Dispersion and Deposition Estimation Issues

Presented at NUMUG

San Francisco, CA

2009

Overview

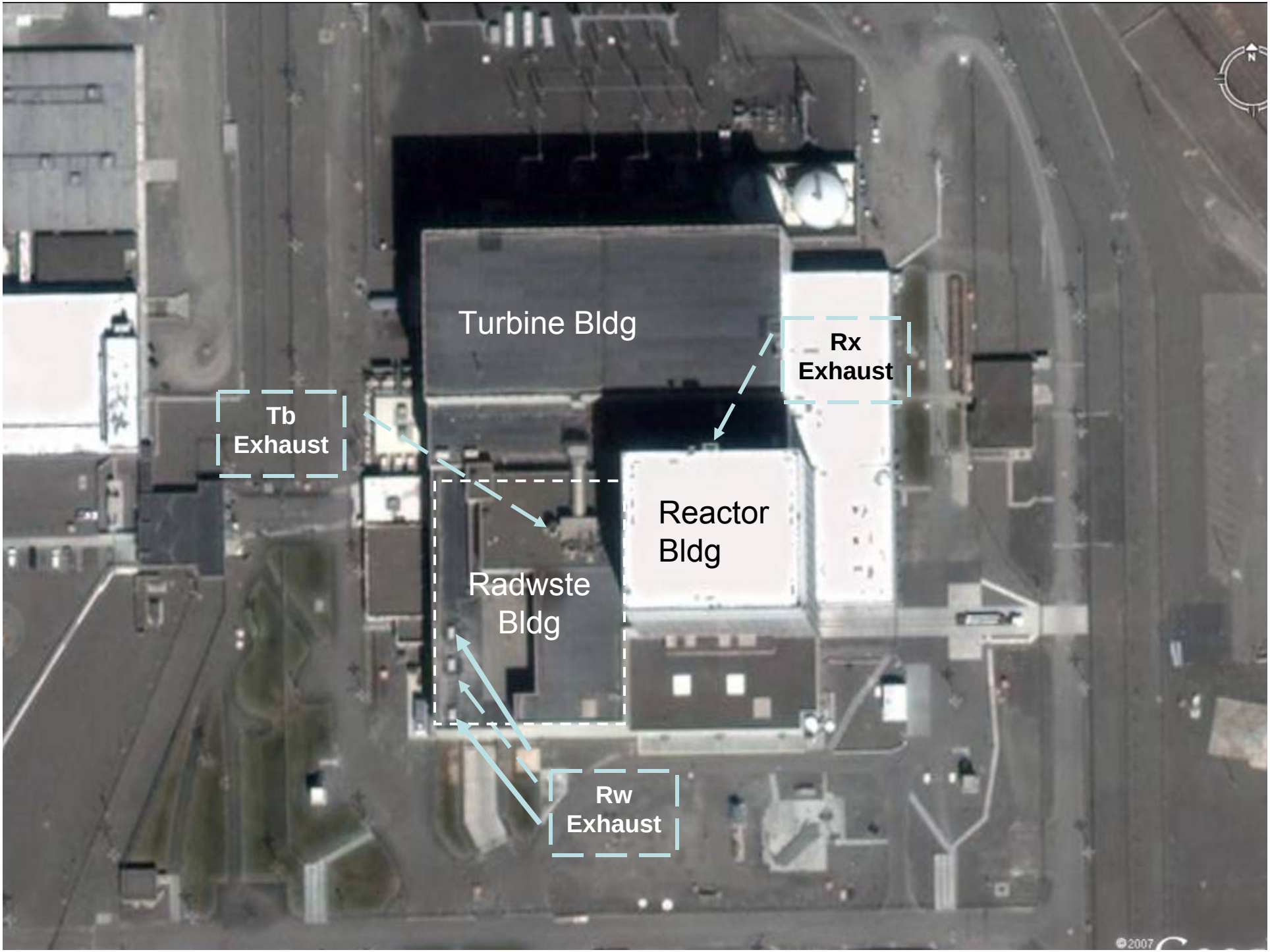
- Site Overview
- Dispersion and Deposition
  - Release Mode
  - Terrain Height
  - Plume Rise: Buoyancy vs Momentum

Release Modes: Elevated? Mixed? Ground-level?

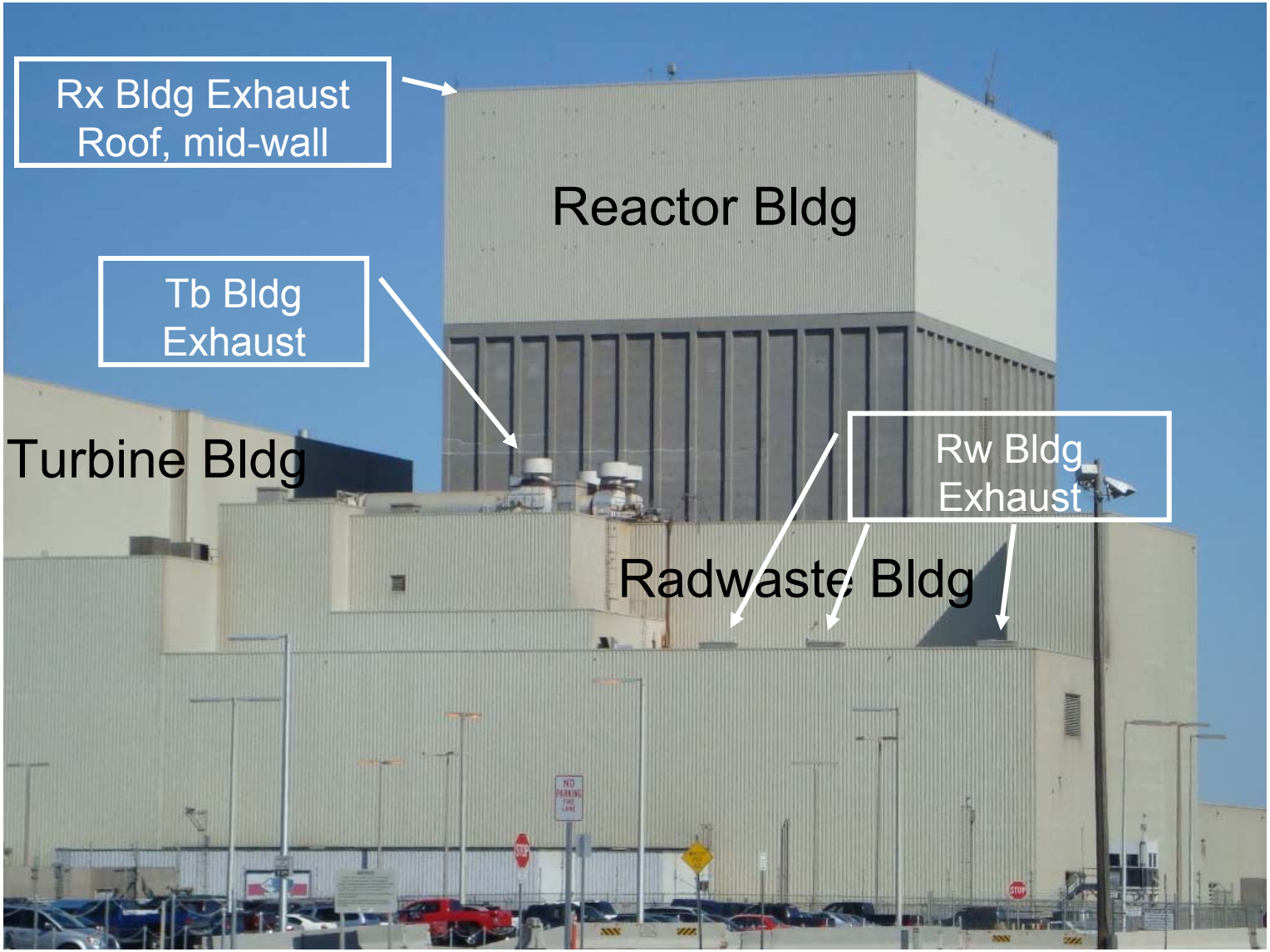
b. Releases Other Than Elevated

For effluents released from points less than the height of adjacent solid structures, a ground-level release should be assumed ($h_e = 0$).

Section C.2.b of RG 1.111 Rev 1 1977


Turbine Bldg
Rx
Exhaust
Tb
Exhaust
Reactor
Bldg
Radwste
Bldg
Rw
Exhaust

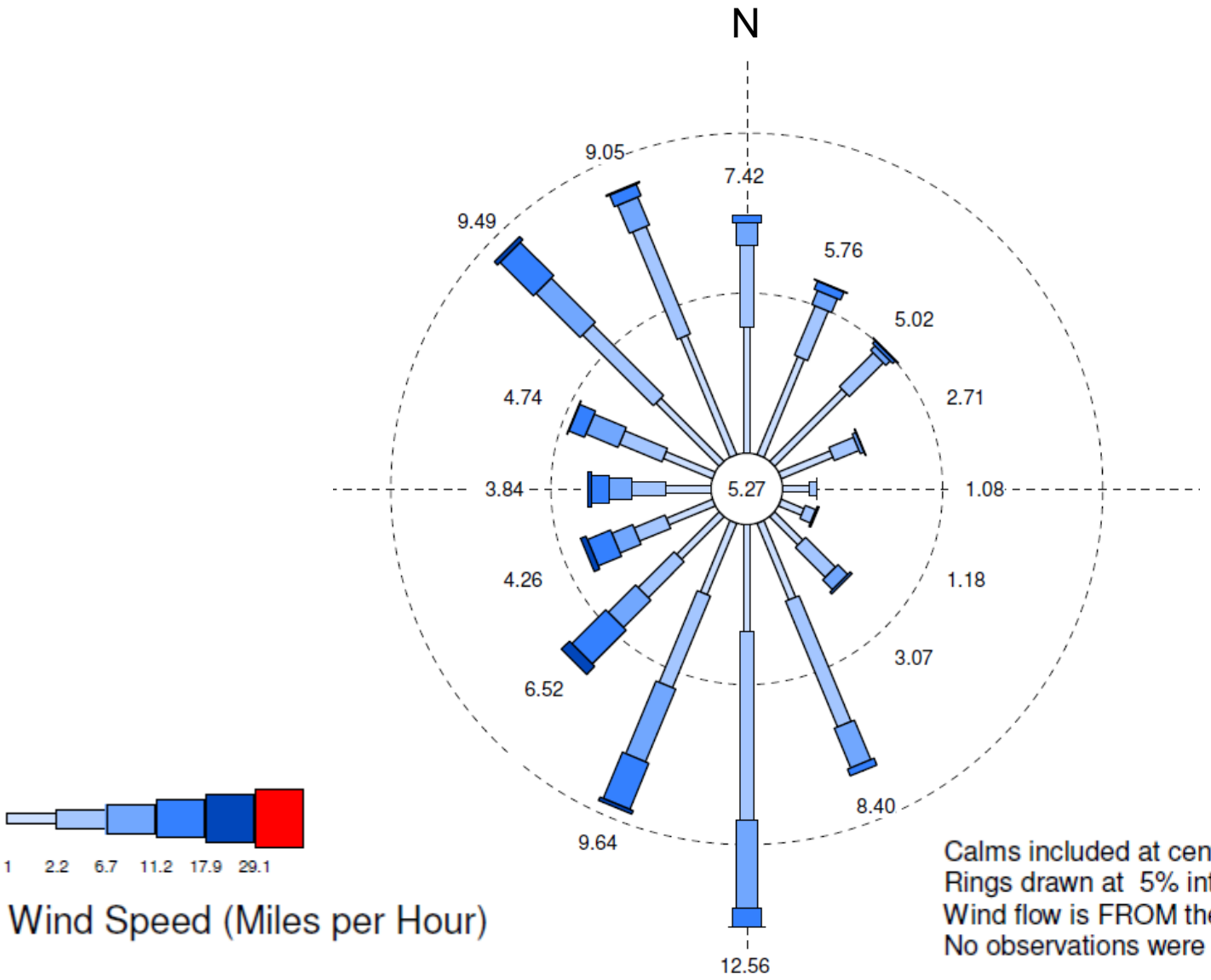
Building/Exhaust Arrangement



Turbine Bldg HVAC Exhaust Vents

Radwaste Bldg Exhaust Vents

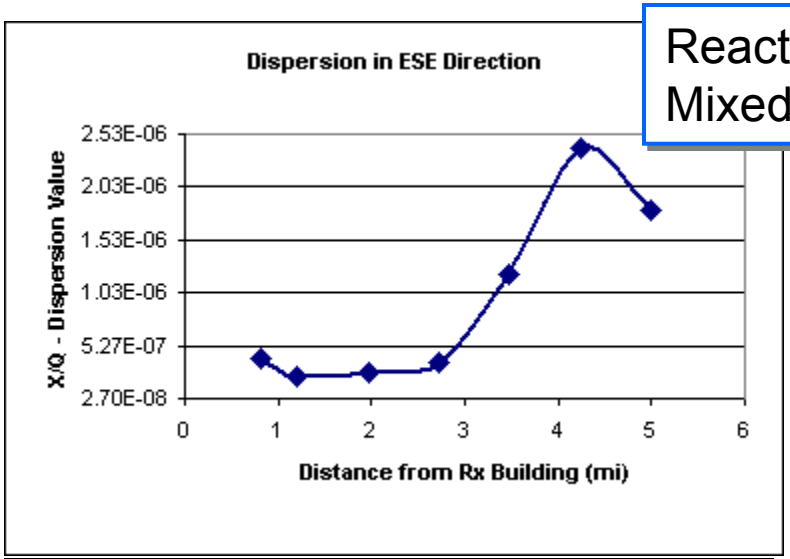
10m Wind Rose (5-yr Ave)

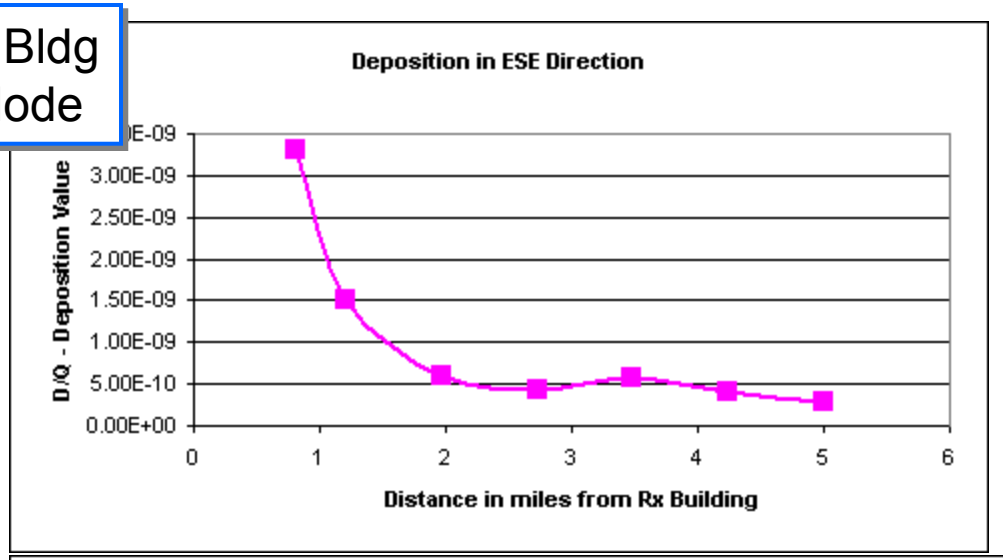


Calms included at center.
Rings drawn at 5% intervals.
Wind flow is FROM the directions shown.
No observations were missing.

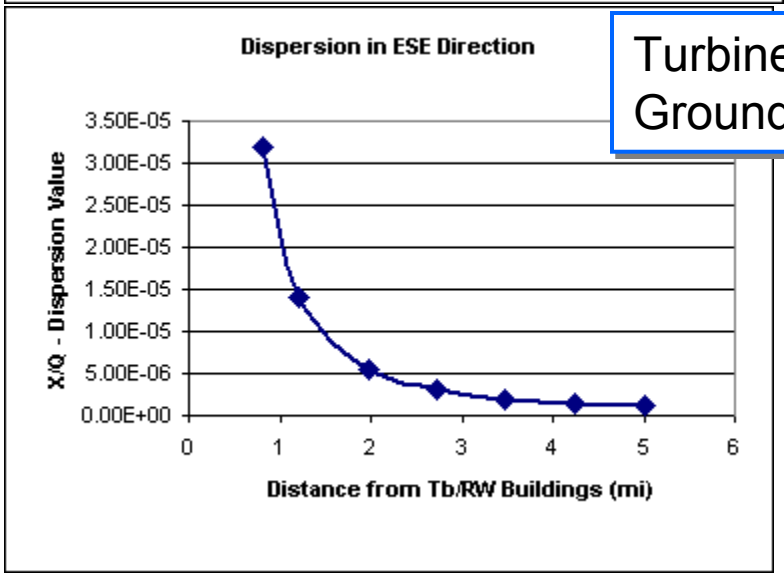
Dispersion and Deposition Values

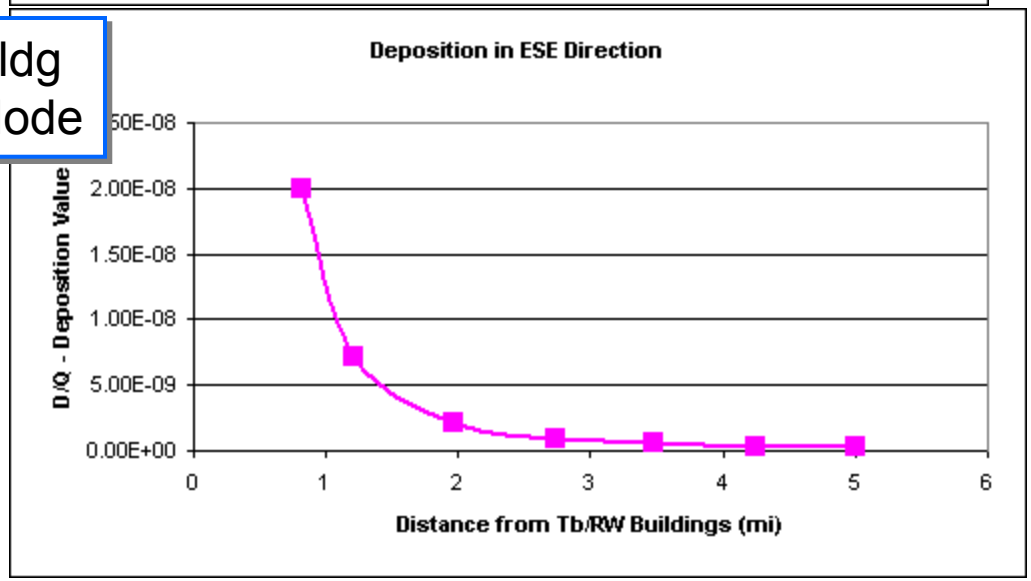
Reactor Bldg
Mixed Mode





Turbine Bldg
Ground Mode





Release Mode Issue?

2. Release Mode

At ground-level locations beyond several miles from the plant, the annual average concentrations of effluents are essentially independent of the release mode; however, for ground-level concentrations within a few miles, the release mode is very important.

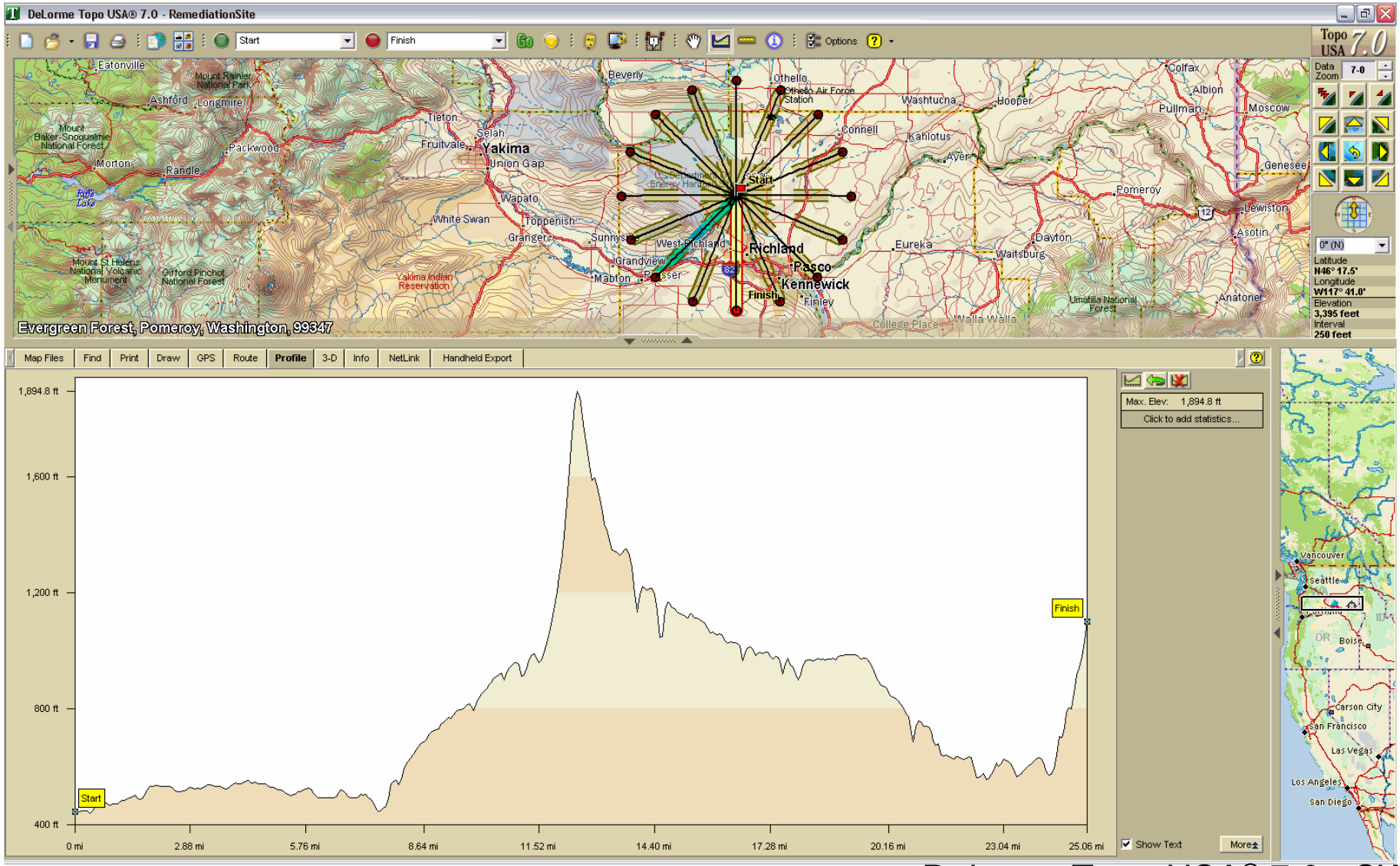
Section B.2 of RG 1.111 Rev 1 1977

Based on CGS XOQDOQ results, the above generates confusion.

Terrain Heights - XOQDOQ

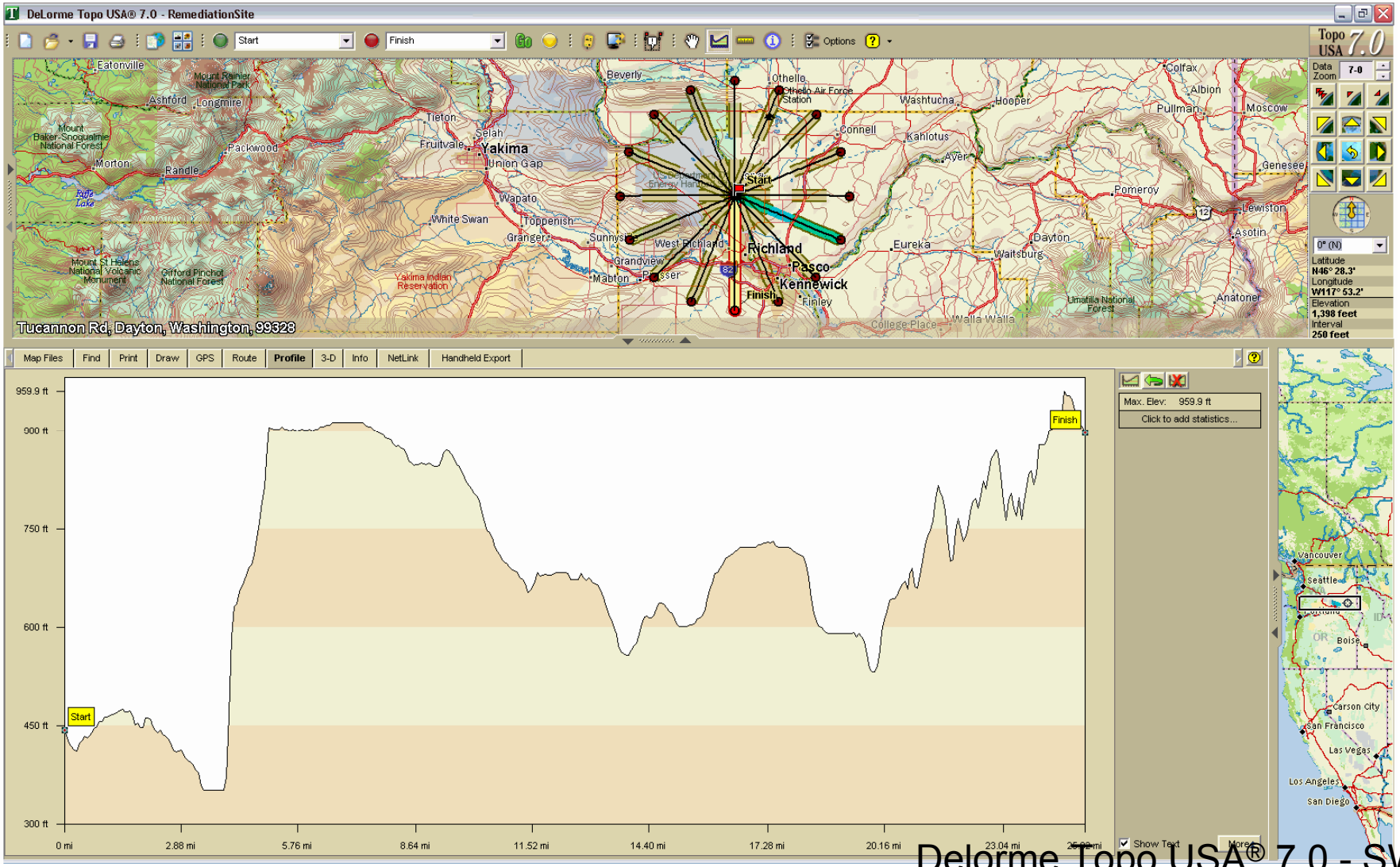
S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
4827	4827	4827	4827	4827	4827	4827	4827	4827	4827	4827	4827	4827	4827	4827	4827
0	0	15	15	15	15	0	0	0	0	0	76	76	76	15	0
6436	6436	6436	6436	6436	6436	6436	6436	6436	6436	6436	6436	6436	6436	6436	6436
0	0	15	15	15	15	0	0	0	0	15	106	137	106	76	0
8045	8045	8045	8045	8045	8045	8045	8045	8045	8045	8045	8045	8045	8045	8045	8045
0	0	15	15	15	15	0	15	0	15	76	137	137	137	76	0
9654	9654	9654	9654	9654	9654	9654	9654	9654	9654	9654	9654	9654	9654	9654	9654
0	15	15	15	15	15	15	15	0	45	76	137	137	137	76	76
11263	11263	11263	11263	11263	11263	11263	11263	11263	11263	11263	11263	11263	11263	11263	11263
0	15	15	15	15	15	15	15	15	76	106	137	137	137	76	15
16090	16090	16090	16090	16090	16090	16090	16090	16090	16090	16090	16090	16090	16090	16090	16090
0	0	76	76	15	45	15	15	137	137	106	137	106	76	76	0
32180	32180	32180	32180	32180	32180	32180	32180	32180	32180	32180	32180	32180	32180	32180	32180
200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200

Terrain Heights – SW Sector



Delorme Topo USA® 7.0 - SW

Terrain Heights – ESE Sector



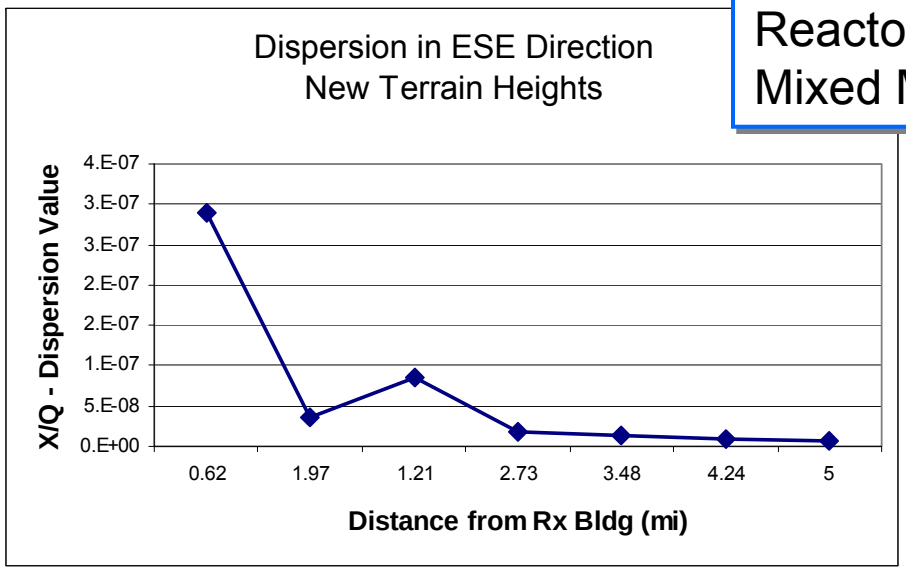
Delorme Topo USA® 7.0 - SW

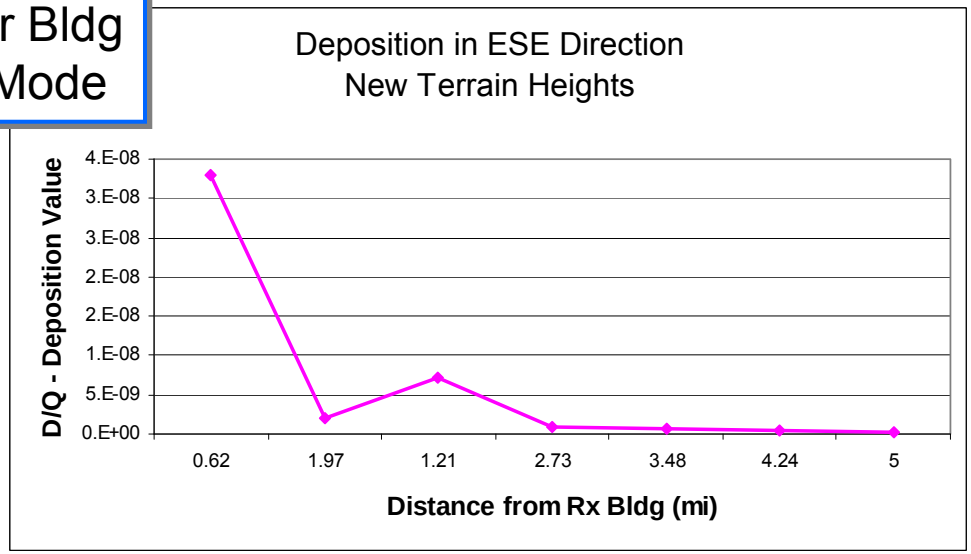
Terrain Heights-Revised

S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000	6000
5	41	29	31	36	30	9	12	17	18	7	9	9	10	3	1
8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000	8000
6	41	33	32	36	30	19	20	18	18	35	100	143	133	3	1
12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000	12000
7	41	33	32	36	33	28	26	25	150	71	139	146	143	135	1
16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000	16000
9	41	114	150	41	82	28	26	156	168	71	146	146	143	135	1
19000	19000	19000	19000	19000	19000	19000	19000	19000	19000	19000	19000	19000	19000	19000	19000
9	41	205	278	41	91	28	26	156	168	75	159	146	143	135	19
21000	21000	21000	21000	21000	21000	21000	21000	21000	21000	21000	21000	21000	21000	21000	21000
56	235	443	567	68	95	182	26	156	180	84	161	146	143	135	19
25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000
74	235	443	948	126	95	182	26	156	195	110	161	146	143	135	21
28000	28000	28000	28000	28000	28000	28000	28000	28000	28000	28000	28000	28000	28000	28000	28000
281	235	443	948	154	109	182	26	159	195	130	161	146	143	135	21
33000	33000	33000	33000	33000	33000	33000	33000	33000	33000	33000	33000	33000	33000	33000	33000
281	400	443	948	253	112	182	87	276	254	163	162	156	143	135	33
40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000	40000
437	400	443	948	504	423	182	570	398	254	215	209	216	158	135	191

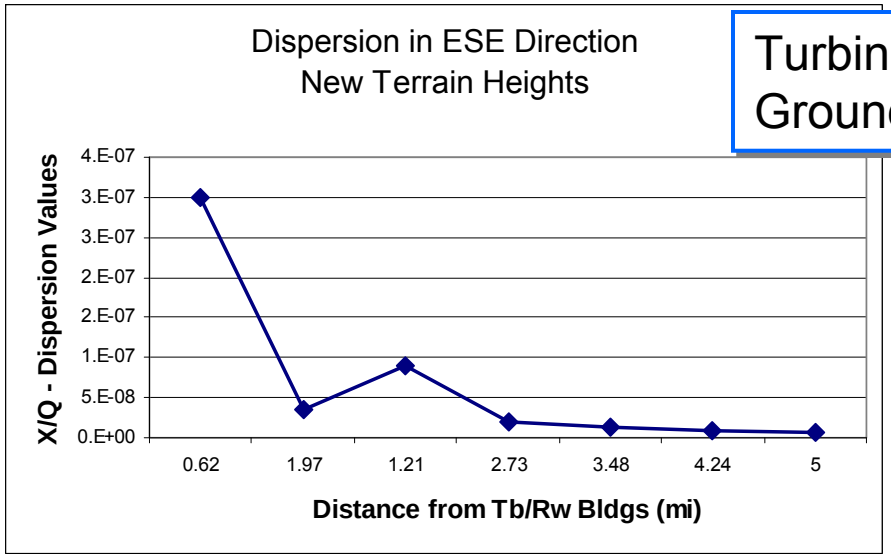
Terrain Heights

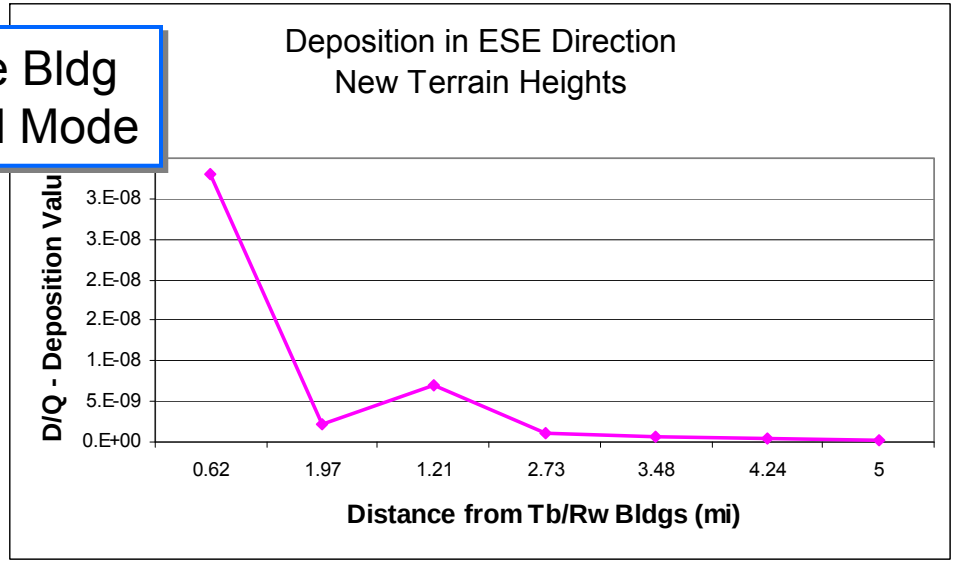
Reactor Bldg
Mixed Mode



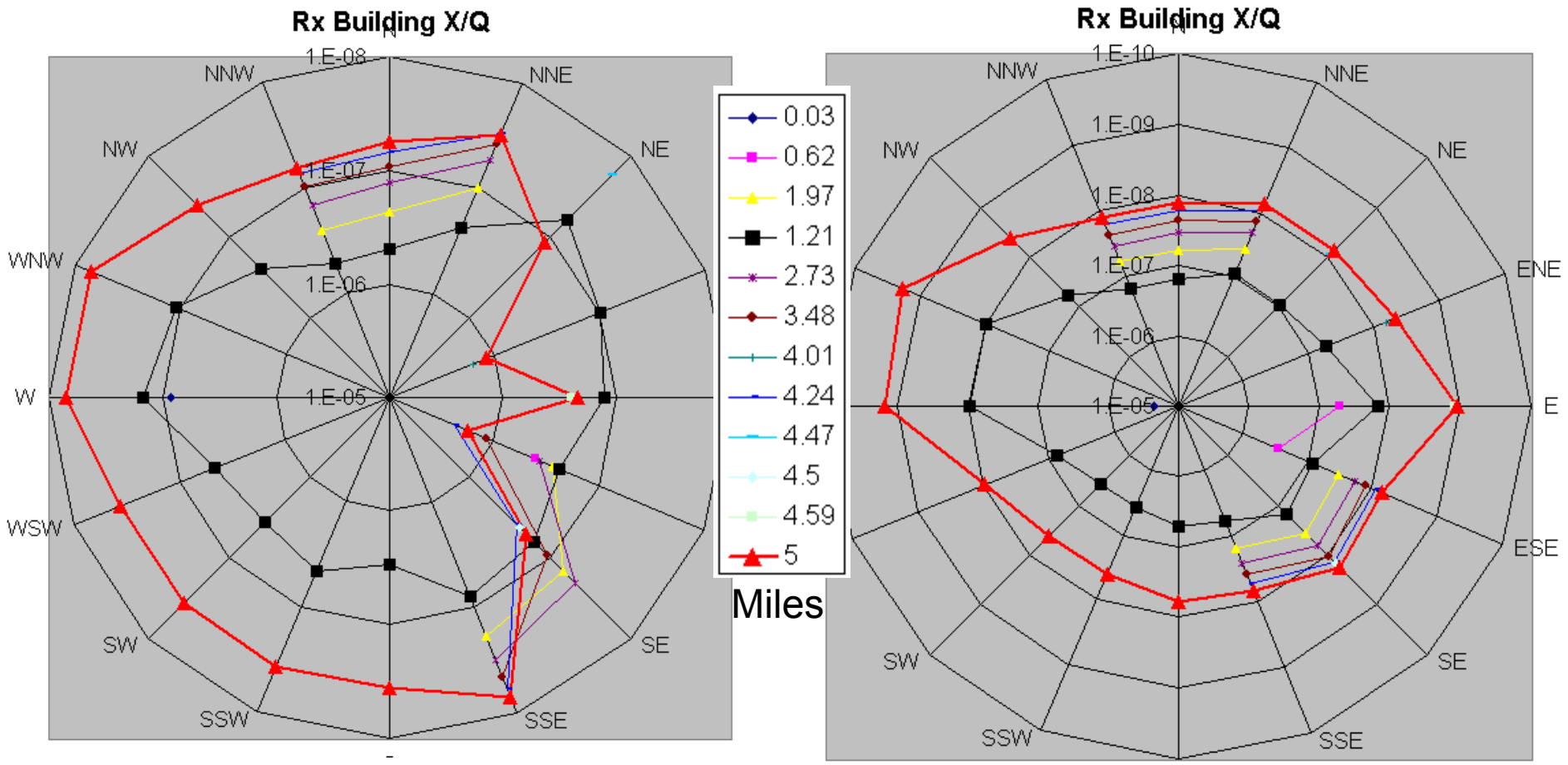


Turbine Bldg
Ground Mode





Dispersion



Old Terrain Heights

New Terrain Heights

Plume Buoyancy

- Whereas page 8 of NUREG /CR-2919 (XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations) notes that the normal value of the vent heat emission rate is zero (Card 16; variable name HEATR(I)).
- Whereas the format for the HEATR variable is F5.0 (the code contains an input value range from 0 to 99,999 cal/sec).
- Whereas Page 34 of NUREG /CR-2919 states that nuclear power stations have ambient temperature plumes, so the heat emission rate, HEATR is read in as zero; and the plume rise is calculated from the momentum equations.
- Whereas the average annual vent heat emission for one of the CGS effluent release points is 2.9E+06 calories/second with a range such that plume density can be both negative or positive relative to ambient air density.
- Therefore code review and site-specific plume buoyancy should be considered.

CGS Release Characteristics

	Reactor	Radwaste	Turbine
Bldg height above ground (m)	70.1	31.8	42.4
Annual average exhaust flow rate (m^3/sec)	37.8	39.2	169.9
Exit Velocity (m/sec)	10.9	3.4	**19.5**
Annual average heat emission rate (cal/sec)	1.1E6	2.9E6	**9.1E5**

Plume Rise - NUREG/CR-2919

- Effective Stack Height He =Hs+Hpr-Ht-c (in meters)
- Where
  - Hs = Stack or Release Point Height
  - Hpr = Plume Rise (Subroutine Rise page 33)
  - Ht = Terrain Height
  - c = Downwash Correction (applied if exit velocity < 1.5 times wind speed)

Momentum Rise - NUREG

- For neutral or Unstable conditions where heat emission is 0
  - Hpr = 1.44(Wo/u)^(2/3)*(X/D)^(1/3)*D --- Eq #16
    - x=distance downwind in meters
    - D = inside diameter of stack or other release point = assume area is circle; A=(d/2)(d/2)pi; d=sqrt(A*4/pi)
    - Wo = vertical exit velocity (m/s)
    - u = mean wind speed at height of release (m/sec)
  - When Wo is LT 1.5*u, downwash (C) is subtracted
    - C = 3*(1.5 – Wo/u)*D
  - Comparing Value = Hpr = 3(Wo/u)D --- Eq #18

Momentum Rise - NUREG

- For stable conditions where heat emission is 0
  - Hpr = 4(Fm/S)^1/4 --- Eq #19
  - Hpr = 1.5(Fm/u)^1/3/S^1/6 --- Eq #20
  - Where:
    - Fm = momentum flux parameter = ((Wo*D)/2)^2 ---Eq #21
    - S = restoring acceleration per unit vertical displacement = (g/T)(vertical potential temperature gradient) --- Eq #22
      - For E Stability Class, S= 8.7E-4
      - For F Stability Class, S= 1.75E-3
      - For G Stability Class, S= 2.45E-3
  - The smallest value of Equations 16, 18, 19, & 20 used.

Buoyancy Rise - NUREG

A downwind distance is first calculated

- For neutral or Unstable conditions
  - x* = 0.5*F^2/5*Hs^3/5 when Hs < 1,000 ft ---Eq #23
  - x* = 33*F^2/5 when Hs GE 1,000 ft Eq #24
  - Where
    - Hs = physical stack height
    - F = buoyancy flux parameter = 4.3E-3*Qh

      Where Qh = Heat emmission rate (HEATR)
- For stable conditions
  - x* = 2.4*US^1/2 --- Eq #26

Buoyancy Rise - NUREG

- For x LT x*
  - Hpr = [1.6*F^1/3*u^-1*x^2/3] --- Eq #27
- For x GTE x* (unstable or neutral conditions)
  - Hpr = [1.6*F^1/3*x*^2/3*[2/5+(16/25)(x/x*)+(11/5)(x/x*)^2]]/[.30480061*u* (1+4x/5x*)^2] --- Eq #28
- For x GT 5*x* (max height for stable conditions)
  - Hpr =2.4*(F/uS)^1/3 --- Eq #29

Analysis Values

Summer	Winter	Parameter
90	20	Outside ambient air temp (degrees F)
360000	260000	Exhaust flow rate (cfm)
110	110	Exhaust air (degrees F)
3.34	3.34	Diameter of stack (meters)
1.57	1.57	Average wind speed at 33' (m/s)
21.08	21.08	Exit velocity (m/s)
36.30	36.30	Height of stack above ground level (meters)
1,7	1,7	Stability Classes

Plume Rise per NUREG

Values in meters

Fb=Buoyant flux; Fm=Momentum flux; Values in meters	At 3 meters	At Site Boundary (1950 m)	At 4.5 miles (7242 m)
Extremely Unstable to Neutral (A - D)			
Winter Hpr (Fm)	26	135	135
Hpr (Fb)	9	342	207
Summer Hpr (Fm)	26	135	135
Hpr (Fb)	0	0	0
Stable (E, F, G)			
Winter Hpr (Fm)	26	38	38
Hpr (Fb)	35	112	1582
Summer Hpr (Fm)	26	38	38
Hpr (Fb)	0	0	0

Calculation in Turner, 1994

Briggs Buoyancy Flux

- $F_b = gV_sD_s^2[(\Delta T)/4T_s]$
  - F_b = buoyancy flux
  - g = gravitational constant (9.8 m/s^2)
  - V_s = stack exit velocity, m/s
  - D_s = diameter of the stack, m
  - T_s = stack gas temperature, deg. K
  - ΔT = difference between T_s and T_a (ambient temp), deg K.

Buoyant Rise - Turner

For neutral or Unstable conditions

- Final Buoyant Rise for $F_b < 55$:

  $$\Delta H = 21.425 F_b^{3/5} / u_h$$

  - Where
    - Uh = wind speed at height of release (m/sec)
- Final Buoyant Rise for $F_b >/= 55$:

  $$\Delta H = 38.71 F_b^{3/5} / u_h$$

Momentum Rise - Turner

For neutral or Unstable conditions

- Final Momentum Rise:

  $\Delta H = 3dv/u_h$

  – Where
    - Eq #18 in Nureg.
    - Uh = wind speed at height of release (m/sec)
    - d = inside diameter of vent
    - V = exit velocity

- The **highest** of the momentum or buoyant rise is used.

Buoyant Rise - Turner

For stable conditions

- Stability parameter (s) is calculated

$$= (g/T)(d\theta/dz)$$

  - g = acceleration of gravity, 9.8 m/s^2
  - T = ambient temperature
  - $d\theta/dz = dT/dz + \Gamma$ = vertical potential temperature gradient

    Γ = adiabatic lapse rate = 0.0098 K/m

Buoyant Rise - Turner

For stable conditions

- Final buoyant rise is:

$$\Delta H = 2.6[(F/u_h s)]^{1/3}$$

- Under calm conditions:

$$\Delta H = 4*F^{1/4}/S^{3/8}$$

- The lowest of these is compared to the momentum rise

Momentum Rise - Turner

For stable conditions

- Stable momentum rise is:

$$\Delta H = 1.5[(v^2 d^2 T)/4T_s u_h)]^{1/3} s^{-1/6}$$

- The equation for unstable-neutral momentum rise is also recalculated:

$$\Delta H = 3dv/u_h$$

- Then the lowest of these is used for the final momentum rise

Final Rise - Turner

For stable conditions

- The highest value of either stable buoyant rise or stable momentum rise is used.

Distance to Final Rise - Turner

Distance to final rise:

- For F<55

$$X_f = 49*F^{5/8}$$

- For F>/= 55:

$$X_f = 119*F^{2/5}$$

- For Stable conditions:

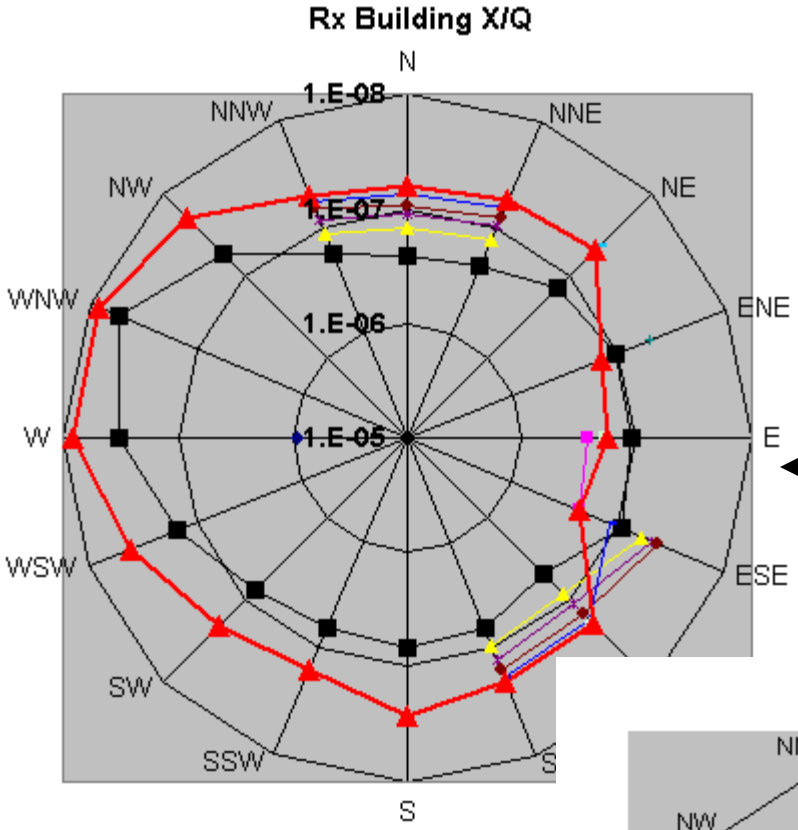
$$X_f = 2.07*u_h/s^{1/2}$$

NUREG vs Turner

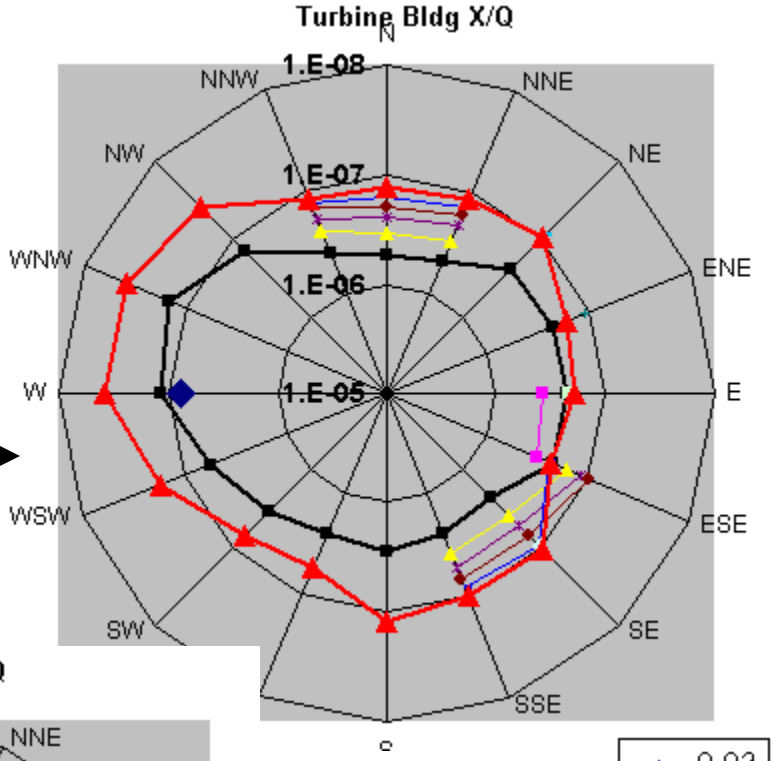
Fb=Buoyant flux; Fm=Momentum flux; Values in meters	At 3 meters	At Site Boundary (1950 m)	At 4.5 miles (7242 m)	Turner Final Rise
Extremely Unstable to Neutral (A - D)				
Winter Hpr (Fm)	26	135	135	
Hpr (Fb)	9	342	207	
Turner Rise	809	60,741	145,668	1,094,837
Summer Hpr (Fm)	26	135	135	
Hpr (Fb)	0	0	0	
Turner Rise	774	58,044	139,201	1,008,913
Stable (E, F, G)				
Winter Hpr (Fm)	26	38	38	
Hpr (Fb)	35	112	1,582	
Turner Rise	428	428	428	428
Summer Hpr (Fm)	26	38	38	
Hpr (Fb)	0	0	0	
Turner Rise	392	392	392	392

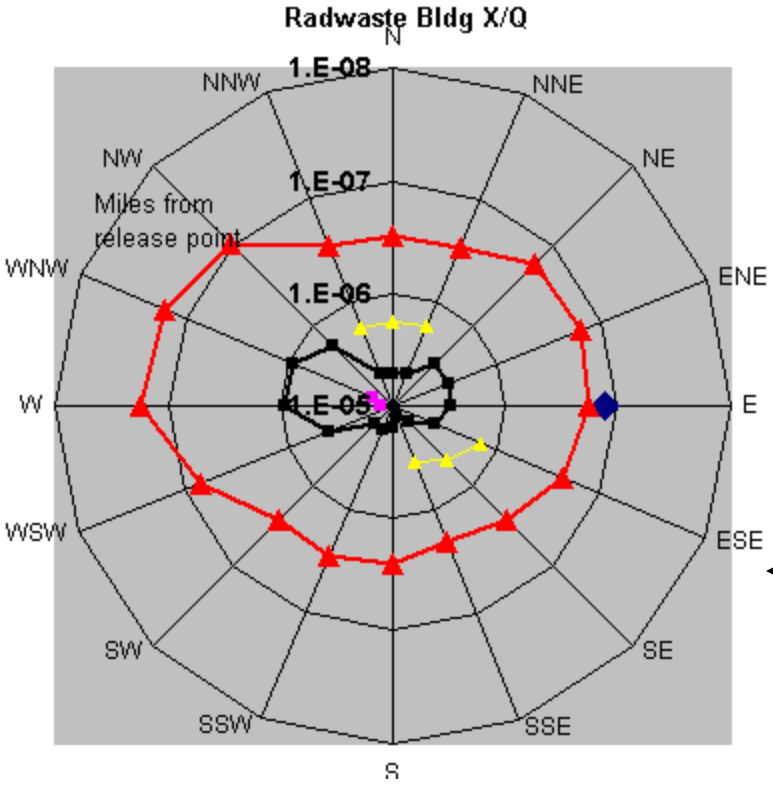
XOQDOQ Output

- XOQDOQ Input
  - Heat emission rate = 99,999 calories/sec
  - Vertical Exit Velocity for Turbine Bldg = 19.5 m/s
- XOQDOQ Output
  - Reactor Bldg (all stability classes)
    - Elevated with WS < 2.2 m/s (4.9 mph) (18%)
    - Ground with WS > 10.9 m/s (24.4 mph) (1%)
  - Turbine Bldg (all stability classes)
    - Elevated with WS < 3.9 m/s (8.7 mph) **(75.5%)**
    - Ground with WS > 19.5 m/s (43.6 mph) (0%)

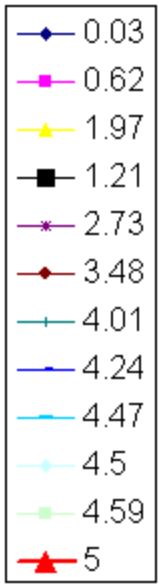


Mixed Mode



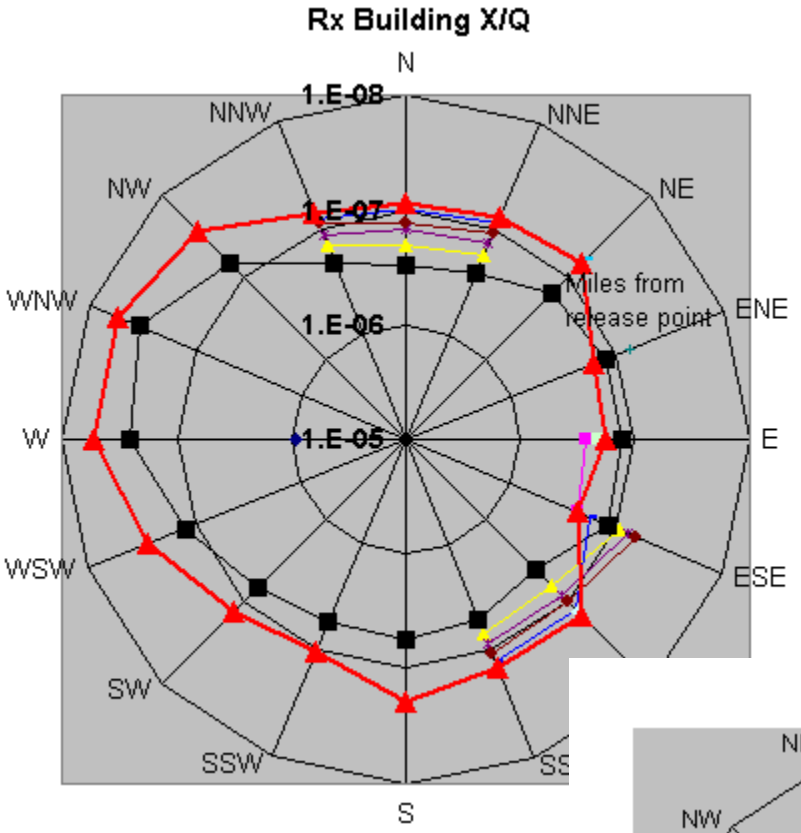


Ground Mode

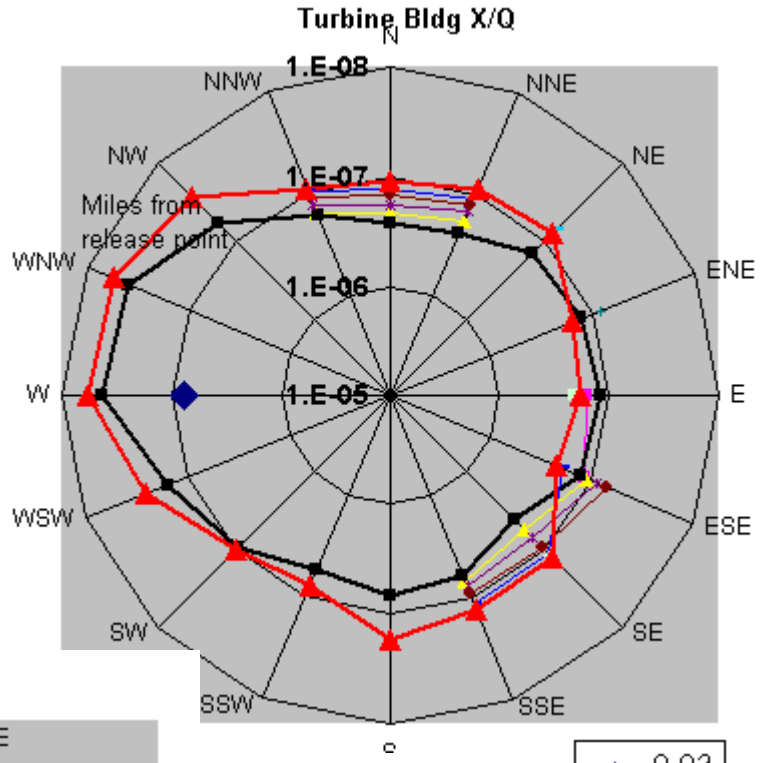


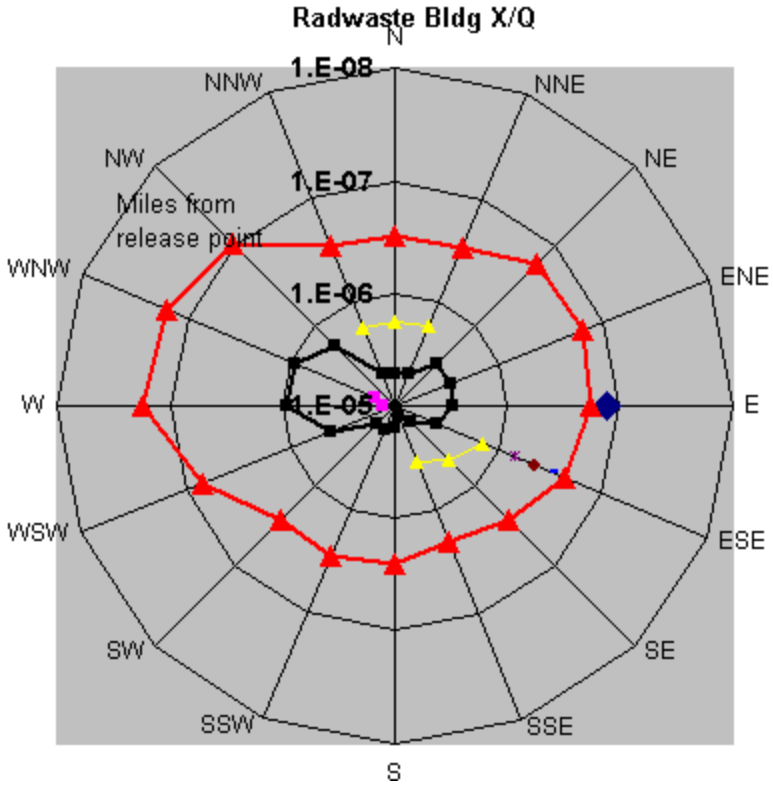
Miles

2008 Dispersion With HEATR



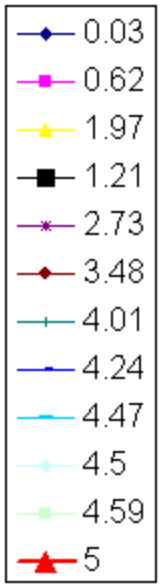
Mixed Mode





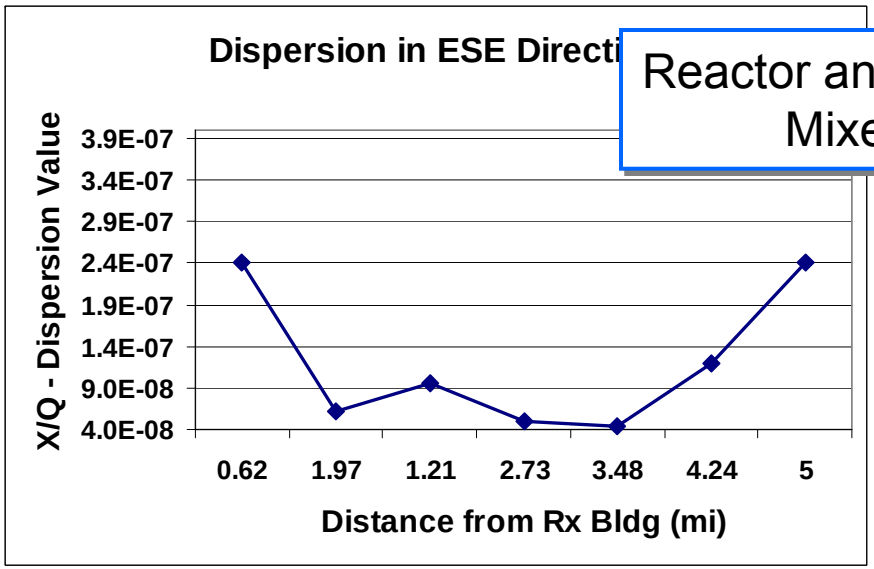
2008 Dispersion No HEATR

Ground Mode

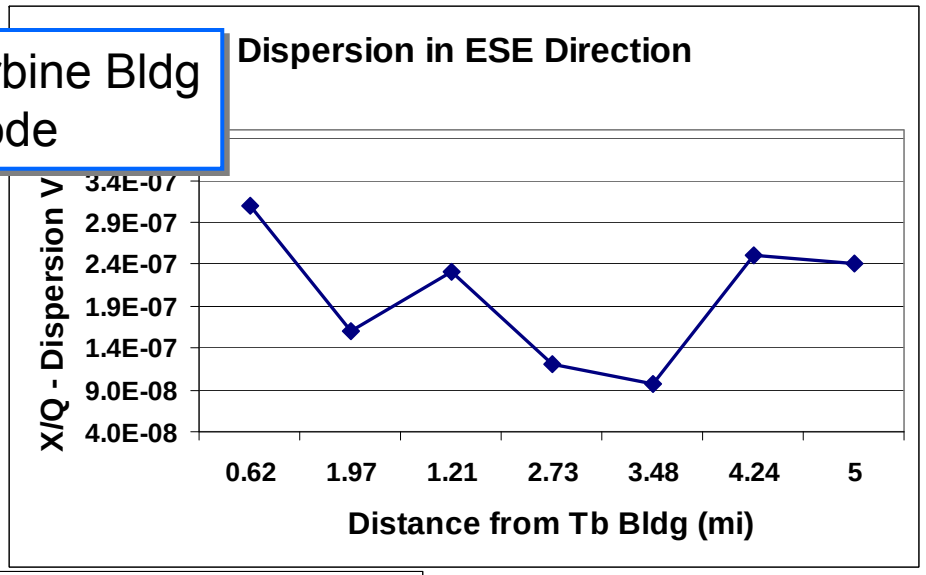


Miles

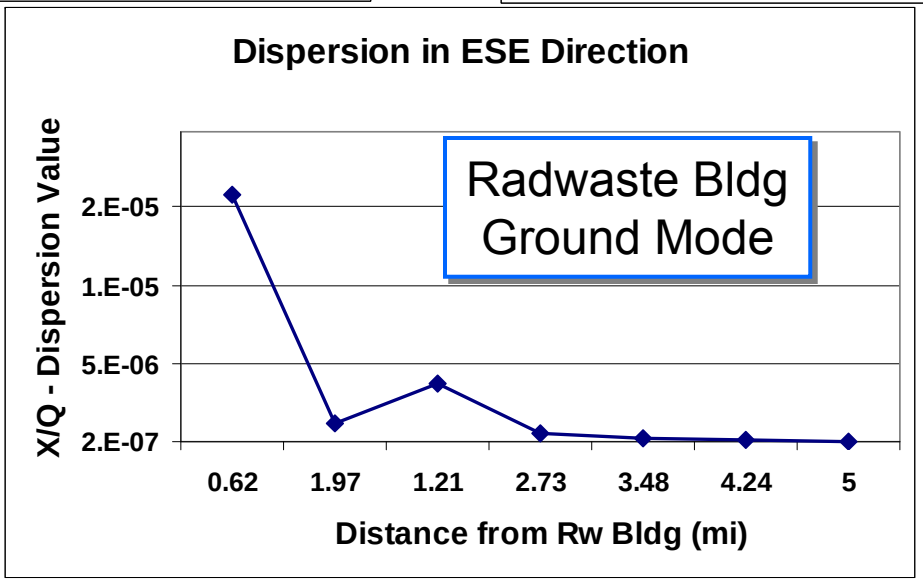
Dispersion Values



Reactor and Turbine Bldg
Mixed Mode

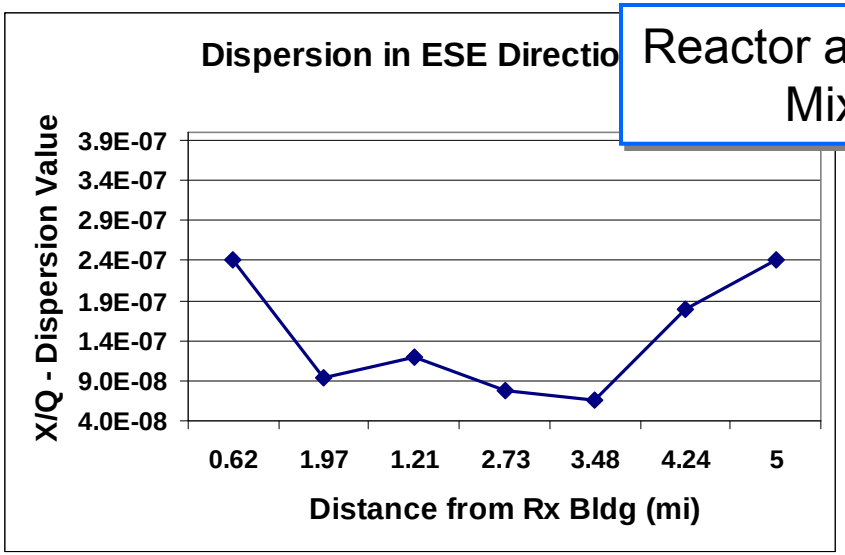


2008 Dispersion With HEATR

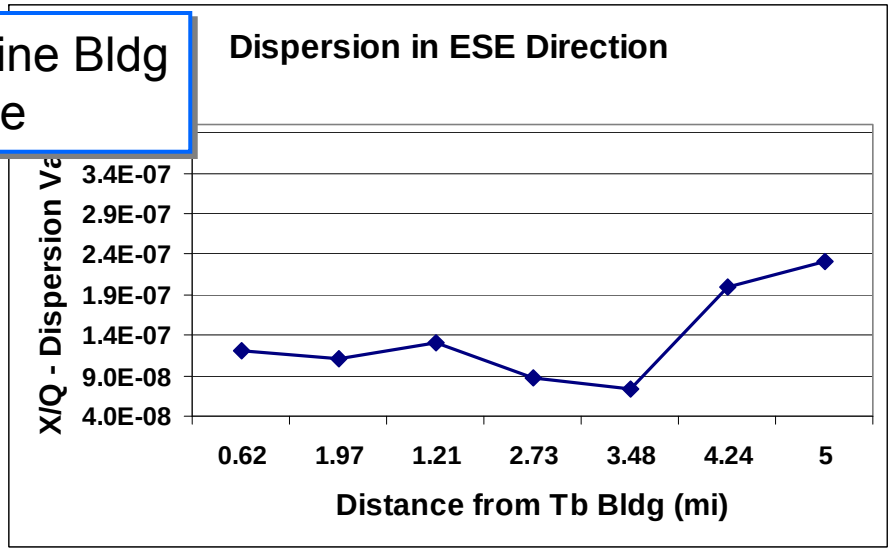


Radwaste Bldg
Ground Mode

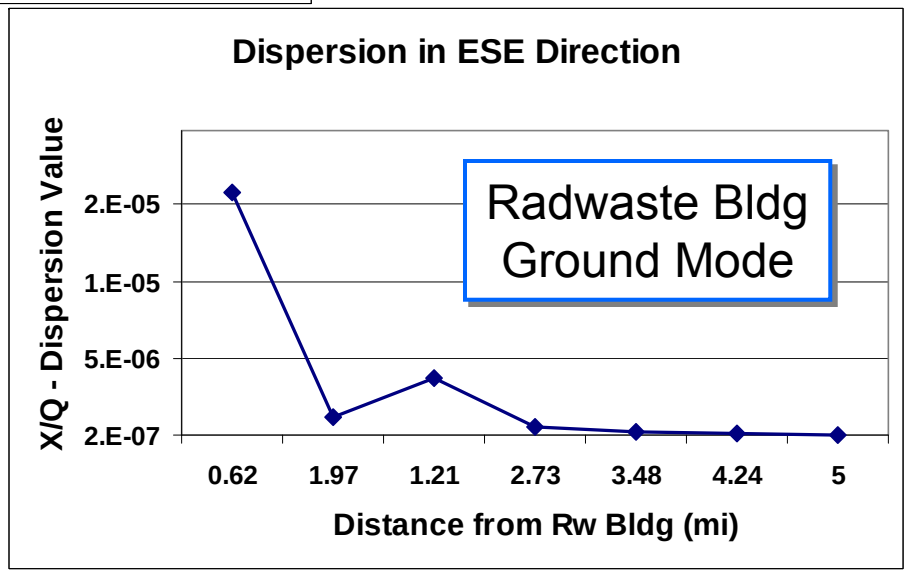
Dispersion Values



Reactor and Turbine Bldg
Mixed Mode



2008
Dispersion
No
HEATR



GASPAR Comparisons

2008	Turbine Bldg-Ground Mode	Turbine Bldg-Mixed Mode
Highest Site Boundary Beta Air Dose (mrad)	2.78E-03	4.37E-04
Highest Site Boundary Gamma Air Dose (mrad)	7.46E-03	1.24E-03
Highest Site Boundary Organ Dose (mrem)	1.44E-02	9.19E-03
Location	1.21 Mi N	1.21 Mi N
Gamma Air Dose ESE 4.24 Miles (mrad)	8.76E-04	1.75E-04
Organ Dose ESE 4.24 Miles (mrem)	1.29E-03	1.24E-03

Confusion/Problems with NUREG

- Buoyancy and Momentum are not additive
  - When heat emission rate is >0, code only models plume rise from buoyancy.
  - When heat emission rate is 0, code only models plume rise from momentum.
- Leads user to assume no buoyancy;
- Plant employees take NUREG verbatim
- Takes lowest value of calculations – Conservative? Realistic?

Confusion/Problems with NUREG

- NUREG test cases do not include rise test
- Not tested outside current value format restrictions
- Newer estimation methods based on more empirical data
- MEI could be many miles from release point.
- Needs revision to .Net framework

Confusion/Problems with RG 1.111

- Does not provide details for plume rise calculation.
- Suggests using ground mode for all vents at level of, or below roof level of adjacent buildings.

Primary References

- Turner, D. Bruce. Workbook of Atmospheric Dispersion Estimates. Lewis Publishers. 1994.
- Sagendorf, JF; JT Goll; and WF Sandusky. NUREG/CR-2919; XOQDOQ: Computer Program for Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations. 1982.
- Atmospheric Science and Power Production. Randerson, Darryl. Ed. DOE/TIC-27601. National Technical Information Center. 1984.
- Regulatory Guide 1.111. Methods for estimating atmospheric transport and dispersion of gaseous effluents in routine releases from light-water-cooled reactors. Rev 1, 1977.