Radiological impact

A release of radioactive materials may lead to harmful radiological consequences to humans.

Dilution and distance are key measures to mitigate such releases

After this lecture you will be able to:

- **Calculate the reduction in dose resulting from dilution and distance**
- **Estimate the size of the emergency planning zone of a small reactor**

Radio-toxicity

- Important distinction between
- Activity A , measured in Bq – calculable
- Absorbed dose D, measured in Gy = J/Kg – calculable
- Dose equivalent H =$\varepsilon *$ A, measured in Sv
- The dose coefficient ε is an estimation based on observation
- Excess risk for lethal cancer: 5% per Sievert (ICRP).
- Lethal instantaneous dose: 10 Sv.

Dose coefficient

Nuclide	ε
Sr-90	30 [nSv/Bq]
Te-132	3 [nSv/Bq]
I-131	20 [nSv/Bq]
I-133	4 [nSv/Bq]
Xe-133	0.1 [nSv/d/(Bq/m^3)]
Xe-135	1 [nSv/d/(Bq/m^3)]
Cs-137	13 [nSv/Bq]
Ba-140	2 [nSv/Bq]

- The dose coefficient (Sv/Bq) is averaged over tissues and exposure time. It is dependent on age, gender and body-size.
- Tabulated values are often given for a 20 year old average person, assuming an integrated dose exposure time of 50 years (ε_{50}).
- For volatiles: inhalation dose coefficients ≈ ingestion dose coefficients
- For noble gases ”Cloud shine” is the dominating contribution to exposure. Dose coefficients are in the unit of Sv/d/(Bq/m^3).

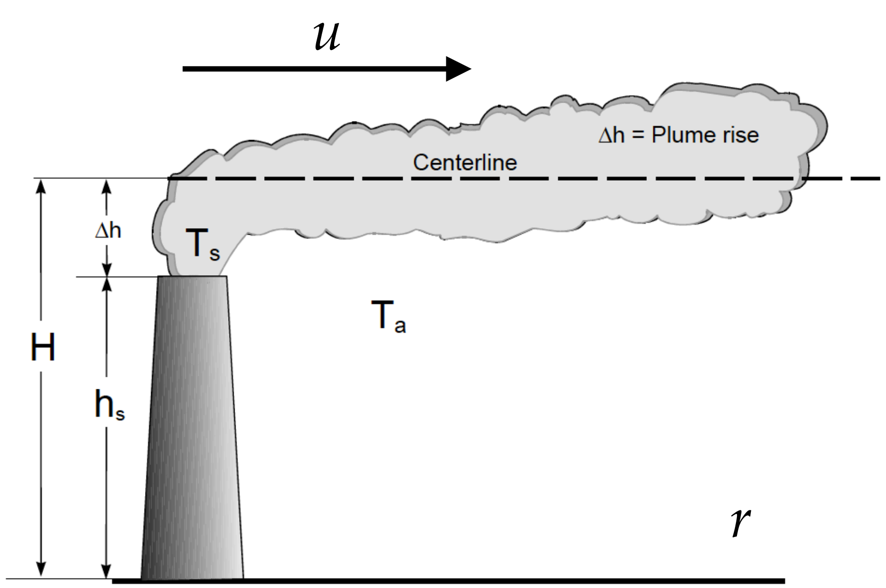
Inhalation

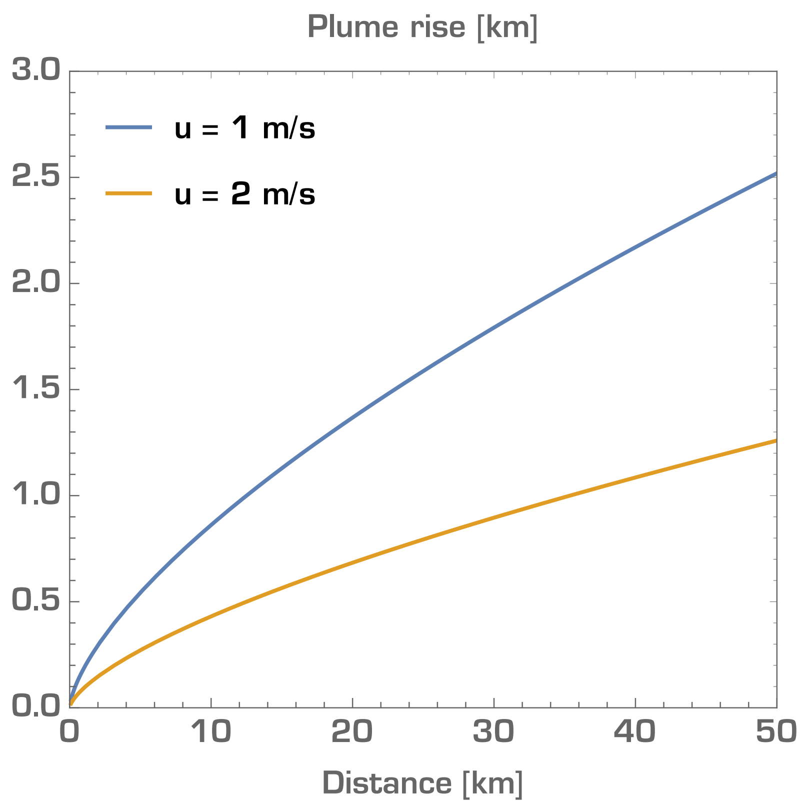
Human Inhalation Rates (m^3/hour)

Person	Resting	Walking	Physical work/ exercise
Child (6 years)	0.4	0.8	2.0
Male adult	0.7	0.8	2.5
Female adult	0.3	0.5	1.6

- For inhalation exposure, one needs to assess concentration of radionuclide in the atmosphere
- Depends on dispersion of release & breathing rate of the individual
- Depends on age, gender & activity

Plume rise



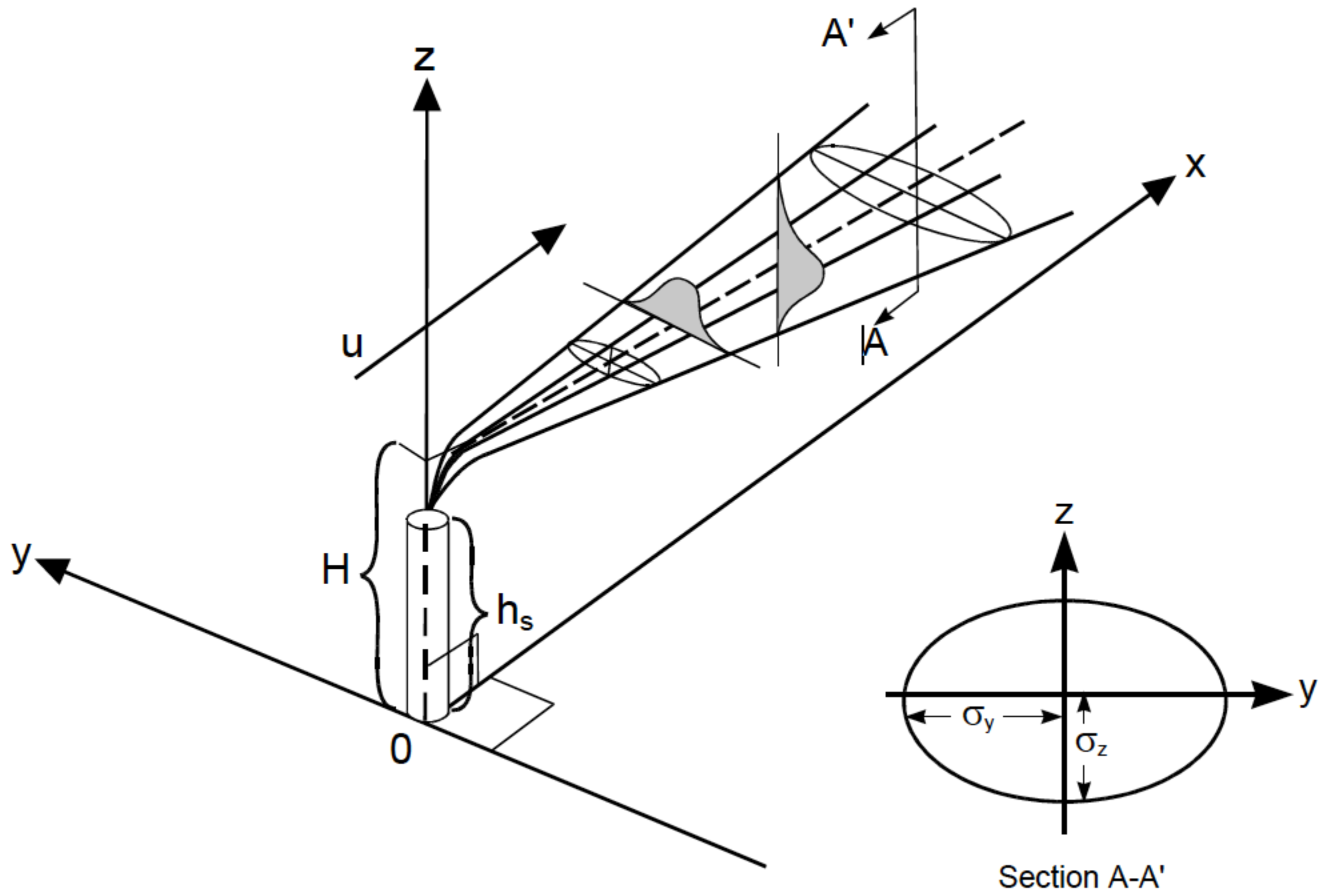


- Release with volumetric flow rate V occurs from stack of reactor building (if intact).
- Plume rises if released gas is warmer than atmosphere
- Wind conditions determines transition to horisontal transport and plume rise Δh

$$\Delta h(r) = \frac{1.6}{u} \times r^{2/3} \left(\frac{g}{\pi} V \left(\frac{T_s - T_a}{T_s} \right) \right)^{1/3}$$

- Presence of buildings can cause turbulent wakes and ”downwash” of plume

Dispersion of plume



- Gaussian dispersion models are used in some codes estimating atmospheric concentration of radionuclides.
- Valid only for flat ground, uniform wind speed & direction
- Dispersion half widths σ_z and σ_y are functions of wind speed, cloud cover and heating from the sun. The half-widths are categorised according to Pasquill atmospheric stability classes (A-F), where A is most and F least turbulent.

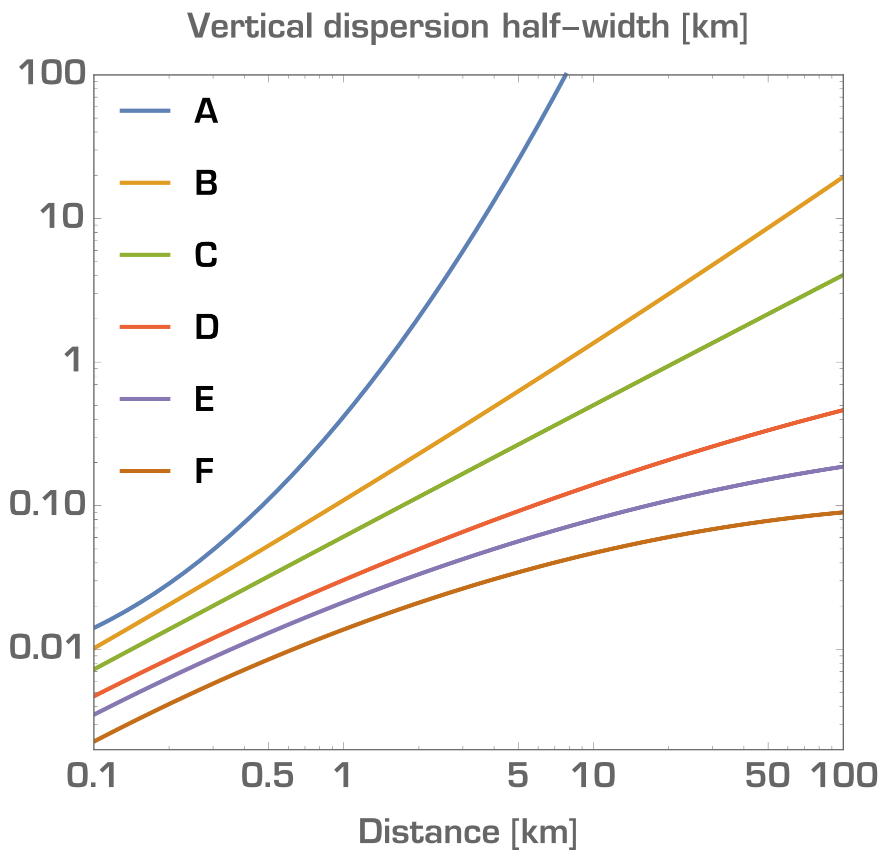
Atmospheric stability

Pasquill atmospheric stability classes

	Day	Day	Day	Night	Night
u[m/s]	Strong insolation	Moderate insolation	Slight insolation	> 50% cloud cover	< 50% cloud cover
< 2	A	A-B	B	E	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
> 6	C	D	C	D	D

Dispersion half-widths

$$\sigma_i = Exp\left[a_i + b_i \times ln\frac{r}{1000} + c_i\left(ln\frac{r}{1000}\right)^2\right]$$



Stability condition	a_y	b_y	c_y
A	5.357	0.8828	-0.0076
B	5.058	0.9024	-0.0096
C	4.651	0.9181	-0.0076
D	4.230	0.9222	-0.0087
E	3.922	0.9222	-0.0064
F	3.533	0.9181	-0.0070

Stability condition	a_z	b_z	c_z
A	6.035	2.1097	0.2770
B	4.694	1.0629	0.0136
C	4.110	0.9201	-0.0020
D	3.414	0.7371	-0.0316
E	3.057	0.6794	-0.0450
F	2.621	0.6564	-0.0540

Fission product inventory

- EoL inventory in the SEALER-55 core (average burn-up: 60 GWd/ton)

SEALER-55 fission product inventory

Nuclide	Mass [g]	Activity [PBq]	Half-life	Dose coefficient
Sr-90	1 530	79	29 y	30 [nSv/Bq]
Te-132	17.0	195	78 h	3 [nSv/Bq]
I-131	31.1	143	8 d	20 [nSv/Bq]
I-133	6.7	281	21 h	4 [nSv/Bq]
Xe-133	41.1	285	5 d	0.1 [nSv/d/(Bq/m^3)]
Xe-135	3.1	289	9h	1 [nSv/d/(Bq/m^3)]
Cs-137	32 400	104	30 y	13 [nSv/Bq]
Ba-140	89.6	242	13 d	2 [nSv/Bq]

Dose acceptance criteria

- Differs from regulator to regulator
- CNSC (Canada):
  - Evacuation required if 30 day dose > 20 mSv
- EPA (USA):
  - Evacuation required if 4 day dose > 10 mSv
  - Relocation required if 1 year dose > 20 mSv
- ONR (UK)
  - Evacuation required if 5 day dose is higher than 50 mSv
- SSM (Sweden)
  - Protective action planning required if 7 day dose is higher than 100 mSv

Home assignment: Radiological impact

- Estimate the 5 day (120 h) cloud-shine exposure resulting from 100% release of Xenon inventory at end-of-life in SEALER-55, for persons residing 0.1, 1.0 and 10.0 km in the wind direction from a failing reactor unit. Assume:
  - A wind speed of 1 m/s and Pasquill conditions A for 6 h/day, B for 6 h/day and E for 12 h/day.
  - A stack height of 10 m, stack volumetric release rate of 1 m^3/s, release temperature of 300°C and time for release of full inventory equal to 120 h.
  - In which cases would emergency planning measures be required?
- Compare this with the inhalation exposure for humans following fractional release of the volatile fission product inventory in the same time. At which retention factor does the inhalation dose become of second order, i.e. less