CRITICAL FACTORS FOR DETERMINING RADIOLOGICAL DOSES FROM ROUTINE GASEOUS RELEASES FROM NUCLEAR POWER PLANTS

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Introduction

The release of gaseous effluents from light-water-cooled reactors in the United States is regulated by the dose limits of 10 CFR 50 Appendix I. These limits apply to areas at and beyond the unrestricted area boundary during any calendar quarter. Regulatory Guide 1.111[1] provides the basic guidance on modeling and meteorology for use in performing dose calculations to document compliance with these limits. The results of the dose calculations are included in the annual effluent and waste disposal report to the Nuclear Regulatory Commission, as discussed in Regulatory Guide 1.21[2].

Normalized effluent concentrations (χ/Q) have been calculated for numerous quarters at the Tennessee Valley Authority's (TVA) nuclear plants for use in preparing the annual reports. Review of these χ/Qs indicates significant variability in location and magnitude of the maximum value from quarter to quarter with no readily apparent relationship between them and the underlying meteorology. This paper seeks to establish a methodology for determining which factors are indicative of the location and magnitude of the critical χ/Q for each quarter. These same factors would then be indicative of the critical dose.

The purposes for establishing the critical factors for dose estimates are as follows:

- To determine how the maximum dose relates to model input.
- To be able to estimate the impact of a measurement error on the dose.
- To establish how characteristics of the computer model impact dose estimates, and how modifications could impact the doses.
- To quantify the contribution of meteorological factors in dose estimate variability by quarter.

Background

TVA's computer model for estimating doses to the public uses a Gaussian straight-line model[3] as outlined in section B.1.b. of Regulatory Guide 1.111. A joint frequency distribution of actual hourly wind direction and speed by atmospheric stability class for each quarter is used as input to the model. An example is included as Table 1. A χ/Q is calculated for each combination of the 16 wind direction sectors, nine wind speed category mid-points, and seven stability classes. The χ/Q is weighted by the frequency that each combination occurred.

The methodology for determining the critical factors was developed using quarterly meteorological data from 1985 through 1995 for the Sequoyah Nuclear Plant near Chattanooga, Tennessee. Since the effluents are released from points less than the height of the adjacent shield building, all Sequoyah releases are treated as ground level. Therefore, the dose resulting from the effluents will be directly proportional to the χ/Q. The distance from the release point to the unrestricted area boundary for each of the 16, 22.5° sectors is shown in Table 2. This distance varies from 660 meters in both the west northwest and northwest directions to 2470 meters in the southwest direction.

Table 3 shows the highest χ/Q for each quarter at Sequoyah and in which sector it occurred, sorted by quarter. Table 4 shows the same values sorted by the magnitude of the χ/Qs. The highest χ/Q (1.32 E-05 s/m^3) occurred in the third quarter of 1995 and the lowest (4.11 E-06 s/m^3) occurred in the first quarter of 1988.

Approach

The following approach was used to determine the critical factors in location and magnitude of the highest χ/Q for Sequoyah:

1. Determine the factors which affect the χ/Q.
2. Analyze the data by the different factors.
3. Eliminate the factors which obviously do not significantly affect the χ/Q.
4. Evaluate the relationship of the remaining factors to the χ/Qs.
5. Rank the factors as to their criticality to the χ/Qs.

For a routine airborne release, Regulatory Guide 1.111 states that, "the concentration of radioactive material in the surrounding region depends on the amount of effluent released; the height of the release; the momentum and buoyancy of the emitted plume; the wind speed, atmospheric stability, and airflow patterns of the site; and various effluent removal mechanisms." Since the relationship of site factors to the χ/Q is desired, several factors are not relevant. These include the amount of effluent released and various effluent removal mechanisms, such as dry and wet deposition and radioactive decay. In addition, since the release is treated as ground-level, the height of release and the momentum and buoyancy of the emissions is not relevant.

The remaining factors include the following:

- Wind speed

- Atmospheric stability
- Airflow patterns (characterized by the wind direction frequency)
- Distance to the unrestricted area boundary
- Quarter of the year

Results

These factors were analyzed individually to establish any relationships to the highest χ/Qs. The analysis is discussed in the following.

Wind speed

The wind speed is inversely proportional to the χ/Q, so the highest χ/Qs should occur with the lowest wind speeds. The lowest wind speed categories in the TVA joint frequency distributions are calms (defined as wind speeds less than 0.3 m/s), 0.3 to 0.6 m/s (0.6 to 1.4 mi/h), and 0.7 to 1.5 m/s (1.5 to 3.4 mi/h). The relationship of calm frequency to χ/Q is shown in Figure 1. The higher calm occurrence shows a correlation to the magnitude of the χ/Q. The three highest calm frequencies coincide with three of the top four χ/Qs. However, the critical sector is not known. This is because of the way wind directions are assigned for calms. As outlined in Regulatory Guides 1.111 and 1.145[4], the wind direction for a calm is assigned in proportion to the non-calm wind speeds less than or equal to 1.5 m/s (3.4 mi/h). Therefore, the critical sector will be influenced by the frequency of the wind directions for these wind speeds.

Atmospheric stability

The χ/Q increases with increasing atmospheric stability. Therefore, the highest χ/Q will occur with a G stability class, all other factors being equal. Figure 2 shows the relationship between the stability class G frequency and the χ/Q. Little relationship seems to be indicated. Therefore, other factors must be overshadowing this relationship.

Plume sector and quarter

Table 5 shows the percent probability of occurrence of the highest χ/Q by sector and quarter. The plume sector is 180° opposite from the wind direction sector. All of the following directional references are in terms of plume sector. The highest quarterly χ/Q

for the period from 1985 to 1995 occurred in only five sectors with 75% of them occurring in the south southwest and north sectors. The second quarter is the only one showing a predominance of one sector, this being the north sector.

Distance

As shown previously in Table 2, the boundary distance associated with each sector varies considerably. For a ground-level release, the χ/Q is inversely proportional to the downwind distance. Therefore, all other factors being equal, the highest χ/Q would occur in the sector with the smallest boundary distance. For Sequoyah this would be the west northwest and northwest directions. However, the highest χ/Q only occurred once in these sectors. Therefore, other factors must be overshadowing this relationship also.

Analysis of these individual factors indicates that they will not, taken by themselves, be an adequate indicator of the location and magnitude of the χ/Q. This is especially true for the atmospheric stability and distance. The frequency of calms will be helpful in indicating the magnitude of the χ/Q. The combination of the factors was analyzed as the next step. The frequency of occurrence of wind speeds less than or equal to 1.5 m/s (3.4 mi/h) in stability classes E, F, and G was calculated for each of the critical sectors for each quarter from 1989 to 1995. This is summarized in Table 6. Comparison of these frequencies with the sector with the highest χ/Q allowed a series of relationships to be developed. They can be used to determine which sector will have the highest χ/Q. These are as follows:

1. The maximum sector should be northwest when the frequency of low wind speeds concurrent with a G stability class is $\geq 0.69\%$.

2. The maximum sector should be north northwest when the frequency of low wind speeds concurrent with a G stability class is $\geq 0.55\%$.

3. In the absence of 1 and 2, check the ratio of the frequency of the south sector to the south southwest sector. If this ratio is ≤ 0.8, go to step 4. If it is > 0.8, go to step 5.

4. Check the ratio of the frequency of the south southwest sector to the north sector. If the ratio is ≤ 3.7, the north sector is usually the critical sector. If the ratio is > 3.7, the south southwest sector is usually the critical sector.

5. Check the ratio of the frequency of the south sector to the north sector. If the ratio is ≤ 2.7, the north sector is usually the critical sector. If the ratio is > 2.7, the south sector is usually the critical sector.

These relationships hold because of the boundary distance for each of these sectors. Since the northwest and north northwest sectors are much closer than the other three sectors where the maximums have occurred, it takes a much smaller frequency in just the G stability class to cause the highest χ/Q. Similarly, the ratio of low wind speed frequencies in the E, F, and G stability classes for the south, south southwest, and north sectors can be used to account for distance differences.

The magnitude of the χ/Q can be indicated by the frequency of low wind speed occurrence relative to other quarters. For example, the two highest χ/Qs for the period 1985 to 1995 occurred with the highest frequency of south and south southwest sectors from Table 6.

Summary

The dose limits for routine releases of gaseous effluents from nuclear reactors are strongly influenced by the underlying meteorology. One way of characterizing this meteorology is through the use of normalized effluent concentrations (χ/Q). This paper has shown that the location and magnitude of quarterly maximum χ/Qs can be explained by a methodology using critical meteorological factors. The contribution of meteorology to the estimated doses can then be quantified.

Eleven years of meteorological data from the Sequoyah Nuclear Plant were used to establish the relationships. The methodology should be useful in establishing similar relationships at TVA's other two nuclear plants. The critical factors for location of the maximum χ/Q were the frequency of occurrence of wind speeds less than or equal to 1.5 m/s (3.4 mi/h) in stability classes E, F, and G and which quarter is being examined. The critical factor for the magnitude of the χ/Q was the frequency of low wind speed occurrence in stability classes E, F, and G relative to other quarters.

References

1. Nuclear Regulatory Commission, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," Regulatory Guide 1.111, Revision 1, July 1977.

2. Nuclear Regulatory Commission, "Measuring, Evaluating, and Reporting Radioactivity in Solid Wastes and Releases of Radioactive Materials in Liquid and Gaseous Effluents from Light-Water-Cooled Nuclear Power Plants, Regulatory Guide 1.21, Revision 1, June 1974.

3. Tennessee Valley Authority, Gaseous Effluent Licensing Code Users Manual, Revision 2, November 1995.

4. Nuclear Regulatory Commission, Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants, Regulatory Guide 1.145, Revision 1, November 1982.

Table 1

JOINT PERCENTAGE FREQUENCIES OF WIND SPEED BY WIND DIRECTION DISREGARDING STABILITY CLASS

SEQUOYAH NUCLEAR PLANT

OCT 1, 95 - DEC 31, 95

WIND	WIND SPEED(MPH)									
DIRECTION	CALM	0.6-1.4	1.5-3.4	3.5-5.4	5.5-7.4	7.5-12.4	12.5-18.4	18.5-24.4	>=24.5	TOTAL
N	0.360	1.418	6.699	3.374	3.961	2.103	0.049	0.000	0.000	17.964
NNE	0.438	2.005	7.873	3.081	2.983	3.765	0.196	0.000	0.000	20.341
NE	0.137	0.929	2.152	1.271	0.685	0.147	0.098	0.000	0.000	5.418
ENE	0.054	0.342	0.880	0.147	0.000	0.000	0.000	0.000	0.000	1.423
E	0.028	0.196	0.440	0.147	0.000	0.000	0.000	0.000	0.000	0.811
ESE	0.020	0.293	0.147	0.000	0.000	0.049	0.000	0.000	0.000	0.509
SE	0.037	0.538	0.293	0.098	0.000	0.000	0.000	0.000	0.000	0.966
SSE	0.054	0.587	0.636	0.098	0.000	0.000	0.098	0.000	0.000	1.472
S	0.163	1.027	2.641	1.222	0.587	1.320	0.196	0.000	0.000	7.155
SSW	0.267	0.685	5.330	3.912	1.418	0.733	0.000	0.000	0.000	12.345
SW	0.258	0.440	5.379	4.548	1.222	0.342	0.000	0.000	0.000	12.190
WSW	0.078	0.244	1.516	0.293	0.391	0.685	0.000	0.000	0.000	3.208
W	0.041	0.293	0.636	0.293	0.049	0.293	0.000	0.000	0.000	1.606
WNW	0.056	0.391	0.880	0.587	0.147	0.342	0.049	0.000	0.000	2.453
NW	0.076	0.538	1.174	1.222	0.685	0.489	0.000	0.000	0.000	4.184
NNW	0.132	0.880	2.103	1.711	2.200	0.929	0.000	0.000	0.000	7.956
SUBTOTAL	2.200	10.807	38.778	22.005	14.328	11.198	0.685	0.000	0.000	100.000

TOTAL HOURS OF VALID WIND OBSERVATIONS	2045
TOTAL HOURS OF OBSERVATIONS	2208
RECOVERABILITY PERCENTAGE	92.6
TOTAL HOURS CALM	45

METEOROLOGICAL FACILITY: SEQUOYAH NUCLEAR PLANT
WIND SPEED AND DIRECTION MEASURED AT 9.73 METER LEVEL

DATE PRINTED: 23-JAN-96

MEAN WIND SPEED = 4.05

NOTE: TOTALS AND SUBTOTALS ARE OBTAINED FROM UNROUNDED NUMBERS

Table 2

Sequoyah Nuclear Plant Unrestricted Area Boundary Distances by Sector

Plume Sector	Distance (meters)
North	950
North northeast	2260
Northeast	1910
East northeast	1680
East	1570
East southeast	1460
Southeast	1460
South southeast	1550
South	1570
South southwest	1840
Southwest	2470
West southwest	910
West	670
West northwest	660
Northwest	660
North northwest	730

Table 3

Sequoyah Maximum Quarterly X/Q (1985 - 1995) Sorted by Quarter

QTR	YEAR	X/Q (10^{-6} s/m^3)	Maximum Sector
1	1985	4.72	SSW
1	1986	5.88	NNW
1	1987	6.87	SSW
1	1988	4.11	N
1	1989	5.58	NNW
1	1990	5.38	N
1	1991	4.41	SSW
1	1992	6.83	NW
1	1993	9.15	SSW
1	1994	7.51	SSW
1	1995	4.86	N
2	1985	5.32	N
2	1986	6.99	NNW
2	1987	10.00	N
2	1988	6.00	SSW
2	1989	5.97	N
2	1990	4.47	N
2	1991	7.63	N
2	1992	7.05	N
2	1993	9.59	N
2	1994	7.73	N
2	1995	6.02	N
3	1985	5.81	SSW
3	1986	5.66	N
3	1987	7.55	S
3	1988	6.05	N
3	1989	7.48	S
3	1990	6.22	SSW
3	1991	6.76	S
3	1992	6.37	N
3	1993	6.53	N
3	1994	8.77	N
3	1995	13.20	S
4	1985	6.32	N
4	1986	9.01	SSW
4	1987	9.45	SSW
4	1988	5.30	SSW
4	1989	6.67	N
4	1990	6.50	NNW
4	1991	5.91	NNW
4	1992	6.19	SSW
4	1993	5.81	N
4	1994	10.20	SSW
4	1995	6.01	S

Table 4

Sequoyah Maximum Quarterly X/Q (1985 - 1995) Sorted by Magnitude of X/Q

QTR	YEAR	X/Q (10^{-6} s/m^3)	Maximum Sector
3	1995	13.20	S
4	1994	10.20	SSW
2	1987	10.00	N
2	1993	9.59	N
4	1987	9.45	SSW
1	1993	9.15	SSW
4	1986	9.01	SSW
3	1994	8.77	N
2	1994	7.73	N
2	1991	7.63	N
3	1987	7.55	S
1	1994	7.51	SSW
3	1989	7.48	S
2	1992	7.05	N
2	1986	6.99	NNW
1	1987	6.87	SSW
1	1992	6.83	NW
3	1991	6.76	S
4	1989	6.67	N
3	1993	6.53	N
4	1990	6.50	NNW
3	1992	6.37	N
4	1985	6.32	N
3	1990	6.22	SSW
4	1992	6.19	SSW
3	1988	6.05	N
2	1995	6.02	N
4	1995	6.01	S
2	1988	6.00	SSW
2	1989	5.97	N
4	1991	5.91	NNW
1	1986	5.88	NNW
3	1985	5.81	SSW
4	1993	5.81	N
3	1986	5.66	N
1	1989	5.58	NNW
1	1990	5.38	N
2	1985	5.32	N
4	1988	5.30	SSW
1	1995	4.86	N
1	1985	4.72	SSW
2	1990	4.47	N
1	1991	4.41	SSW
1	1988	4.11	N

Table 5

Percent Probability of Occurrence of Highest χ/Q by Sector and Quarter for Sequoyah Nuclear Plant From 1985 - 1995

	Distance	Quarter			
Plume Sector	(meters)	1	2	3	4
South southwest	1840	45	9	18	45
North northwest	730	18	9	0	45
North	950	27	82	45	27
South	1570	0	0	36	9
Northwest	660	9	0	0	0

Table 6

Frequency of Low Wind Speeds for E, F, and G Stability Classes by Quarter for Sequoyah (1989 - 1995)[1]

	Quarter, Year											
Plume Sector	4.95	3.95	2.95	1.95	4.94	3.94	2.94	1.94	4.93	3.93	2.93	1.93
South	6.90	14.52	8.96	3.39	6.75	12.06	6.37	6.86	6.40	8.80	6.40	5.50
South southwest	7.74	7.24	5.83	7.70	14.18	7.98	7.17	9.67	10.80	9.40	9.00	9.20
Northwest	0.62	0.34	1.15	0.73	0.87	1.45	0.82	0.89	1.00	0.90	1.30	0.30
North northwest	0.82	1.55	1.15	0.48	1.83	2.07	1.79	1.34	1.30	1.90	1.50	0.60
North	2.49	1.93	3.95	2.73	3.47	3.85	3.97	3.02	3.00	3.10	4.00	1.80
Ratio												
S/N	2.8	7.5	2.3	1.2	1.9	3.1	1.6	2.3	2.1	2.8	1.6	3.1
SSW/N	3.1	3.8	1.5	2.9	4.1	2.1	1.8	3.2	3.6	3.0	2.3	5.1
S/SSW	0.9	2.0	1.5	0.4	0.5	1.5	0.9	0.7	0.6	0.9	0.7	0.6

	Quarter, Year											
Plume Sector	4.92	3.92	2.92	1.92	4.91	3.91	2.91	1.91	4.90	3.90	2.90	1.90
South	5.50	9.60	6.30	3.80	5.50	10.10	7.00	2.70	6.70	8.90	4.60	2.00
South southwest	9.00	7.30	6.70	9.70	9.30	9.50	5.70	8.80	12.50	13.10	8.10	8.90
Northwest	1.00	1.00	0.80	1.00	0.80	0.90	1.40	0.70	1.10	1.10	0.70	0.60
North northwest	0.50	1.30	1.10	1.40	1.80	1.30	1.70	1.20	2.20	0.80	1.10	0.80
North	1.80	2.80	2.70	2.70	3.60	2.90	4.50	2.10	3.30	2.60	2.20	2.90
Ratio												
S/N	3.1	3.4	2.3	1.4	1.5	3.5	1.6	1.3	2.0	3.4	2.1	0.7
SSW/N	5.0	2.6	2.5	3.6	2.6	3.3	1.3	4.2	3.8	5.0	3.7	3.1
S/SSW	0.6	1.3	0.9	0.4	0.6	1.1	1.2	0.3	0.5	0.7	0.6	0.2

	Quarter, Year			
Plume Sector	4.89	3.89	2.89	1.89
South	5.20	11.10	4.70	1.80
South southwest	8.70	8.40	7.70	5.90
Northwest	0.80	0.80	1.10	0.90
North northwest	1.30	1.40	1.70	1.50
North	3.70	4.00	2.40	1.90
Ratio				
S/N	1.4	2.8	2.0	0.9
SSW/N	2.4	2.1	3.2	3.1
S/SSW	0.6	1.3	0.6	0.3

1. The shaded cell indicates where the maximum X/Q occurred in each quarter.

Figure 1

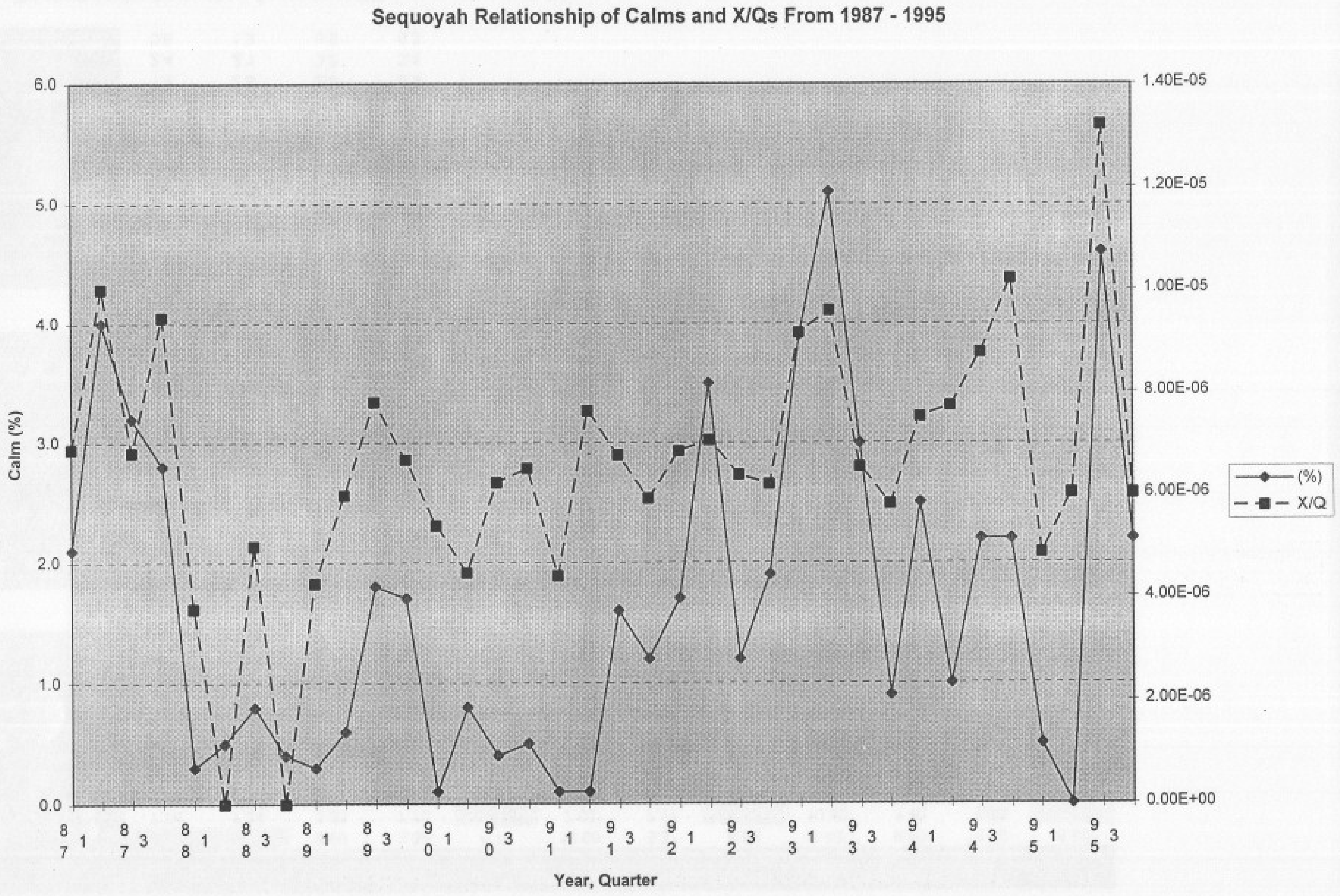
Sequoyah Relationship of Calms and X/Qs From 1987 - 1995

Figure 2

Sequoyah Stability Class 'G' Frequency versus Dispersion Values by Quarter (1987-93)