RAPIDC

Regional Air Pollution In Developing Countries

# Statistical analysis of corrosion attack and environmental data, dose-response functions

# Start with the simple - triplicates

- If the error in detmining the corrosion attack for one specimen is s then the error in determining the average corrosion attack for n number of specimens is

  $s / n^{0.5}$

- The more the better but a minimum of three samples is recommended = ”triplicates”

# Distribution of errors

- Lognormal distributions, i.e. normal distributions of logarithmic values, are observed for the corrosion rates.

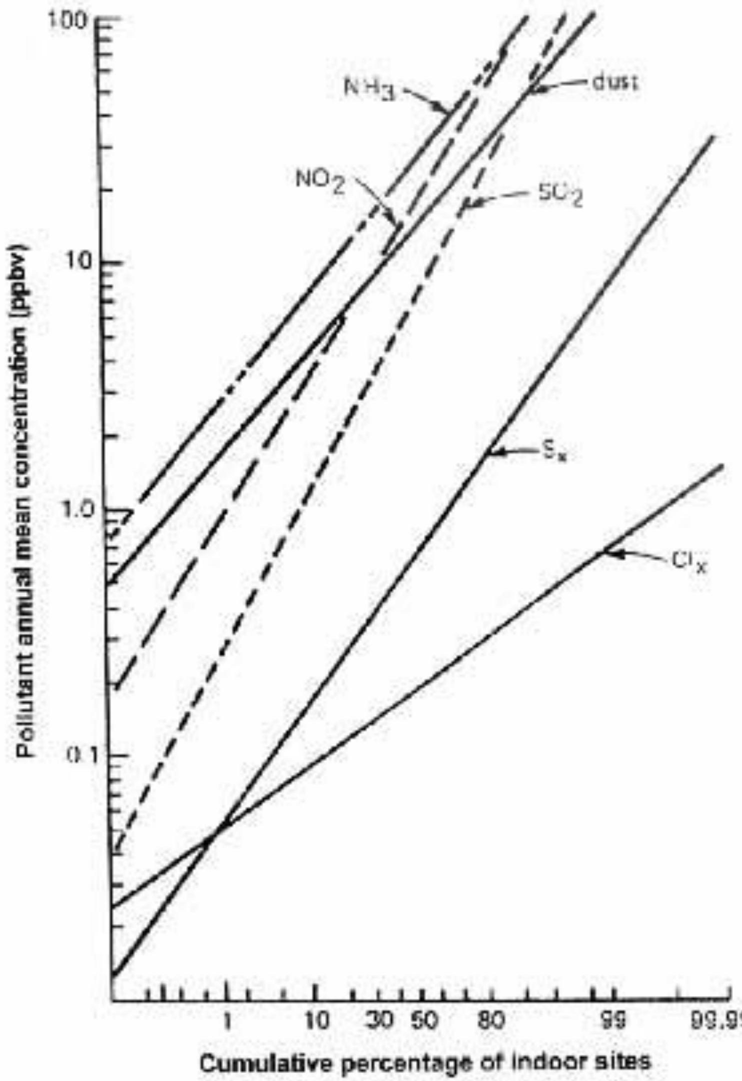
- If the uncertainty is expressed by a standard deviation of logarithmic values, s, then

  $\Delta \ln(rcorr) = \pm s$

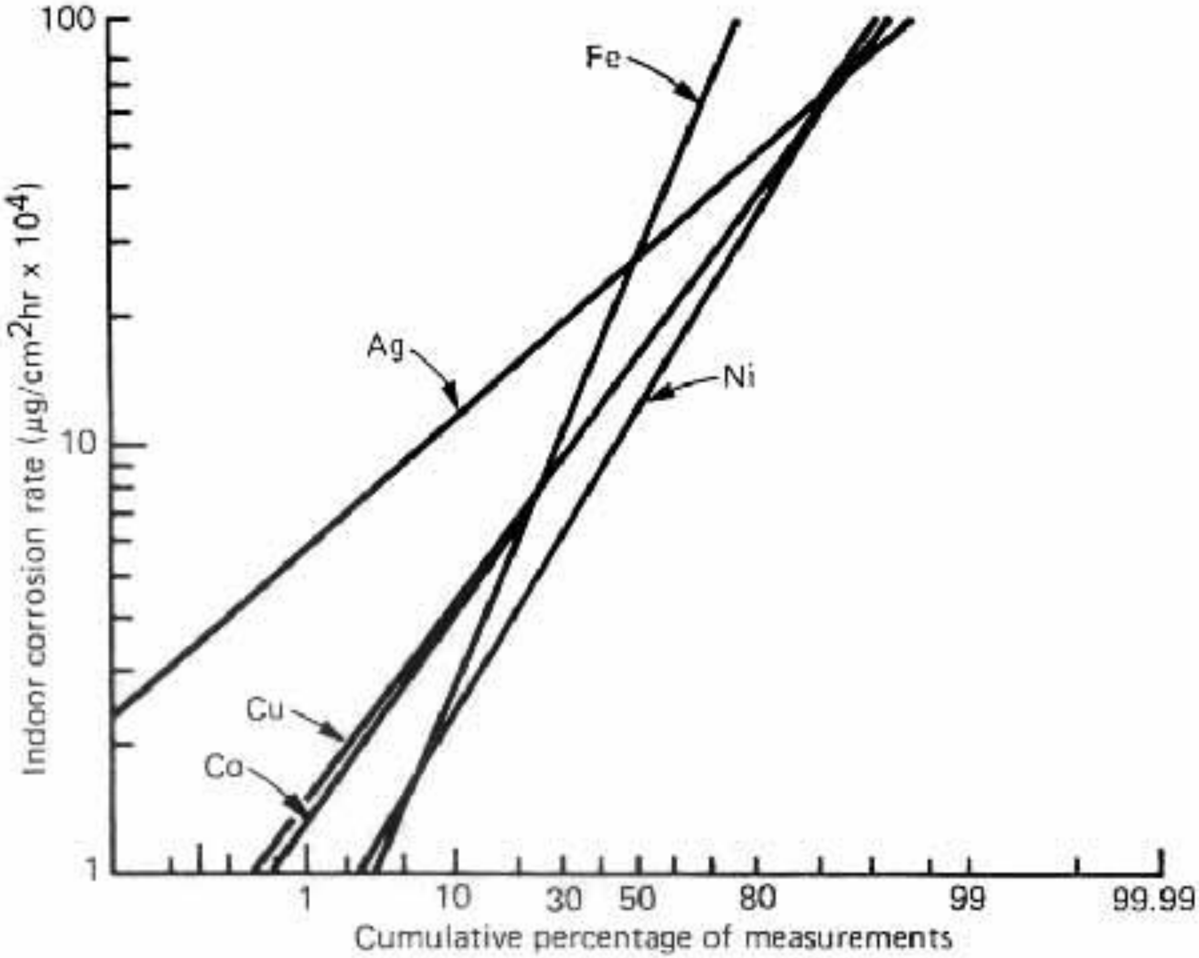
- This means that the uncertainty interval in general is asymmetric

KTH
Corrosion Science

***Average concentrations of indoor pollutants as a function of cumulative percentage.***



# *Average indoor corrosion rates of Fe, Cu, Co, Ni and Ag as a function of cumulative percentage.*



# Dose-response and damage functions

- A **dose-response function** links the dose of pollution, measured in ambient concentration and/or deposition, to the rate of material corrosion;
- A **physical damage function** links the rate of material corrosion (due to the pollution exposure given by the dose-respose function) to the time of replacement of maintenance of the material. Performance requirements determine the point at which replacement of maintenance is considered to become necessary;
- A **cost function** links changes in the time of replacement, repair or repainting to monetary cost; and
- An **economic damage function** links cost to the dose of pollution, as derived from (a) - (c) above.

*Source: Report by the Chairmen of the UN/ECE Workshop on Economic Evaluation of Air Pollution Abatement and Damage to Buildings including Cultural Heritage, Stockholm, Sweden, 1996*

# Statistical methods for deriving dose-response functions

- Pattern recognition and identification of important variables
  - Principal component analysis (PCA)
- Correlation analysis
  - Distinguishing real and artificial correlations
- Estimation of dose-response functions
  - Multiple linear regression
  - Nonlinear regression
- Knowledge of many different statistical methods necessary
- The analysis should go hand in hand with knowledge of basic corrosion mechanisms since correlation between many parameters increase the risk of creating equations that fit the data but do not predict new data

# Levels of uncertainty

- Large difference between determination by evaluation of corrosion attack and estimation by calculation from dose-response functions

**Estimated levels of uncertainty for assessment of the corrosivity category based on determination (exposure of specimens) and estimation (dose-response function)**

| Metal | Level of uncertainty | |
|---|---|---|
| | determination | estimation |
| carbon steel | ±2% | - 33% to +50% |
| zinc | ±5% | - 33% to +50% |
| copper | ±2% | - 33% to +50% |
| aluminium | ±5% | - 50% to +100% |

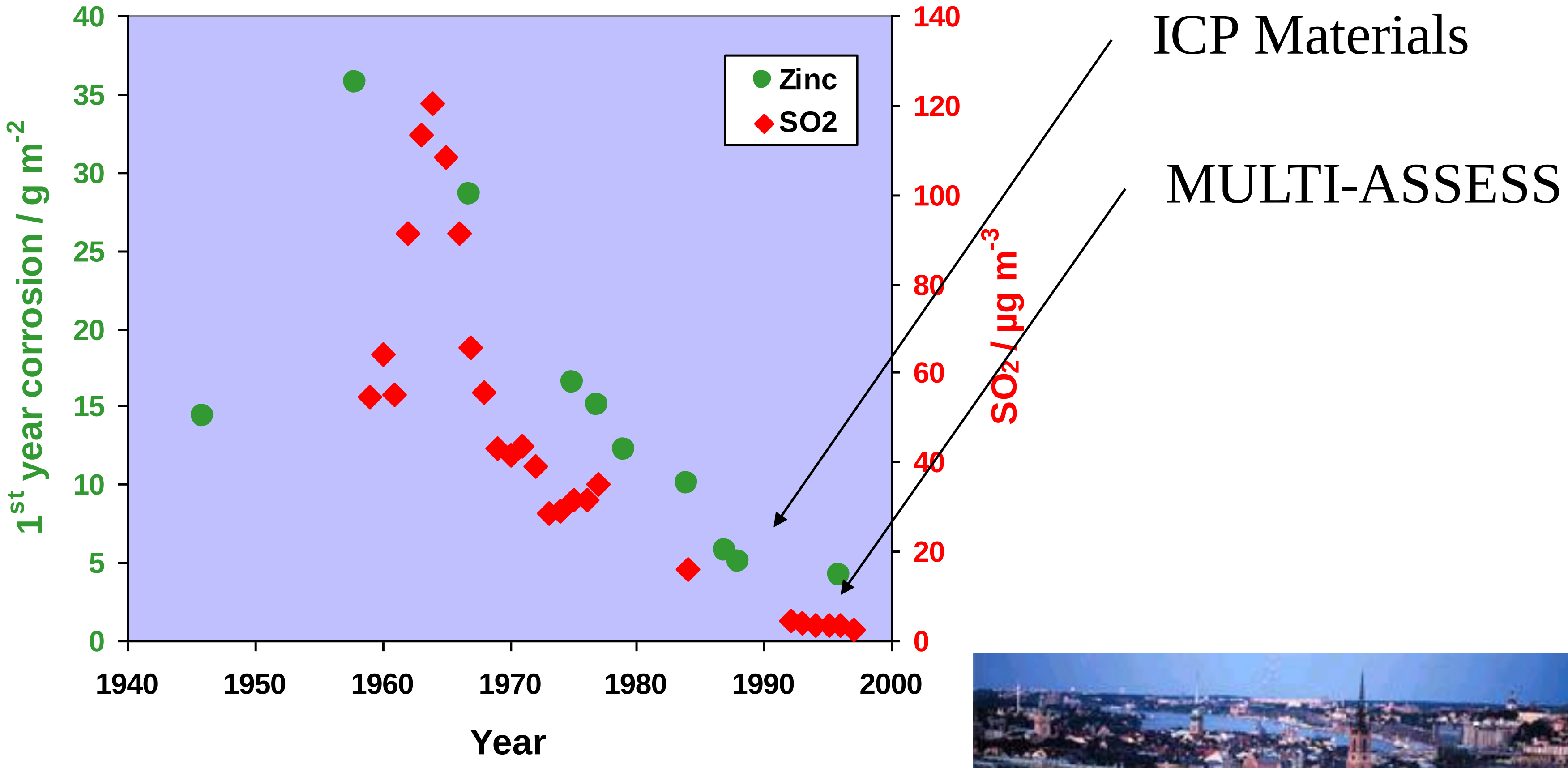
# Sources of uncertainty

- By materials specimens
  - Pickling and gravimetric procedure
  - Natural variation in climate from year to year
  - Uneven exposure conditions within a rack
- By dose-response functions
  - Uncertainty in the measurement of environmental parameters
  - Mathematical form of the dose-response function is simplified
  - Not all corrosion effects can be included in a simple dose-response function
  - If the dose-response function is extrapolated then very large statistical errors can occur. The most common extrapolation is in time

# Use of dose-response functions

- Estimation of corrosion attack
- Mapping of corrosion attack
- Calculation and mapping of exceedance values
- Calculation and mapping of costs of corrosion

# Zinc, Stockholm (Vanadis)




# Dose-response functions for zinc before ICP Materials

| | |
|---|---|
| Hudson and Stanners (1956): | $SO_2$ |
| Guttman(1968): | $SO_2$, Tow |
| Haynie and Upham (1970): | $SO_2$, Rh |
| Barton and Cerny (1980): | $SO_2$, Tow |
| Michailovskii et al (1980): | $SO_2$, Tow, T |
| Munier et al. (1980): | $SO_2$ |
| Haynie (1980): | $SO_2$ |
| OECD (1981): | $SO_2$ |
| Atteraas and Haagenrud (1982): | $SO_2$ |
| Mikhailoski (1982): | $SO_2$ |
| Haagenrud (1985): | $SO_2$, Tow |
| Lipfert (1986): | $SO_2$, t, $H^+$, $f_{85}$ |
| Benarieand Lipfert (1986): | $SO_2$, $Cl^-$ |
| Kucera (1986): | $SO_2$, Tow |
| Lipfert (1987): | $SO_2$, t, $H^+$, $f_{86}$, $Cl^-$ |
| Feliu and Morcillo (1993): | $SO_2$, $Cl^-$, T |
| Shaw (1997): | $SO_2$ |

# General dose-response function

$$K = f_{dry}(T, RH, [SO_2]) + f_{wet}(Rain[H^+])$$

| | |
|---|---|
| K | = Corrosion rate |
| **T** | **= Temperature** |
| **RH** | **= Relative humidity** |
| **$[SO_2]$** | **= $SO_2$ concentration (air)** |
| Rain | = Amount of precipitation |
| $[H^+]$ | = $[H^+]$ concentration (precipitation) |

# A selected *drf*

*Zinc, unsheltered* (N=98, $R^2$=0.84)

**ML = $1.4[SO_2]^{0.2}\exp\{0.02Rh + f(T)\}$ + $0.03Rain[H^+]$**

f(T) = 0.06(T-10) when T<10°C,
otherwise -0.02(T-10)

ML - mass loss

# Pollution parameters in *drf*

| Material | $SO_2$ | $NO_2$ | $O_3$ | $H^+$ | $Cl^-$ |
|---|---|---|---|---|---|
| Carbon steel | x | | | x | |
| Weathering steel | x | | | | |
| Zinc | x | | | x | |
| Aluminium | x | | | | x |
| Copper | x | | x | x | |
| Cast bronze | x | | | x | x |
| Nickel[a] | x | (x) | | | |
| Tin[a] | | | x | | (x) |
| Alkyd/galvanised[b] | x | | | | |
| Silicon alkyd/steel[b] | x | | | | |
| Sandstone | x | | | x | |
| Limestone | x | | | x | |
| Glass | x | x | | x | |

[a]sheltered only
[b]unsheltered only

# Dose-response functions from the multi-pollutant/MULTI-ASSESS programme: $HNO_3$ and $PM_{10}$

| Material | T | Rh | $SO_2$ | $NO_2$ | $O_3$ | $HNO_3$ | $PM_{10}$ | Rain | pH |
|---|---|---|---|---|---|---|---|---|---|
| carbon steel | X | X | X | | | | X | X | X |
| zinc | X | X | X | | | X | | X | X |
| copper | X | X | X | | X | | | X | X |
| bronze | X | X | X | | | | X | X | X |
| limestone | | X | X | | | X | X | X | X |
| glass | X | X | X | X | | | | | |