

Comparison of the AEOLUS3 Atmospheric Dispersion Computer Code with NRC Codes PAVAN and XOQDOQ

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Abstract

AREVA NP uses the AEOLUS3 computer code (Reference 1) to determine atmospheric dispersion (χ/Q) and deposition factors (D/Q) for accidental and routine effluent releases from commercial nuclear power plants in the U.S. The AEOLUS3 computer code is licensed for use by AREVA NP from ENTECH Engineering. AEOLUS3 implements the guidance in U.S. Nuclear Regulatory Commission (NRC) Regulatory Guides 1.145 (Reference 2) and 1.111 (Reference 3).

The AEOLUS3 computer code has been used in submittals to the NRC from operating nuclear plants (References 4 and 5). AREVA NP has also used AEOLUS3 for four combined license applications (COLAs) to date.

This paper compares the AEOLUS3 computer code with the NRC computer codes PAVAN and XOQDOQ, which implement the guidance in NRC Regulatory Guides 1.145 (Reference 2) and 1.111 (Reference 3), respectively. The computer codes were run using the same input information (plant-specific input as well as site-specific meteorological data).

The comparison between AEOLUS3 and PAVAN indicates that the accident atmospheric dispersion results are within a factor of 1.4 on average and within a factor of 2.8 at most, with the AEOLUS3 results being more conservative in almost all cases.

The comparison between AEOLUS3 and XOQDOQ indicates that the normal effluent ground-level release atmospheric dispersion results are within a factor of 0.9 on average and within a factor of 0.8 at most. For normal effluent elevated releases, results are within a factor of 0.8 on average and within a factor of 0.42 at most. XOQDOQ results are slightly higher in almost all ground and elevated release cases. For normal effluent mixed-mode releases, results are within a factor of 2.4 on average and within a factor of 5.48 at most. AEOLUS3 produces more conservative results within the first 7,000 to first 15,000 meters (4.3 to 9.3 miles) downwind (depending on the meteorological data set) and XOQDOQ produces more conservative results further downwind.

The effect of terrain varies depending on how the terrain values are input to XOQDOQ:

- Using a grid of terrain values provides results that are closer to the AEOLUS3 results;
- Using two sets of downwind distance/terrain values to bracket all downwind distances and allowing XOQDOQ to linearly interpolate values for each receptor – worst agreement of the methods tested.

Differences between the Computer Codes

While AEOLUS3 and PAVAN implement the guidance in NRC Regulatory Guide 1.145 and AEOLUS3 and XOQDOQ implement the guidance in NRC Regulatory Guide 1.111, there are some differences in how guidance is implemented as well as in features provided in the models.

AEOLUS3 calculates average wind speed values for each wind speed group input by the user – as well as the stability class combination - using every pertinent wind speed in the meteorological database. Hence, these calculations are not based just on the wind speed group values input to the code. PAVAN and XOQDOQ do compute average wind speed values based just on the wind speed group values input to the codes.

PAVAN and XOQDOQ compute atmospheric dispersion coefficient values for atmospheric stability class G according to the following equation, where σ stands for either the horizontal or vertical dispersion coefficient:

$$\sigma (G) = \sigma (F)^2 / \sigma (E)$$

Regulatory Guide 1.145 indicates that the atmospheric dispersion coefficient values for atmospheric stability class G should be computed using the following equations:

$$\sigma_y (G) = (2/3)\sigma_y (F)$$

$$\sigma_z (G) = (3/5)\sigma_z (F)$$

AEOLUS3 uses the same methodology to compute atmospheric dispersion coefficient values for atmospheric stability class G as PAVAN and XOQDOQ for the sake of consistency, but also provides another option that follows the guidance provided in Regulatory Guide 1.145.

While both AEOLUS3 and XOQDOQ allow for the input of terrain heights, AEOLUS3 reads the terrain height values for each receptor (sector and downwind distance). XOQDOQ reads a grid of terrain height values, not necessarily at the receptor location, and linearly interpolates as necessary. Similarly, AEOLUS3 reads the recirculation correction factor to be applied to each receptor as input by the user, while XOQDOQ uses a linear-interpolation scheme.

AEOLUS3 includes features not available in either PAVAN or XOQDOQ:

- Dispersion and deposition at coastal sites (sea breeze effects) and in deep river valleys.
- Use of multi-year hourly meteorological data (20 year maximum).
- Vertical plume reflection correction in all cases.
- Gamma atmospheric dispersion factors. Physically speaking, the gamma χ/Q for a given finite plume can be used to define the equivalent concentration in a semi-infinite cloud at ground-level which will yield the same gamma radiation exposure as the finite plume itself.
- A parabolic interpolation option that exactly matches the horizontal and vertical dispersion coefficient curves presented in Figures 1 and 2 in NRC Regulatory Guide 1.145. (See Appendix A)
- Dry and wet deposition capability.

Comparison Methodology

The computer codes were run using the same input information (plant-specific input as well as site-specific meteorological data). In cases where AEOLUS3 provided an ENTECH Engineering algorithm and an NRC algorithm (e.g., determination of horizontal and vertical dispersion coefficients), the NRC algorithm was used.

A ground-level accidental release was modeled using AEOLUS3 and PAVAN. Typically, design basis accidental releases are modeled as ground-level releases since the applicant/licensee would have to prove that the equipment needed to cause an elevated release (stack, fans) were available for the entire time period of the accident (see section C.1.3.2 of Regulatory Guide 1.145). Also, an elevated release requires that the release point be at least two and one-half times the height of adjacent solid structures. A ground-level, an elevated, and a mixed-mode normal effluent release were modeled using AEOLUS3 and XOQDOQ. The effects of terrain and recirculation correction were considered in a subset of normal effluent release cases.

Accident and normal effluent atmospheric dispersion factors were plotted on log-log graphs. In addition, the numeric differences between the codes were determined by dividing the AEOLUS3 value by the corresponding PAVAN or XOQDOQ value.

Results

Accident Atmospheric Dispersion Results

Figures 1 and 2 present the results of the comparison of accident atmospheric dispersion factors from AEOLUS3 and PAVAN using plant-specific input and meteorological data specific to site 1¹. Note that for both the Exclusion Area Boundary (EAB) and the Low Population Zone (LPZ), the AEOLUS3 results are more conservative than the PAVAN results. Note also that AEOLUS3 provides results for the 0-2 hour, 2-8 hour, 8-24 hour, 1-4 days, and 4-30 days time periods of the accident. PAVAN provides results for the 0-2 hour, 0-8 hour, 8-24 hour, 1-4 days, and 4-30 days time periods of the accident. Table 1 presents the numeric differences between the codes; it can be seen that the AEOLUS3 results range from a factor of 1.1 to 1.6 times higher than the PAVAN results.

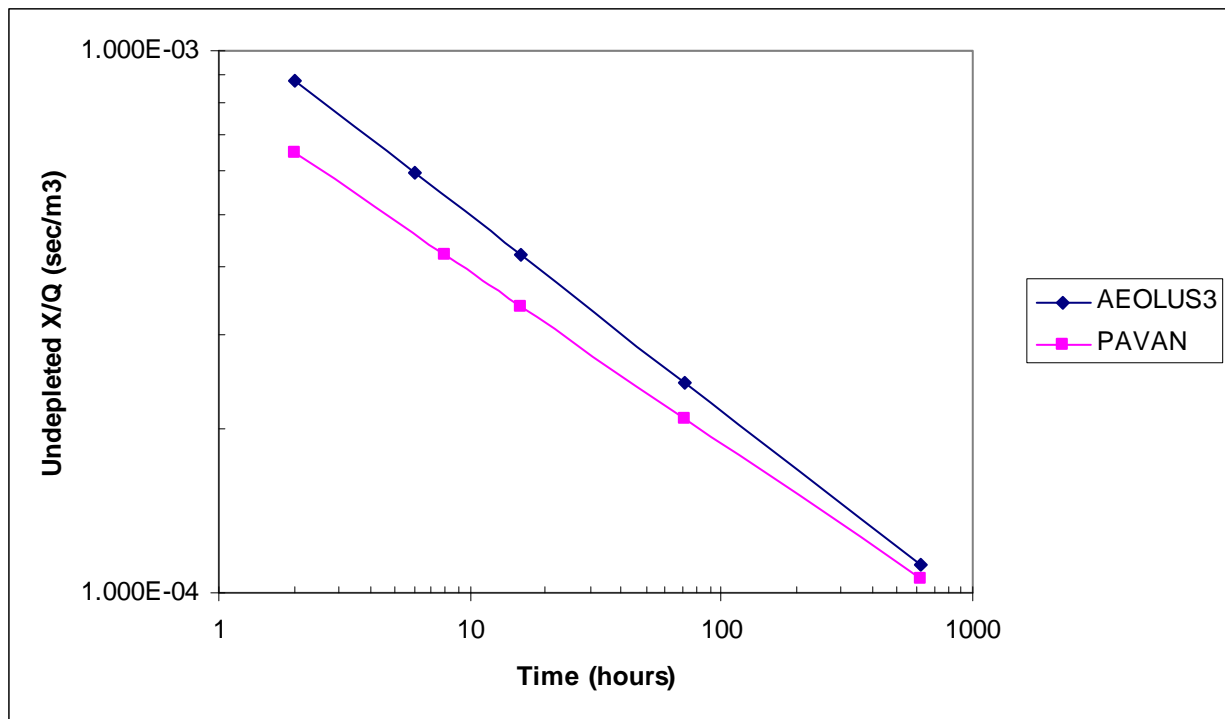


Figure 1: Accident X/Q Comparison, EAB Maximum of Sector Values, Site 1

¹ All test data sets are from actual operating or proposed nuclear power plant sites but are referred to as site 1, site 2, etc., to maintain anonymity.

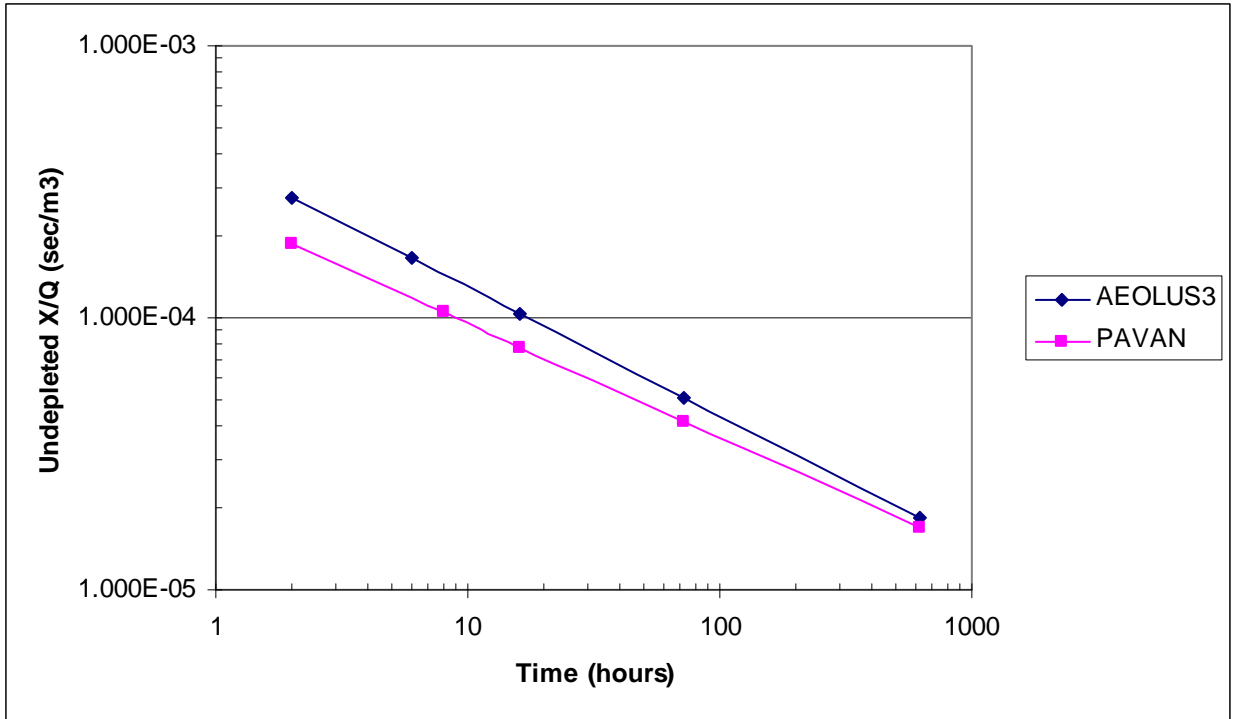


Figure 2: Accident X/Q Comparison, LPZ Maximum of Sector Values, Site 1

Table 1: AEOLUS3 Accident Value/PAVAN Accident Value for Site 1

EAB	Ratio	1.4	1.4	1.2	1.2	1.1
LPZ	Ratio	1.5	1.6	1.3	1.2	1.1

Figures 3 and 4 present the results of the comparison of accident atmospheric dispersion factors from AEOLUS3 and PAVAN using plant-specific input and meteorological data specific to site 2. Note that for all of the EAB results and most of the LPZ results, the AEOLUS3 results are more conservative than the PAVAN results. Table 2 presents the numeric differences between the codes; it can be seen that the AEOLUS3 results range from slightly lower (ratio of AEOLUS3 to PAVAN is 0.9) to 2.8 times higher than the PAVAN results.

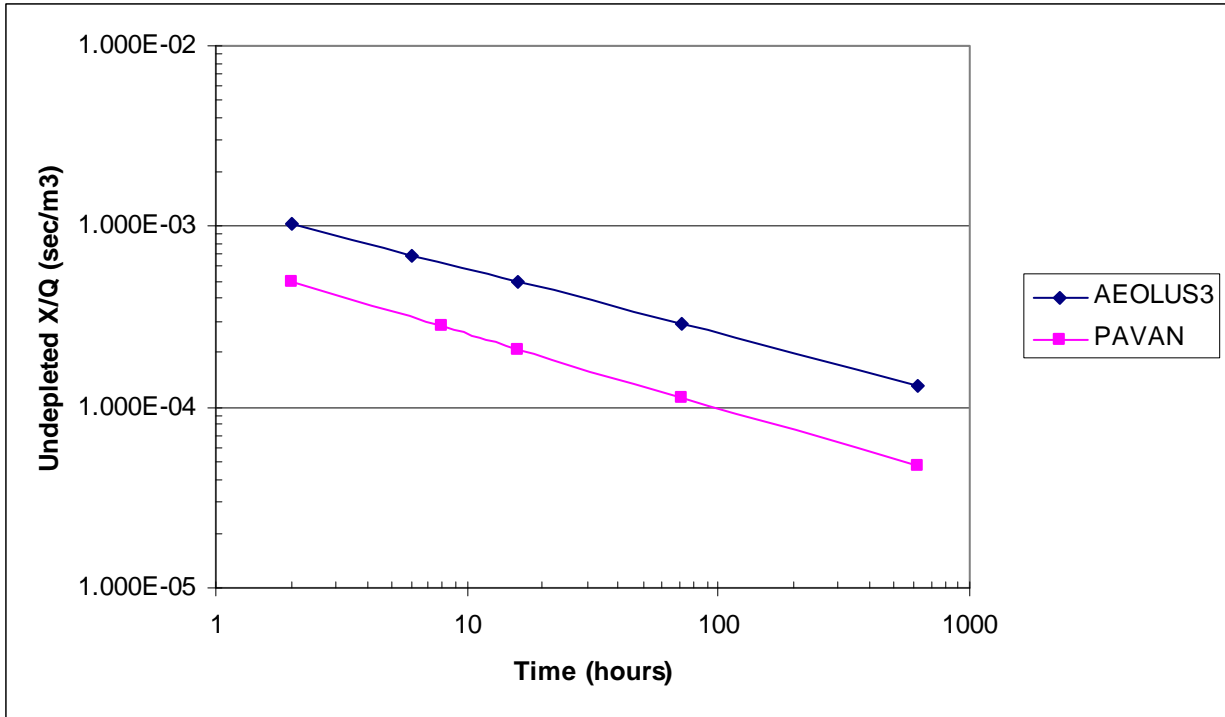


Figure 3: Accident X/Q Comparison, EAB Maximum of Sector Values, Site 2

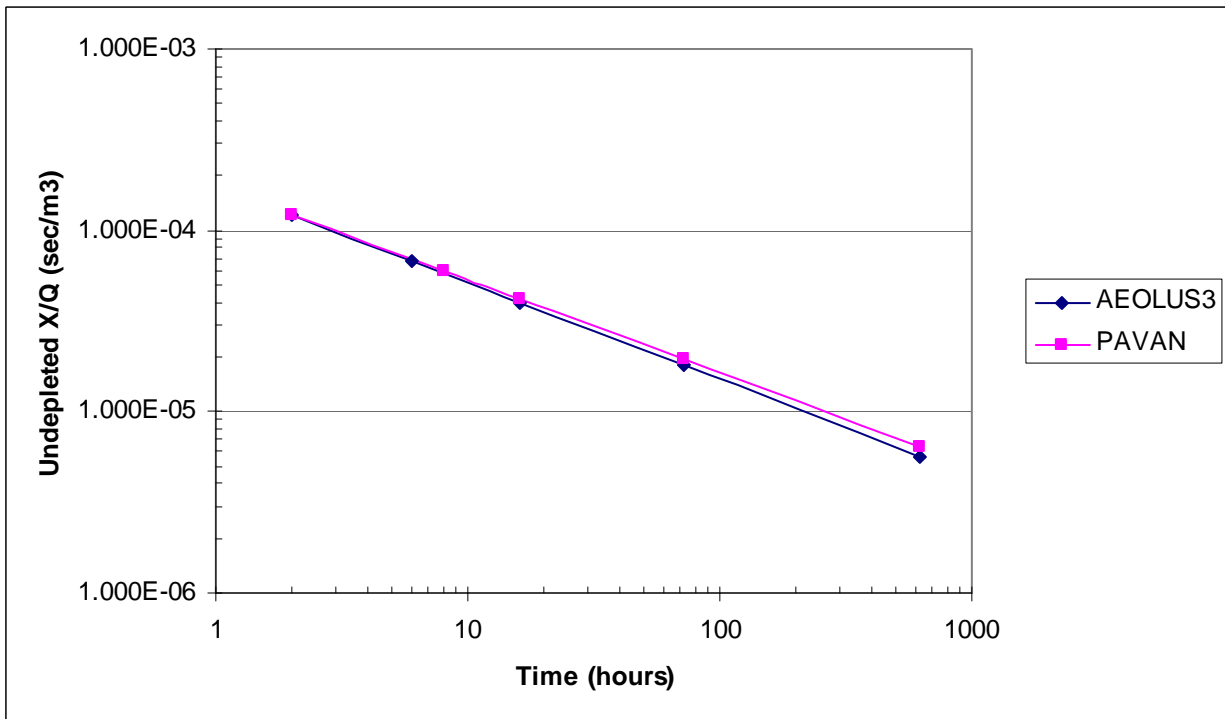


Figure 4: Accident X/Q Comparison, LPZ Maximum of Sector Values, Site 2

Table 2: AEOLUS3 Accident Value/PAVAN Accident Value for Site 2

EAB	Ratio	2.1	2.5	2.3	2.5	2.8
LPZ	Ratio	1.0	1.1	1.0	0.9	0.9

Figures 5 and 6 present the results of the comparison of accident atmospheric dispersion factors from AEOLUS3 and PAVAN using plant-specific input and meteorological data specific to site 3. Note that for both the EAB results and the LPZ results, the AEOLUS3 results match the PAVAN results. Table 3 presents the numeric differences between the codes; it can be seen that the AEOLUS3 results range from slightly lower (ratio of AEOLUS3 to PAVAN is 0.9) to 1.2 times higher than the PAVAN results.

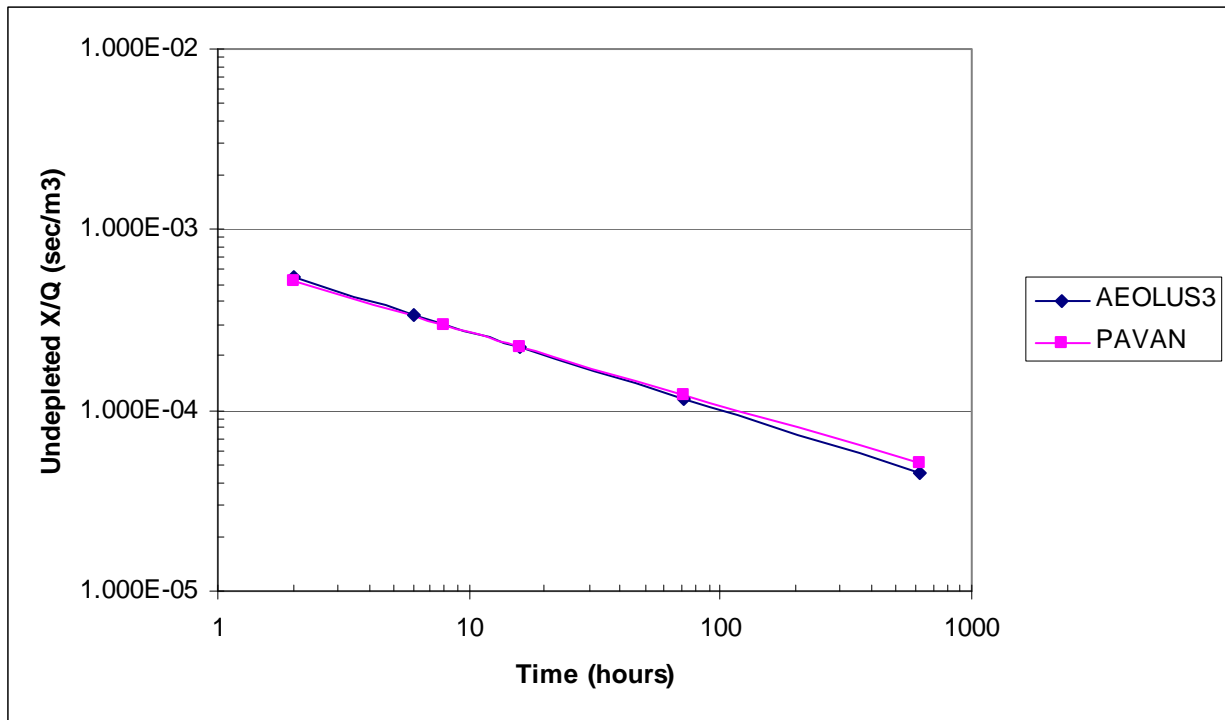


Figure 5: Accident X/Q Comparison, EAB Maximum of Sector Values, Site 3

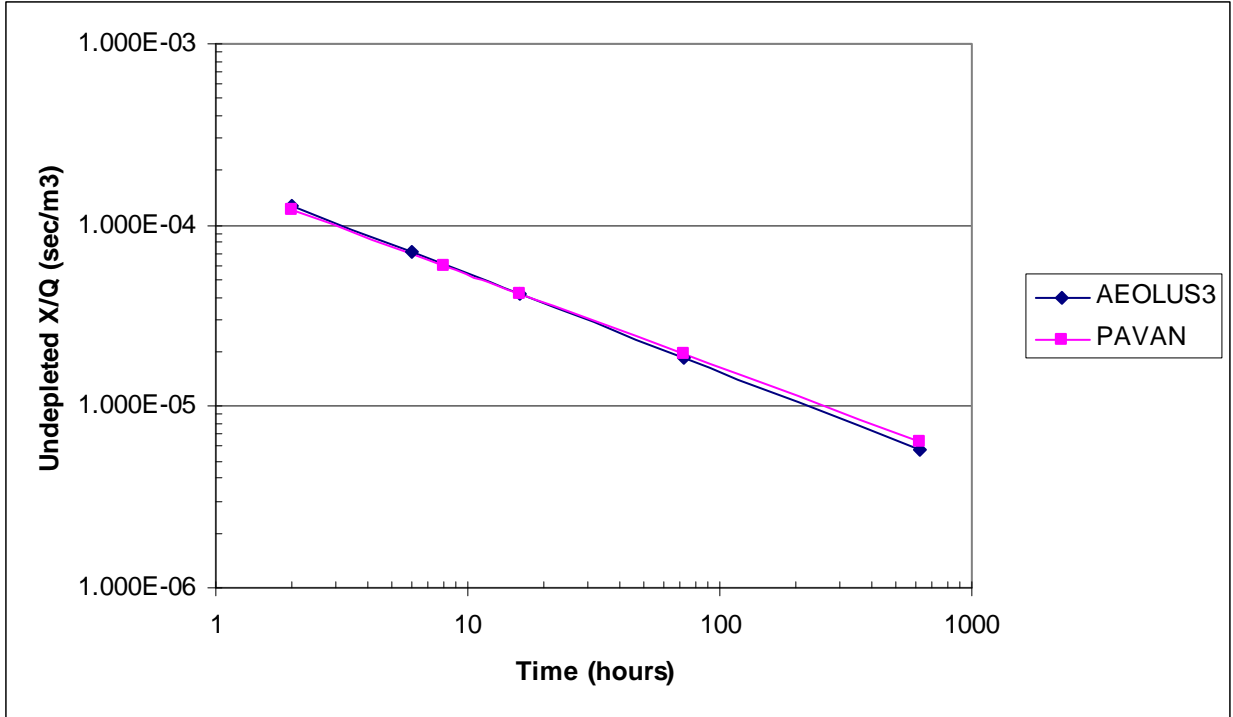


Figure 6: Accident X/Q Comparison, LPZ Maximum of Sector Values, Site 3

Table 3: AEOLUS3 Accident Value/PAVAN Accident Value for Site 3

EAB	Ratio	1.1	1.1	1.0	1.0	0.9
LPZ	Ratio	1.1	1.2	1.0	1.0	0.9

Figures 7 and 8 present the results of the comparison of accident atmospheric dispersion factors from AEOLUS3 and PAVAN using plant-specific input and meteorological data specific to site 4. Note that for both the EAB results and the LPZ results, the AEOLUS3 results are more conservative than the PAVAN results. Table 4 presents the numeric differences between the codes; it can be seen that the AEOLUS3 results range from a factor of 1.1 to 1.8 times higher than the PAVAN results.

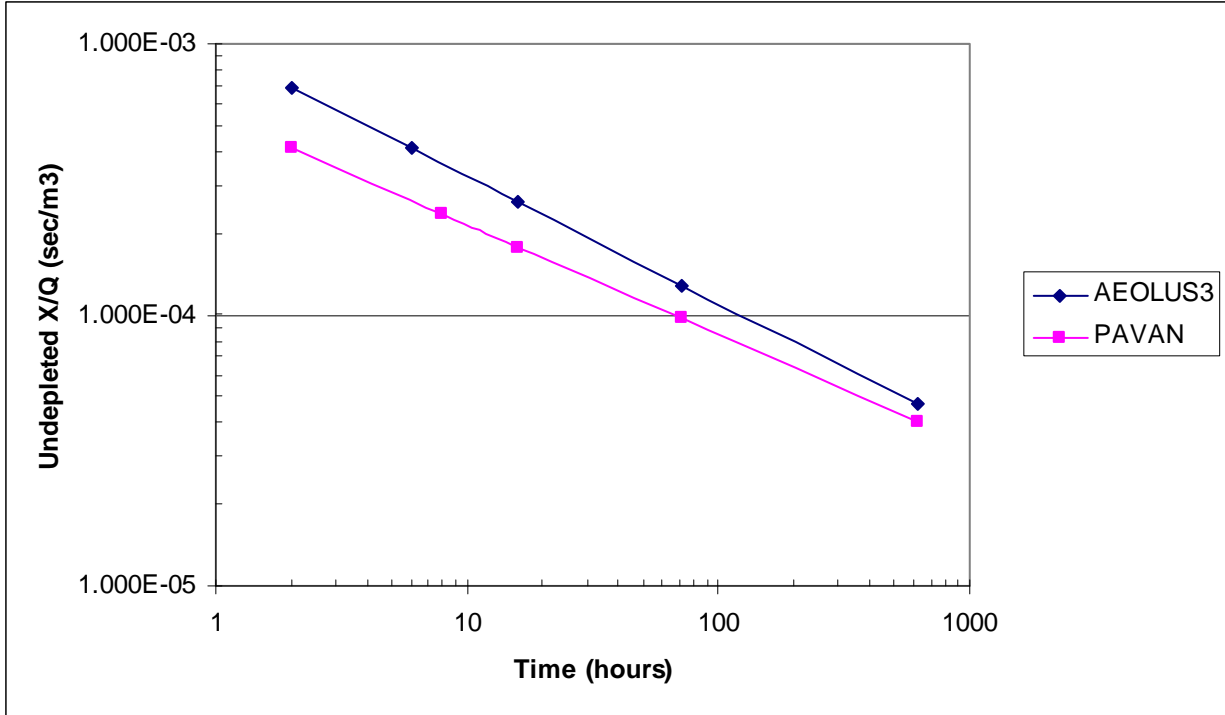


Figure 7: Accident X/Q Comparison, EAB Maximum of Sector Values, Site 4

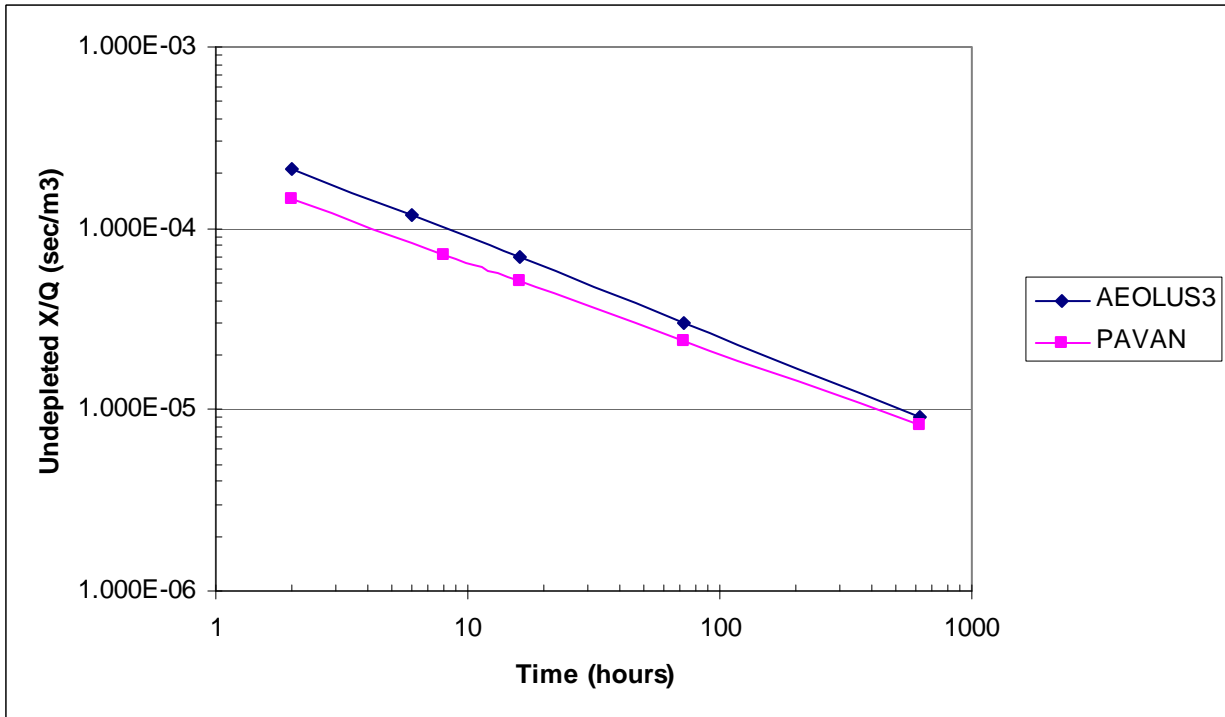


Figure 8: Accident X/Q Comparison, LPZ Maximum of Sector Values, Site 4

Table 4: AEOLUS3 Accident Value/PAVAN Accident Value for Site 4

EAB	Ratio	1.7	1.8	1.5	1.3	1.2
LPZ	Ratio	1.5	1.6	1.3	1.2	1.1

Normal Effluent Atmospheric Dispersion Results – Ground-level Release

Figure 9 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 1. The values for the maximum sector (WSW) are plotted. Note that the models are in agreement with the XOQDOQ values being slightly higher. Table 5 presents the numeric differences between the codes; it can be seen that the AEOLUS3 results are slightly lower (ratio of AEOLUS3 to XOQDOQ is 0.93 to 0.96) than the XOQDOQ results.

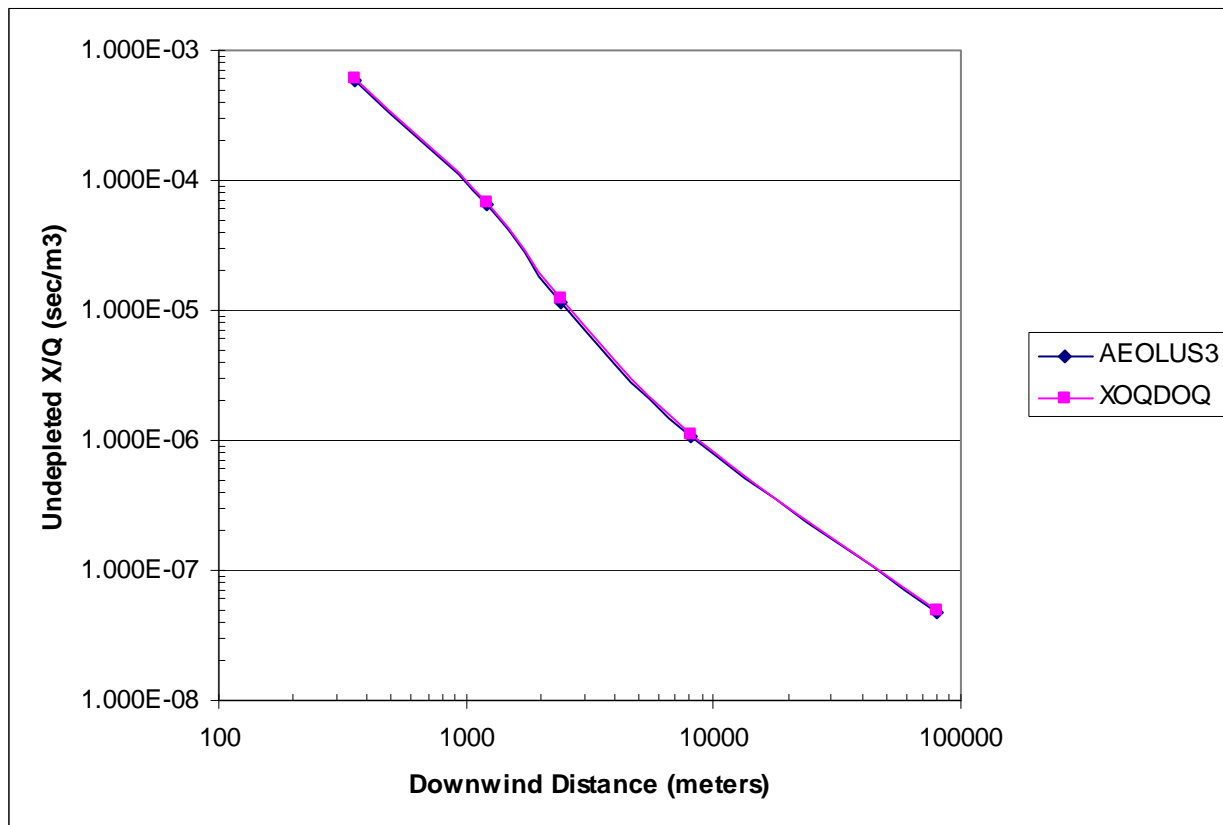


Figure 9: Normal Effluent X/Q Comparison, Ground-level Release, Maximum Sector Values, Site 1

Table 5: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Ground Release Site 1

Distance (m)	354	1208	2414	8045	80450
Ratio	0.95	0.95	0.93	0.94	0.96

Figure 10 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 2. The values for the maximum sector (NNW) are plotted. Note that the models are in agreement with the XOQDOQ values being slightly higher. Table 6 presents the numeric differences between the codes; it can be seen that the AEOLUS3 results are slightly lower (ratio of AEOLUS3 to XOQDOQ is 0.82 to 0.86) than the XOQDOQ results.

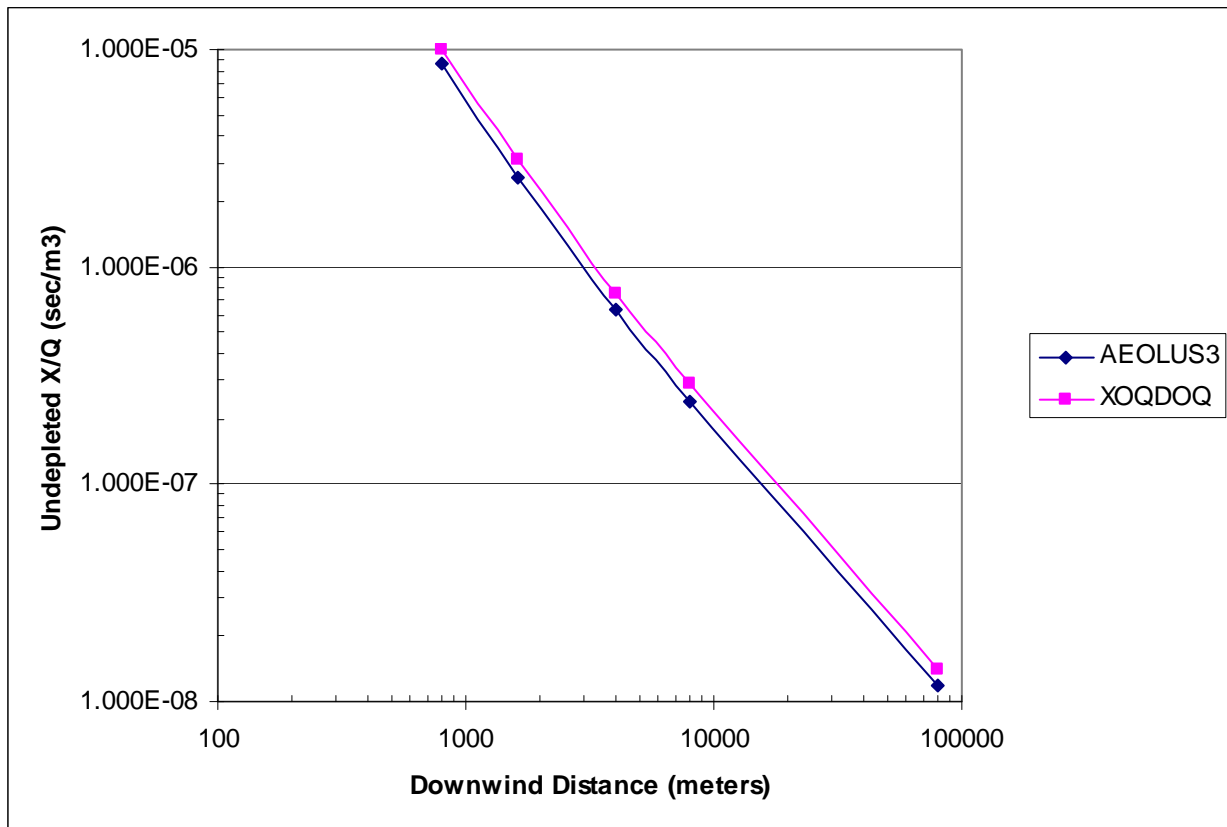


Figure 10: Normal Effluent X/Q Comparison, Ground-level Release, Maximum Sector Values, Site 2

Table 6: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Ground Release Site 2

Distance (m)	805	1609	4023	8045	80450
Ratio	0.86	0.83	0.84	0.82	0.84

Figure 11 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 4. The values for the maximum sector (NE) are plotted. Note that the models are in agreement with the XOQDOQ values being slightly higher at four of five distances. Table 7 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 to XOQDOQ ranges from 0.97 to 1.02.

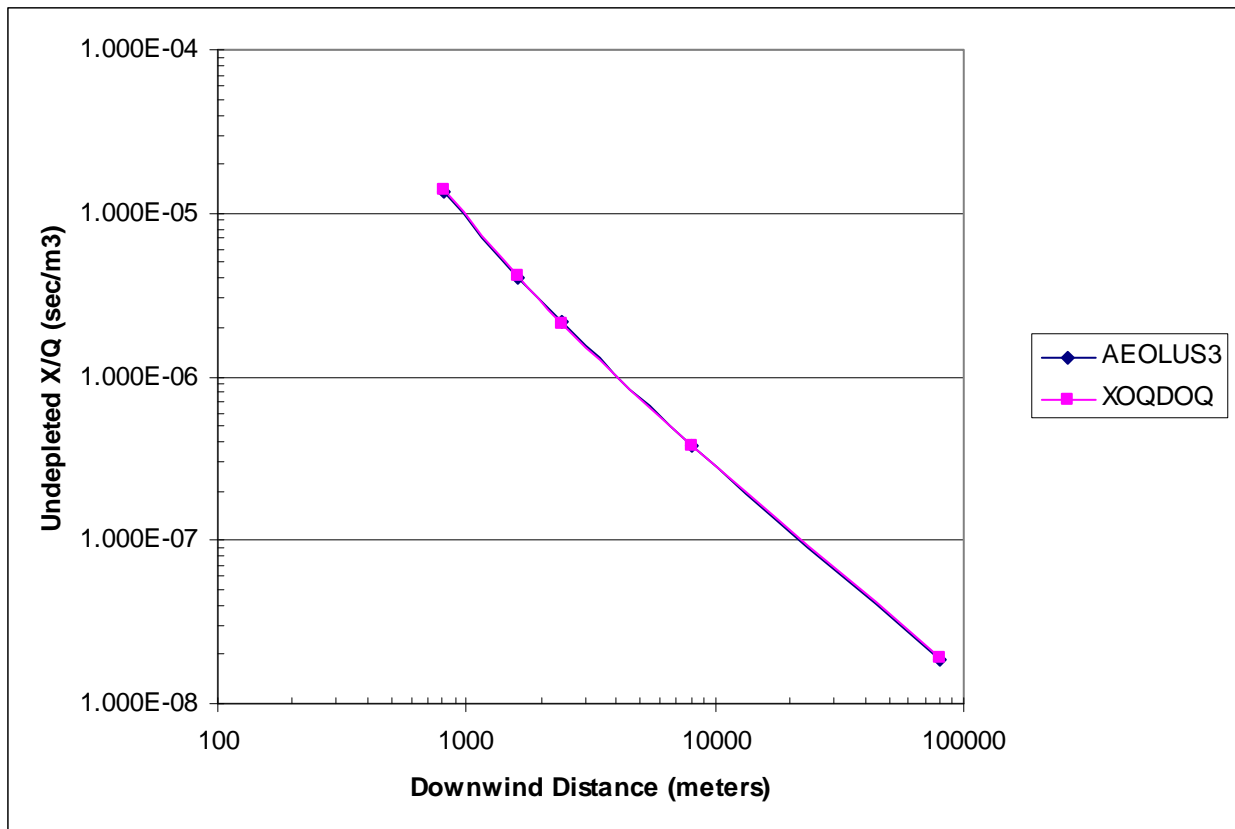


Figure 11: Normal Effluent X/Q Comparison, Ground-level Release, Maximum Sector Values, Site 4

Table 7: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Ground Release Site 4

Distance (m)	805	1609	2414	8045	80450
Ratio	0.97	0.99	1.02	0.996	0.99

Figure 12 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 3. The values for the maximum sector (NW) are plotted. Note that the models are in agreement with the XOQDOQ values being slightly higher at all distances. Table 8 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 to XOQDOQ ranges from 0.80 to 0.84.

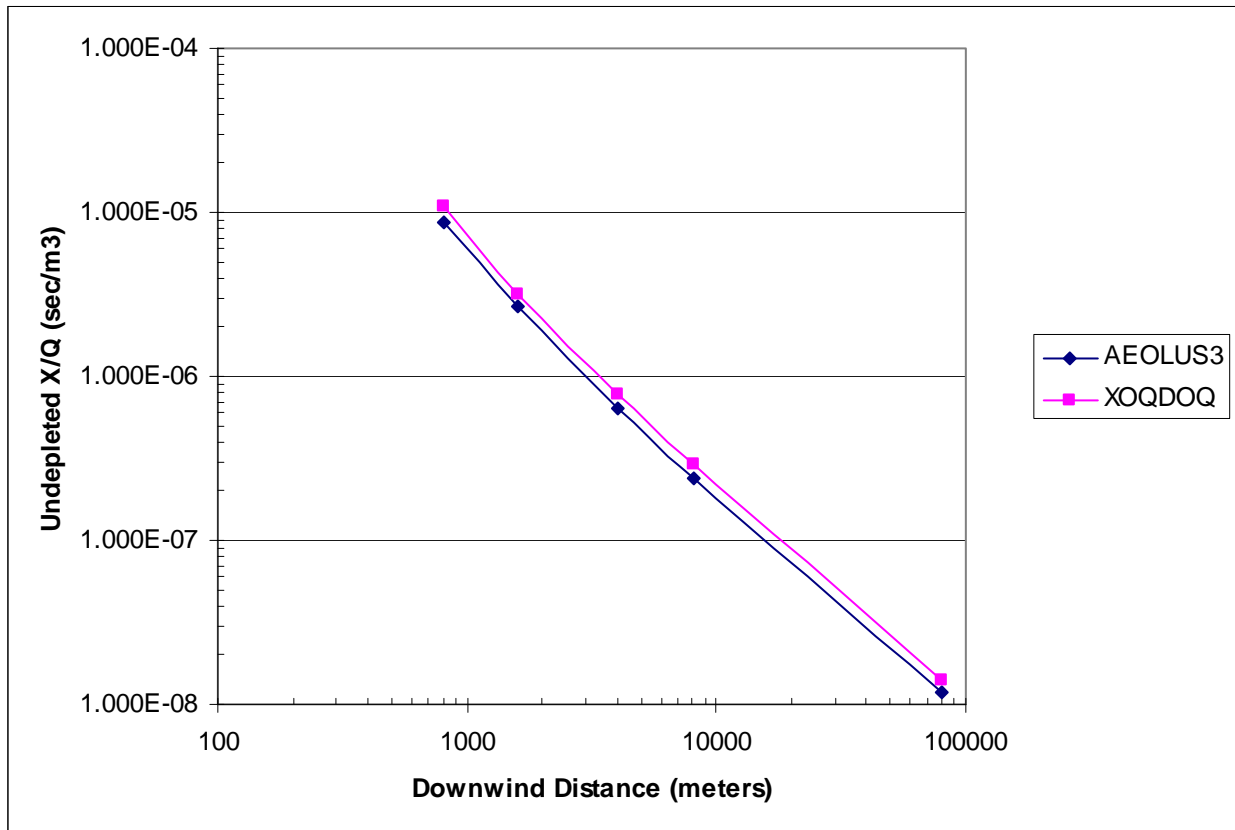


Figure 12: Normal Effluent X/Q Comparison, Ground-level Release, Maximum Sector Values, Site 3

Table 8: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Ground Release Site 3

Distance (m)	805	1609	4023	8045	80450
Ratio	0.80	0.82	0.84	0.83	0.84

Normal Effluent Atmospheric Dispersion Results – Elevated Release

Figure 13 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using site-specific input and meteorological data specific to site 5. This case did not include the effects of terrain or recirculation correction. The values for the maximum sector (SSE) are plotted. Note that the models are in agreement with the ratio values being close to unity. Table 9 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 to XOQDOQ ranges from 0.98 to 1.01.

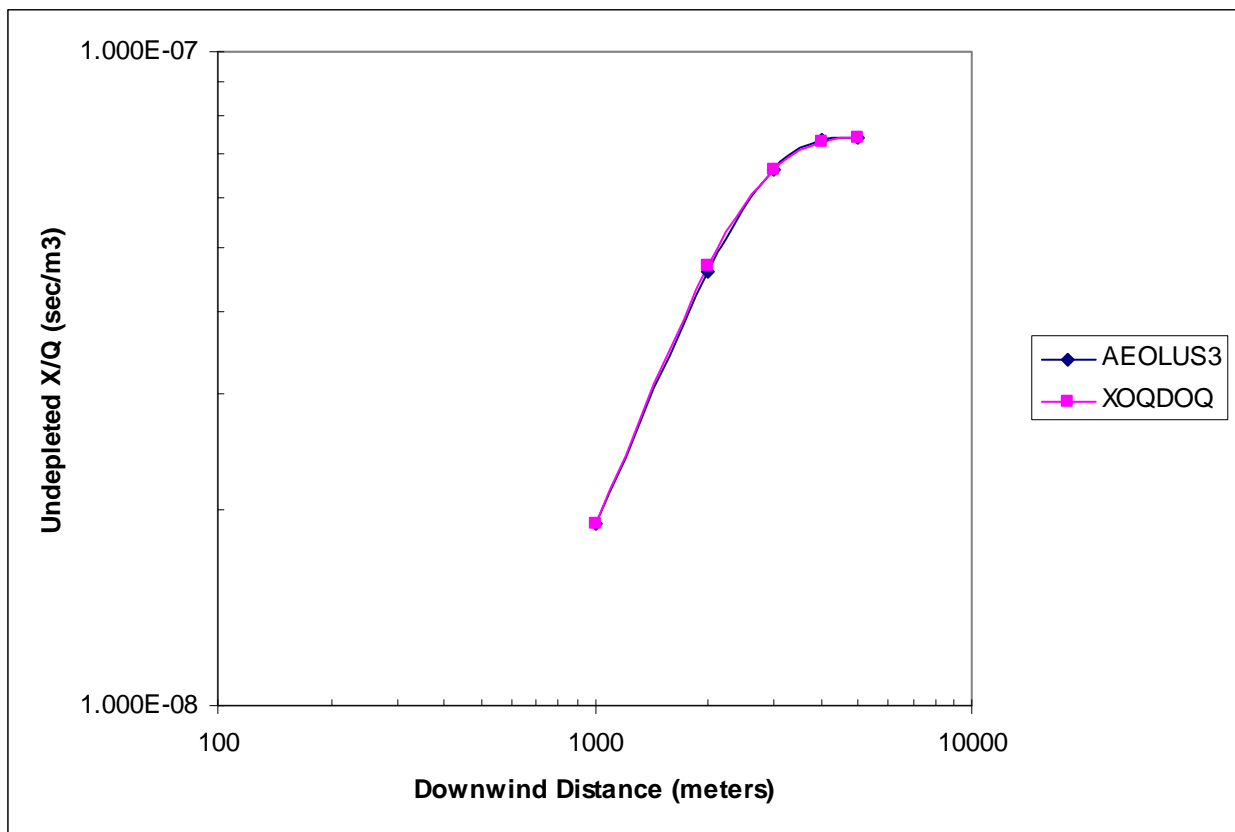


Figure 13: Normal Effluent X/Q Comparison, Elevated Release, Maximum Sector, Site 5

Table 9: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Elevated Release Site 5

Distance (m)	1000	2000	3000	4000	5000
Ratio	0.998	0.98	1.00	1.01	0.999

Figure 14 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using site-specific input and meteorological data specific to site 5. This case included the effect of recirculation correction. The values for the maximum sector (SSE) are plotted. Note that the models are in agreement, with the XOQDOQ values being slightly higher. Table 10 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 to XOQDOQ ranges from 0.92 to 0.998.

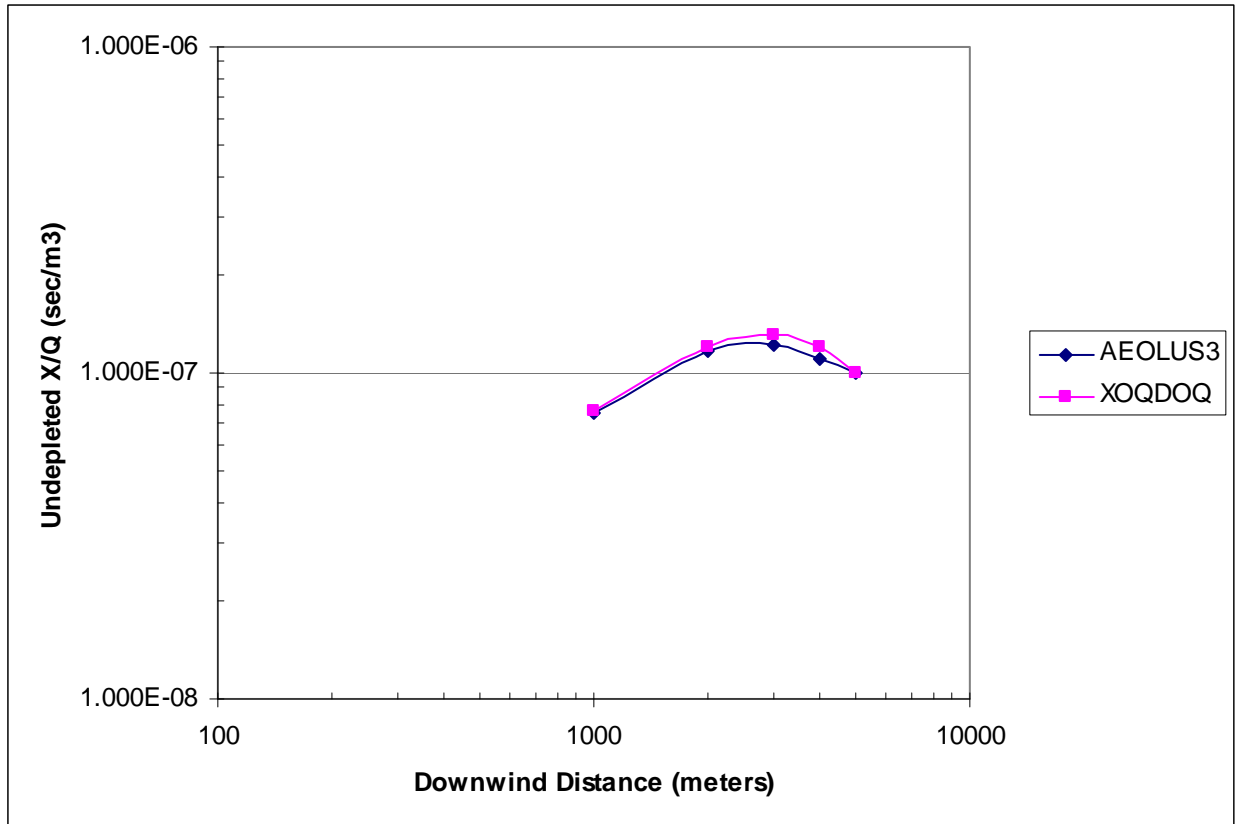


Figure 14: Normal Effluent X/Q Comparison, Elevated Release with RCFs, Maximum Sector, Site 5

Table 10: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Elevated Release Site 5

Distance (m)	1000	2000	3000	4000	5000
Ratio	0.998	0.98	0.94	0.92	0.995

Figure 15 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using site-specific input and meteorological data specific to site 5. This case included the effect of terrain. The

maximum values (not all in the same sector) are plotted. Note that the models are in agreement with the XOQDOQ values being slightly higher within the first 3000 meters (1.9 miles) and the AEOLUS3 values being slightly higher beyond 3000 meters. Table 11 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 to XOQDOQ ranges from 0.75 to 1.02.

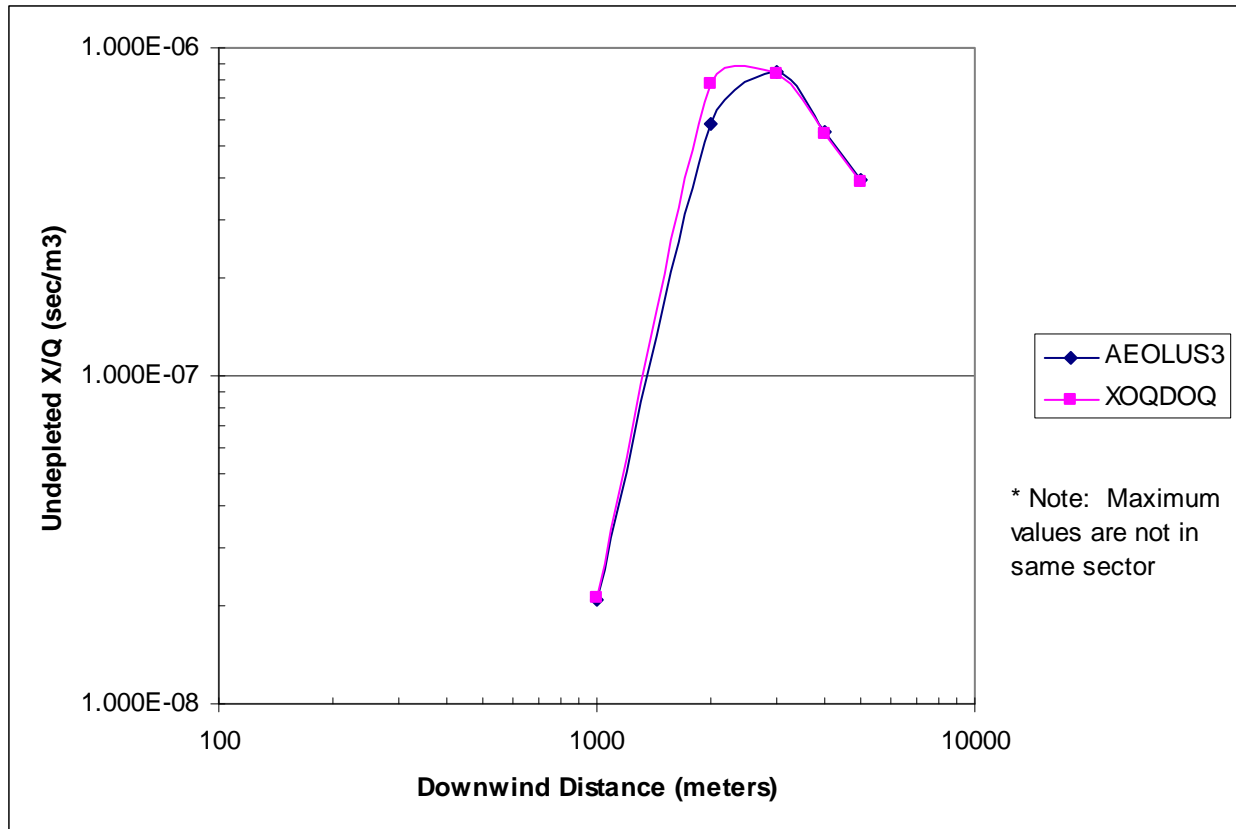


Figure 15: Normal Effluent X/Q Comparison, Elevated Release with Terrain, Maximum Values, Site 5

Table 11: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Elevated Release Site 5

Distance (m)	1000	2000	3000	4000	5000
Ratio	0.98	0.75	1.02	1.01	1.02

Figure 16 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using site-specific input and meteorological data specific to site 1. This case did not include the effects of terrain or recirculation correction. The maximum values are plotted. Note that the models are in agreement with the XOQDOQ values being slightly higher. Table 12 presents the

numeric differences between the codes; it can be seen that the ratio of AEOLUS3 to XOQDOQ ranges from 0.45 to 0.93.

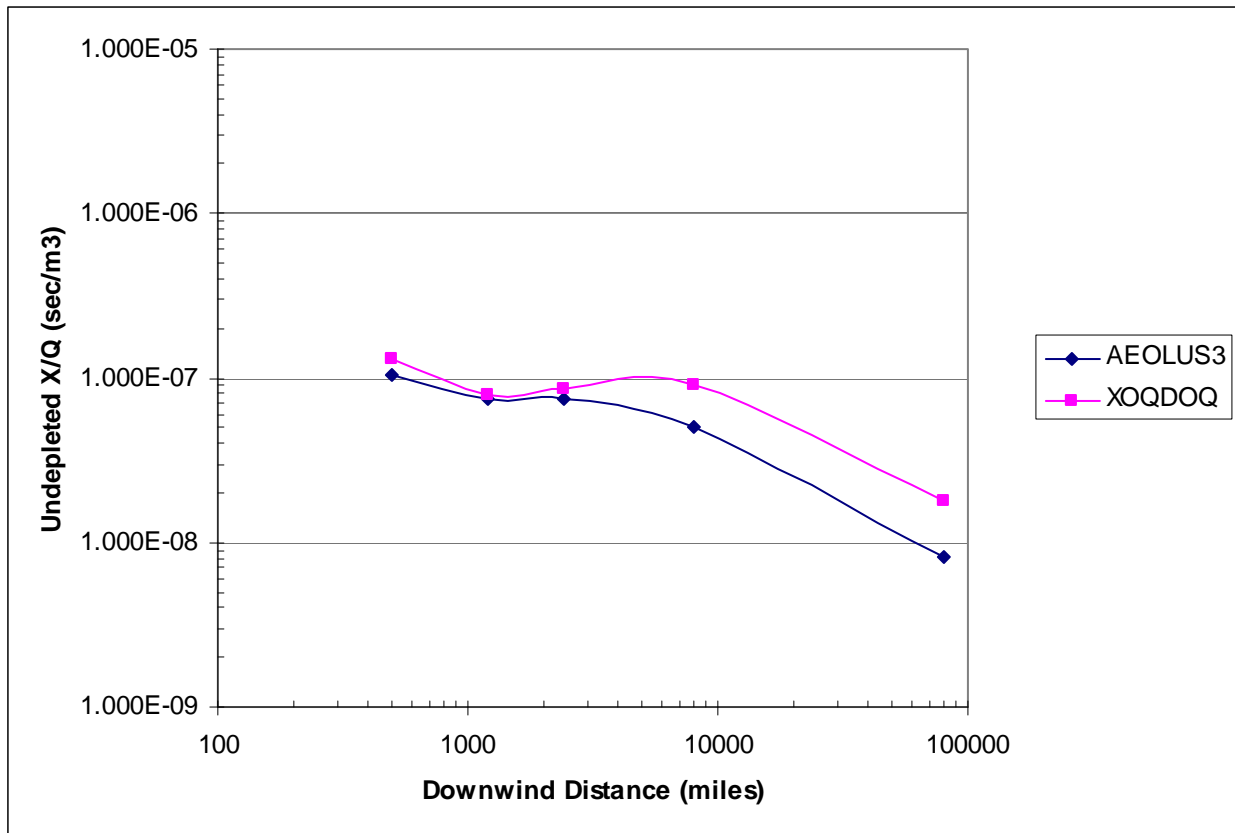


Figure 16: Normal Effluent X/Q Comparison, Elevated Release, Maximum Values, Site 1

Table 12: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Elevated Release Site 1

Distance (m)	500	1208	2414	8045	80450
Ratio	0.80	0.93	0.87	0.56	0.45

Figure 17 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using site-specific input and meteorological data specific to site 4. This case did not include the effects of terrain or recirculation correction. The maximum values are plotted. Note that the models are in agreement with the XOQDOQ values being slightly higher. Table 13 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 to XOQDOQ ranges from 0.49 to 0.97.

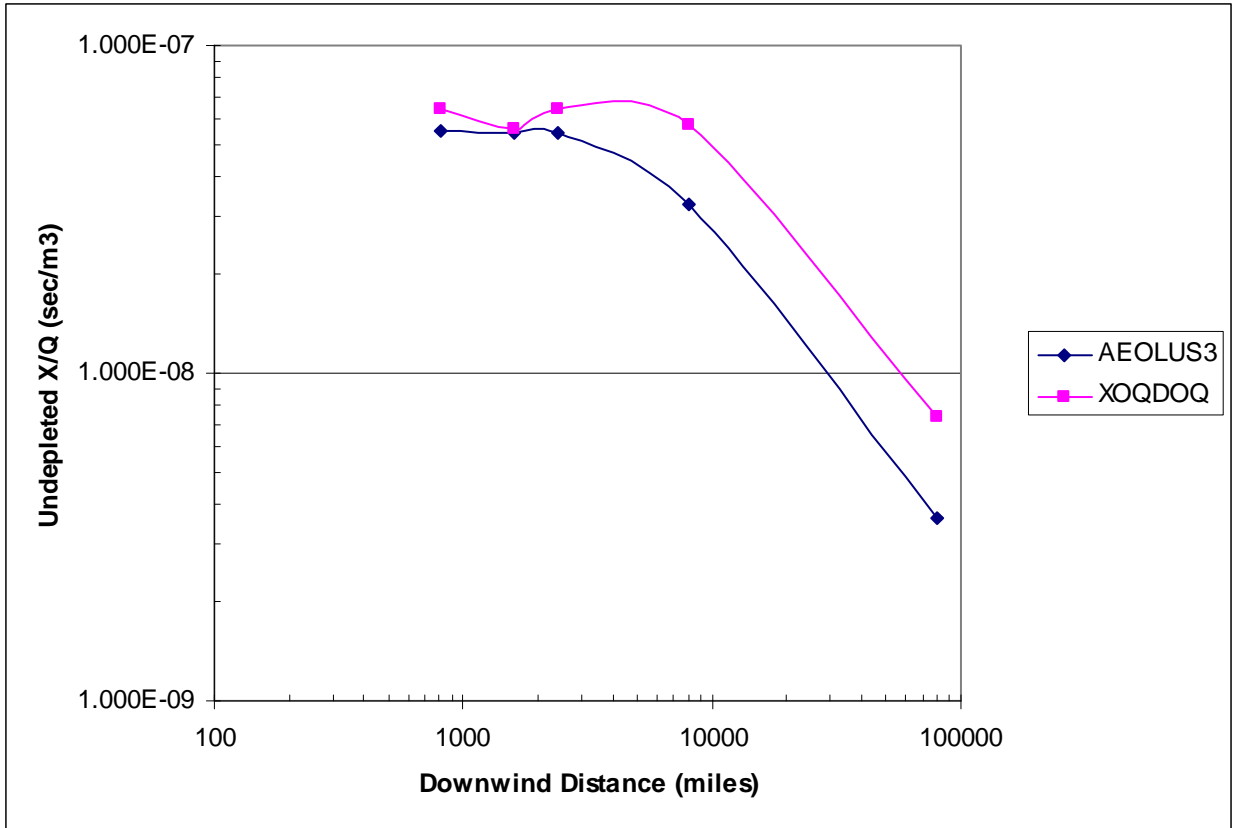


Figure 17: Normal Effluent X/Q Comparison, Elevated Release, Maximum Values, Site 4

Table 13: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Elevated Release Site 4

Distance (m)	805	1609	2414	8045	80450
Ratio	0.85	0.97	0.84	0.57	0.49

Figure 18 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using site-specific input and meteorological data specific to site 3. This case did not include the effects of terrain or recirculation correction. The maximum values are plotted. Note that the models are in agreement with the XOQDOQ values being slightly higher. Table 14 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 to XOQDOQ ranges from 0.42 to 0.85.

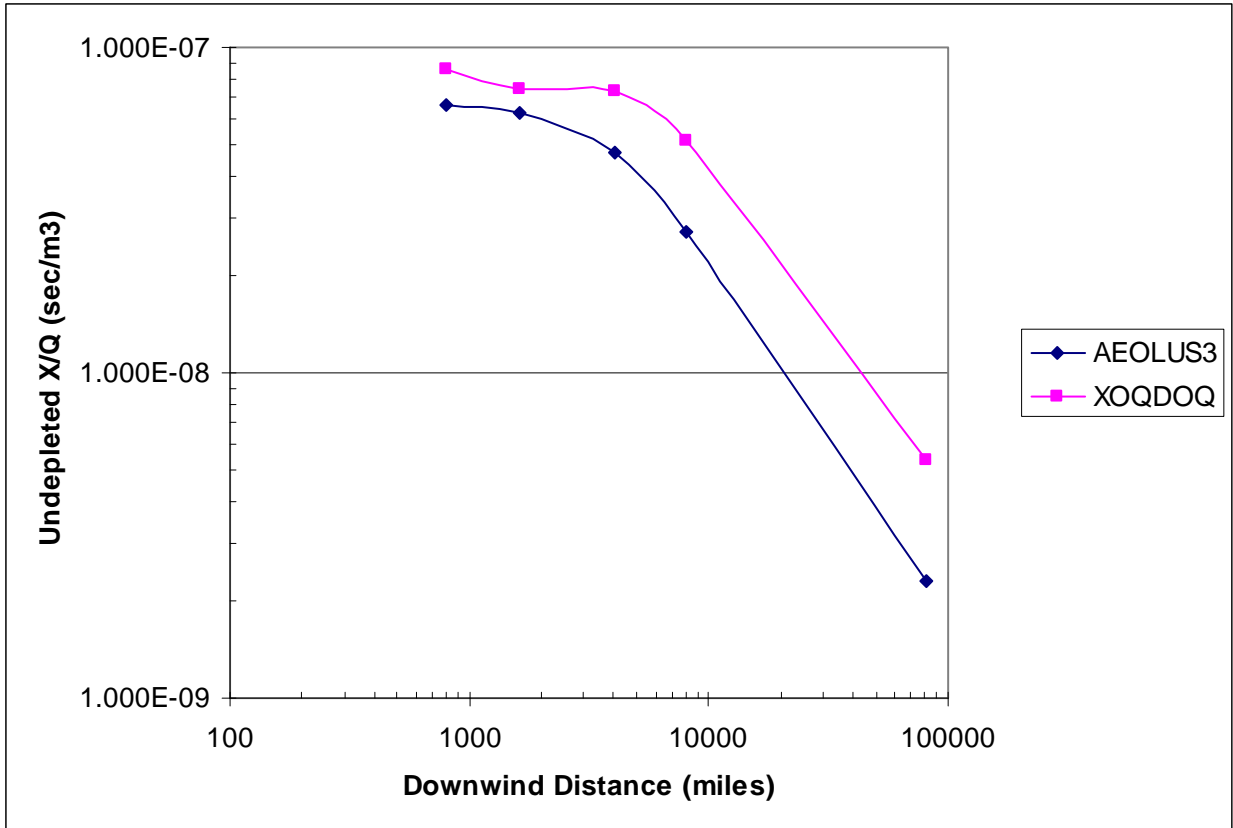


Figure 18: Normal Effluent X/Q Comparison, Elevated Release, Maximum Values, Site 3

Table 14: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Elevated Release Site 3

Distance (m)	805	1609	4023	8045	80450
Ratio	0.77	0.85	0.65	0.52	0.42

Figure 19 presents the effect of terrain and recirculation correction on model comparison using information from Tables 9, 10, and 11. A value of 1.0 denotes perfect agreement between the two models. Note that the model agreement is best when neither terrain nor recirculation correction effects are included.

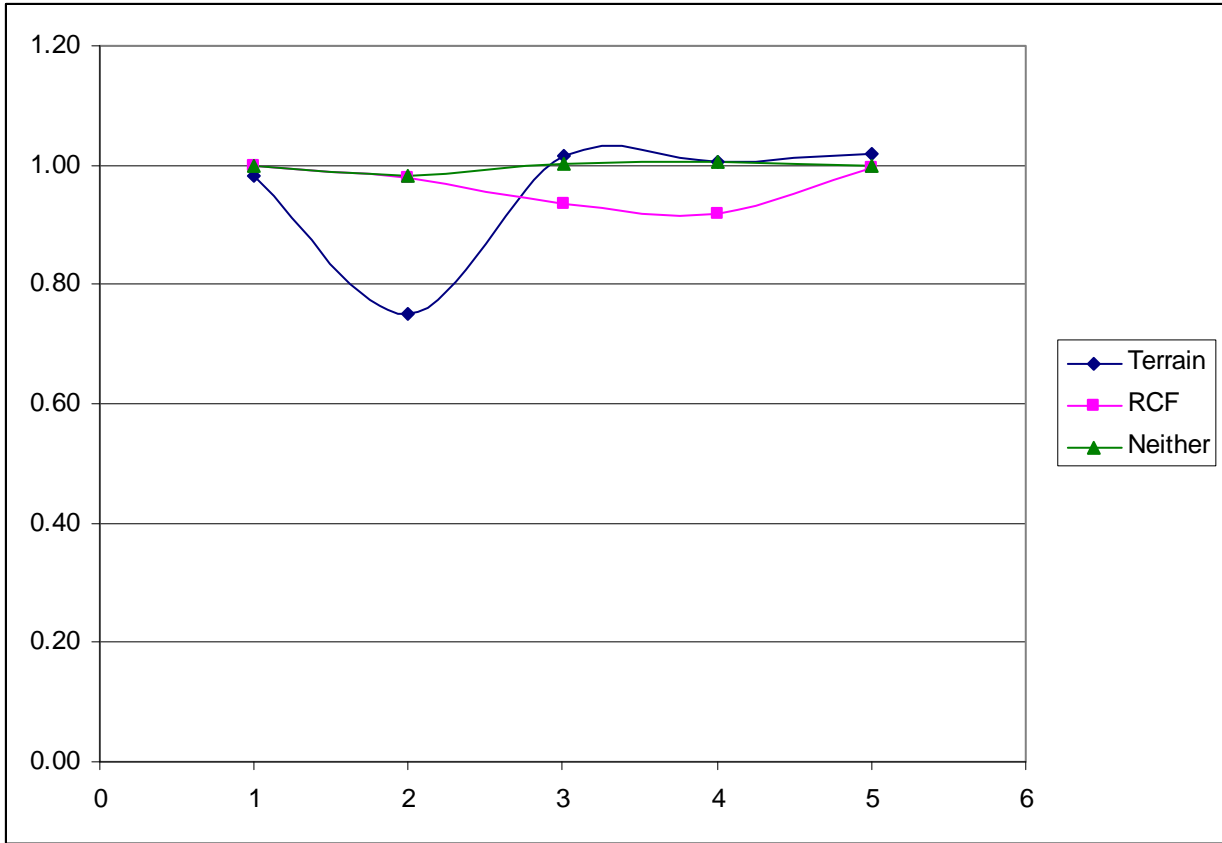


Figure 19: Effect of Terrain and Recirculation Correction on Model Comparison of Elevated Releases

Normal Effluent Atmospheric Dispersion Results – Mixed-Mode Release

Figure 20 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 1. This case did not include the effects of terrain or recirculation correction. The maximum values are plotted. AEOLUS3 determined that the maximum values at each of the five downwind distances were in the same sector (WSW); XOQDOQ determined that the maximum values were in the NE sector for the first three downwind distances and in the WSW sector for the last two downwind distances. Note that the models are in agreement with the AEOLUS3 values being higher over the first 7,000 meters (4.3 miles) downwind and the XOQDOQ values being higher beyond 7,000 meters downwind. Table 15 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 results to XOQDOQ results range from 0.54 to 4.85.

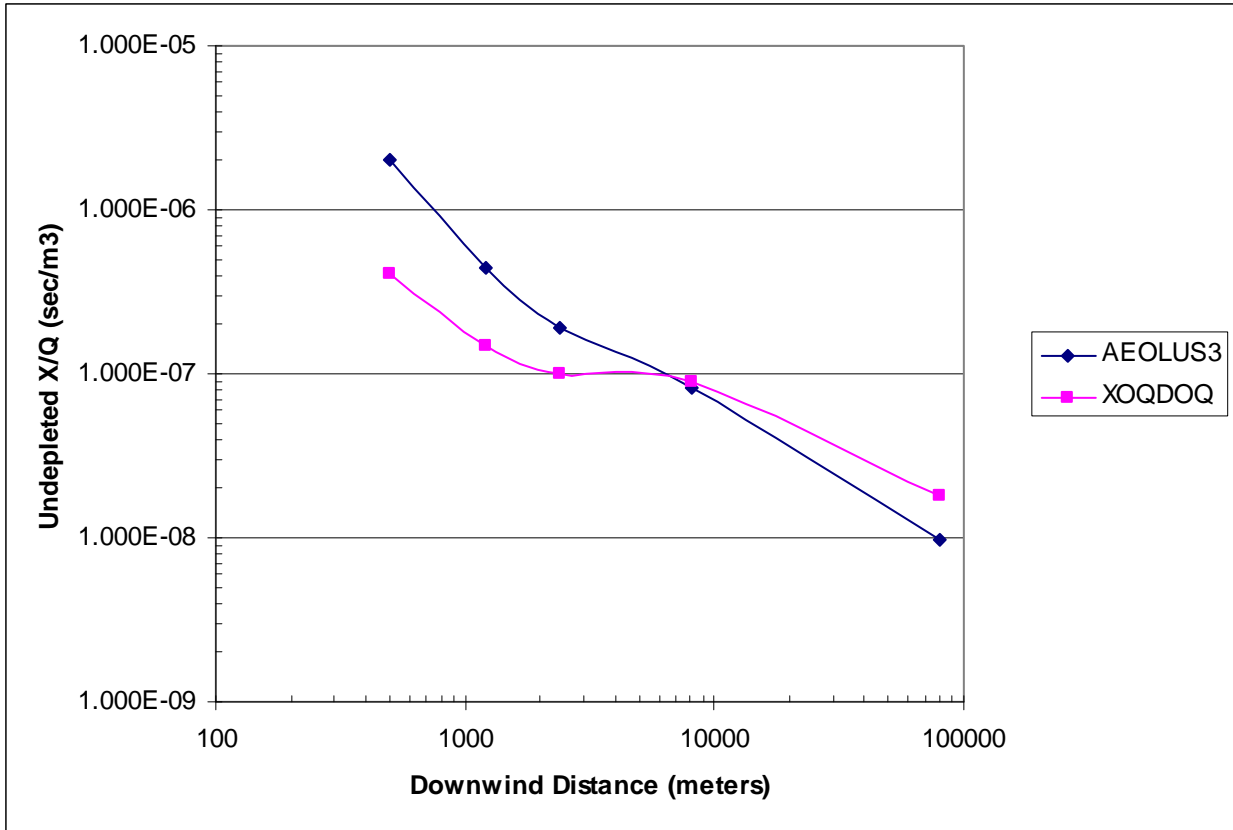


Figure 20: Normal Effluent X/Q Comparison, Mixed-Mode Release, Maximum Values, Site 1

Table 15: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Mixed-Mode Release Site 1

Distance (m)	500	1208	2414	8045	80450
Ratio	4.85	2.91	1.91	0.91	0.54

Figure 21 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 1. This case did include the effect of terrain, using a grid of terrain values in XOQDOQ that did not mimic the values used in AEOLUS3 (i.e., not all downwind distances were the same). The maximum values are plotted. AEOLUS3 determined that the maximum values at the five downwind distances were in the N (first), W (second), and WSW (third through fifth) sectors; XOQDOQ determined that the maximum values were in the NE (first), W (second and third), and WSW (fourth and fifth) sectors. Note that the models are in agreement with the major difference being at the site boundary, where the AEOLUS3 value was more conservative than the XOQDOQ value. Table 16 presents the numeric differences

between the codes; it can be seen that the ratio of AEOLUS3 results to XOQDOQ results range from 0.41 to 4.06.

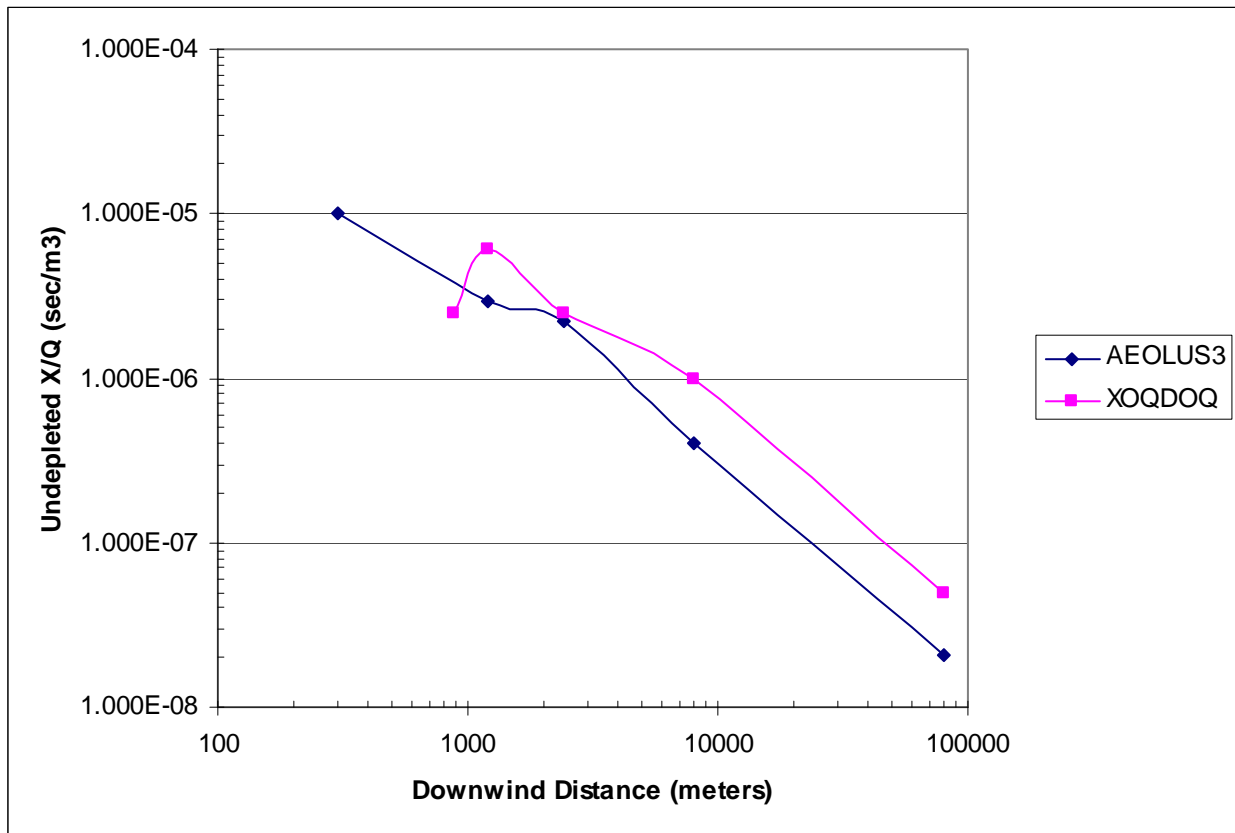


Figure 21: Normal Effluent X/Q Comparison, Mixed-Mode Release with Terrain, Maximum Values, Site 1

Table 16: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Mixed-Mode Release with Terrain Site 1

Distance (m)	300/876*	1208	2414	8045	80450
Ratio	4.06	0.48	0.88	0.41	0.41

* AEOLUS3 maximum value at the Site Boundary was at 300 m in the North sector; XOQDOQ maximum value at the Site Boundary was at 876 m in the Northeast sector.

Figure 22 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 1. This case did include the effect of terrain, using a grid of terrain values in XOQDOQ that matched the values used in AEOLUS3. The maximum values are plotted. AEOLUS3 determined that the maximum values at the five downwind distances were in the N (first), W (second), and WSW (third through fifth) sectors; XOQDOQ determined that the maximum values were in the NE (first), W

(second), and WSW (third through fifth) sectors. Note that the models are in agreement with the major difference being at the site boundary, where the AEOLUS3 value was more conservative than the XOQDOQ value. Table 17 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 results to XOQDOQ results range from 0.38 to 3.69.

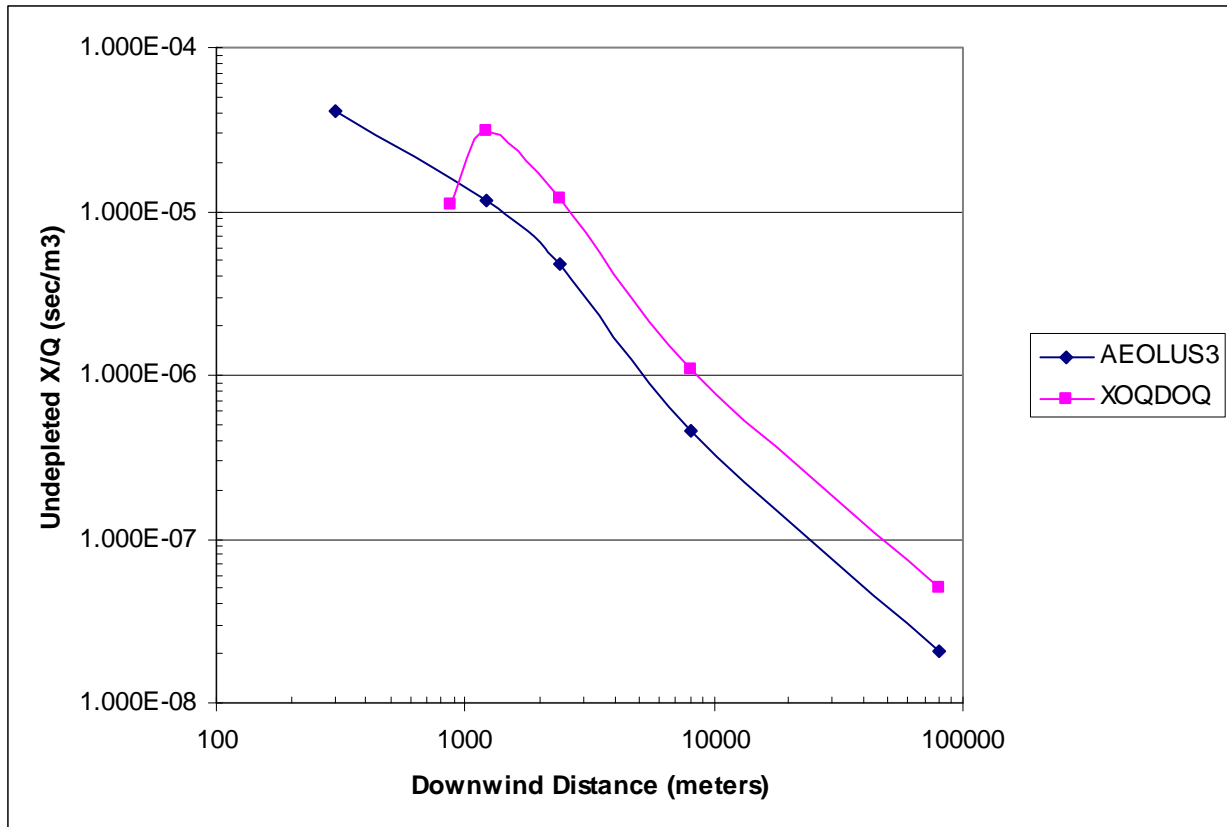


Figure 22: Normal Effluent X/Q Comparison, Mixed-Mode Release with Matching Terrain, Maximum Values, Site 1

Table 17: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Mixed-Mode Release with Matching Terrain Site 1

Distance (m)	300/876*	1208	2414	8045	80450
Ratio	3.69	0.38	0.40	0.41	0.41

* AEOLUS3 maximum value at the Site Boundary was at 300 m in the North sector; XOQDOQ maximum value at the Site Boundary was at 876 m in the Northeast sector.

Figure 23 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 1. This case did include the effect of terrain, using two sets of terrain values in XOQDOQ (at 0.5 mile and 10 miles). The maximum values

are plotted. AEOLUS3 determined that the maximum values at the five downwind distances were in the N (first), W (second), and WSW (third through fifth) sectors; XOQDOQ determined that the maximum values were in the NNE (first), N (second), NW (third), and WSW (fourth and fifth) sectors. Note that the models are in agreement with the AEOLUS3 values being higher over the first 7,000 meters (4.3 miles) downwind and the XOQDOQ values being higher beyond 7,000 meters downwind. Table 18 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 results to XOQDOQ results range from 0.41 to 4.19.

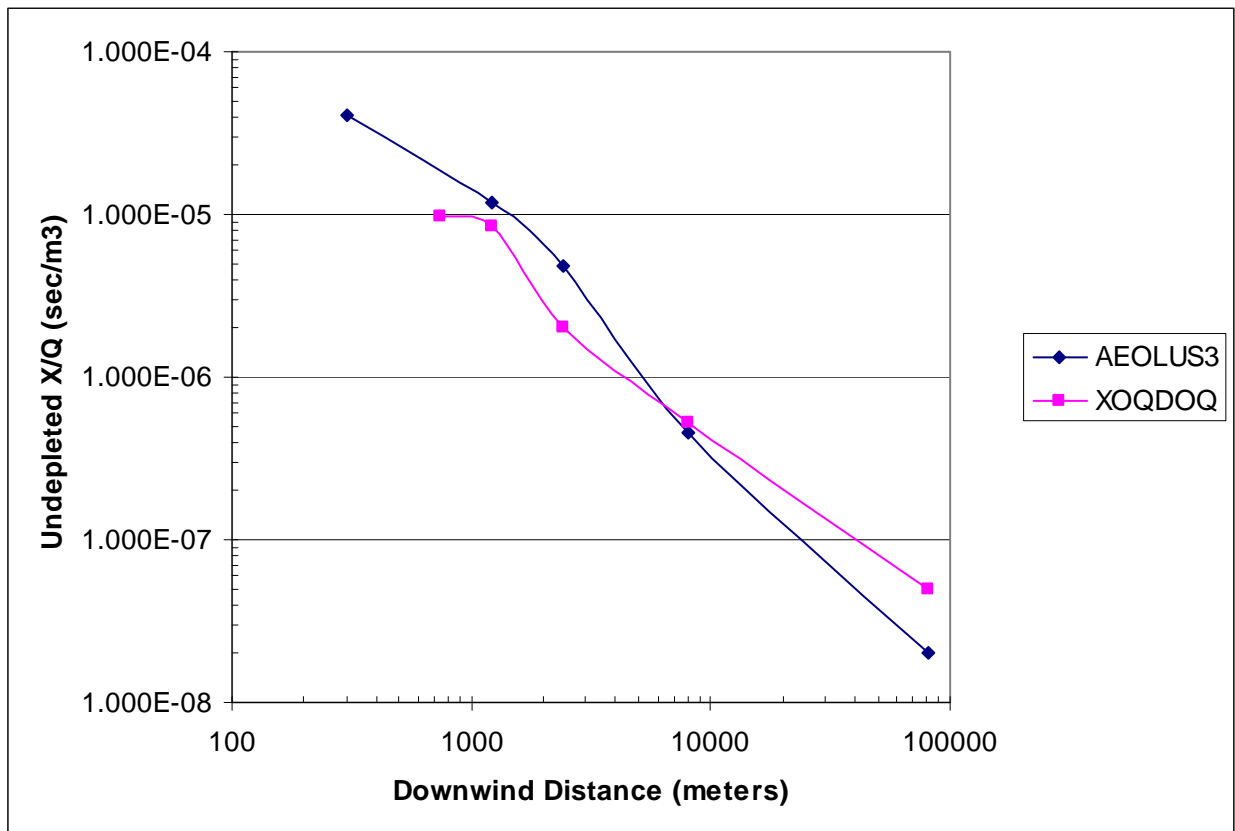


Figure 23: Normal Effluent X/Q Comparison, Mixed-Mode Release with Terrain at 0.5 and 10 miles, Maximum Values, Site 1

Table 18: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Mixed-Mode Release with Terrain at 0.5 and 10 miles, Site 1

Distance (m)	300/738*	1208	2414	8045	80450
Ratio	4.19	1.40	2.39	0.85	0.41

* AEOLUS3 maximum value at the Site Boundary was at 300 m in the North sector; XOQDOQ maximum value at the Site Boundary was at 738 m in the North-Northeast sector.

Figure 24 presents the effect of terrain on model comparison using information from Tables 16, 17, and 18. The best agreement between the two models was obtained by supplying XOQDOQ with matching downwind distance/terrain values as provided to AEOLUS3. The next best agreement between the two models was obtained by supplying XOQDOQ with a grid of terrain data that did not match downwind distance/terrain values provided to AEOLUS3. The worst agreement of the three approaches was obtained by supplying XOQDOQ with two sets of downwind distance/terrain values to bracket all downwind distances.

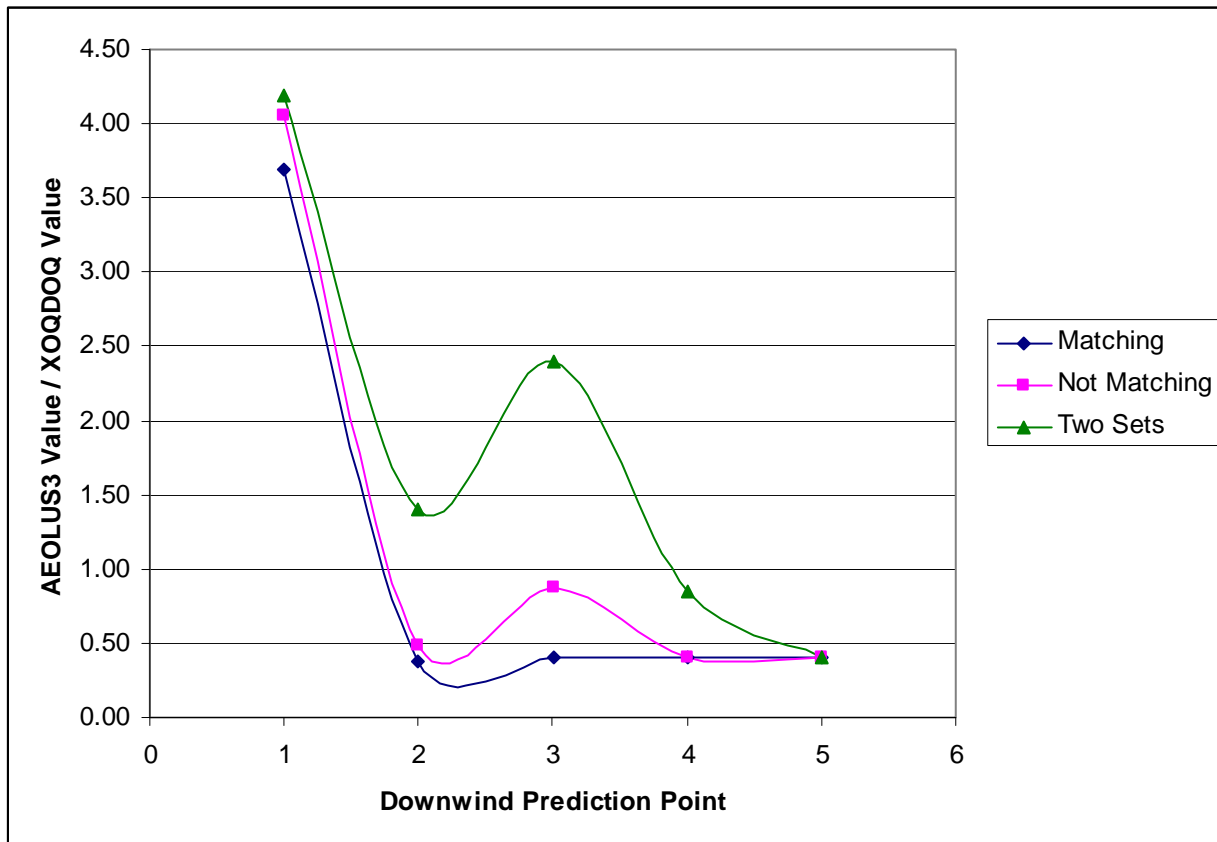


Figure 24: Effect of Terrain on Model Comparison of Mixed-Mode Releases

Figure 25 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 4. This case did not include the effects of terrain or recirculation correction. The maximum values are plotted. Both AEOLUS3 and XOQDOQ determined that the maximum values were in the NE sector. Note that the AEOLUS3 values are higher, and therefore more conservative, over approximately the first 15,000 meters (9.3 miles) downwind and the XOQDOQ values are higher beyond

15,000 meters downwind. Table 19 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 results to XOQDOQ results range from 0.71 to 5.48.

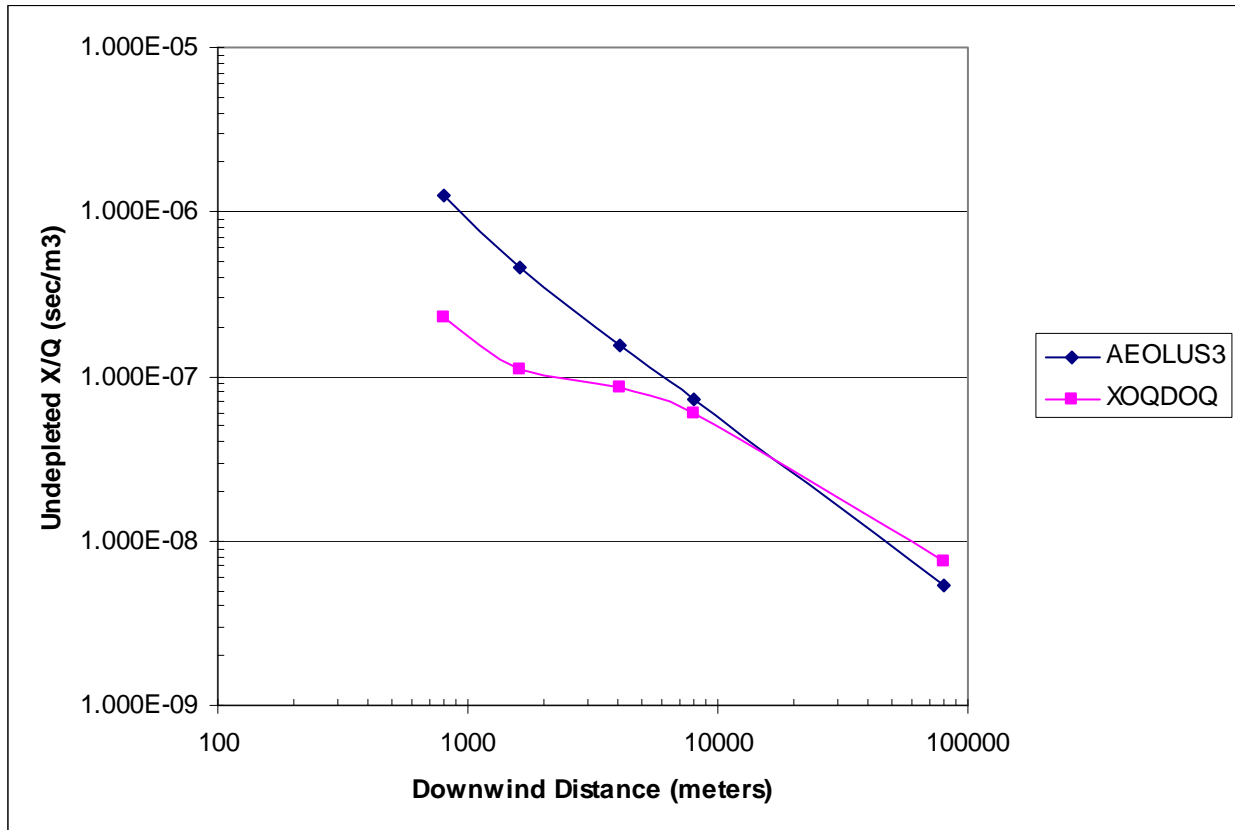


Figure 25: Normal Effluent X/Q Comparison, Mixed-Mode Release, Maximum Values, Site 4

Table 19: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Mixed-Mode Release Site 4

Distance (m)	805	1609	4023	8045	80450
Ratio	5.48	4.21	1.84	1.20	0.71

Figure 26 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 3. This case did not include the effects of terrain or recirculation correction. The maximum values are plotted. AEOLUS3 determined that the maximum values at each of the five downwind distances were in the same sector (NW); XOQDOQ determined that the maximum values were in the E sector for the first two downwind distances and in the NW sector for the last three downwind distances.

Note that the models are in agreement with the AEOLUS3 values being higher, and therefore more conservative, over approximately the first 8,100 meters (5 miles) downwind and the XOQDOQ values being higher beyond 8,100 meters downwind. Table 20 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 results to XOQDOQ results range from 0.67 to 3.53.

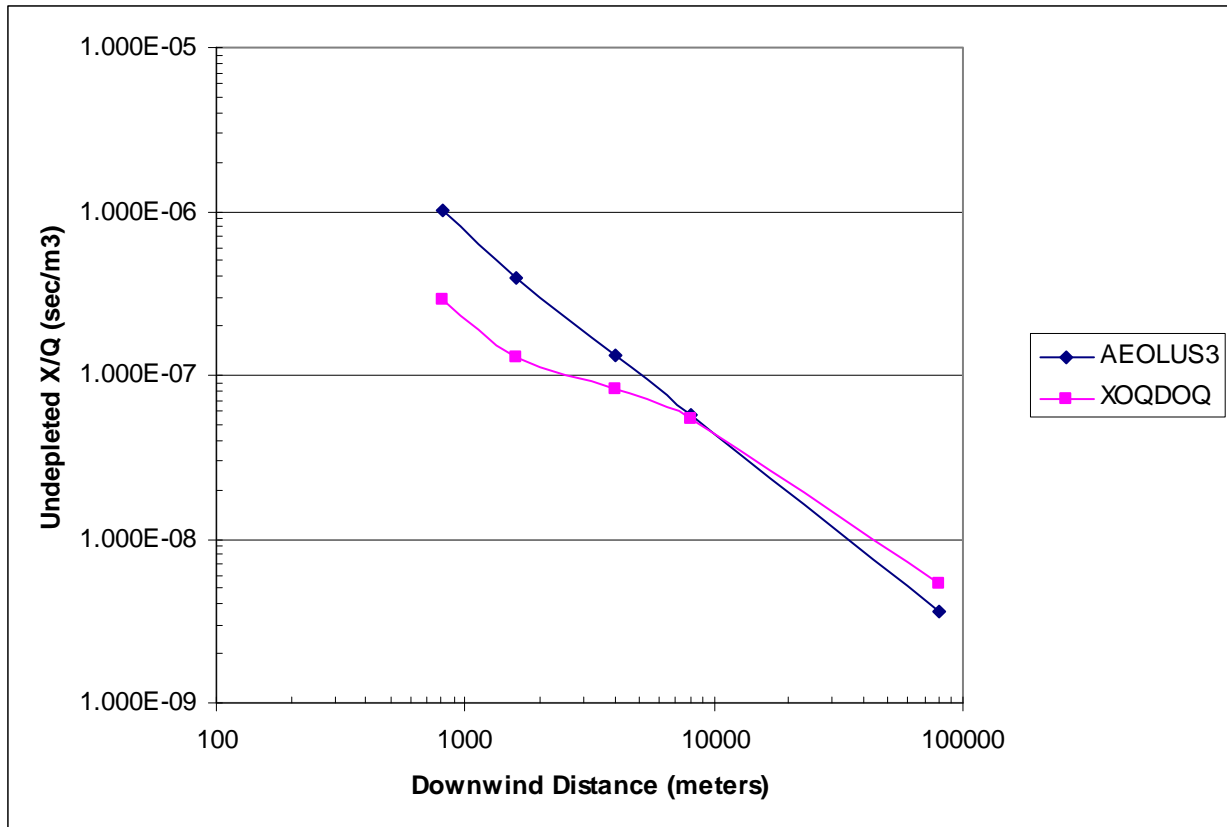


Figure 26: Normal Effluent X/Q Comparison, Mixed-Mode Release, Maximum Values, Site 3

Table 20: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Mixed-Mode Release Site 3

Distance (m)	805	1609	4023	8045	80450
Ratio	3.53	3.00	1.59	1.06	0.67

Figure 27 presents the results of the comparison of normal effluent atmospheric dispersion factors from AEOLUS3 and XOQDOQ using plant-specific input and meteorological data specific to site 2. This case did not include the effects of terrain or recirculation correction. The maximum values are plotted. Both AEOLUS3 and XOQDOQ determined that the maximum values were in the NNW sector. Note that

the models are in agreement with the AEOLUS3 values being higher, and therefore more conservative, over approximately the first 15,000 meters (9.3 miles) downwind and the XOQDOQ values being higher beyond 15,000 meters downwind. Table 21 presents the numeric differences between the codes; it can be seen that the ratio of AEOLUS3 results to XOQDOQ results range from 0.66 to 5.48.

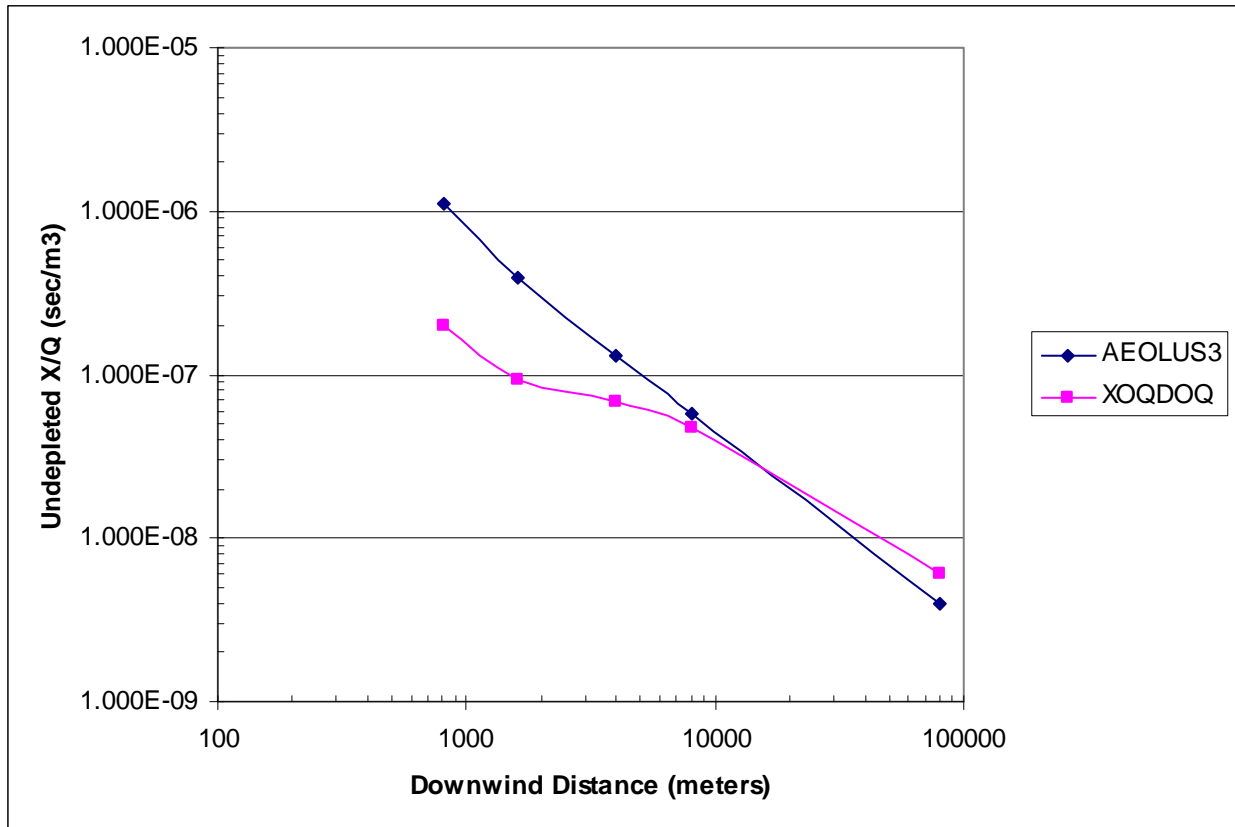


Figure 27: Normal Effluent X/Q Comparison, Mixed-Mode Release, Maximum Values, Site 2

Table 21: AEOLUS3 Normal Effluent Value/ XOQDOQ Normal Effluent Value for Mixed-Mode Release Site 2

Distance (m)	805	1609	4023	8045	80450
Ratio	5.48	4.32	1.88	1.21	0.66

Disagreements between Source Code and Documentation

In PAVAN subroutine CHIQ, the maximum wind speed value for each wind speed group is used to determine the short-term atmospheric dispersion factors for each location for both ground-level and elevated releases. Section 4.4 of NUREG/CR-2858 (Reference 6) states that, for ground-level releases, the average wind speed value for

each wind speed group is used to determine the short-term atmospheric dispersion factors.

The site 2 test case, chosen because it showed the largest differences between AEOLUS3 and PAVAN, was run with the PAVAN code changed to use the average wind speed values. The results were lower than those determined using the maximum wind speed values, as is predicted by Gaussian plume theory. Tables 22 and 23 present the ratio of AEOLUS3 to PAVAN results for PAVAN using the maximum wind speed values and the average wind speed values, respectively.

Table 22: AEOLUS3 Accident Value/PAVAN Accident Value for Site 2 (Maximum Wind Speed Values Used by PAVAN)

EAB	Ratio	2.1	2.5	2.3	2.5	2.8
LPZ	Ratio	1.0	1.1	1.0	0.9	0.9

Table 23: AEOLUS3 Accident Value/PAVAN Accident Value for Site 2 (Average Wind Speed Values Used by Modified PAVAN)

EAB	Ratio	1.7	2.1	2.0	2.3	2.6
LPZ	Ratio	0.9	1.0	0.9	0.9	0.8

In XOQDOQ subroutine RISE, the value for the variable S (restoring acceleration per unit vertical displacement for adiabatic motion in the atmosphere) is given as 8.75E-04 for stability class E. Section 4.20 of NUREG/CR-2919 (Reference 7) states that the value for the variable S is 8.7E-04 for stability class E.

A test case was run to determine the effect of this change on the XOQDOQ results. Differences were noted in the third digit to the right of the decimal point in some calculated values.

Summary

The comparison of AEOLUS3 with PAVAN using several sets of site-specific meteorological data indicated that the ratio of the AEOLUS3 results to the PAVAN results ranges from 0.9 to 2.8, and is within a factor of 1.4 on average. In almost all cases, AEOLUS3 produced more conservative results.

It is postulated that the differences in code results are due to:

- AEOLUS3 computes average wind speed values for each wind speed group input by the user and stability class combination using every pertinent wind speed in the meteorological database, not just based on the wind speed group

values input to the code. PAVAN computes average wind speed values based just on the wind speed group values input to the codes.

- PAVAN uses the maximum, rather than the average, wind speed value for each wind speed group to determine the short-term atmospheric dispersion factors for ground-level releases. Since atmospheric dispersion factors are inversely proportional to wind speed according to Gaussian plume theory, the higher wind speeds would make for lower atmospheric dispersion factors.
- PAVAN limits the size of the horizontal dispersion coefficient (σ_y) to 1000 meters (AEOLUS3 does the same if the code is run using the NRC dispersion coefficient option but does not limit the size of σ_y if the code is run using the ENTECH dispersion coefficient option).

The comparison of AEOLUS3 with XOQDOQ using several sets of site-specific meteorological data indicated that the ratio of the AEOLUS3 results to the XOQDOQ results for mixed-mode releases without terrain or recirculation correction consideration ranges from 0.54 to 5.48 and is within a factor of 2.4 on average. In almost all cases, AEOLUS3 produced more conservative results within the first 7,000 to first 15,000 meters (4.3 to 9.3 miles) downwind (depending on the meteorological data set) and XOQDOQ produced more conservative results further downwind.

For ground-level normal effluent releases, the ratio of the AEOLUS3 results to the XOQDOQ results ranges from 0.80 to 1.02 and is within a factor of 0.9 on average. In almost all cases, XOQDOQ produced slightly higher values. For elevated normal effluent releases, the ratio of the AEOLUS3 results to the XOQDOQ results ranges from 0.42 to 1.01 and is within a factor of 0.8 on average. In almost all cases, XOQDOQ produced slightly higher values.

It is postulated that the differences in code results are due to:

- AEOLUS3 analyses the hourly wind speed observations in the entire meteorological database to determine the average wind speed corresponding to each stability class and wind-speed-group combination input by the user. XOQDOQ computes average wind speed values based just on the wind speed group values input to the codes.
- XOQDOQ limits the size of the horizontal dispersion coefficient (σ_y) to 1000 meters (AEOLUS3 does the same if the code is run using the NRC dispersion coefficient option but does not limit the size of σ_y if the code is run using the ENTECH dispersion coefficient option).

The effect of terrain varies depending on how the terrain values are input to XOQDOQ, as can be seen from the results of the site 1 cases presented in Figure 23:

- Using a grid of terrain values provides results that are closer to the AEOLUS3 results.
- Using only two sets of downwind distance/terrain values to bracket all downwind distances provides results that are furthest apart of the approaches presented.

References

1. ENTECH Engineering, Inc., P100-R19-A, "AEOLUS-3 – Technical Description; A Computer Code for the Determination of Atmospheric Dispersion and Deposition of Nuclear Power Plant Effluents During Continuous, Intermittent and Accident Conditions in Open-Terrain Sites, Coastal Sites and Deep-River Valleys; Software Release V00L00 – 02/21/89," 1989.
2. NRC Regulatory Guide 1.145, Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants, Revision 1, 1982.
3. NRC Regulatory Guide 1.111, Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors, Revision 1, 1977.
4. Entergy Nuclear Operations, Entergy Nuclear Vermont Yankee, LLC, Technical Specifications Change No. 262, Alternative Source Term, NRC ADAMS Accession Number ML032190646, July 31, 2003.
5. Entergy Nuclear Operations, Pilgrim Nuclear Power Plant Proposed Amendment to the Technical Specifications, NRC ADAMS Accession Number ML043650064, December 6, 2004.
6. NUREG/CR-2858, "PAVAN: An Atmospheric Dispersion Program for Evaluating Design Basis Accidental Releases of Radioactive Materials from Nuclear Power Stations," 1982.
7. NUREG/CR-2919, "XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations," 1982.

Appendix A: Comparison of ENTECH and NRC Algorithms for Determination of Atmospheric Dispersion Coefficients

The AEOLUS3 computer code has two user-selectable methods to determine atmospheric dispersion coefficients (σ_y and σ_z):

- ENTECH parabolic interpolation method;
- NRC method.

AEOLUS3 was run twice, once using the ENTECH method, and once using the NRC method.

The results are provided in Figures A-1 through A-4. Figures A-5 and A-6 are Figures 1 and 2 from Regulatory Guide 1.145.

Comparison indicates that the ENTECH method better matches the curves from Regulatory Guide 1.145.

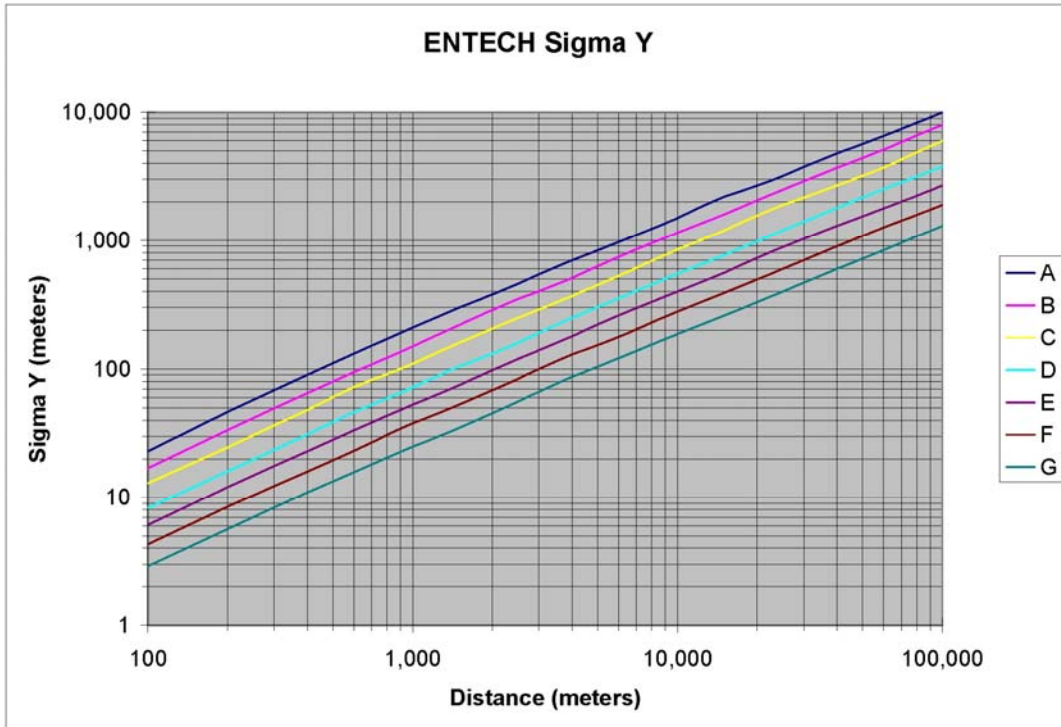


Figure A-1: Horizontal Dispersion Coefficient versus Distance Using the ENTECH Methodology

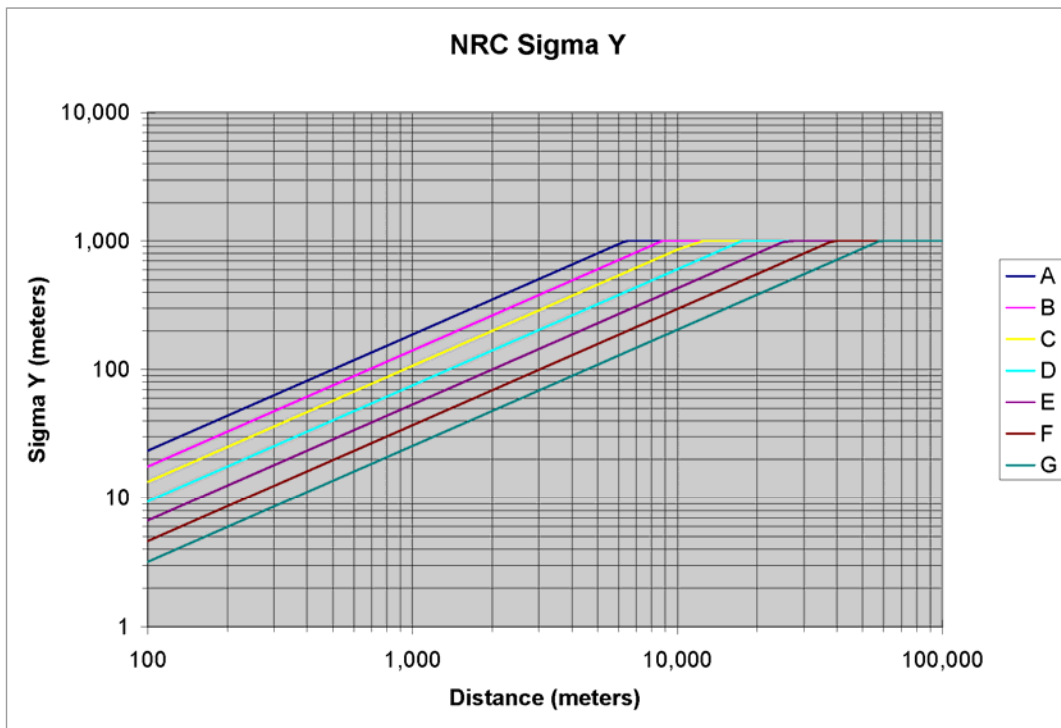


Figure A-2: Horizontal Dispersion Coefficient versus Distance Using the NRC Methodology

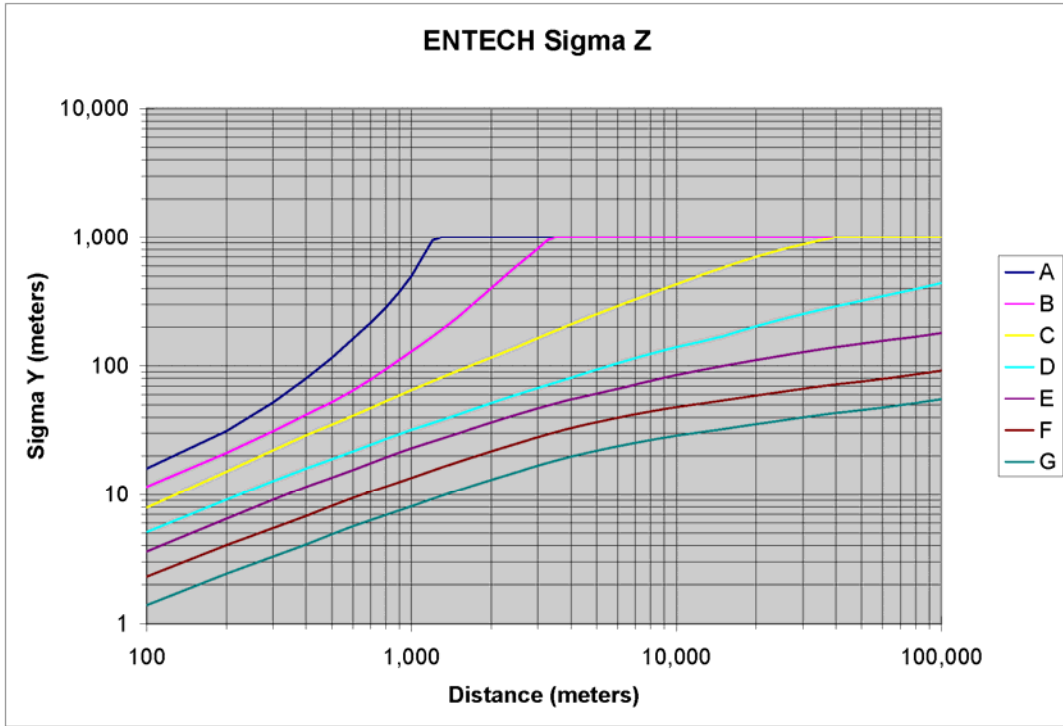


Figure A-3: Vertical Dispersion Coefficient versus Distance Using the ENTECH Methodology

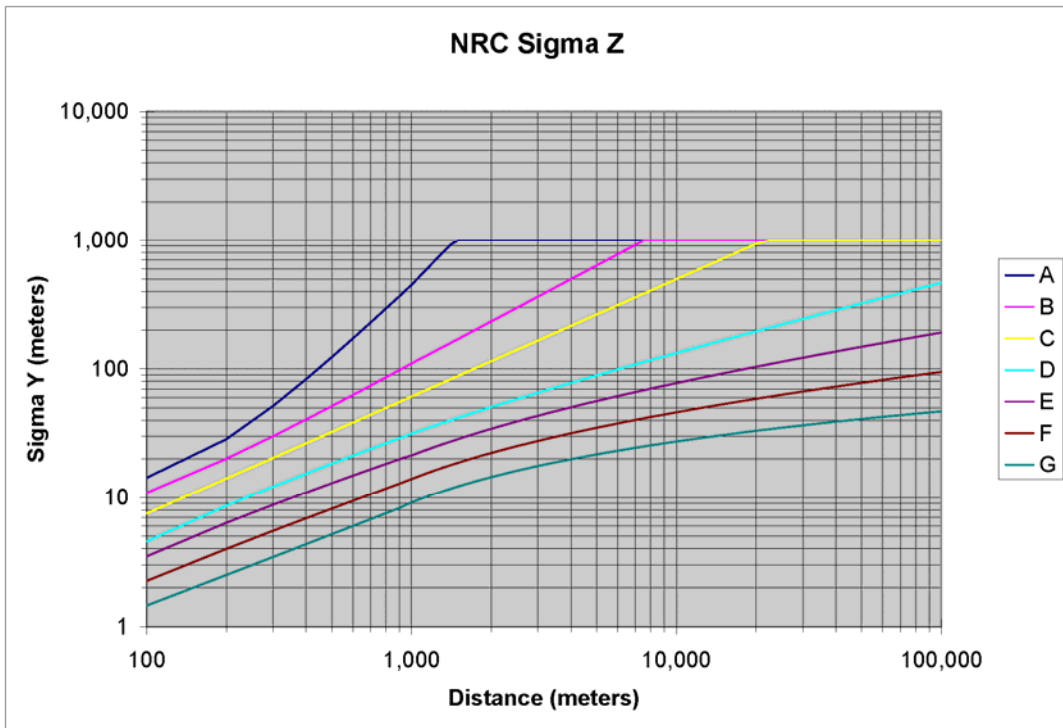


Figure A-4: Vertical Dispersion Coefficient versus Distance Using the NRC Methodology

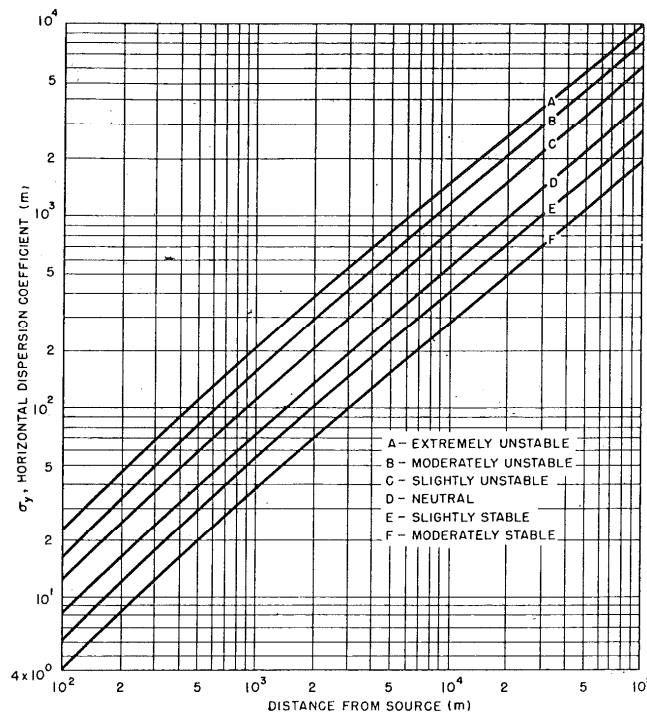


Figure 1. Lateral diffusion without meander and building wake effects, σ_y , vs. downwind distance from source for Pasquill's turbulence types (atmospheric stability) (Ref. 7).

The sigma values presented above are for unrestricted flow over relatively flat, uniform terrain. They may require modification before application in situations in which rough terrain or restricted flow conditions (e.g., within the confines of a narrow valley) must be considered or in coastal and desert areas. (See Ref. 12 for additional information.)

For purposes of estimating σ_y during extremely stable (G) atmospheric stability conditions, without plume meander or other lateral enhancement, the following approximation is appropriate:

$$\sigma_y(G) = \frac{2}{3}\sigma_y(F)$$

1.145-7

Figure A-5: Figure 1 from Reg Guide 1.145

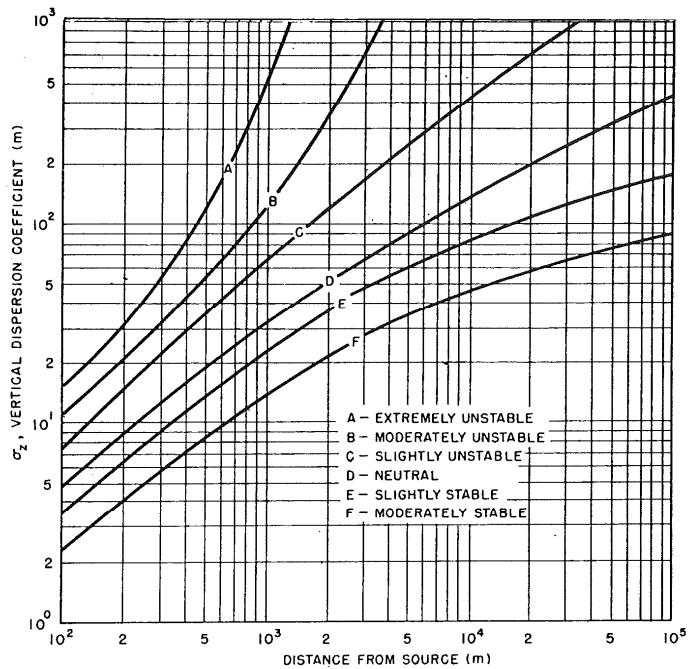


Figure 2. Vertical diffusion without meander and building wake effects, σ_z , vs. downwind distance from source for Pasquill's turbulence types (atmospheric stability) (Ref. 7).

The sigma values presented above are for unrestricted flow over relatively flat, uniform terrain. They may require modification before application in situations in which rough terrain or restricted flow conditions (e.g., within the confines of a narrow valley) must be considered or in coastal and desert areas. (See Ref. 12 for additional information.)

For purposes of estimating σ_z during extremely stable (G) atmospheric stability conditions, the following approximation is appropriate:

$$\sigma_z(G) = \frac{3}{5}\sigma_z(F)$$

1.145-8

Figure A-6: Figure 2 from Reg Guide 1.145