Researching ways to refine the Scaling Factor Approach

DIFFICULT TO MEASURE (DTM) RADIONUCLIDES:

PROGRESS AND NEW CHALLENGES

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Jose Luis Leganés Nieto, ENRESA

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Scaling Factors for Metallic Waste

SCALING FACTORS APPROACH:

Semiempirical method aimed to find correlation among Difficult to to Measure, DTM, isotopes and Easy to Measure, ETM or Key Nuclides, in radioactive waste

- **Arithmetic Mean, Geometric Mean, Log-Linear Regression, those all are valid as Scaling Factors. Data behavior will constrain the chosen one.**
- **Collection of samples for radiochemical analysis.**
- **Time consuming and expensive approach.**
- **Manner of sampling is a critical aspect.**

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SF APPROACHES

SCALING FACTOR THEORETICALLY DETERMINED

Solubility

Chemical properties

Mechanical filtration

Calibrate the model

Cumbersome

Transport processes

Chemical filtration

Evaporation

SAMPLING

Time consuming

Budget impact

SCALING FACTOR EMPIRICALLY DETERMINED

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Scaling Factors Definition

Finding correlation between Difficult to Measure isotopes, DTM, and Easy to Measure, ETM (Key Nuclides)

Key Nuclides (K.N.):

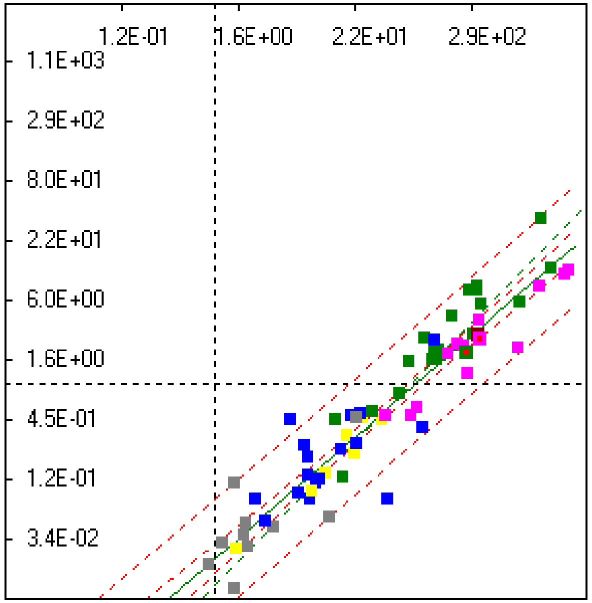
- **Gamma emitter easily detected for any gamma spectrometry**
- **Relatively long lived (^{60}Co and ^{137}Cs)**

Difficult to Measure Isotopes and K.N.:

- **Activation Products (AP), or Fission Products (FP)**
- **Similar solubility**
- **Similar transport process**

1) ISO 21238 "Scaling factor method to determine the radioactivity of low and intermediate-level radioactive waste packages generated at nuclear power plants"

2) IAEA TECDOC NW-T-1.18 "Determination and Use of Scaling Factors for Waste Characterization in Nuclear Power Plants"



- **Geometric Mean, Arithmetic Mean, Log-Linear Regression**
- **Collection of samples**
- **Manner of sampling as critical aspect**
- **Time Consuming, High budget**

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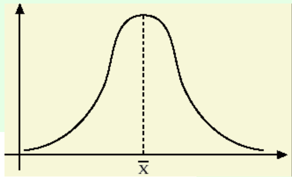
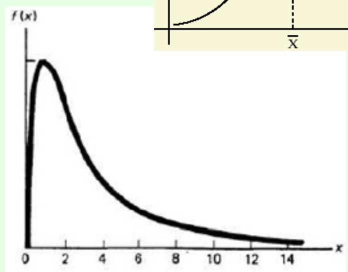
SF relationship

Regression in Logarithmic Scale:
$y' = a' + b'x' + u$; Normal distribution





Original Scale:
$y = ax^{b}\upsilon$; Lognormal distribution

if b=1 y = SF x; SF Geometric Mean, i.e. the Median estimator.
If $b \neq 1$; Nonlinear relationship

The one slope is usually inside the confidence interval of the regression slope.
If the one slope is obtained by regression analysis, 'a' is the Geometric Mean.

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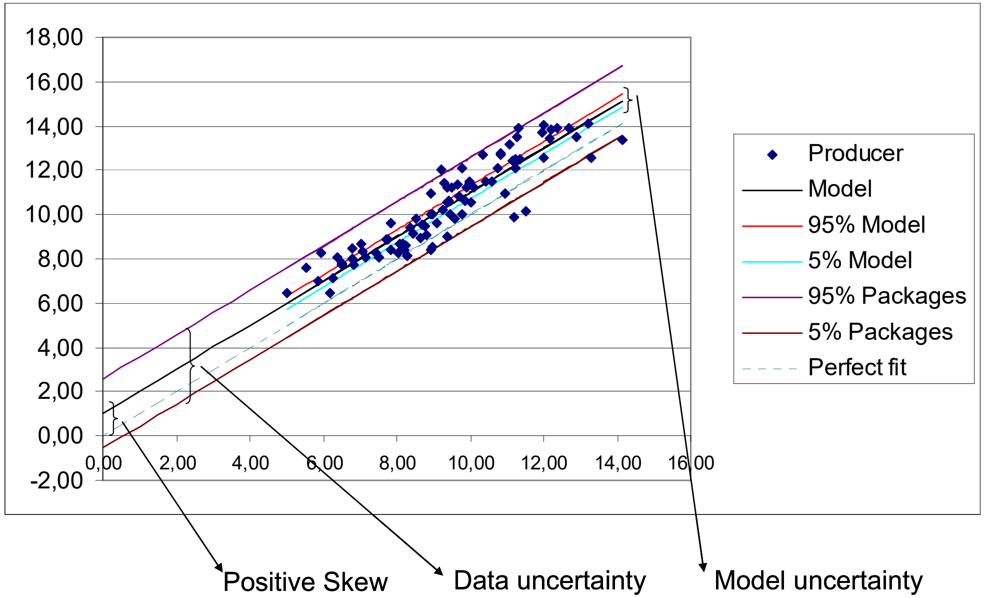
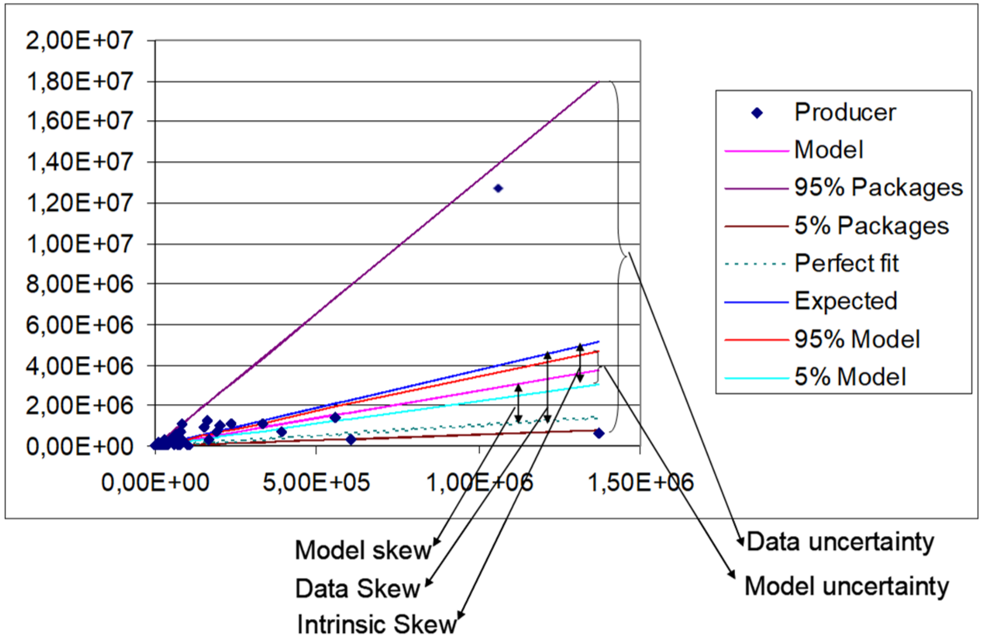
Log Scale vs Original Scale





Homocedasticity

Uncertainty constant

Heterocedasticity

Uncertainty growing with activity

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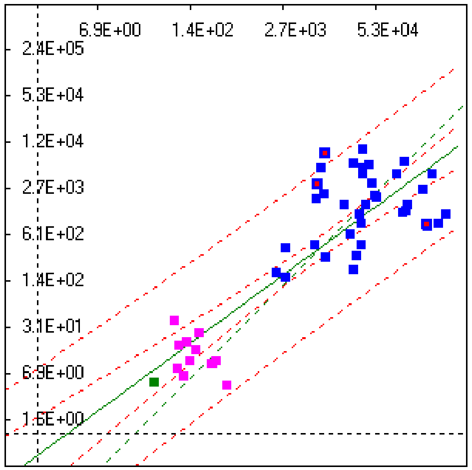
SF IMPROVEMENT

1. **SCALING FACTOR UNCERTAINTY AND BIAS IMPROVEMENT**
2. **PACKAGE UNCERTAINTY AND BIAS IMPROVEMENT**

- **NORMALLY U_{SF} IS DIRECTLY APPLIED TO PACKAGES**
- **NORMALLY BIAS IS NOT TAKEN INTO ACCOUNT**



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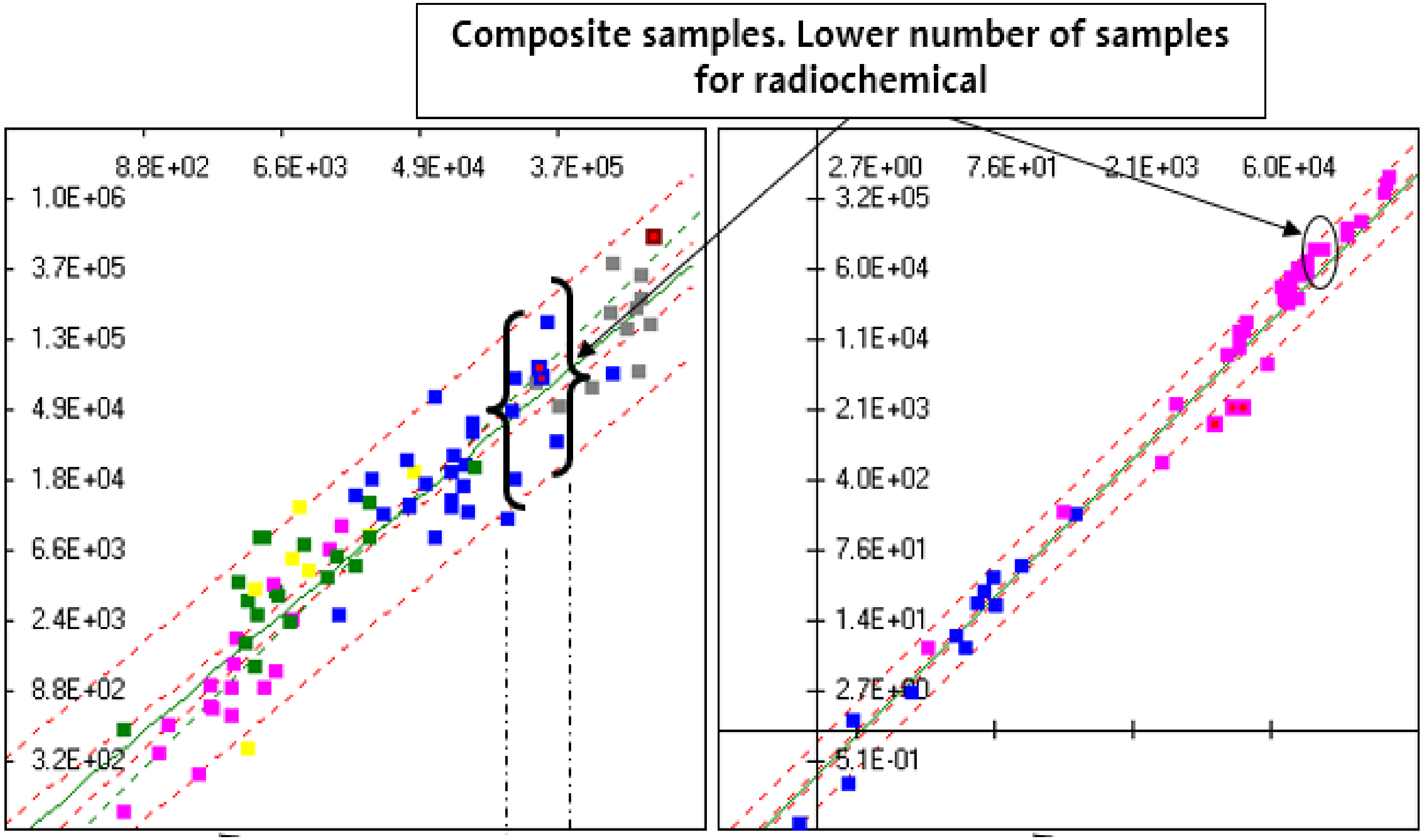
SF UNCERTAINTY IMPROVEMENT



Lowering Uncertainty

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SF UNCERTAINTY IMPROVEMENT

One Key nuclide

DTM=a + b·ETM +NEV1

Regression with more than one nuclide

DTM =a + b·ETM1+ c· ETM2+ NEV2

When Not Explained Variability, NEV, is reduced, then SF improvement, NEV2<NEV1

In the same way for secondary correlation

DTM1=a + b·DTM2

DTM2=c + d·ETM

Then a relationship between DTM1 and ETM, sometimes better than directly DTM1=e+f·ETM

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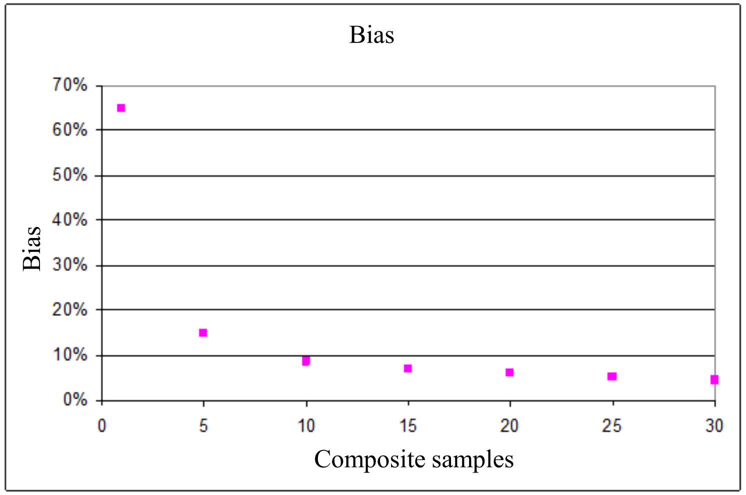
SF Bias due to log transformation

Regression in Logarithmic Scale:

y'=a' + b'x'+ u; Normal distribution

Original Scale:

$y=ax^b\upsilon$; Lognormal distribution



$E[y]= ax^b \exp(0.5u^2)$; Mean value.

Normally the Median value is used $y=ax^b$, but not the Mean.

As before, composite samples reduce u to $u/\sqrt{n}$, reducing the bias to $\exp(\frac{u^2}{2n})$

Composite samples implicitly reduce the bias.

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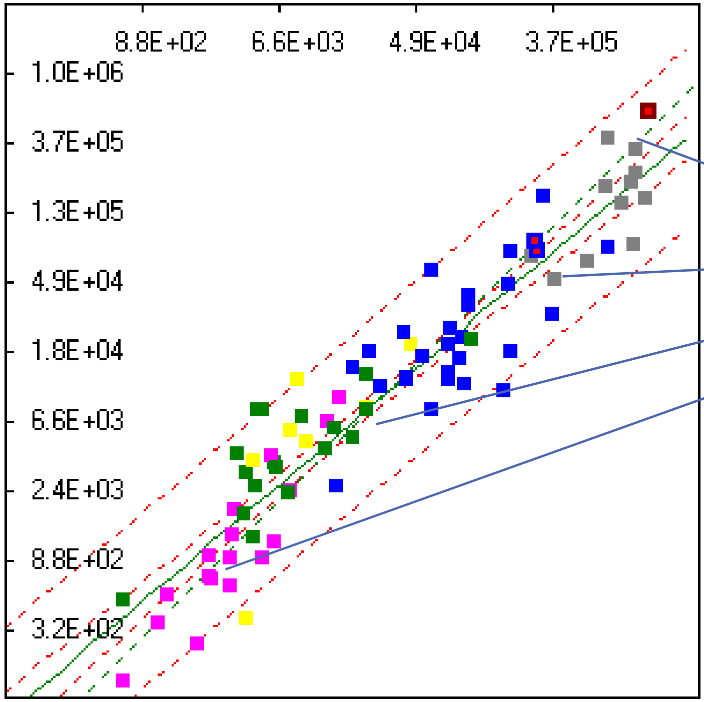
Package DTM Estimation



Waste in package coming exactly from the same places/ways as in the sampling process

Package like a big Composite sample

$U_{pk}=U_s\ m_s/M_{pk}$

Bias analysis

?

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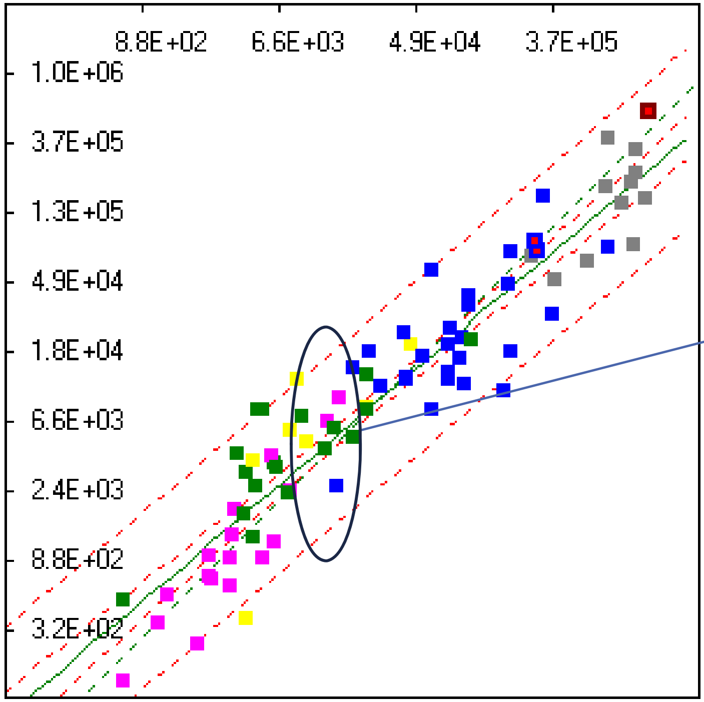
Package DTM Estimation



Waste in package only with a fix ETM range regarding the sampling process

Package like a big Composite sample

$U_{pk}=U_s\, m_s/M_{pk}$

Bias analysis

?

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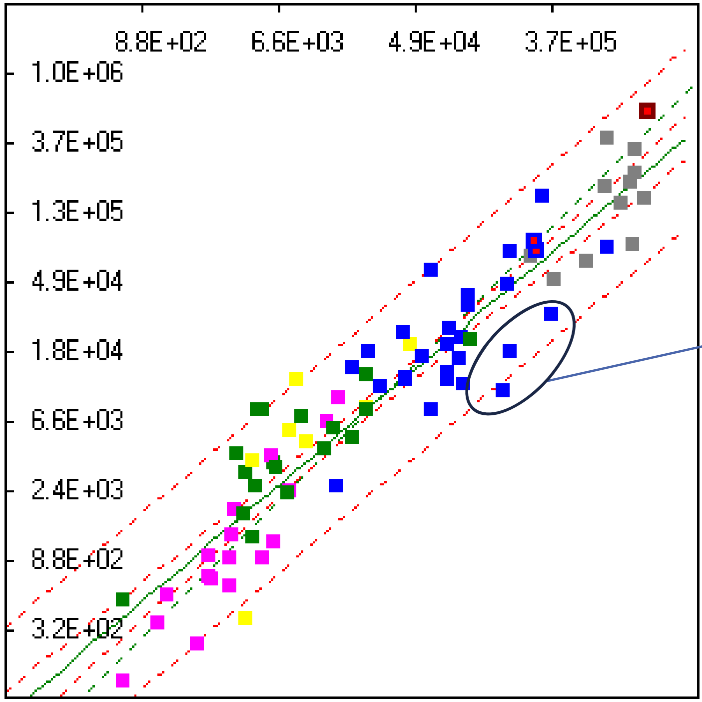
Package DTM Estimation



Waste in package only from a specific place/way regarding the sampling process

Drift plus residues prediction.
Kriging with external drift,
Universal Kriging, Intrinsic
Random Function, IRF(k).
Correlogram/Variogram.
Spatial/Time dependence.

?

Digitalize the RW Management, from raw waste(x,t)->Package->Storage->Disposal

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DTM Confidence interval

Confidence interval (95%) of the Scaling Factor (as a mean value):

$$\frac{SF}{e^{t_{n-1}\frac{SD'}{\sqrt{n}}}} \leq SF_T \leq SF\ e^{t_{n-1}\frac{SD'}{\sqrt{n}}}$$

Asymmetric confidence interval!

(--|------)

Confidence interval (95%) of total data :

$$\frac{SF}{e^{t_{n-1}SD'}} \leq SF_T \leq SF\ e^{t_{n-1}SD'}$$

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SF Refining Conclusions

- **Theoretical SF vs empirical SF**
  - **Model parameters.**
  - **Sampling as reference.**
  - **Time & Budget.**
- **SF model refining**
  - **Uncertainty analysis.**
  - **Bias/skewness analysis.**
- **Implement SF model to Package activity.**
  - **Different support than samples.**
  - **Sample space of waste package regarding SF model sample space.**
  - **RW digitalization.**

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THANK YOU VERY MUCH FOR YOUR ATTENTION

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