The rehab of measurement uncertainty in exposure assessment

On the waves of novelties in the evaluation of workplace air exposure assessment of the last decades, the random measurement error in workplace atmosphere sampling has gone under. Justifiable? At the IOHA 2024 (Thursday 13th June 11:35 - 13:05 in Session 11B 1872. Avion Stadium Dublin) the influence of measurement uncertainty on the upper tolerance limit in the usual small occupational hygiene sample sizes is presented.
That exposure assessments guidelines and tools in upcoming updates should quickly include this in their parameter free, frequentist and Bayesian antics. Measurement uncertainty: very boring and you don't make friends with it, but continuing to deny the influence seems to be a serious threat to the reputation of the quantitatively minded appraisers in our profession who juggle with measurement series between 2 and 10 in Similar Exposure (sub)Groups or Exposure Scenarios.

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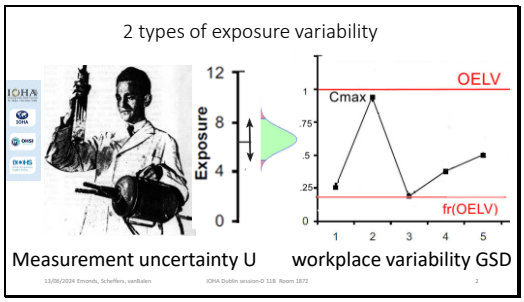
Slide 2



There are two types of variability in exposure assessment
The random errors made by performing a measurement. They are assumed to have a normal or bell-shaped distribution (left side of the slide).
And the much larger day by day variability due to temporary changes in source, application and controls (right side of the slide).

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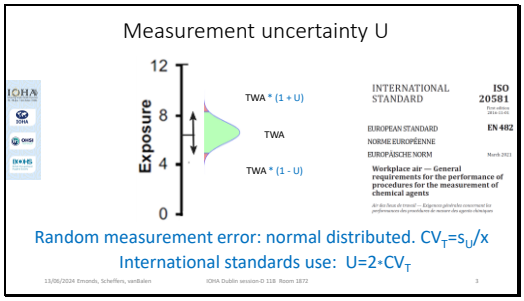
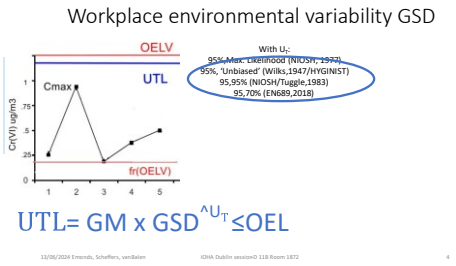
Slide 3



What causes measurement uncertainty, how it can be measured and what level of uncertainty is acceptable for workplace air is described in 2 international standards.
The random error is often expressed as CVt, the total coefficient of variation.
If you are able to perform several parallel samples at the same time and the same place, then you will find the TWA outcome distributed as the green and red figure. The CVt is the ratio of the standard deviation s_u and the mean x of multiple TWA parallel samples.
To establish the confidence interval around the measured value CVt is multiplied by a factor. This multiplier of CVt varied in time but at the moment is agreed to use 2.

Slide 4



The day-by-day variability in a similar exposure group or exposure scenario is mostly expressed in the lognormal measure for space-time dispersion: the geometric standard deviation or GSD.
Using this GSD, all serious exposure assessment guidelines calculate a so-called upper tolerance limit UTL.
If the upper tolerance limit of a series measurements in a similar exposure group is below the OELV then the SEG is said to be in compliance on all non-measured days.

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Let me share a charming anecdote about the city of Dublin where we find ourselves during the IOHA conference. In the early 1900s, William Sealy Gosset was working as the head experimental brewer at Guinness in Dublin. Gosset was conducting experiments with barley to determine the best yielding varieties. Like us, he often dealt with small sample sizes, sometimes as small as three.

To address the challenges posed by these small samples, Gosset developed a statistical theory using a specific distribution, which he published in 1908 in the scientific journal Biometrika. He used the pseudonym 'Student' because his employer preferred employees to use pen names when publishing scientific papers.

It was Ronald Fisher who later named the distribution 'Student's distribution' which we use nowadays in adapted forms (noncentral, lognormal) for UTL calculations, compliance testing, when comparing two subgroups and to test the credibility of Bayesian priors.

So, dear colleagues, let us be mindful that we are standing in the very cradle of the t-distribution we so often are obligated to rely upon in our work.

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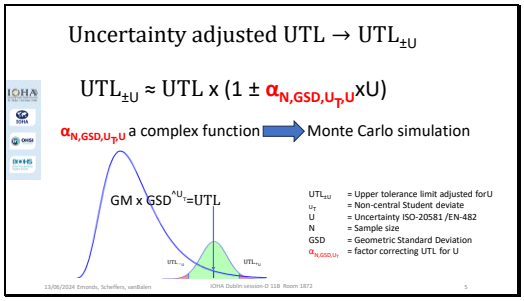
Slide 6



Should we combine the larger workplace variability expressed in the GSD with the mostly smaller measurement error U?
Based on the work of Nicas in 1991 showing the measurement error U is small compared to the GSD and the mathematical difficulties in combining a normal and a lognormal distribution the U was ignored in the last decades.
As your measurements may vary due to uncertainty, GM and GSD will vary too, leading to a confidence or reliability interval around UTL.

So, we are looking for a number α that addresses the influence of measurement uncertainty to the UTL.
A mathematical function for α does not exist but with current fast processors you can use straight forward Monte Carlo simulation to calculate α.
α depends on sample size, GSD and Gosset's deviate U_T, for given values of U.

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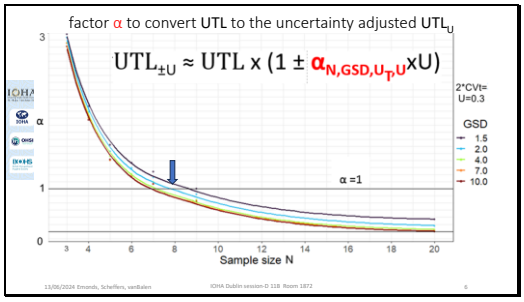

This fslide shows the value of α on the y-axis as a function of sample size N on the horizontal axis for different values of GSD (the parallel curves) and an expanded uncertainty of U=0.3 (CVt=15%).

The results of the Monte Carlo simulations show as expected that for large sample size the influence of U on UTL becomes smaller and smaller.
But also, that α rises over one when sample size decreases below 9.
N=2 is not included as the lower confidence limit of UTL becomes negative.
So, as you can see for the small sample sizes we use in occupational hygiene (N=2 to ~10) , the influence of U on UTL cannot be ignored.
What does that mean then, not ignored?

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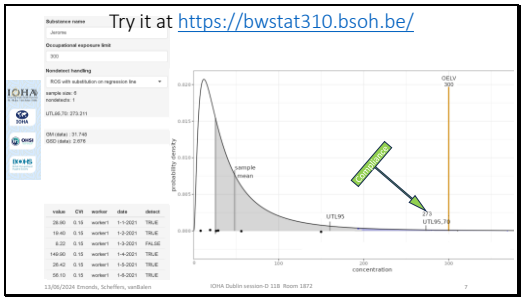
Slide 8



@Robert.Emonds@bsoh@be developed a try out variant of BWStat in which the upper tolerance UTL_U includes the measurement uncertainty U.
With the example data set of Jerôme Lavoué , we use to exchange our experience. BWStat calculates an $UTL_{95,70\%}$ of 273 which is in compliance with an OEL of 300.

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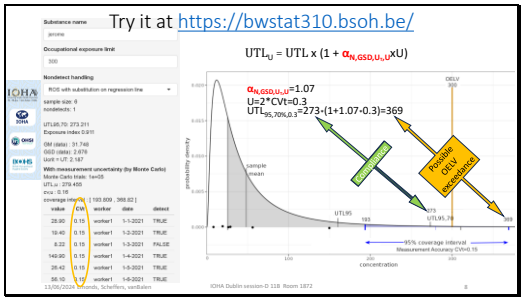
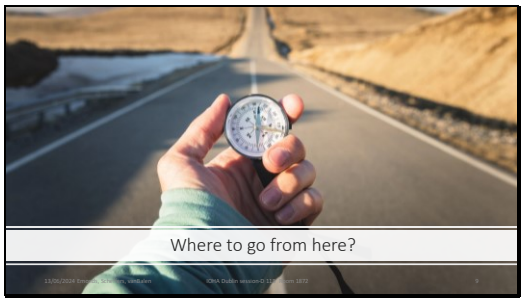


However, if we include an uncertainty of 30%, it indicates that there is a possibility of overexposure due to measurement uncertainty.
And you may find this in all SEG's sampled with a limited number and an exposure distribution UTL just below the OELV

Slide 10



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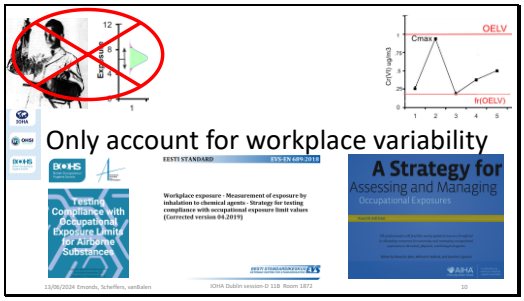
Slide 11



There are many exposure assessment guidelines, but these 3 recent ones do not mention anything about measurement uncertainty.
None of these guidelines take measurement uncertainty into account.

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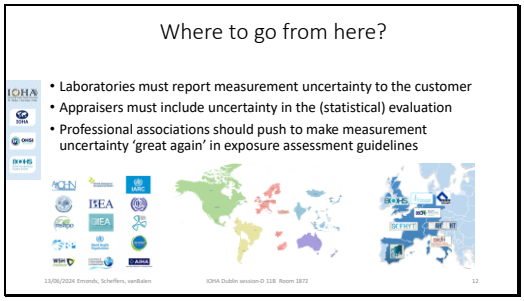

Where to go from here?

- Laboratories must report measurement uncertainty to the customer.
- Appraisers must include uncertainty in the (statistical) evaluation.
- Professional associations should push to make measurement uncertainty 'great again' in exposure assessment guidelines.

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