Computer-assisted technique for airborne dust sampling data representativeness and worker's exposure assessment - CAT-ReADS

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Politecnico di Torino, 23 e 24 Maggio 2018

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Occupational Safety and Health

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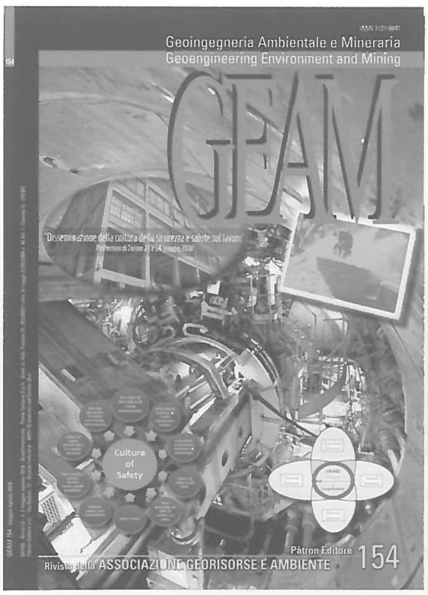

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Computer-assisted technique for airborne dust sampling data representativeness and worker's exposure assessment – CAT-ReADS

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1. Foreword

An effective Occupational Risk Management in a Quality approach consistent with the ISO 45001:2018 standard should copy with the statement "the *intended outcomes of an OH&S management system include:*

a) continual improvement of OH&S performance;
b) fulfilment of legal requirements and other requirements;
c) achievement of OH&S objectives."

"Performance" is a measurable result: Organizations should define the risk scenario through a quantification of the characterizing parameters on the basis of

Nowadays, occupational exposure to airborne dust is still one of the most concerning problems our society should face, since both airborne dust is a common pollutant in almost all the NACE sectors activities, and the occupational exposure quantification is critical. One of the possible causes can be identified in determining the real conditions of dust pollution in the workplaces, attributable to the delicacy of the various phases of acquisition of the measures, and on the variability of operations carried out by workers, affecting the pollutant emission rates. A research project in progress discusses the causes of uncertainty attributable to laboratory and sampling activities, and to the identification of the most appropriate techniques of the results' representativeness assessment. A recent result is the development of an original Computer-Assisted Technique for Airborne Dust Sampling data representativeness and worker's exposure assessment – CAT-ReADS. Developed Vbasic® MS-Excel® – it supports the companies and external audit technicians, from the setting of the surveys and the laboratory activities to the verification, in a rigorous metrological and statistical approach, of compliance/noncompliance of the field measurement results vs the limit values. The resulting workplaces pollution and workers' exposure assessment are free from subjective simplifications: CAT-ReADS includes various sections of guided selection and data analysis, covering Instruments and their calibration, Recording of environmental parameters and activities carried out by the workers during the samplings, Calculation of concentrations, Calculation of expanded uncertainty, Statistical tests for estimating the probability of exceeding the limit value, both referring – as is common practice – to the mean value, and, in a more cautionary way, to the upper uncertainty values (assuming a confidence level of 95%). The paper provides some examples of the implementation of CAT-ReADS in different production scenarios, and an in-depth discussion of the results.
Keywords: *representativeness of measures, quality approach to OS&H, workers' exposure assessment, dust sampling and analysis, OS&H software*

Approccio computer assistito alla valutazione di rappresentatività dei dati da campionamenti di polveri aerodisperse nei luoghi di lavoro e delle derivanti condizioni espositive dei lavoratori – CAT-ReADS. *Ancora oggi l'esposizione lavoro correlata a polvere aerodispersa costituisce uno dei maggiori problemi che la nostra società deve affrontare, poiché questo fattore di pericolo è presente in numerose attività lavorative e i metodi per la sua quantificazione sono critici. Una delle possibili cause può essere individuata nelle oggettive difficoltà nel determinare le reali condizioni di inquinamento da polveri nei luoghi di lavoro, imputabile da un lato alla delicatezza delle varie fasi di acquisizione delle misure, d'altro lato alla variabilità delle operazioni effettuate dai lavoratori, che si ripercuote sull'entità delle emissioni.*
Nell'ambito di un progetto di ricerca in corso si è proceduto ad una analisi delle cause di incertezza ascrivibili alle attività di laboratorio e sul campo, ed alla identificazione delle tecniche di valutazione di rappresentatività dei risultati più rigorose e confacenti.
Un risultato recente della ricerca è la messa a punto di un approccio originale computer-assistito – CAT-ReADS, impostato in MS-Excel® Vbasic® – sviluppato per supportare i tecnici aziendali ed i responsabili degli audit esterni dalla impostazione dei rilevamenti e delle operazioni di laboratorio alla verifica della conformità/non conformità rispetto ai valori limite normati (o riferimenti tecnici autorevoli) in rigoroso approccio metrologico e statistico, così da permettere una valutazione in qualità ed esente da semplificazioni soggettive.
CAT-ReADS comprende varie sezioni di selezione guidata e analisi dati, tra cui: Strumenti utilizzati e loro taratura, Registrazione parametri ambientali e attività svolte dai lavoratori durante il campionamento, Calcolo delle concentrazioni, Calcolo dell'incertezza estesa di tutto il processo di misurazione, Test statistici per la stima della probabilità di superamento del valore limite, entrambi riferendosi – come è prassi comune – al valore medio, e, in modo più cautelativo, agli estremi superiori di incertezza (assumendo un livello di confidenza del 95%). In questo lavoro vengono proposti esempi tratti da diversi scenari produttivi in cui il modello è stato applicato e validato, e discussi i risultati ottenuti.
Parole chiave: *rappresentatività delle misure, approccio in qualità alla sicurezza e salute del lavoro, valutazione dell'esposizione, campionamento e analisi di polvere, software per la sicurezza e salute del lavoro.*

Tab. 1. Ranking of operating and workplace pollution typical situations[1].
Categorie di attività e condizioni di inquinamento nei luoghi di lavoro.

1. Fixed operating position – almost constant pollutant concentration;	Increasing complexity in the characterization of the exposure conditions	Situation typical of macro productive organizations, (e.g. assembly-line); less frequent today than in the past years
2. Fixed operating position – limited fluctuations in the pollutant operating concentration;		increasing operating and pollution variability
3. Fixed position – variable pollutant concentration;		
4. Variable operating position – constant pollutant concentration;		
5. Variable operating position – variable pollutant concentration (the permanence time in each position is known);		
6. Variable operating position – constant or variable pollutant concentration (the permanence time is in each position unknown).		Situation today common in many production activities, where the raw materials used vary sometimes in composition, often in size.

[1] Even the ordinary maintenance interventions or programmed macro-steps assume different characteristics according to the typologies described above, with the additional problem of industrial choices in terms of conduction in own or relying on third parties.

reliable measurement results; such results can be achieved only through methods based on both the selection of suitable measuring devices, and on the definition of use procedures adequate to the case. Clearly, the single measure can in no case be considered significant for a correct Risk Evaluation: the quantification of risks, based on a consistent population, involves representative surveys scheduled to cover the totality of the investigated work activities and sub-activities, complete with exhaustive information on the characterizing uncertainty due to random factors.

A recent result of a research project in progress is the definition, for the special case of air-dispersed pollutants, of an organized and comprehensive approach suitable to ensure, even in such a complex contest, reliability of the resulting workplaces pollution and workers' exposure assessments, free from subjective simplifications[1], clearly consistent with the EN standards on the strategies of assessment of the pollutant concentrations at the workplaces.

Based on the aforesaid approach, Authors made also available the computer-assisted CAT-ReADS developed in MS-Excel® Vbasic®, fitted with guided selection forms and data analysis facilities, to support the companies' and external audit technicians.

2. *Method*

In almost all the modern production scenarios, the characterization of the workers' exposure entails firstly a general understanding of the workplace layout and production activities. This step is rather challenging, due to the variability of the activities of the workers and of the workplaces environmental conditions, as summarized in Tab. 1.

In these situations, taking into account confirmed research results (e.g. Patrucco, 2002), it is generally considered appropriate to give preference to personal samplings, even if they may increase the discomfort, and may be affected by alterations caused by the worker's behaviors. The exposure conditions assessment based on the results of a number of stationary samplings can in fact be laborious and inaccurate.

Similar to what suggested by the UNI EN 689:2018 Standard, the approach consists of the following steps, manageable through the CAT-ReADS software:

Step 0. preliminary survey:

The strategy begins with the characterization of the workplace processes, control measures, worker tasks, and pollutant properties. Based on this information, in some cases the workers can then be divided into groups with similar exposure profiles (Ramachandran, 2005, De Cillis *et al.*, 2015); the Authors strongly underline that this approach can sometimes be critical and misleading (Padovese *et al.*, 2017).

This preliminary survey requires walking through the plant, interviewing workers and gathering information about the processes and agents (Perkins, 2008).

The preliminary survey leads to the definition of the duration (representative of the shift or its subparts) and type of sampling (personal/ stationary, respirable/inhalable dust, etc.), the number of samples in each campaign, the reference production rates, etc. (Bisio *et al.*, 2016).

Step 1. investigational survey: it is the exposure assessment phase, whose goal is to gather exposure values to the pollutants, and entails five sub-steps:

Step 1.1. laboratory activities preliminary to the in-field samplings:

[1] Simplification and subjectivity are notoriously the main causes of incorrect assessments (and deriving management) of occupational risks.

Sampling lines are set (one for each worker), and sampling equipment is verified (UNI EN 13137:2015). In addition, the pumps' flow is calibrated; the filters (in our case mixed cellulose esters membranes with 346 mm^2 filtering surface and 0.8 μm pores' free light), in number covering both the scheduled samples and the "blank" of reference, are conditioned for 24 hours in a climatic cabinet at constant temperature and relative humidity (20 ± 1 °C and 50 ± 5 %); the filters mass is then measured by means of an analytical electronic balance resolution: 0,1÷0,01 mg (ref. to 2010:2011 and 1998:2013 Unichim procedures).

Step 1.2. in-field sampling: the pumps' flow is verified before and after each use, and the activities carried out by each individual worker[2], the materials handled, the equipment involved and any other significant parameter are registered, to clear up, in the following step 1.5, the possible outliers. During the samplings, the average, maximum and minimum values of the meteorological and microclimatic parameters are also recorded[3]; "blank filters" used to correct the result for the thermal and hygrometric variations remain in the sampling area, disconnected from the pump.

Step 1.3. laboratory activities following the in-field samplings: as in step 1, filters are conditioned and the mass of the "charged" filters and "blanks" is determined. Causes of possible errors in the transport and manipulation of samples – typically overcharged membranes – should be avoided, and, in the case the resulting data discarded on the base of pratical evidence (known inadequate handling) or suspect of unknown handling accident (using a statistical exclusion principle).

Step 1.4. calculation of the expanded uncertainty and check of quality objectives: firstly, the measurand is specified through a model, to make possible and univocal the comparison of the obtained concentration with the Occupational Exposure Limits – OEL or Threshold Limit Value – TLV. The model implies the normalization of the sampled air volume (Tref = 298,16 K, Pref = 1013 hPa reference conditions) (Tab. 2)

The uncertainty of the measurand results is calculated following the BIPM guide GUM (BIPM-JCGM 100: 2008) from the uncertainties of every variable of the model (every variable has many components of uncertainty (of A and/or B type according to GUM). Introducing a coverage factor selected on the basis of the desired level of confidence (UNI CEI 70098-3:2016) we can then calculate the expanded uncertainty[4].

Tab.2. The model representing the measurand.
Il modello adottato per rappresentare il misurando.

$$C = \frac{(m_2 - m_1) - (m_{2b} - m_{1b})}{(Q \cdot t) \cdot \left(\frac{P}{P_{ref}}\right) \cdot \left(\frac{T_{ref}}{T}\right)}$$

C = airborne particulate concentration;
m_2 = mass of filter after sampling;
m_1 = mass of filter before sampling;
t = sampling time;
Q = pump volumetric flowrate;
m_{2b} = mass of blank after sampling,
m_{1b} = mass of blank before sampling,
P = pressure,
T = temperature.

Table 3 provides an example of the output of CAT-ReADS, applied to the calculation of the expanded uncertainty in a real case (investigation on airborne dust concentrations). The columns list respectively:

- "Symbol": the variables' symbols of the physical-mathematical model;
- "Value": the variables' values of the model;
- "Note": types of uncertainty contributions;
- "Statistic" (Type A) and "Non statistic" (Type B): information on every contribution depending on their variability declaration data;
- "Assigned parameters": information on the degrees of freedom of each uncertainty contribution, input variability information obtained on single data or n_d data average, output variability information given on single data or n_r data average;
- the following column contain the equivalent variance $u^2(x_j)$, calculated from the previous variability data. Thereafter, calling generically y the dependent variable of the mathematical model (in this case y is the concentration C), there are the sensitivity coefficients c_j, calculated as partial derivatives $\partial y/\partial x_j$ the contributions $u_j2(y)$ to the variance of y for each uncertainty factor, and data necessary for calculating the y degrees of freedom. The last column contains the rank of the contributions $u_j^2(y)$, thus allowing to see immediately the more critical factors. The sum

[2] To get a representative result, it is important to verify carefully that the workers equipped with personal samplers carry out their activity according to what documented during the preliminary survey.

[3] The measurement instruments must be chosen according to the criteria pointed out in step 0; in the case of the exemples discussed in the following, multiprobe microclimate set with range 0 ÷ 50 °C ± 0,5 °C, RH 0 ÷ 100 % ± (1,8 % RH + 0,7 % of a.v.), 700 ÷ 1100 hPa ±3,0 hPa, 0 ÷ 5 m/s ± (0,03 m/s + 4% of a.v.), and meteorological station with range 0 ÷+60 °C ± 1°C; 12 ÷ 99 %RH ± 5 %; 919 ÷1080hPa ± 3 hPa.

[4] According to UNI EN 482:2015, if the expanded uncertainty exceeds 30%, in the range 0,5÷2 times limit value, or 50%, in the range 0,1÷0,5 times limit value (long-term sampling), the concentration data should be discarded.

Tab. 3. Example of output of the CAT-ReADS software:
Esempio di output del software CAT-ReADS.

Variable x_j			Statistics					Non-Statistics		Assigned parameters							
Symbol	Value	Note	U_j	P_{dj}	n_{dj}	k_{dj}	s_j	a_j	k_a	n_j	n_d	n_r	$u^2(x_f)$	$c_i = Dy/Dx$	$u_j^2(y)$	$u_j^4(y)/n_j$	Rank
m_2	1,88E+01	Ripr		95,0%	100	2,0	8,1E-03		3	30	1	1	6,6E-05	9,4E-01	5,9E-05	1,1E-10	22
		Ris		95,0%	100	2,0		5,0E-03	3	100	1	1	8,3E-06	9,4E-01	7,4E-06	5,5E-13	16
		Pres. Eff		95,0%	100	2,0		5,5E-03	3	30	1	1	1,0E-05	9,4E-01	9,0E-06	2,7E-12	20
		trasp.		95,0%	100	2,0			3	30	1	1	0,0E+00	9,4E-01	0,0E+00	0,0E+00	
m_1	1,87E+01	Ripr		95,0%	100	2,0	8,1E-03		3	30	1	1	6,6E-05	-9,4E-01	5,9E-05	1,1E-10	24
		Ris		95,0%	100	2,0		5,0E-03	3	100	1	1	8,3E-06	-9,4E-01	7,4E-06	5,5E-13	18
m_{2b}	1,89E+01	Ripr		95,0%	100	2,0	8,1E-03		3	30	1	1	6,6E-05	-9,4E-01	5,9E-05	1,1E-10	24
		Ris		95,0%	100	2,0		5,0E-03	3	100	1	1	8,3E-06	-9,4E-01	7,4E-06	5,5E-13	18
		Pres. Eff		95,0%	100	2,0			3	30	1	1	0,0E+00	-9,4E-01	0,0E+00	0,0E+00	
		trasp.		95,0%	100	2,0			3	30	1	1	0,0E+00	-9,4E-01	0,0E+00	0,0E+00	
m_{1b}	1,91E+01	Ripr		95,0%	100	2,0	8,1E-03		3	30	1	1	6,6E-05	9,4E-01	5,9E-05	1,1E-10	22
		Ris		95,0%	100	2,0		5,0E-03	3	100	1	1	8,3E-06	9,4E-01	7,4E-06	5,5E-13	16
Qrif	2,20E+00	Ripr		95,0%	100	2,0	3,7E-03		3	30	1	1	1,4E-05	-6,9E-02	6,6E-08	1,4E-16	12
		Ris		95,0%	100	2,0		5,0E-04	3	100	1	1	8,3E-08	-6,9E-02	4,0E-10	1,6E-21	7
Q	2,18E+00	Acc		95,0%	100	2,0	6,0E-03		3	9	1	1	3,6E-05	-6,9E-02	1,7E-07	3,3E-15	13
		Ris		95,0%	100	2,0		5,0E-02	3	100	1	1	8,3E-04	-6,9E-02	4,0E-06	1,6E-13	15
		Ripr		95,0%	100	2,0	1,9E-02		2	9	1	1	3,6E-04	-6,9E-02	1,7E-06	3,3E-13	14
	flow stability			95,0%	100	2.0		1,1E-01	3	30	1	1	4,0E-03	-6.9E-02	1,9E-05	1,3E-11	21
t	4,9E+02	Acc		95,0%	100	2,0		3,4E-01	3	30	1	1	3,9E-02	-3,1E-04	3,7E-09	4,5E-19	9
		Ris		95,0%	100	2,0		5,0E-01	3	100	1	1	8,3E-02	-3,1E-04	7,9E-09	6,3E-19	10
		Ripr		95,0%	100	2,0		5,0E-03	2	100	1	1	1,3E-05	-3,1E-04	1,2E-12	1,4E-26	4
P	9,96E+02	Ripr		95,0%	100	2,0	1,0E-01		3	30	1	1	1,0E-02	-1,5E-04	2,3E-10	1,8E-21	6
		Ris		95,0%	100	2,0		5,0E-01	3	100	1	1	8,3E-02	-1,5E-04	1,9E-09	3,7E-20	8
T	2,27E+01	Acc		95,0%	100	2,0		5,0E-01	3	30	1	1	8,3E-02	5,1E-04	2,2E-08	1,6E-17	11
		Ris		95,0%	100	2,0		5,0E-02	3	100	1	1	8,3E-04	5,1E-04	2,2E-10	4,7E-22	5

C	0,15	mg/m³

Variance $u^2(v)$	3,0E-04	4,7E-10
Combined standard uncertainty u(y)	1,7E-02	
Degrees of freedom n(y)	187	
Confidence Level	95%	
Coverage factor (t Student)	2,0E+00	
Expanded uncertainty U(y)	22,54%	

of the contributions $u_j^2(y)$ is the total variance of y, its square root the standard uncertainty, thereafter, using the confidence level corresponding to the relevant acceptable risk of error, the coverage factor and the expanded uncertainty is calculated (Barbato *et al.*, 2013).

Step 1.5. Analysis and interpretation of result[5]: the outliers are pointed out and – where appropriate – excluded from the log-transformed concentration data set: the decision necessarily involves the judgement of the technician entrusted of the in-field operations who monitored the activities of the workers. Subsequently the hipothesis of normality of the logtransformed is verified by means of the Shapiro-Wilk test (Shapiro and Wilk, 1965). Finally, the One-sided Tolerance Limit – OTL Tuggle method (minimum number of required measures = 3) (Tuggle, 1982) – or Leidel & Busch method (Leidel *et al.*, 1977) are used. In particular, the Leidel method can be applied also in non-stationary working situations imposing short-term samplings during an 8-hours shift, from 3 (minimum) to 25 (maximum). The estimate of the probability of exceeding the

[5] Based on a preliminary critical survey on a number of techniques for evaluating the samples' correlation: the opportunity to operate directly on the log-transformed values, and to first identify the outliers played a role in the selection.

limit value is then possible, within a selectable risk error (confidence level), also with a small number of measures; if the number of measures is not sufficient (no decision situation), the sample size should be increased, and the same methods make possible to complete the analysis reaching a compliance/ noncompliance result[6] (the approach is compatible with the suggestion of both UNI EN 689:2018 and the French regulation (Ministère du travail, des relations sociales, de la famille, de la solidarité et de la ville. Arrêté du 15 décembre 2009), as will be discussed for a practical case).

[6] In particular, the OTL Tuggle method can directly help the analyst in the prevision on of the number of additional samples necessary (the definition of the number of necessary samples derives from the model itself).

The measurement's uncertainty should be considered in the use of these methods, since if it is necessary to verify the non-compliance (ISO IEC Guide 98-4:2012), it is advisable to add the expanded uncertainty to the concentration values obtained.

Step 2. combined hygiene and medical survey: the results of the investigational survey should be integrated with medical examinations by Occupational Medicine experts. Thus, the accuracy of exposure assessments is a fundamental step for subsequent epidemiological studies based, for example, on the analysis of mortality of the workers (Donato *et al.*, 2016, Pira *et al.*, 2017).

This approach, and the CAT-ReADS software, were validated in three real situations characterized by different operating and pollution conditions (scenarios 1,2 and 3 of Tab. 1), assuming TLV=10 mg/m^3 for the

Tab. 4. CAT-ReADS Software home page, logical structure, and main options available.
Home page del software CAT-ReADS, struttura logica e principali opzioni incluse.

POLITECNICO DI TORINO
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COMPUTER ASSISTED TECHNIQUE FOR AIRBORNE DUST SAMPLING DATA REPRESENTATIVENESS AND WORKER'S EXPOSURE ASSESSMENT
CAT-ReADS

START

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Research team. ing Rebecca Nebbia, Luisa Maida, Paolo Fargione
software engineering: Rebecca Nebbia

Step	Content	Note
Preliminary data collection	– Company general data; – information on the departments to be investigated, and on the productive activities; – technical, organizational and procedural measures adopted in accordance with the safety documentation of the Company.	1. it is possible to insert documents in PDF format (e.g. layout, parts from OS&H documentation, etc.); 2. all information is anonymously entered by reference codes, whose reading key is managed in a separate list.
Pre-Sampling laboratory activities	– specifications of the instruments to be used; – results of laboratory calibration operations; – filters' conditioning, and subsequent mass determination.	
Sampling	– testing of samplers' flow, and determination of local microclimatic parameters; – record of the activities carried out by the workers;	3. it is possible to insert photographic documentation of the field activities (in JPG format).
Post-Sampling laboratory activities	– filters' conditioning, and subsequent mass determination;	
Calculation for every measure	– determination of dust concentrations, complemented by their expanded uncertainty, and calculation of the detection limit of the method.	
Calculation for data set	– identification of outliers of the data set, and verification of its lognormal adaptation variability; – use of statistical representativeness criteria on the data set.	4. it is possible, through external links, the identification of the most appropriate technical reference values: 5. several options for the verification of the representativeness of the samples from homogeneous groups of different size.
Other	– printing and archiving options.	6. it is possible to store the results of individual campaigns; 7. various options for printing results.

inhalable fraction and TLV=3 mg/m^3 for the respirable fraction (ACGIH, 2018, UNI EN 481:1994); the duration of each sampling covers the entire work shift in all situations. In paragraph 4.1, the Authors provide a discussion on the achieved results.

Variable operating position – variable pollutant concentration situations (scenarios 5 and 6 of Tab. 1), typical e.g. of the laboratories of dimension stones, where the mineralogical nature of the materials, and the typology and duration of processes can vary in time, are still under investigation.

3. The CAT-ReADS software

Table 4 summarizes the structure of the CAT-ReADS software, and the main available options.

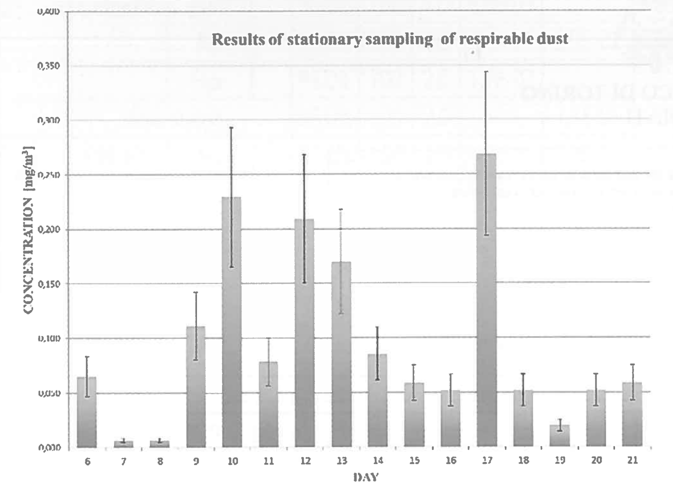
4. Results and discussion

4.1. Fixed operating position – almost constant pollutant concentration

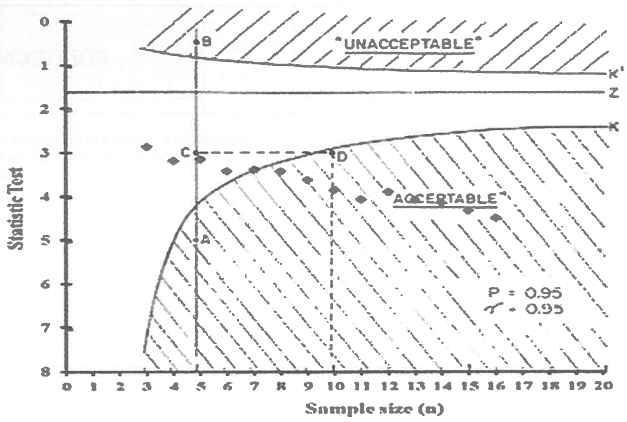
Stationary samplings (Tab. 5 on the left) were carried out from July to September, and show a high variability (Geometric Standard Deviation – GSD = 3,03), with an expanded uncertainty of almost 28%. A GSD greater than 2.0 indicates unreliable control of worker's exposures (Ziembicki *et al.*, 2015).

In addition, the use of the OTL Tuggle method (Tab. 5 on the right) shows an acceptable situation (with 95% confidence) only after 7/8 measurements. Because of the data high variability, it is not possible yet, with only 6 measures, to make decisions on compliance or non-compliance.

Tab. 5. Fixed operating position – almost constant pollutant concentration (respirable fraction) (Bisio P. *et al.*, 2017).
Postazione di rilevamento fissa, concentrazione di particolato pressoché costante, risultati sulle polveri respirabili (Bisio P. et al., 2017).



Concentrations of respirable dust obtained by stationary sampling in an office and related uncertainty bars

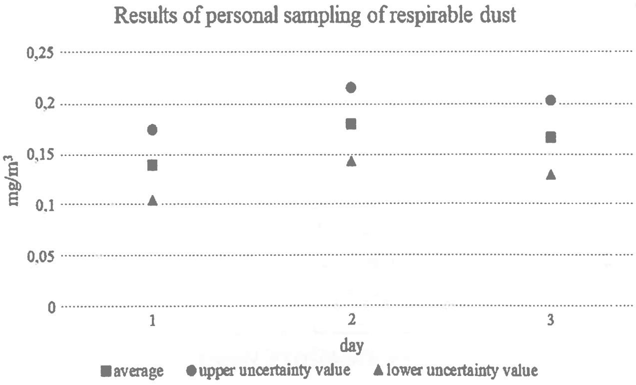


Result of use of the Tuggle method

Tab. 6. Fixed operating position – limited fluctuations in the pollutant concentration: respirable dust concentration values resulting from personal samplings on a shell molds manufacturing operator.
Postazione di rilevamento fissa, concentrazione di particolato semi-costante, risultati della indagine sulle polveri respirabili (campionamenti di tipo personale) – formatura motte

Mean of Logtrasformed Normalized Measurements x	$\frac{\sum Log(PR_i)}{n}$	-1,267
Sample Standard Dev. of Logtrasformed Normalized Measurements S	$\sqrt{\frac{\sum [Log(PR_i)]^2 - n \cdot x^2}{(n-1)}}$	0,057
Statistic Test- T	$-\frac{x}{S}$	22,137
Sample size n		3

OTL Tuggle test: CAT-ReADS output. The T and n values directly confirm an *acceptable* situation



This demonstrates that even if a worker is in a working environment theoretically with a constant pollutant concentration, this should still be verified by at least 3 initial measurements, as recommended also by the British Occupational Hygiene Society, EN 689:2018 standard, and French Regulations.

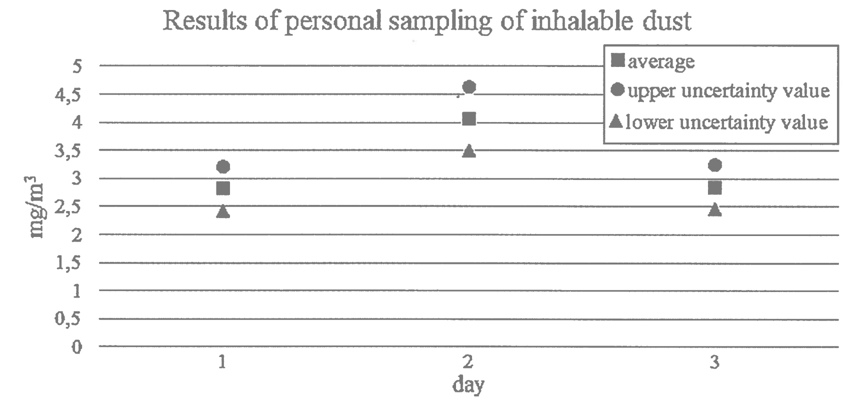
4.2. Fixed operating position – limited fluctuations in the pollutant concentration

Table 6 shows respirable dust concentrations collected with personal sampling on a shell molds manufacturing operator during a 3-day sampling campaign. The use of the OTL Tuggle method shows that less than 5% of the exposures exceed the TLV with a 95% confidence; moreover, GSD = 1,14, witch confirmed the little variability of data: the situation results then *acceptable* without need of additional measurements, in accordance also to UNI EN 689:2018.

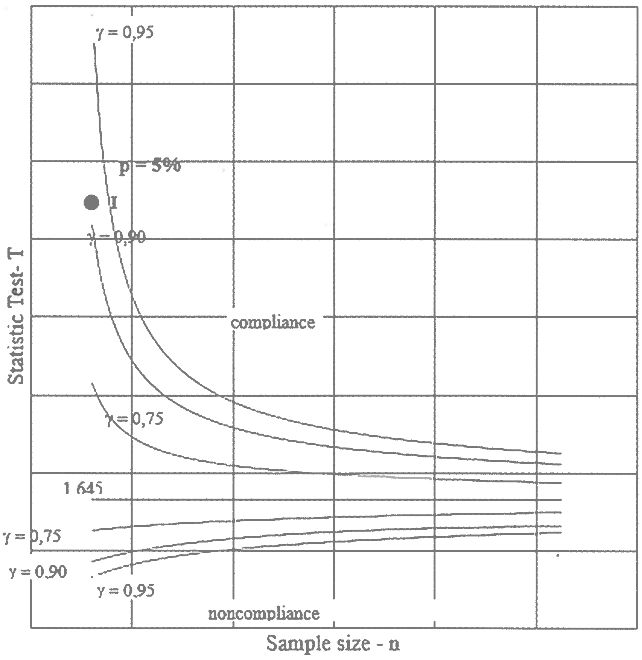
4.3. Fixed operating position – variable pollutant concentration

Table 7 shows the results in the case of a press operator. The use of the OTL method after 3 days of sampling shows the need of additional measures, since the point I falls into the no-decision region: we are not able to make judgement about the compliance/

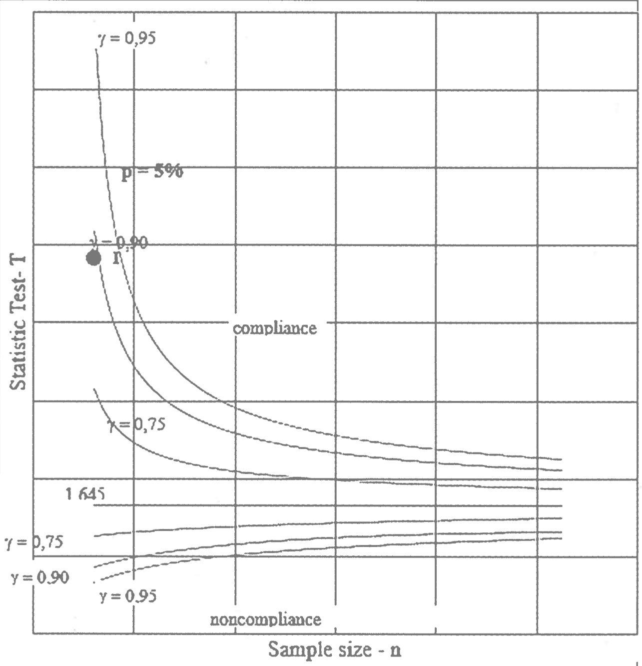
Tab. 7. Fixed position – variable pollutant concentration, inhalable dust concentration values resulting from personal samplings.
Postazione di rilevamento fissa, concentrazione di particolato variabile, risultati della indagine sulle polveri inalabili (campionamenti di tipo personale).



inhalable dust concentrations resulting from personal samplings on a press operator in the case of fixed position and variable pollutant concentration.



OTL Tuggle method applied to the mean concentration values in the case of fixed position and variable pollutant concentration – final output of the CAT-ReADS software



OTL Tuggle method applied to the upper uncertainty value of the pollutant concentration values in the case of fixed position and variable pollutant concentration – final output of the CAT-ReADS software not compliance with the adopted reference value. In particular, if we consider only the average values of concentrations (graph on the left of Tab. 7), the method involves the minimum number of four measures; if we include also the expanded uncertainty (graph on the right of Tab. 7) we need at least five additional measures with 95% confidence.

A previous study (Nicas *et al.*, 1991) states that the environmental variability (which can be represented by the geometric standard deviation) of the lognormally distributed 8-hr time-weighted average exposures measurements is far more important than the analytical variability (related to the normally distributed collection, and analytical errors). However, considering the upper uncertainty value, as in the lower right box of Tab. 7, is cautionary particularly in no-decision or close to the limit situations.

The OTL method demonstrates – with 90% confidence and considering the upper uncertainty value – a tendency towards a noncompliance situation, and the need of technical countermeasures, after 7 measurements in two visits. Such result is coherent with both UNI EN 689, that recommends a total of at least 6 measurements, and the French regulation, envisaging however three visits spaced into one year, each involving at least three measurements, so that a complete program generates at least 9 measures (Ogden *et al.*, 2012).

5. Conclusion

The present study summarizes the results of the development of a Computer-Assisted approach (CAT-ReADS), aimed at supporting the activity of analysts – companies' and external audit technicians of confirmed OS&H background – in the evaluation of the airborne particulate exposure of workers in the workplace along the entire decision making process, from the setup of measurement campaigns and laboratory operations, to calculations (e.g. concentration expanded uncertainty), and selection of the best analysis technique of data sets from sampling campaigns for compliance – noncompliance assessment with selected limit values.

The technique is methodologically rigorous, and points out directly the need of technical countermeasures if necessary. Moreover, it is consistent with the EN standards on the strategies of assessment of the pollutant concentrations at the workplaces, and can contribute to an effective Occupational Risk Management in a Quality approach according to the ISO 45001 Standard.

CAT-ReADS is well-tested, and the results achieved in three markedly different production situations are proposed and discussed.

Apart from a considerable saving of time, CAT-ReADS reduces the probability of manual errors in data processing, and brings the following advantages:

a) the storage of all filled data during the different sampling steps (workshop layout, photo images on activities and organization, data on equipment, etc., in the current formats);
b) the development of a database of the measurement campaigns for each Company.

The software can also produce, in a semi-automatic way, final reports specially designed to preserve the confidentiality of sensitive data, associating independent reading keys.

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