The Finite Plume

REEW 2016

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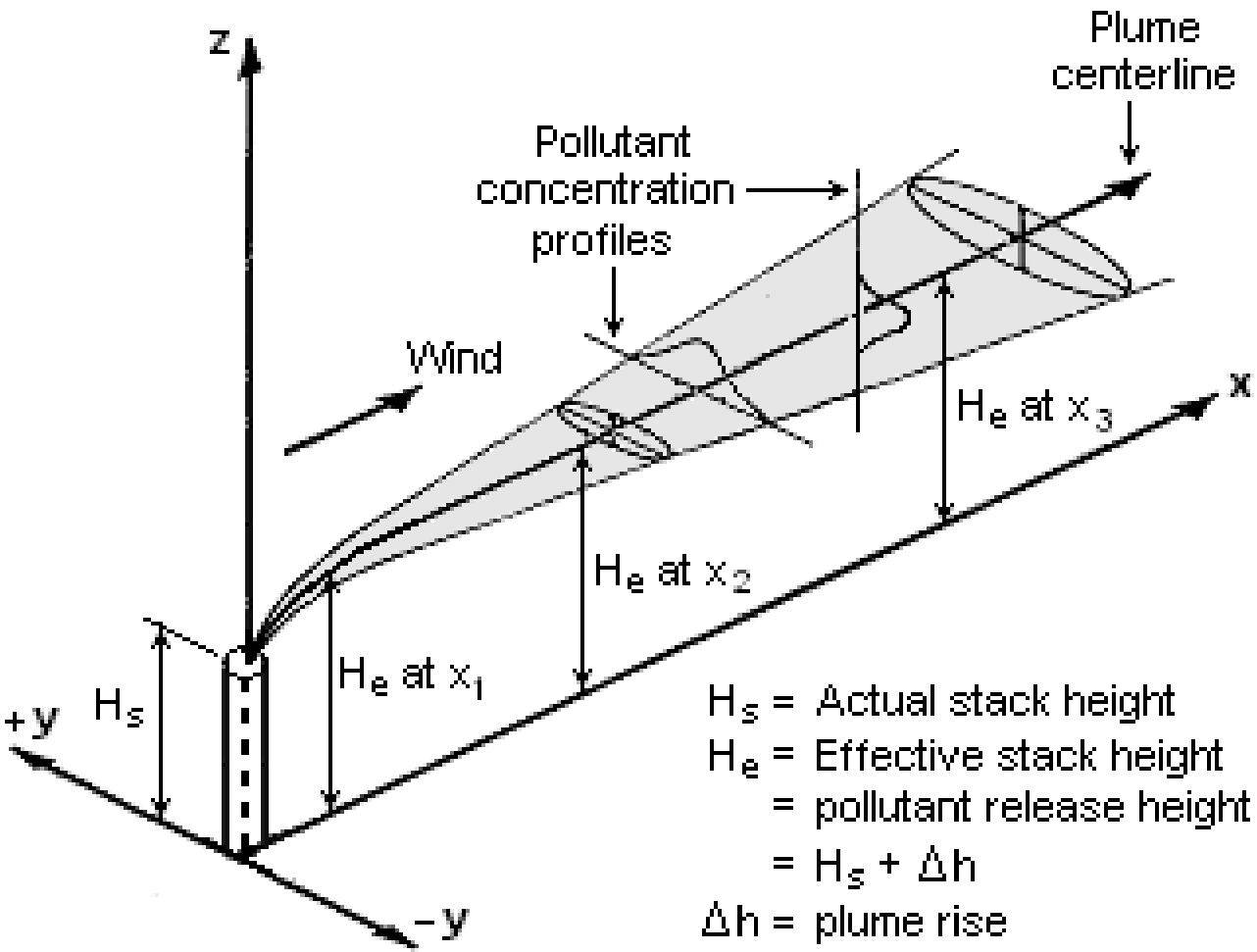
Gaussian Plume Model



Gaussian Plume Model

Concentration χ is given by:

$$\frac{Q}{2\pi\, u\, \sigma_y \sigma_z} \times \left\{ exp\left[-\frac{(H-z)^2}{2\,\sigma_z^2}\right] + exp\left[-\frac{(H+z)^2}{2\,\sigma_z^2}\right]\right\} \times exp\left[-\frac{y^2}{2\,\sigma_y^2}\right]$$

Gaussian Plume Model

Sector Average Concentration (χ) is given by:

$$\frac{Q}{2\pi\,\bar{u}\,\sigma_y\,\sigma_z}\int_{-\infty}^{+\infty} exp\left[-\frac{y^2}{2\sigma_y^2}\right]dy$$
$$\times\left\{exp\left[-\frac{(H-z)^2}{2\sigma_z^2}\right]+exp\left[-\frac{(H+z)^2}{2\sigma_z^2}\right]\right\}$$

Gaussian Plume Model

Sector Average Concentration χ

$$\bar{\chi} = \frac{Q}{\sqrt{2\pi}\sigma_z \bar{u}} \times \left\{ exp\left[-\frac{(H-z)^2}{2\sigma_z^2}\right] + exp\left[-\frac{(H+z)^2}{2\sigma_z^2}\right] \right\}$$

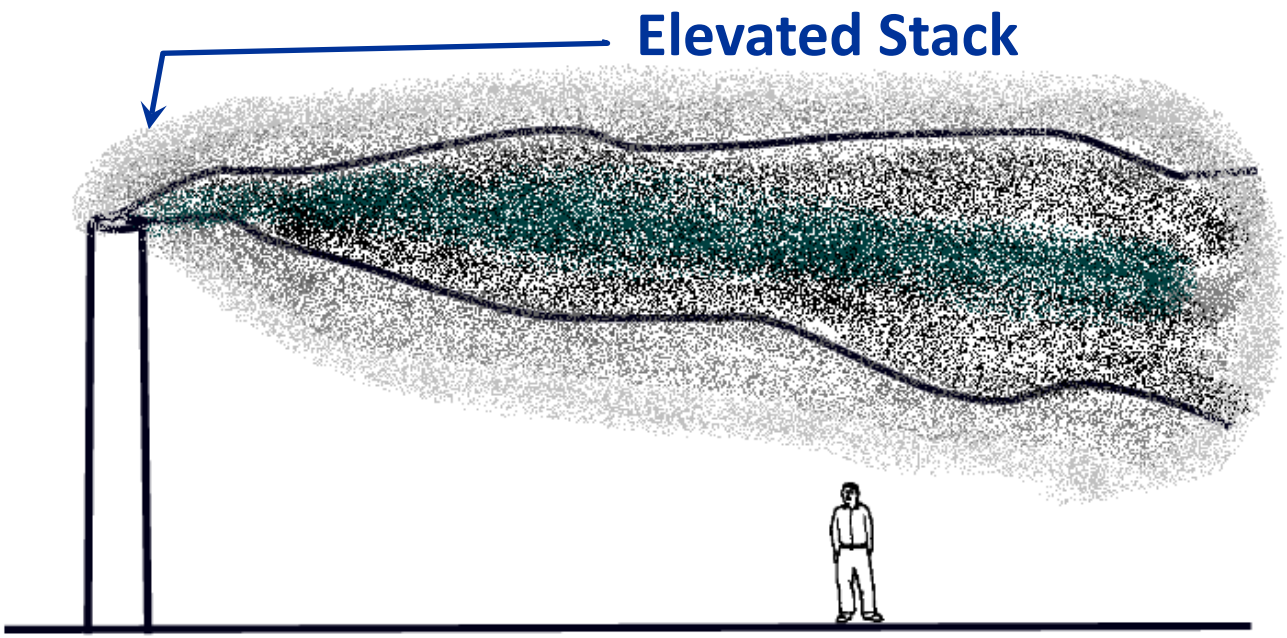
Semi-Infinite Plume

Reg Guide 1.109 NG Dose Factors

- Dependent on Ground Level Concentration
- Semi-Infinite Cloud
  - Concentration is Same Throughout the Cloud
- Immersion Dose

Finite Plume – Elevated Stack

- Semi-Infinite Model Underestimates Dose Close In
- Dose From Plume Shine – Not Immersion

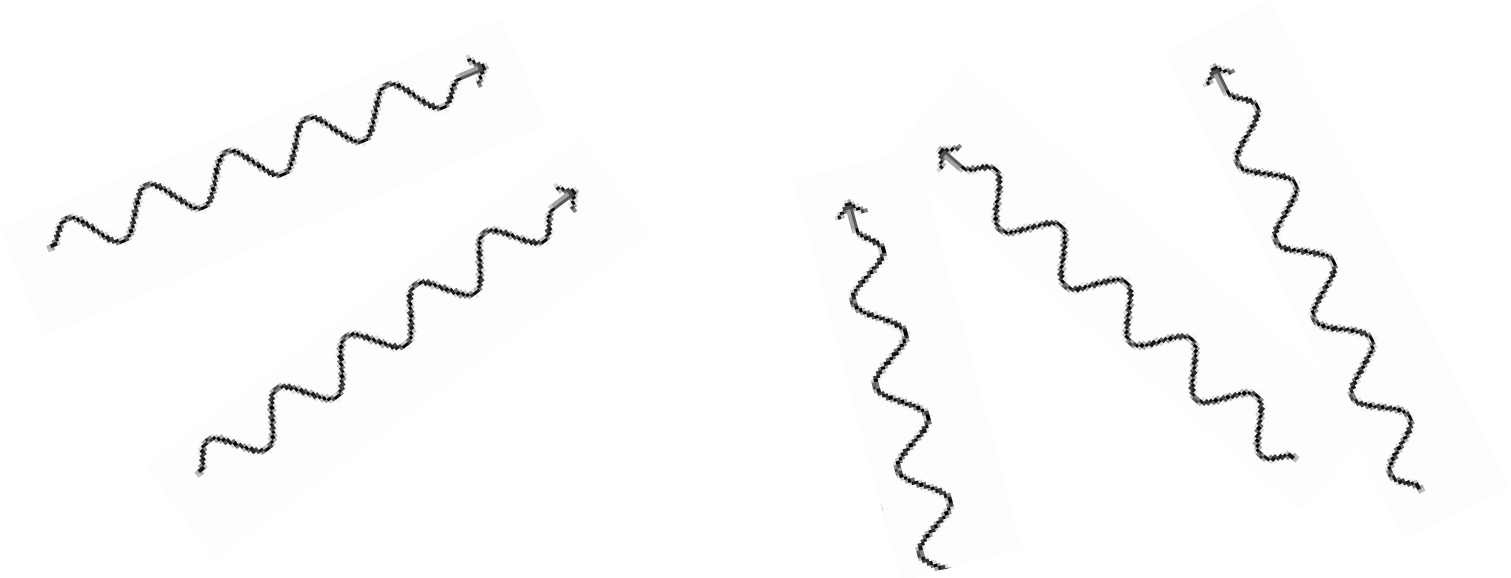


Elevated Stack Definitions

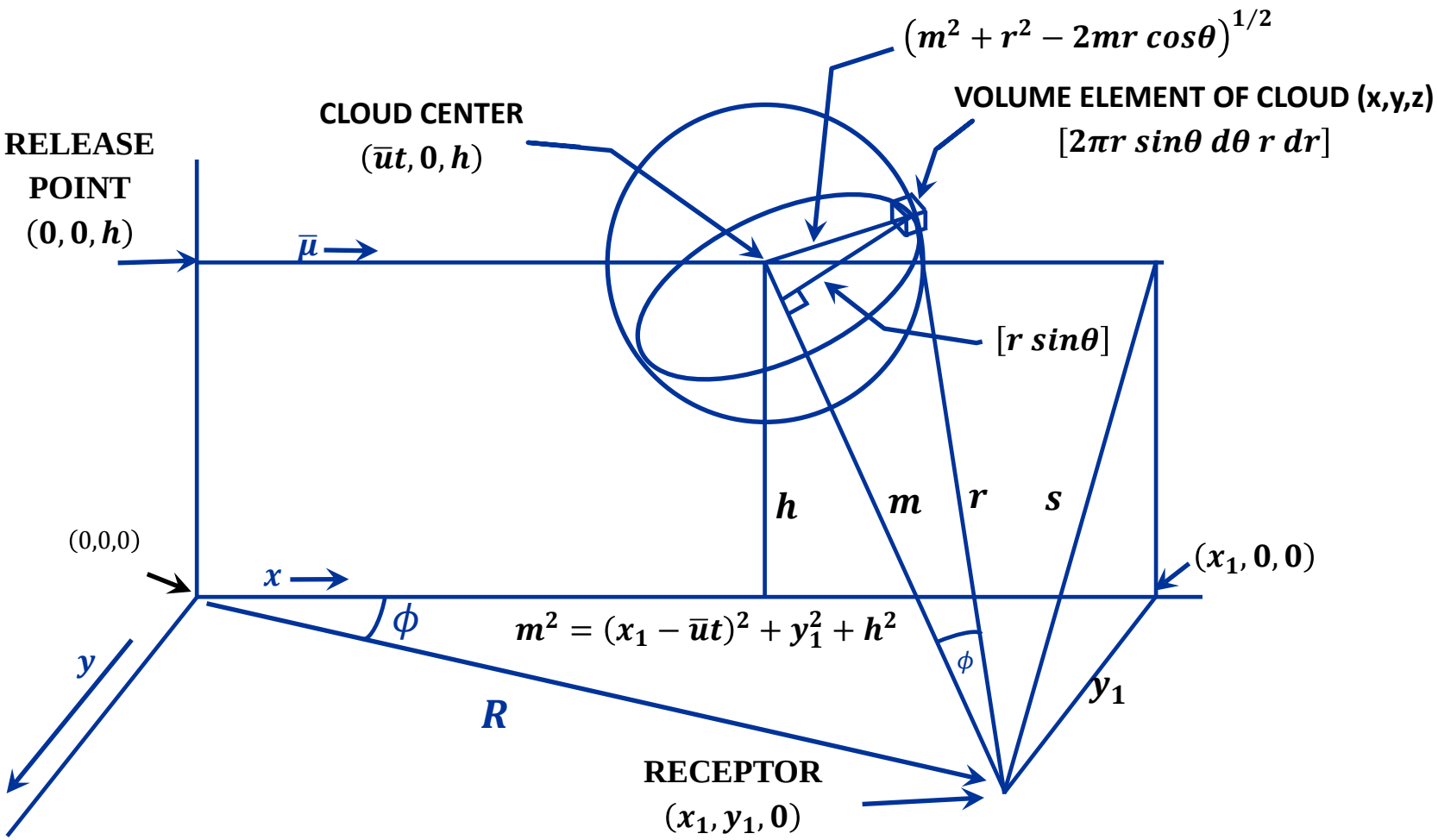
- RG 1.109
  - Free Standing Stack > 80 m
- NUREG 3332
  - Stack > 100 m
- RG 1.111
  - 2 x Height of Adjacent Structures
- RG 1.183
  - 2 ½ x Height of Adjacent Structures
- NUREG 2919
  - (Exit Velocity) / (Avg Wind Speed) > 5

Gamma Air Dose Rate

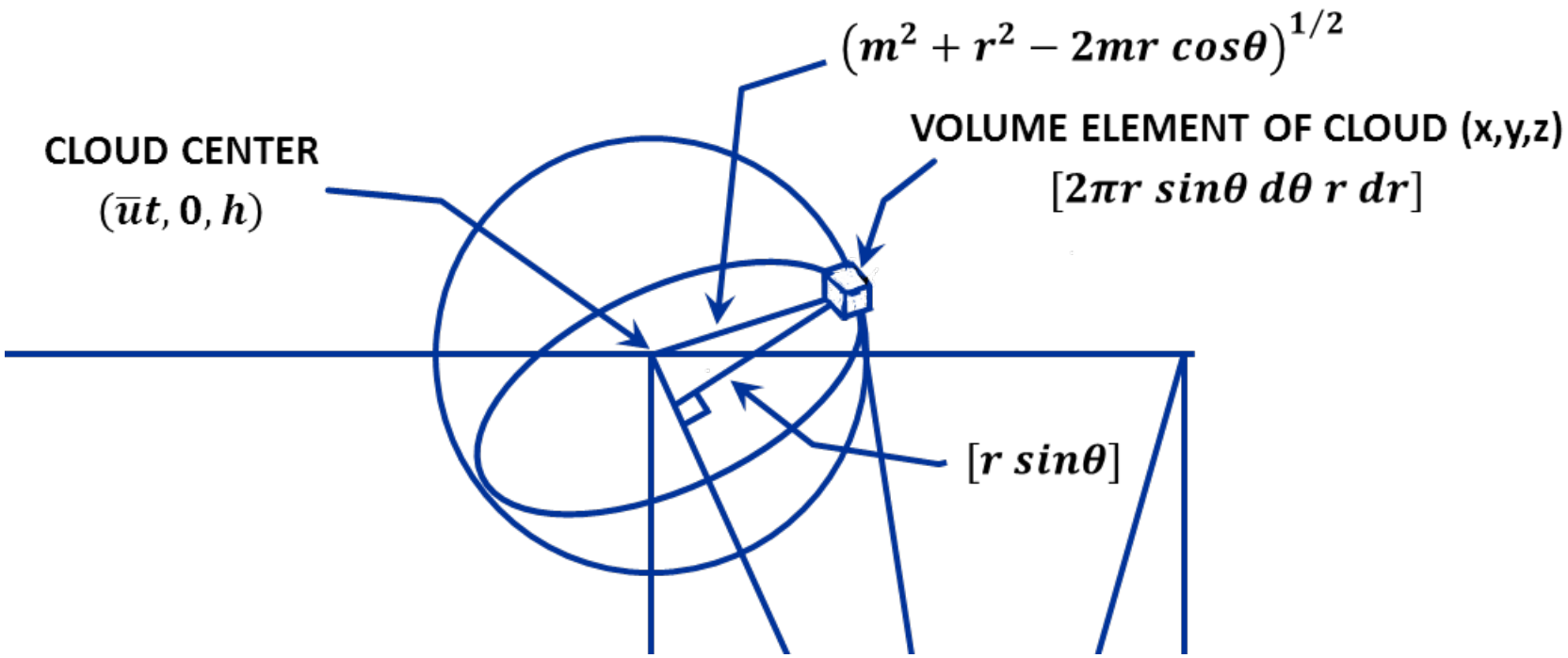
$$D'(r,\theta) = \frac{K\ \mu_a\ \chi(r,\theta)\bar{E}_\gamma(1 + k\mu r)exp(-\mu r)}{r^2}$$



Define Coordinate System



Determine Volume Element

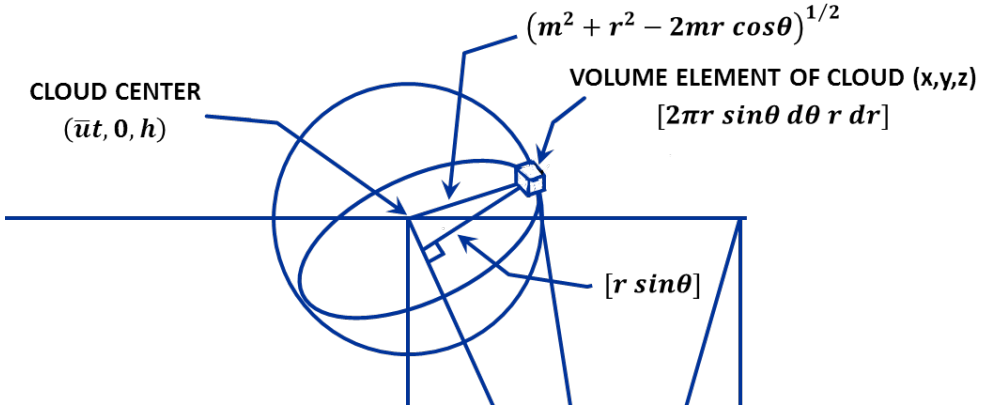


Gamma Air Dose Rate

Gamma Dose Rate

$$= K\,\mu_a\,\bar{E}_\gamma\,\bar{\chi}(R,\phi)\int_0^\infty\int_0^\pi \frac{(1+k\mu r)\,exp(-\mu r)}{r^2}$$

$$\times\, 2\pi r^2 sin\theta\; d\theta\; dr$$



Gamma Air Dose Rate

Gamma Dose Rate:

$$K\,\mu_a\,\bar{E}_\gamma \frac{Q}{\sqrt{2\pi}\sigma_z\bar{u}} \times \left\{ exp\left[-\frac{(H-z)^2}{2\sigma_z^2}\right] + exp\left[-\frac{(H+z)^2}{2\sigma_z^2}\right]\right\} \int_0^\infty \int_0^\pi \frac{(1+k\mu r)\,exp(-\mu r)}{r^2} \times 2\pi r^2 sin\theta\, d\theta\, dr$$

Enter RABFIN

- Calculates the B_i and V_i of NUREG 0133 Section 5.2.1
- B_i and V_i are Location (Sector) Specific (like χ/Q and D/Q)
- No User Guide
- Documentation Found Only in Source Code

RABFIN Input Parameters

- Descriptive Title
- Release Point Info
  - Height
  - Diameter
  - Exit Velocity
  - Building Height

RABFIN Input Parameters

- Flag to Calculate Bi and Vi
- Hours of Purge per Year.
- Wind Speed Measurement Height
- Building Cross Section Area

RABFIN Input Parameters

- Source Term (Ci)

Kr-83m	**Rb-88**	**Xe-133**	**Cs-138**
Kr-85m	**Kr-89**	**Xe-135m**	**Xe-139**
Kr-85	**Rb-89**	**Xe-135**	**Cs-139**
Kr-87	**Xe-131m**	**Xe-137**	**Ba-139**
Kr-88	**Xe-133m**	**Xe-138**	**Ar-41**

- Order is Important!

RABFIN Input Parameters

- Joint Frequency Distribution Info
  - Number of Stability Classes
  - Number of Wind Speeds
  - Max Velocity for Wind Speed Classes
- Title Card for Sector Data

RABFIN Input Parameters

- Joint Frequency Distribution Data
  - Wind Frequency
  - Stability Class
- Receptor Information
  - Distance
  - Height
- Flag for Processing Additional Data

Raw Input File

Parameters: **[See Notes Below]**

Title of Run

```
` BRUSNWICK TEST RUN
100.9    3.6     4.7     0.0     1.0     0.     104.0    0.
3.70E+04  7.20E+04  2.40E+02  2.05E+05  2.40E+05  3.50E+03  1.90E+02  3.60E+03  1.10E+05
8.80E+04  2.80E+05  1.10E+04  2.60E+05
  7   7
0.36 1.56 3.35 5.59 8.27 10.9515.65
```

# of Stability Classes / # of Wind Speed Classes

Wind speed is in m/sec

RABFIN Input File

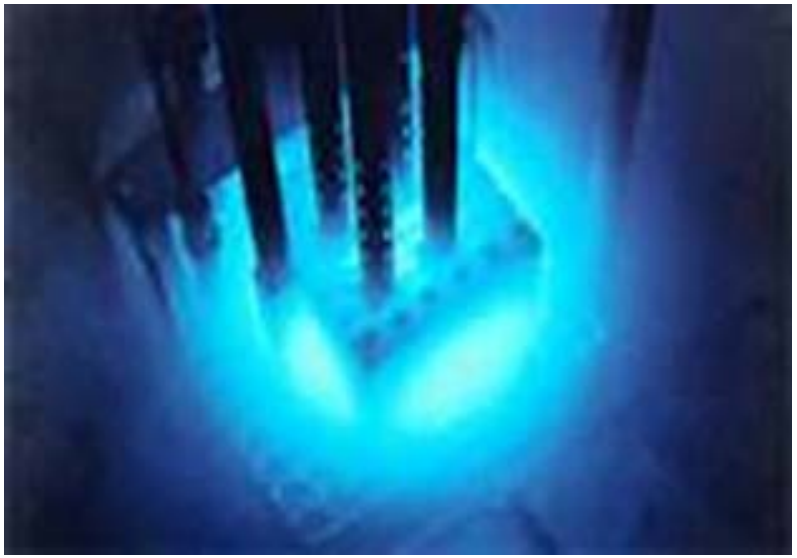
```
 BRUNSWICK TEST RUN
100.9     3.6       4.7      0.0       0.0       0.        104.0     0.
3.70E+04  7.20E+04  2.40E+02  2.05E+05  2.40E+05  0.0       3.50E+03  0.0
1.90E+02  3.60E+03  1.10E+05  8.80E+04  2.80E+05  1.10E+04  2.60E+05

   7    7
0.36 1.56 3.35 5.59 8.27 10.9515.65
  N site boundary calculation 0.75 mi
0.00 0.00 0.01 0.06 0.04 0.00 0.00
0.00 0.00 0.01 0.08 0.02 0.00 0.00
0.00 0.00 0.05 0.17 0.06 0.02 0.00
0.00 0.04 0.23 0.44 0.31 0.16 0.08
0.00 0.02 0.11 0.42 0.49 0.33 0.14
0.00 0.03 0.09 0.17 0.12 0.04 0.02
0.00 0.04 0.16 0.16 0.06 0.01 0.00
0.75
```

RABFIN Output

SOURCE TERM CI/YR

KR-83M	1.00E+00
KR-85M	1.00E+00
KR-85	1.00E+00
KR-87	1.00E+00
KR-88	1.00E+00
KR-89	1.00E+00
XE-131M	1.00E+00
XE-133M	1.00E+00
XE-133	1.00E+00
XE-135M	1.00E+00
XE-135	1.00E+00



RABFIN Output

N site boundary calculation 0.20 mi

		MAX WIND SPEED						
STAB	TOTAL	0.36	1.56	3.35	5.59	8.27	10.95	15.65
1	0.11	0.00	0.00	0.01	0.06	0.04	0.00	0.00
2	0.11	0.00	0.00	0.01	0.08	0.02	0.00	0.00
3	0.30	0.00	0.00	0.05	0.17	0.06	0.02	0.00
4	1.26	0.00	0.04	0.23	0.44	0.31	0.16	0.08
5	1.51	0.00	0.02	0.11	0.42	0.49	0.33	0.14
6	0.47	0.00	0.03	0.09	0.17	0.12	0.04	0.02
7	0.43	0.00	0.04	0.16	0.16	0.06	0.01	0.00
TOTAL	4.19	0.00	0.13	0.66	1.50	1.10	0.56	0.24
ENTRAPMENT		0.00	0.00	0.00	0.00	0.00	0.00	0.00
GRND VEL		0.06	0.30	0.76	1.39	2.15	2.98	4.12
ELEV VEL		0.18	0.95	2.42	4.40	6.83	9.47	13.10

RABFIN Output

```
AVERAGE WIND SPEED

 MEAN        GROUND   ELEVATED   COMBINED
 ----------------------------------------
ARITHMETIC   0.00      5.79       5.79
HARMONIC     0.00      4.23       4.23

  AIR + TISSUE DOSES FOR FINITE PLUME
 RECEPTOR AT     322. METERS + ELEV OF   0.0 METERS
 HS = 100.9 METERS DIAM =   3.6 METERS   EXIT VEL =   4.7 M/SEC
 BUILDING  HEIGHT =   0.0 METERS   CROSS SECT AREA =   0.0 M2
 WIND HEIGHT = 104.0 METERS  PURGE HOURS =   0.0
 GRD FRACT X/Q =  0.00E+00
 ELV FRACT X/Q =  3.00E-09 AVG HEFF=    111.3
 X/Q= 3.00E-09 SEC/M**3 AVG HEFF=    111.3 METERS , UBAR=  4.23 M/SEC
```

RABFIN Output

FINITE PLUME DOSES

NUCLIDE	AIR GAMMA (MRAD)	TOTAL BODY (MREM)	SKIN (MREM)
KR-83M	3.71E-09	4.96E-11	2.88E-09
KR-85M	6.42E-06	4.32E-06	5.12E-06
KR-85	1.03E-07	6.79E-08	2.07E-07
KR-87	3.28E-05	2.18E-05	2.64E-05
KR-88	8.12E-05	5.41E-05	6.34E-05
KR-89	7.13E-05	4.75E-05	5.62E-05
XE-131M	1.49E-06	9.67E-07	1.20E-06
XE-133M	1.18E-06	7.44E-07	1.01E-06
XE-133	1.11E-06	7.25E-07	8.90E-07
XE-135M	1.87E-05	1.23E-05	1.46E-05
...	...	...	...
TOTALS	3.51E-04	2.34E-04	2.77E-04

RABFIN Output

SEMI-INFINITE PLUME DOSES ***(From Table B-1 of RG 1.109)***

NUCLIDE	AIR GAMMA (MRAD)	AIR BETA (MRAD)	TOTAL BODY (MREM)	SKIN (MREM)
KR-83M	1.82E-09	2.72E-08	5.00E-12	1.42E-09
KR-85M	1.17E-07	1.87E-07	7.77E-08	2.29E-07
KR-85	1.64E-09	1.86E-07	1.07E-09	1.29E-07
KR-87	5.81E-07	9.70E-07	3.90E-07	1.37E-06
KR-88	1.44E-06	3.51E-07	9.75E-07	1.47E-06
KR-89	1.25E-06	8.01E-07	8.38E-07	1.79E-06
XE-131M	1.49E-08	1.06E-07	6.10E-09	5.69E-08
XE-133M	3.11E-08	1.41E-07	1.67E-08	1.19E-07
XE-133	3.36E-08	1.00E-07	1.96E-08	5.52E-08
XE-135M	3.02E-07	6.65E-08	1.97E-07	2.99E-07
...	...	...	...	...
TOTALS	5.77E-06	4.89E-06	3.85E-06	8.84E-06

RABFIN Output

TABLE 4.11-3 ***(From Table B-1 of RG 1.109)***

DOSE PARAMETERS FOR SEMI-INFINITE PLUMES*
FROM VENTS IN SPECIFFICATIONS 3.11.2.1 AND .2

NOBLE GAS RADIO-NUCLIDE	K TOTAL BODY (MREM/YR UCI/M3)	L SKIN (MREM/YR UCI/M3)	M GAMMA AIR (MRAD/YR UCI/M3)	N BETA AIR (MRAD/YR UCI/M3)
KR-83M	7.56E-02	0.00E+00	1.93E+01	2.88E+02
KR-85M	1.17E+03	1.46E+03	1.23E+03	1.97E+03
KR-85	1.61E+01	1.34E+03	1.72E+01	1.95E+03
KR-87	5.92E+03	9.73E+03	6.17E+03	1.03E+04
KR-88	1.47E+04	2.37E+03	1.52E+04	2.93E+03
KR-89	1.66E+04	1.01E+04	1.73E+04	1.06E+04
XE-131M	9.15E+01	4.76E+02	1.56E+02	1.11E+03
...	...	...	...	...

*THE LISTED DOSE PARAMETERS ARE FOR RADIONUCLIDES THAT MAY BE DETECTED IN GASEOUS EFFLUENTS.

RABFIN Output

TABLE 4.11-5
DOSE PARAMETERS FOR FINITE ELEVATED PLUMES*
IN SPECIFICATIONS 3.11.2.1 AND 3.11.2.2

NOBLE GAS RADIONUCLIDES	TOTAL BODY ANNUAL (MREM/YR UCI/SEC)	GAMMA AIR ANNUAL (MRAD/YR UCI/SEC)	GAMMA AIR 500 HR (MRAD/YR UCI/SEC)
KR-83M	1.56E-09	1.17E-07	1.17E-07
KR-85M	1.36E-04	2.02E-04	2.02E-04
KR-85	2.14E-06	3.24E-06	3.24E-06
KR-87	6.87E-04	1.03E-03	1.03E-03
KR-88	1.70E-03	2.56E-03	2.56E-03
KR-89	1.50E-03	2.25E-03	2.25E-03
XE-131M	3.05E-05	4.69E-05	4.69E-05
XE-133M	2.34E-05	3.71E-05	3.71E-05
XE-133	2.28E-05	3.49E-05	3.49E-05
...	...	...	...

Gamma X/Q

- Simplifies Calculation
- Uses RABFIN B_i and V_i Values
- Based on Assumed Source Term
  - Source Term May Be Easily Changed if Desired

Gamma X/Q

$$\chi/Q_\gamma \left[\frac{sec}{m^3}\right] = \frac{\sum_i f_i\, B_i \left[\frac{mrad/yr}{\mu Ci/sec}\right]}{\sum_i f_i M_i \left[\frac{mrad/yr}{\mu Ci/m^3}\right]}$$

$f_i =$ Source Term Fraction for Nuclide “i” (Assumed)
$B_i =$ RABFIN Gamma Factor for Elevated Plume
$M_i =$ Gamma Air Dose Factor From Reg Guide 1.109.

Gamma X/Q – How Used

- Calculate Noble Gas Total Body Dose Rate

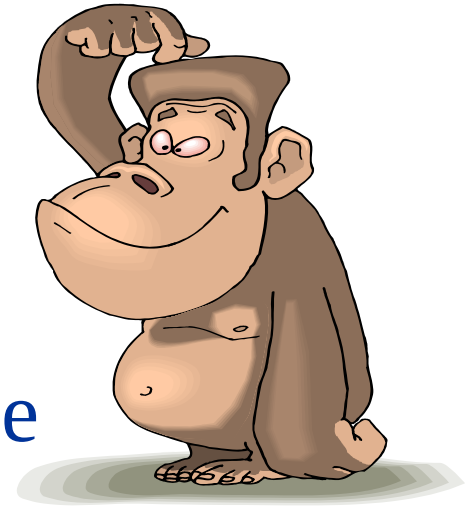
Semi Infinite Plume

$$D' = \chi/Q \sum_i (L_i + 1.1M_i)\,\dot{Q}_i$$

Finite Plume

$$D' = \sum_i \left(\chi/Q\, L_i + \chi/Q_\gamma\, 1.1M_i\right)\dot{Q}_i$$

Gamma X/Q - Thoughts



- Dependent Upon
  - Site Specific Meteorology
  - Site Specific Default Source Term
- JFD used for RABFIN should use same JFD to calculate X/Q.
  - Update RABFIN Factors When X/Q is Updated
  - Update Source Term as Appropriate

Questions?