that tornado lengths, widths, and areas are distributed log-normally. Figures 3 through 5 confirm that the lengths, widths, and areas of tornadoes in the contiguous United States may be assumed to be log-normally distributed as working hypotheses.

TORNADO STATISTICS FOR NEVADA STATE AREA = 110540. SQ MI

THE NUMBER OF TORNADOES FROM 1954 THROUGH 1983 WAS 20.
THE TOTAL NUMBER OF SEGMENTS WAS 20
EXPECTED LENGTH = 8.81 MI; EXPECTED WIDTH = 0.000 MI; EXPECTED AREA = 0.000 SQ MI
AVERAGE LENGTH = 5.67 MI; AVERAGE WIDTH = 0.050 MI; AVERAGE AREA = 0.047 SQ MI.
THE TORNADO STRIKE PROBABILITIES FOR THE STATE ARE 0.00E+00 PER YEAR (EXP) AND 2.85E-07 PER YEAR (AVE).

Rounded off would be "3"

	TORNADO INTENSITY (F - SCALE)						
	0	1	2	3	4	5	MISSING
NUMBER	6	3	0	0	0	0	11
CUMULATIVE TOTAL	6	9	9	9	9	9	
COND. EXCEEDANCE PROB.	1.00000	0.33333	0.00000	0.00000	0.00000	0.00000	
EXPECTED LENGTH (MI)	0.000	0.000	0.000	0.000	0.000	0.000	
AVERAGE LENGTH (MI)	0.433	13.520	0.000	0.000	0.000	0.000	
NUMBER	3	2	0	0	0	0	15
EXPECTED WIDTH (MI)	0.000	0.000	0.000	0.000	0.000	0.000	
AVERAGE WIDTH (MI)	0.051	0.045	0.000	0.000	0.000	0.000	
NUMBER	3	1	0	0	0	0	16
EXPECTED AREA (SQ MI)	0.000	0.000	0.000	0.000	0.000	0.000	
AVERAGE AREA (SQ. MI)	0.048	0.045	0.000	0.000	0.000	0.000	
NUMBER	3	1	0	0	0	0	16
EXPECTED CLASS STRIKE PROB.	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
CLASS STRIKE PROB.	1.93E-07	9.14E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
EXPECTED STRIKE EXCEEDANCE PR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	
STRIKE EXCEEDANCE PROB.	2.85E-07	9.14E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	

STATISTICS OF THE LENGTH, WIDTH AND AREA DISTRIBUTIONS, ASSUMING LOG-NORMALITY

LENGTH						
LOWER 5 PERCENT POINT	2.56E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MODE	8.71E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MEDIAN	8.78E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MEAN	8.81E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
UPPER 5 PERCENT POINT	3.00E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
WIDTH						
LOWER 5 PERCENT POINT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MODE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MEDIAN	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MEAN	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
UPPER 5 PERCENT POINT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
AREA						
LOWER 5 PERCENT POINT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MODE	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MEDIAN	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
MEAN	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
UPPER 5 PERCENT POINT	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

TORNADO STATISTICS FOR NEVADA

STATE AREA = 110540. SQ MI

JOINT FREQUENCY TABLES (LENGTH, WIDTH, AND AREA VS F - SCALE)

LENGTH IN MILES

F-SCALE	<0.1	<0.2	<0.5	<1.0	<2.0	<5.0	<10.0	<20.0	<50.0	<100.	>100.	MISSING
0	1	1	0	1	0	0	0	0	0	0	0	3
1	0	0	0	1	0	0	0	0	1	0	0	1
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
MISSING	0	0	1	2	1	0	1	0	0	0	0	8

WIDTH IN MILES

F-SCALE	<0.01	<0.02	<0.04	<0.08	<0.12	<0.16	<0.24	<0.32	<0.48	<0.64	>0.64	MISSING
0	2	0	0	0	0	1	0	0	0	0	0	3
1	0	0	0	1	0	0	0	0	0	0	0	2
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
MISSING	0	0	2	0	0	0	0	1	0	0	0	8

AREA IN SQUARE MILES

F-SCALE	<.01	<0.02	<0.05	<0.1	<0.2	<0.5	<1.0	<2.0	<5.0	<10.0	>10.0	MISSING
0	2	0	0	0	1	0	0	0	0	0	0	3
1	0	0	1	0	0	0	0	0	0	0	0	2
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
MISSING	0	1	1	0	0	0	0	1	0	0	0	8