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Definition and Validation of approaches special for OS&H in Research Universities, from Risk Assessment to Quality Management in the frame of PoliTo-UniTo Guideline

Paolo Fargione

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Supervisor
Prof. Eng. M. Patrucco

Doctoral Examination Committee:
Prof. D. Hoeneveld, Referee, Technical University of Delft
Prof. A. Martinetti, Referee, University of Twente
Prof. J. Dennerlein, Northeastern University
Prof. M. Galetto, Politecnico di Torino
Prof. E. Pira, Università degli Studi di Torino

Politecnico di Torino
August 24, 2019

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Paolo Fargione

Turin, August 24, 2019

Summary

Occupational Safety and Health - OS&H is particularly complex in the case of research universities due to a number of typical characteristics that make inadequate the usual approaches to OS&H in industries or secondary educational institutions.

The PhD research project provides substantial developments in some sub-phases of the well-tested Guideline for the Occupational Risk Assessment and Management of employees, students and people in research universities, resulting from a multidisciplinary cooperation of experts from Politecnico di Torino and Università degli Studi di Torino. The research work concerns the analysis of two strictly connected topics of basic relevance for an exhaustive Occupational Risk Assessment and Management for particularly critical areas in research universities:

- *Systematic evaluation of the operating contexts;*
- *Workers' exposure model definition.*

With regard to the first topic, the research validates a special sub-part approach of the Guideline, ensuring a systematic evaluation of the operating contexts in complex facilities, where the most serious criticalities are often of no direct identification. The approach is based on an original development of Forensic Investigation techniques to support the Hazard Identification on shell, services and interior spaces of premises containing workplaces, and on their not-operative content. A series of tests confirmed the effectiveness of the approach in terms of completeness and repeatability, and made possible to draw suggestions on the selection of the better technique in different scenarios. The approach was extended in contexts where "concealed criticalities" (i.e. asbestos containing materials) can be present. Within a Quality Management strategy of these contexts, preliminary tests on high-quality image taking technologies and computerized procedures of image processing and interpretation made possible

systematic checks on the state of conservation of artefacts not needing immediate action, for a real time updated database on critical materials present in the different areas.

Within the second topic, the definition of the workers' exposure to identified Hazard(s) requires measuring processes to quantify the Hazard Factor(s): the measuring processes quality and the measures interpretation lay at the very base of an effective OS&H Risk Assessment, and of the decision-making processes leading to an effective Prevention. The research work discusses an approach to prove the measuring equipment capability to comply the metrological requirements, ensuring the quality of results in terms of metrological confirmation and measuring process efficiency, thanks to key performance indicators used in process quality assessments. The research work also provided a rigorous approach for the design and management of sampling campaigns (as starting point for a subsequent PhD project "Management of work related risks through the measures quality"), making possible the use of formalized evaluation techniques for the measures interpretation, from the potential outliers' analysis to the data representativeness evaluations. Within the same topic, a special study enabled to assess the influence of measure uncertainties in very low measured values, e.g. in contexts where degradation phenomena on artefacts containing asbestos can make airborne asbestos fibres. The scenario is frequent in some research universities sited in settlements built, or involved in maintenance interventions, during the '90s.

A visiting study abroad made possible a research context exploration and a sharing of methods, approaches and ideas on the Safety management in the research field, through an overview of the approaches adopted in different scientific research contexts, making clear as the OS&H management approaches shall be specific and tailored for each context.

PhD research work also covered the study of some complex situations (e.g. highway maintenance yards and tunnelling operations) aimed to draw indications for an effective assessment and management of work-related risks, adoptable to address criticalities that sometimes occur also in large public facilities and universities.

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Introduction

1.1 Context of research

The Occupational Safety and Health – OS&H, multidisciplinary field aimed to protect the safety and health of workers, is an ethic issue but also social requirement and political priority, which plays a key role in the sustainable development of all countries.

In Europe, the commitments of different governments to improve the OS&H conditions are encouraged by the European Directives providing the principles to improve the safety and health of workers at work. According to the European regulations, first of all the Framework European Directive 89/391/EEC, an effective improvement of the OS&H conditions can be achieved only through a careful and exhaustive Risk Assessment and Management resulting in a complete and continuously updated consciousness of the residual risks concerning each worker. The correct approach for an effective Risk Assessment and Management requires to select the modus operandi really effective in the special situation under exam. This statement, of general value, is clear from the Hazard Identification – H.I. technique selection, very first step of the Risk Analysis process; the H.I. represents a critical phase since Hazard Factors not correctly identified cannot be correctly assessed and managed.

An exhaustive Risk Assessment, leading to a clear risks hierarchy upon which to base the Management phase, can result a demanding task particularly in complex situations, e.g. where the analysis focuses on activities which are involved in both high degree university education and in advanced research, the latter performed in special working environments, e.g. research laboratories.

As confirmed also by the results of the abroad visiting research aimed to study the formalized approaches and special research works for the OS&H management in European research institutes, the OS&H in research universities represents a challenging field due to a number of peculiarities characterizing these special workplaces.

To endorse this concept, the journal article "Urging universities to act on safety", published by Beryl Lieff Benderly in the scientific journal "Science", discusses the effort to rise the Safety awareness in research universities, concretized in the commitment of the Association of Public and Land-grant Universities - APLU to implement the Culture of Safety in the public universities of U.S., Canada, and Mexico (Benderly, 2016).

APLU is an organization dedicated to strengthening and advancing the work of public universities. The association's membership includes 23 university systems and 211 universities, of which 74 are U.S. land-grant institutions. Within the APLU, a special Task Force on Laboratory Safety provides research universities with recommendations and guidance on the most appropriate strategies to enhance a Culture of Safety. The raised awareness and highlighted need for a stronger safety consciousness in U.S. universities, in response to significant events, including serious accidents occurred to research assistants and graduate students, induced the Task Force to some important initiatives. Among these, some Call to Action to all universities to embrace a renewed commitment to improving the Culture of Safety for all academic research, scholarship, and teaching, and the drafting of a report (Fig. 1) titled *A Guide to Implementing a Safety Culture in Our Universities* (Association of Public and Land-grant Universities, 2016), a roadmap for a university-wide effort to strengthen a culture of research safety.

Figure 1 APLU document front page

1.2 The problem statement

The often-large number of different cultural, teaching and research coexisting areas involving different facilities, conditions the Occupational Risk Assessment and Management in the academic/research fields, increasing the number/typology of Hazard Factors. Moreover, in research activities, the exploration of innovative fields can often involve experimental processes, use of innovative physical, chemical, biological substances, design and use of equipment and machinery specially designed and constructed for research purposes etc. In this scenario, a preliminary careful H.I. and an effective workers' exposure definition, on the basis of measurements performed in system quality and correct exposure data interpretation, become pivotal.

A very large number of employees and students with different background and skills (e.g. professors, researchers, fellows, PhD students, technicians, students) co-works in universities. Furthermore, it is frequent the presence of visiting professors and experts, both as individuals and in groups, and students' relatives, for example during the graduations. The difficulty to schedule the number of students, in a growing percentage from foreign countries- due to social and contingent reasons, conditions the organization and makes it necessary a careful plan of information and training, especially for people involved in research programs for a limited time span (research fellows, PhD students, etc.).

The university system organization is complex, in terms of structures and staff: a well-defined chain of responsibilities and obligations on OS&H matters is fundamental.

Many European universities, in particular Italian ones, are settled in premises of different ages; the historical/artistic value of some of these buildings entails the need of a careful preservation, imposing a non-invasive design of the safety structural measures and fittings, and makes inapplicable the safety rules conceived for new buildings. Moreover, the year of construction of some university facilities can entail OS&H problems due to the possible presence of highly critical materials, first of all the asbestos.

Finally, some important security problems (e.g. related to free admission areas, security of data and inventions or patents), typical of universities, need of a careful management.

The brief overview of some peculiar characteristics of the universities/research contexts makes perceive the inadequacy of the approaches usually adopted for the OS&H management in industries or secondary educational institutions, which results in the needed of increased efforts to improve the OS&H conditions mainstreamed with actions to strengthen the dissemination of Culture of Safety.

1.3 Research methodology

The above-discussed research universities peculiarities clarify the necessity of tailored approaches to assess and manage the work-related risks. In this direction, the research activity carried out during the abroad 3-month visiting period in Dutch research institutes, confirmed the implementation of dedicated and specially fit methods to manage the OS&H problems.

Taking into account the complexity of the context, the present research work aims to develop and test approaches to manage peculiar OS&H criticalities, in the frame of the Guideline for Occupational Safety and Health in universities and large public facilities, developed by the Politecnico di Torino (PoliTo) in cooperation with Università degli Studi di Torino (UniTo).

The PoliTo – UniTo Guideline, very important outcome of the research project *The General Safety Issues and Goals in Turin Universities – TGSIGTU*, results from the multidisciplinary cooperation of PoliTo and UniTo experts, and the work developed as part of a previous PhD project (Maida, 2015). The Guideline establishes the principles for an effective Occupational Risk Assessment and Management of employees, students and people occasionally involved in the research university activities (Borchiellini et al., 2015) in compliance with the specific Safety regulation (D.Lgs. 81/08 and similar, and D.M. 363/1998).

In line with the PoliTo-UniTo Guideline principles, this research work on the definition and validation of approaches special for OS&H in research universities, from Risk Assessment to Quality Management, was organized according to the following methodology:

1. analysis of the research context, important to gather information for the problem exploration phase;
2. *problem exploration:* identification of specific criticalities for the OS&H in research universities;
3. *solution development*: design and development – based on a metrological rigour and System Quality - of sub-phases of the Guideline aimed to address the identified problems;
4. *solution evaluation*: approaches validation to verify both the feasibility and the results exhaustiveness and effectiveness: increasingly detailed and thoroughly tested results become available, in particular in terms of H.I. and Risk Management in Quality system (according to the ISO 45001:2018 standard) through the identification of effective, up to date and workable solutions in each specific context, contributing also to the promotion of the Culture of Safety.

Some input for the research development were borrowed also from approaches for the OS&H management, validated in contexts, e.g. construction yards, critical in terms of work organization and coordination.

1.4 Outline

According to the structure of the research work, summarized in Table 1, the first part of the Thesis introduces an overview of the general approaches for an effective Occupational Risk Assessment and Management (Chapter 2), providing indications for a common and coherent language together with the logical steps for the Risk Analysis and the guidance of Safety regulations. The study of the relevant methods implemented in abroad research contexts (Chapter 3) makes possible a wide framework on the research context, in terms of OS&H aspects and problems, and adopted approaches for the Risk Assessment and Management.

Being the PoliTo – UniTo Guideline the mainframe of the present research work, Chapter 4 provides an outline of the Guideline and introduces the research development.

Chapters 5 ,6 and 7 represent the core of the research, covering the design and implementation of the sub-phases of the Guideline, and results evaluation by testing the approaches. In particular, Chapters 5 and 6 deal with criticalities related both to the general workplaces safety and to the quality of data for the workers' exposure assessment, strictly linked to the metrological state of the used measuring equipment and to the design of measuring campaigns (final data interpretation included). Chapter 7 addresses the OS&H problems due to the still widespread residual presence of Asbestos Containing Materials – ACMs in large public facilities and research universities.

Chapter and description	Contribution to the research work
1. Introduction	
2. Occupational Safety and Health Basis for an effective Occupational Risk Assessment and Management.	Framework of the research work.
3. OS&H and Research Experience from other institutes on the adopted methods for the OS&H management.	Research context exploration, involving abroad research universities.
4. PoliTo – UniTo Guideline and sub-phases Outline of the Guideline and sub-phases introduction.	Focus on the methodology and principles for the Guideline sub-phases development.
5. Guideline sub-phase: workplace general safety analysis Operational tool of the Guideline for the workplace general safety analysis based on Forensic Investigation techniques / Canvassing, verified effective, complete and rigorous method to support the H.I.	a) *Problem definition*: workplaces OS&H criticalities identification in complex scenarios; b) *Solution development*: Forensic Investigation based approach to support the H.I.; c) *Approach validation*: testing the method in different workplaces typologies.
6. Guideline sub-phase: OS&H analysis of working activities Sub-phase approach aimed to optimize and improve the definition of workers' exposure models (to chemical agents mainly), acting on both the metrological verification of measuring equipment and the correct exposure data gathering and interpretation.	a) *Problem definition*: actual representativeness and effectiveness of workers' exposure models; b) *Solution development*: suitable approach to manage the measuring equipment, the measuring campaigns design and data analysis; c) *Approach validation*: implementation of the method on airborne particulate data.
7. Special asbestos sub-phase of the PoliTo – UniTo Guideline Special approaches to improve the Risk Assessment and Quality Management for the prevention of occupational illness from exposure to respirable asbestos fibres of people at work in universities and large public facilities.	a) *Problem definition*: widespread residual presence of ACMs in universities and large public facilities; b) *Solution development*: exhaustive H.I. (Chapter 5), rigorous workplaces classification, and tailored approaches for the Assessment and Quality Management of each categorized area; c) *Approach validation:* methods tested in areas with existing enclosed ACMs.
8 Discussion and conclusion	

Table 1 Outline of the research

Chapter 2

Occupational Safety and Health

2.1 OS&H definitions

The Science of Safety is the branch of the knowledge studying the Risk in its various forms, with the goal of eliminate or minimize it.

In the OS&H field, a common and coherent language, covering the entire process from the H.I. to the assessment of risks and their management, is fundamental to avoid misunderstandings and ambiguities of language. Official terms and definitions are available in the Framework Directive 89/391/EEC and its “daughter” directives, and official documents and standards (e.g. European Commission documents).

Table 2 summarizes few definitions and their sources, useful for a more understanding of the topics deal with in this Thesis.

Term	Meaning	Source
Hazard	Intrinsic property or ability of something (the Hazard factor, i.e. work materials equipment work methods and practices, etc.) to potentially pose a threat to life, health, property, or environment.	*Guidance on risk assessment at work (European Commission, 1996)*
Hazard identification	The pinpointing of material, system, process and plant characteristics that can produce undesirable consequences through the occurrence of an accident.	*Guidelines for hazard evaluation procedures (Center for Chemical Process Safety, 2008)*
Risk	The likelihood that the potential for harm will be attained under the conditions of use and/or exposure, and the possible extent of the harm.	*Guidance on risk assessment at work*
Risk assessment	The process of evaluating the risk to the health and safety of workers while at work arising from the circumstances of the occurrence of a hazard at the workplace.	*Guidance on risk assessment at work*
Risk management	the systematic application of management policies, procedures and practices to the tasks of analysing, assessing and controlling risk in order to protect employees, the general public, the environment and company assets.	*Guidelines for hazard evaluation procedures*
Prevention	All the steps or measures taken or planned at all stages of work in the undertaking to prevent or reduce occupational risks.	89/391/EEC Directive
Workplace	Place intended to house workstations on the premises of the undertaking and/or establishment and any other place within the area of the undertaking and/or establishment to which the worker has access in the course of his employment.	89/654/EEC Directive

Table 2 Some OS&H terms and definitions

2.2 Risk Assessment and Management principles

Risk can be described as the possibility for a worker to suffer a work related damage, or more precisely as predictable dimension of the consequences of a harmful event.

An effective management of risks requires some logical steps to remove or minimize the risks:

a. *Identification of all the hazards*: this is a really crucial issue in the achievement of safety in any activity: a not correctly identified cause of accident or occupational disease cannot be analysed, and the associated risk cannot be assessed and, above all, managed;

b. *Risk Analysis*: quantitative assessment of the probable damage, and of the expected frequency of occurrence of the unwanted event;

c. *Risk Assessment*: hierarchical organization of the results of the risk analysis, necessary to plan the corrective interventions in terms of priority;

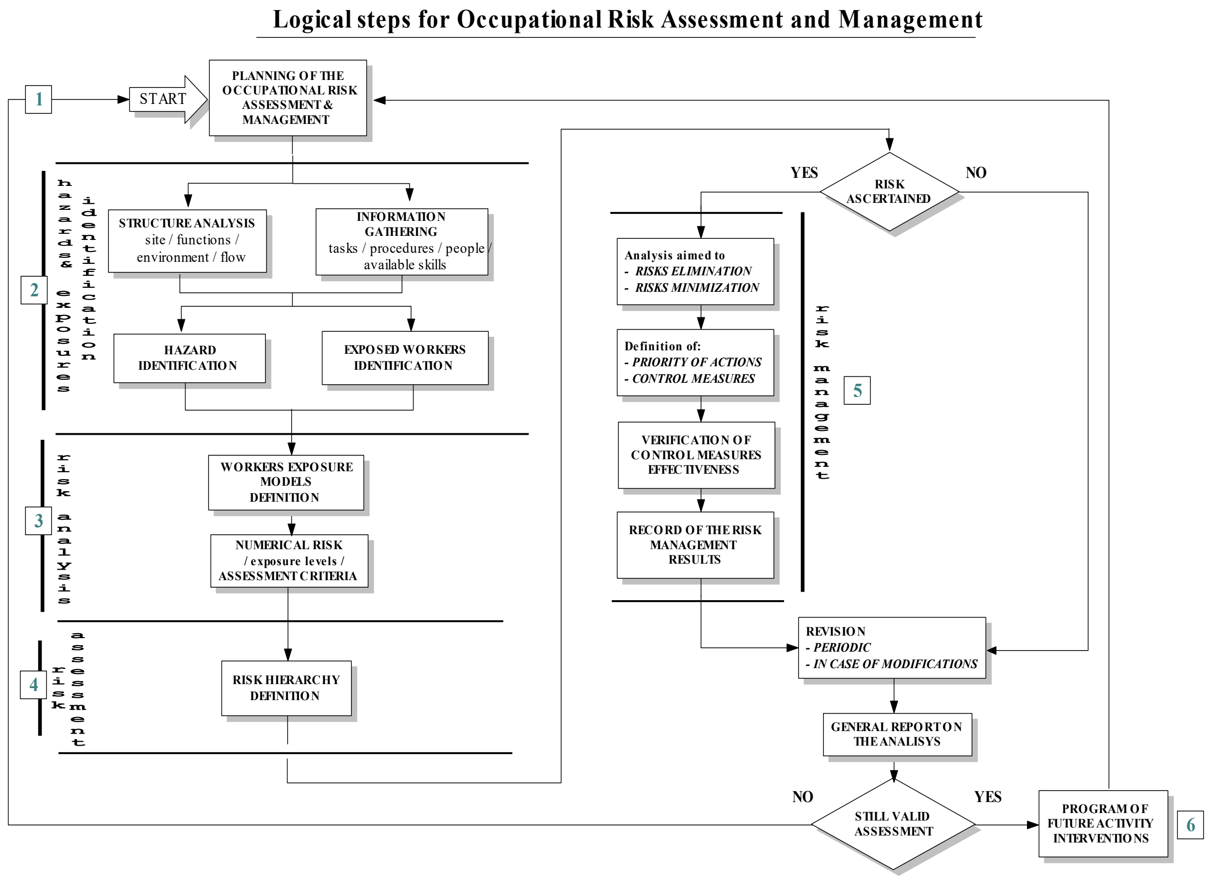
d. *Risk Management (risks elimination or minimization)*, based on Prevention (technical, organizational or procedural actions aimed to reduce the expected frequency of occurrence or the contact factor), and Protection (remedy solution to lessen the seriousness of consequences of an already occurred event).

Since there are not equal situations where the Risk Analysis is developed, every single situation requires a special approach.

The practically attainable prevention level actually depends on the general characteristics of the workplaces and work organization, in terms of selection (realization), ways of use, servicing of machinery and equipment according to what is nowadays available in the field of technical-technological improvements, and information and training of workers, making them part of the organized prevention process.

Moreover, a correct structure analysis and the organization of several emergency and coordination system depending on the background must be necessarily performed before the Risk Assessment. The actions possibly taken during the transitory phase must positively ensure that situations, which are not complicated to be basic requirement on the best technologies and practices, are not in existence any longer, and the use of Personal Protective Equipment - PPE cannot replace technical, organizational or procedural actions aiming to the risk minimization. The risk shall be reduced to an absolute minimum; this minimum is established by what is available on the market - machines and equipment suitable for the particular use at the date of the analysis.

In 1994 the European Working Group Ad Hoc - GAH proposed a model for the Occupational Risk Assessment and Management (European Commission, 1996). The model was structured so as to comply with the continuous advancement in technical progress and knowledge in the field of Safety and Health, and to produce any influence on the selection of analysis procedures by each analyst, limiting itself to stress the need of a careful and systematic new reading of what has been carried out. Figure 2 describes the logical steps of the approach proposed by GAH.



1. ***Risk Assessment strategy definition***
2. ***Hazard and Exposure Identification***
3. ***Risk Analysis***
4. ***Risk Assessment***
5. ***Risk Management***
6. ***Risk Assessment revision (<u>Quality</u> Management)***

Figure 2 Risk Assessment and Management phases according to the GAH

A numerical assessment of the risk, free from a subjective estimate, is fundamental to achieve an effective Risk Assessment and Management, and it is possible according to the approach summarized in Table 3 (Borchiellini et al., 2015).

From the definition: *RISK = consequence of the event M * expected frequency of occurrence of the deviation P* where: *M = ED * FC * n* ED = the worst credible event's consequence; FC = exposure of each worker to each Hazard Factor; n = number of exposed workers ***RISK = ED * FC * P * n*** A numerical risk evaluation, unbiased by subjective estimation, can be reached, evaluating: ✓ ED in lost days through frequency/severity rates statistics and disability indexes; ✓ FC as % of the work shift involving the exposure to a Hazard Factor; ✓ P in coherence with the quoted cornerstones of OS&H regulations.

Table 3 Approach for a numerical risk quantification

The common sense before the law makes it clear the need to face OS&H criticalities in hierarchical order for a more effective management of both human and economic resources. Unfortunately, the widespread use of qualitative techniques (including some risk matrices typologies) for Risk Assessment makes way for the analyst's subjectivity by influencing the outcome of the analysis (De Cillis et al., 2017 a). Moreover, the common lack of information on the used Risk Assessment criteria in the Safety documents affects the repeatability of the analysis also in term of reorganizations of safety tasks in the System. A qualitative approach may give misleading results (Tab. 4):

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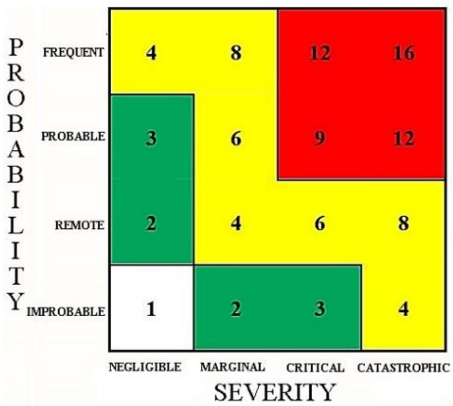

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<td>
1. the same risk values can derive from combinations of M and P values, barely perceptible subjectively for hierarchical interventions;
2. the analysis quality depends on the representativeness of input data;
3. if the input data are not reliable (or subjective) the results have arbitrary nature;
4. ED is independent from the preliminary analysis of the General Support Services[1] - GSS: hence we cannot use as reference the **Worst Credible Case**[2]- WCC;
5. FC is not considered in the assessment: related over/underestimation of risk can affect the whole analysis;
6. if more than 1 worker is exposed to the Hazard Factor, neglecting this circumstance can produce an incorrect Risk Assessment.
</td>
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</table>

Table 4 Potential criticalities of a qualitative approach

Influenced by the GAH approach, the introduction of the expected frequency of occurrence level of deviations makes it possible a rigorous analysis in compliance with the up to date safety regulations taking into account technical and occupational medicine progress. A <u>numerical</u> risk evaluation unbiased by subjective estimation is then possible:

- ED is expressed e.g. in terms of lost days according to Italian standard UNI 7249/2007 (work related accident statistics – injury frequency/severity rates), and law D.M.12/07/2000 (dispositions for worker’s disability insurance);
- FC can be estimated in percentage of the exposure to the Hazard Factors during the work shift;
- also P, i.e. the possibility of deviation from the correct work organization/development, can be numerically evaluated. Stated that the minimum probability of occurrence of hazardous events obviously corresponds to a situation coherent with the up to date technical safety

[1] GSS represent the technical and organizational answer to criticalities according to general and specific regulations.
[2] The WCC is the most severe accident considered plausible or reasonably believable.

standards, a simplified and effective approach for the evaluation of P can be based on the use of the *expected frequency of occurrence level (PR)*, written as:

$$PR = \frac{\begin{array}{c} expected\ frequency\ of\ occurrence \\ of\ the\ event\ (present\ situation) \end{array}}{\begin{array}{c} minimum\ expected\ frequency\ of\ occurrence \\ in\ complinace\ with\ up\ to\ date\ safety\ standards \end{array}} \begin{array}{c} \leq \mathbf{1}\ \boldsymbol{correct\ situation} \\ > \mathbf{1}\ \boldsymbol{unacceptable} \\ \boldsymbol{situation} \end{array}$$

In this situation both the seriousness of the damage and the contact factor are already minimized: therefore, a numerical evaluation of the Residual Risk is possible.

The approach provides an adequate evaluation of the possible severity of events consequences, since in a situation accomplishing to the regulatory requirements there will not be any worsening in consequences due to other flaws (mainly in GSS: e.g. communication system, fire-fighting systems, organization of first aid, etc.). This way of thinking can be applied as general reference for Occupational Risk Assessment and Management covering different NACE sectors (i.e. manufacturing, construction sites, etc.) and special contexts (e.g. large public facilities, universities, etc.). The method, logical before regulated by laws, makes available a careful and systematic approach to OS&H issues considering the continuous technical and occupational medicine evolutions, which can be of good reference to verify the final results by different approaches.

2.3 OS&H laws and regulations

European Directives on Occupational Safety and Health

The obligations and requirements on Occupational Safety and Health introduced in Italian laws and regulations are drawn by the directives issued by the European Union - EU.

The legal foundation of the European directives on Occupational Safety and Health is contained in the Treaty on the Functioning of the European Union (article 153).

The European directives represent legislative acts that sets out goals that all EU countries must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals. Accordingly, the EU directives setting out minimum Safety and Health requirements for the protection of workers. Member states are free to adopt stricter rules when transposing EU directives into national law, and so legislative requirements in the field of Safety and Health at work can vary across EU Member States.

The modern approach to the OS&H began from the Treaty of Rome (1957), which established the Common European Market, where among the others a common commitment was introduced to improve the Safety and Health of workers at the workplaces (art.118a). The Single European Act (1985) amended the artt. 100 and 118 of the Treaty of Rome: Safety was recognized as a shared principle - the compliance to shared safety rules as a commonly accepted basic reference.

The 89/391/EEC Directive, Framework Directive, was the very first directive intended to improve the Safety and the Health of workers, and it was the base for subsequent Specific Directives concerning the improvement of the working environment to ensure a higher level of health of workers. A number of individual directives ("daughter" directives), regulating specific OS&H fields, were approved by the European Parliament, on the basis of the 89/391/EEC Directive article 16. As an example, among the daughter directives, the 89/654/EEC on the *minimum safety and health requirements for the workplace,* is the first individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC.

Italian Occupational Safety and Health laws

The awareness of the importance of Occupational Safety and Health, as a key element in the improvement of living conditions and strengthening of the quality standards of the working life, was already present since the end of the 19th century laws. In particular, the first mentioning of safety aspects in regulations was found in the Civil Code (year 1865) and in the Law 80/1898 (introducing a compulsory insurance against accidents at work).

The Italian Constitution, in 1948, stated that Safety and Health should be protected as a fundamental right of the individual and as a collective interest.

The President of the Republic Decree 547/55 "*Regulations for the prevention of accidents at work*" represents the first important Italian law, which regulates Safety and Health at workplace, introducing the concept of Prevention. Whilst the Decree 547/55 focused on technical aspects, the following President of the Republic Decree 303/56 "*General requirements for Occupational Health*" stressed the importance of health at work. For the first time, the Decree n. 303 introduced the basic concepts of health surveillance, emergency care and other illnesses related topics.

The passing of further local and national regulations (e.g. President of the Republic Decree 164/56 on Safety aspects related to construction) made necessary to harmonize the different regulations among the all member states of the European Union. Therefore, the European Parliament issued the previously mentioned directives, which were then enforced by the different Member States of the Community.

The Italian Legislative Decree 626/1994, national enforcement of the "Framework Directive" 89/391/EEC, is considered the first real legislative improvement in the OS&H field. The Decree established the responsibilities and obligations for all the figures involved in the OS&H system, giving a greater responsibility to the employer, and introduced new figures (e.g. the Responsabile del Servizio di Prevenzione e Protezione - R.S.P.P or Head of Safety Office) with OS&H tasks.

During the time, pursuing the technology advancement, the further issued regulations enabled the use of more precise procedures to measure and to evaluate emerging risks.

Nowadays, the Legislative Decree 81/2008 , come into force in the 2008, is the reference Italian law on OS&H at work and represents the effort to unify the entire Italian regulatory framework in this field.

Finally, it is surely necessary to mention the art. 2087 of the Civil Code, which recognizes the "principle of the protection of health".

Italian OS&H regulations for Universities

Nationwide, the first law introducing the implementation of OS&H principles in the academic field was the Ministerial Decree 363/1998, currently in force. The Decree complies with the Legislative Decree 626/1994 (Italian former enforcement of the European 89/391/EEC Directive), and it is currently in line with the Legislative Decree 81/2008. Indeed, the D.Lgs. 81/08, in art. 3 co. 2, includes universities and institutes of high education among the fields for which its provisions must be applied *"where necessary through the adoption of further specific ministerial decrees",* which to date are unfortunately still pending.

In such a situation, according to the D.M. 363/98, the universities and higher education institutions adopted internal regulations to establish roles, responsibilities and obligations at the different organization levels in the OS&H system.

Abroad (Dutch) OS&H regulations for Universities

The visiting study in The Netherland made possible to understand the management of the OS&H in some Dutch universities (and research institutes), based on OS&H regulations specific for universities, in compliance with general Safety Laws establishing the principles.

The Act of 18 March 1999 - *Working Conditions Act* - containing provisions to improve working conditions, the Decree of 15 January 1997 - *Working Conditions Decree* - including provisions in the interest of health, safety and welfare in connection with work, together with the *Working Conditions Regulation* are the main Dutch Laws regulating the OS&H issues.

The *USHA Health and Safety in Research Guidance 2012* is the principal reference document adopted by many Dutch universities as guide for the OS&H management. USHA is the (British) Universities Safety and Health Association which promotes safety and health in higher education ensuring the wellbeing of university staff, students and visitors. In particular, the document is a guideline for matters concerning the management and responsibilities, using a management system approach to regulate Health and Safety in research, the Safety culture, and the Risk Assessment.

The *Occupational Health and Safety Catalogue of the Association of Universities in the Netherlands* (Association of Universities in the Netherlands, 2012) is a reference manuscript to support the group of Health and Safety professionals in the execution of their duties within the universities. Moreover, each university implements own additional internal safety regulations, to improve the OS&H condition in the university.

ISO 45001:2018 Occupational Health & Safety Management Systems

Among the Safety regulation, a special reference is necessary to the ISO 45001:2018 standard "*Management systems for health and safety at work – requirements for use*", implemented in Italy in March 2018 as UNI EN ISO 45001. The principles of the standard were adopted to achieve an actual System Quality development for the different phases of this research work.

The standard provides a framework and a model for the management of injury prevention and health problems; as for all management systems, a cyclic model is adopted (based on the so-called Deming or PDCA cycle – Plan, Do, Check, Act) aimed at the continuous improvement of health and safety conditions in workplaces. An effective Occupational Risk Management in a Quality approach consistent with the ISO 45001:2018 standard should comply 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 reliable measurement results, attainable only through methods based on both the selection of suitable measuring devices, and on the definition of use of procedures adequate to the case.

Chapter 3

OS&H and Research

3.1 OS&H in research institutes

As discussed, the peculiar characteristics of the universities/research contexts make it necessary specially dedicated approaches to manage the OS&H issues.

The abroad visiting activity, scheduled in the PhD program, was a good opportunity to investigate on the Safety and Health problems for workers in the research field, and to study the formalized approaches and special research works for the OS&H management already adopted by foreign research universities. The research, involving both Dutch research universities and non-academic research institutes, was useful to achieve a wider overview on the OS&H problems and adopted solutions in different research level, fields, and institutes typologies: the survey focused on two important Dutch research universities (Delft University of Technology – TU Delft and the University of Twente – UT) and TNO, an important institute for applied research. These organizations share the research and innovation advancement, but they differ in research levels and fields, presence of teaching activity and system organization.

The information gathering was organized in two phases: a) documentary analysis and b) in situ visits in selected and accessible workplaces. Meetings and discussions with researchers, Safety Officers, Safety Advisers, Area Supervisors, and other figures involved supported both these steps. A data collection form (Fig. 3), designed on the base of the ISO 45001:2018 standard organization, enabled to collect information in an organized and concise way.

Location	Tutor(s)/ reference person
Institution typology - details	
1 GENERAL APPROACH FOR RISK MANAGEMENT	
2 SAFETY DOCUMENTATION	
3 RESEARCH ACTIVITIES Research works aimed to contribute to the improvements of OS&H in the Institute	
4 ON SITE DIRECT INFORMATION	
Date and location	Reference person
Working environment visited - details	
NOTE ON OS&H	
General Support Services	
Occupational Safety & Health	
Special Prevention (and/or Protection) measures	

Figure 3 Extract of the form, simplified, for the information collection

Preliminary information about the visited institute and the typology of activities performed made possible to have an idea of the addressed safety-related problems at different scales (campus, faculty, department, classrooms, laboratories, etc. levels). The analysis of Safety Documents provided an overview about the adopted general method to manage the OS&H (OS&H policy and related objectives, organizational roles, responsibilities and authorities, figures involved in the OS&H, Risk Assessment and Management approach adopted, emergency preparedness and response, Safety performance evaluation, continuous improvement, Safety document, etc.). Moreover, the information gathering included details on the research developed to contribute to the OS&H improvements. In situ observations were useful as practical feedbacks on the implementation of the prevention measures "daughter" of the Risk Analysis.

Delft University of Technology

The Delft University of Technology - TU Delft is the largest and oldest Dutch public technological university. Organized in faculties and research institutes, it hosts over 19.000 students (undergraduate and postgraduate), more than 2.900 scientists, and more than 2.100 support and management staff. Initially, all of the university buildings were located in the historic city centre of Delft. New university neighbourhood, called Mekelpark, is 832-meter-long promenade eased the commute between faculty buildings (Fig. 4). The TU Delft research areas cover very different topics and a wide range of research facilities: wind tunnels, chip facility, high-voltage laboratory, nuclear reactor, etc.

Figure 4 TU Delft Campus

The Safety & Security Section (3S) (which kindly hosted me during my visiting period), in the Department of Values, Technology & Innovation focuses the research on the responsible innovation, developing innovative approaches to risk assessment and safety and security management, by providing insights how to integrate safety and security criteria in technological design.

The approach to the safety (and security) problems adopted by TU Delft is organized in two levels:
- *Safety and Security - Integral Safety program;*
- *Safety in research (experiment).*

The Integral Safety program provides information and procedure to manage very different situations (e.g. safety, risk due to research means, unsafe working environment, injury/illness, undesirable behaviour, fire, theft, external security, etc.). Integral Safety program Pocketbooks constitute a practical tool specific for each faculty. Each Pocketbook describes the safety organization within the faculty, the way to strengthen safety, and actions and behaviours to adopt in the acute phase of critical events. The workplace general safety is managed within the Integral safety program, on the base of relevant national OS&H regulations.

In research activities (and teaching – practical exercises) risks are methodically estimated per experiment or series of experiments, via the Safety Reporting System, specific module of the Lab Servant online tool. The Lab Servant system structured in interlinked modules supports the risk assessments before start new experiments. The fundamental idea of the Lab Servant is to put responsibility for safety in the line-management structure, and to help researchers to internalize the concept of Safety. The method to assess and manage risks related to the research activities entails a close link between:
- *substances, materials, equipment needed, but also by-products and waste:* Inventory and Equipment modules of Lab Servant system are special dynamic databases recording complete information about substances (chemicals, gases,

biological) presence, quantity, storage location, potential hazards etc., and equipment use, calibration, periodic maintenance and available reference material (instruction manuals, fault recording, log books, etc.) at the university;

- *the researcher who performs the experiment and his Safety information level:* authorization to work safely in the specific area is provided through the Instruction & Test (I&T) Lab Servant module, linked to the access policy for new and existing staff, students and contractors;

- *the processes involved, possible failures and deviations included:* the Specific Data module archives the experiment description, flow charts of the processes and indications on failure, exceptional conditions and emergencies;

- *the structures and laboratories to be used:* in the Specific Data module, the researcher specifies the location of the experimental units (labs needed); all laboratories and workshops are equipped with adequate technical safety provisions.

All these aspects are connected, and the relevant information crossed, in the Lab Servant system, contributing to support the management Risk Assessment and Management in such a complex situation.

The complete information form reporting the activity carried out on TU Delft is available in Appendix 1 (OS&H general) and Appendix 2 (OS&H special for laboratories).

University of Twente

The University of Twente - UT is a public research university, located in Enschede, member of the federation of four leading Dutch technical universities - 4TU. The UT is the only Dutch purpose-built campus university (Fig. 5), where cultural and social activities, sports facilities, housing are centralized and hosted within university structures. In the university laboratories, research experiments are performed, and equipment and chemical, biological and toxic substances used.

Figure 5 University of Twente Campus

The approach to assess and manage risks adopted by UT is based on the H.I stage and Risk Assessment distinct for the workplace general safety and research/experiments, in order to ensure everyone a safe environment for work, study and research.

The University of Twente has a range of laboratory areas (chemical, physical and biological, as well as for mechanical and electrical engineering) and workshops. The H.I. and Risk Assessment (RI&E) in Laboratory experiments is performed taking into account the nature, extent and duration of the exposure of the staff member(s). The evaluation requires data on substance or mixture worked, risks related to the substance or mixture, nature of the activities performed, potential exposure paths, exposed identification (e.g. researchers, students and technicians), measures to be taken to avoid exposure.

Among the research work, aimed to improve OS&H in the institute, the study on the emergency response in large public facilities, with particular reference to the UT campus, is particularly significant. The research analyses aspects that influence the emergency response time, with the goal to recommend improvements for responsible units tasked to ensure the Safety within buildings of the UT. The study is based on the identification of causes that could lead to deteriorations of the systems, and on the evaluation of recommendations to improve the performance based on continuous improvement principles and on the concept of antifragility.

The complete information form about the data on OS&H in UT is available in Appendix 3.

TNO applied research organization

TNO is the Dutch Organization for applied scientific research, an independent research organization, with locations in many parts of the world, from the Middle East, to the south East Asia and Caribbean. TNO is organized in Research Units with their peculiar research fields. The Units can be structured in one or more departments (in total approx. 60 departments). The research fields are very different, ranging from buildings and infrastructure, energy, traffic and transport, healthy living, industry, information & communication technology, defence, etc. The locations object of the visiting activity were the TNO New Babylon, in The Hague, and the TNO Space Systems Engineering, in Delft (Fig. 6).

Figure 6 TNO Space System Engineering, Delft

The management of OS&H at TNO is based on two levels of Risk Assessment:

Base Risk Assessment – Base R.A.

Project Risk Assessment – Project R.A.

The Base R.A. aims to evaluate the risks in specific working environments: buildings, offices, laboratories, etc. in TNO facilities. Question lists, whose content is tailored to each typology of environment, guides the evaluator. The Room Manager, having the better knowledge of the characteristics and details of the room he manages, Safety aspects included, is tasked to perform the Base R.A.

In the design phase, the Project Leader carries out the Project R.A., since he designs the research, knows deeply all the aspects involved in the project and related potential safety problems. He can ask support to the Specialist Safety Officers for specific aspects. At project level, the assessment of risks is more dynamic than the Base R.A., since the Project R.A. follows the project during its all development and therefore it could be frequently updated.

All the areas are equipped with adequate technical safety provisions identified thorough the Base R.A. However, the research project development could bring, in the working environments involved, risks not assessed in the Base R.A. These additional risks are carefully evaluated in the Project R.A., and proper prevention measures to manage the risk identified. The laboratory, before the project begins, is equipped with the "additional" technical prevention measures to manage those risks.

The access in TNO buildings is regulated by access policy enabling to manage Safety and Security problems, based on the use of badges: different kind of badges are available, for employees and visitors, with diverse access authorizations. New employees, or a visitors, gain the pass when they has completed the information and instruction session (on general Safety, emergencies, and security matters) required to enter in the specific area. According to authorization obtained, the badge is upgraded and to access in special areas (e.g. special clean room) become possible.

The complete information forms about the TNO is available in Appendix 4.

3.2 In closing

From the information gathered during the abroad experience, interesting considerations emerge about the OS&H issues and the management approaches adopted.

Regarding the universities, where research and teaching activities coexist, two categories of OS&H problems can be identified (i.e. criticalities strictly related to workplace general safety and problems related to research activities), requiring different management approaches.

The first approach, often including the management of Security aspects, aims to ensure a safe workplace (e.g. campus, offices, classrooms etc.) taking into account the complexity of the internal organization in terms of staff and locations. The complex structural organization (extreme diversification of the working environment: campus, faculty, department and laboratory) is managed through a careful definition of roles and responsibilities on Safety matters (many professionals with different Safety tasks and responsibilities e.g. from deans, to Health, Safety and Environment Advisers, from Safety Officers, to Project Leaders, etc.). Special research works about the enhancement of the response in emergencies performed in both UT and TU Delft underline the complexity to ensure Safe conditions during not ordinary situations.

The approach adopted to manage the research-related OS&H issues, similar in the three institutes, is built on strict link between the researcher, who performs the experiment or research, the equipment, materials and substances used and the involved environment (e.g. fuel cell laboratory). The connection is implemented in practice through the access policy that relates the possibility to perform an operation in a proper workplace (equipped with all the needed prevention measures, technical and organizational) and the general and specific Safety information and training of the person who carries out the operation. Computerized systems, making use of special badge, permit the access to the needed workplace only in response of a proved information. This approach makes easier the management of a scenario where in a single research area a number of people with different background performs different operations, using very different materials and equipment. Since such an access policy could introduce criticalities in the case of an emergency occurrence, some research works focuses on this topic (e.g. the emergency response innovation research developed in TU Delft).

The complexity of the Occupational Safety and Health management in research field emerges from the need to ensure, at the same time, safe workplaces for all the people involved and safe research activities, including the OS&H aspects among the input data for the research project design and for every step of the research process. Consequently, the implemented approaches must be tailored, making inadequate the Risk Assessment and Management methods adopted in others NACE sectors.

The information gathered underline as each adopted approach is specially fit to the existing OS&H criticalities, deriving from a Culture of Safety well mainstreamed in the all institutes’ activities.

Chapter 4

PoliTo – UniTo Guideline and sub-phases

4.1 PoliTo-UniTo Guideline for Risk Assessment and Management

With a history of over 150 years, Politecnico di Torino was the first Italian engineering school founded on the wave of the technical and scientific innovation, which gave rise to the most prestigious polytechnic schools in Europe in the mid-19th century. Politecnico di Torino is a comprehensive research university, where education and research complement each other and create synergies, with an eye to internationalization. The Politecnico campus with four main locations in Turin, featuring multi-purpose facilities for teaching, basic & applied research activities, as well as student services. The historical site of our University, located on the banks of the river Po, is the Castello del Valentino (Fig. 7), included in the UNESCO World Heritage List and one of the Savoy residences in the XVII century. The main site, Cittadella Politecnica, houses the Engineering Departments. Besides organizing and managing teaching activities, Politecnico Departments coordinate vertical research and promote the sharing of results. Politecnico di Torino includes 11 Departments, which are University referential structures in the different disciplinary fields of Engineering and Architecture.

Figure 7 Castello del Valentino, historical site of the Politecnico di Torino

This brief description can make evident as the management of Safety and Health for people involved in the Politecnico, besides the OS&H aspects strictly linked to research activities, should cover criticalities peculiar of workplaces sited in historic buildings where some academic activities are performed. The situation is common to many other universities, in Italy and abroad.

In the context of the enhancement of the OS&H conditions in universities, *The General Safety Issues and Goals in Turin Universities – TGSIGTU* multidisciplinary project, encouraged since 2008 by Politecnico di Torino and Universita' degli Studi di Torino, led to the issuing of a Guideline for Occupational Safety and Health in universities and large public facilities (employees, students and people occasionally involved in the research university activities included), completed with a quality approach, and in full agreement with the OS&H national regulations (basically D.Lgs. 81/08, Italian enforcement of the framework EEC Directive 89/391). The Guideline was officially recognized by mutual agreement as "*a basic methodological reference for the Occupational Risk Assessment and Management in large complex structures*" in 2011 (Inter University Meeting, June, 06, 2011) and quoted as basic reference in the Framework agreement between Politecnico di Torino and Universita' degli Studi di Torino, concerning the collaboration to improve the Safety and Health of workers (March, 10, 2015).

The Guideline formalized model establishes the principles (Tab. 5) for an effective Occupational Risk Assessment and Management in universities and large public facilities.

Principle and phases of the endorsed PoliTo – UniTo Guideline	
A.	Well-defined systemic flow of information, and clear and unambiguous definition of responsibilities and obligations of each figure involved in OS&H system.
B.	Reference to a well-established methodology of Risk numerical quantification based of the adoption of the PR (see Table 3).
C.	Three hierarchical phases of approach: ***C.1.*** *Workplace general Safety and General Support Services;* ***C.2.*** *Working activities analysis: Job Safety Analysis - JSA (equipment included) and interferences management;* ***C.3.*** *Management in System Quality.*

Table 5 Principles established in the PoliTo-UniTo Guideline

The three hierarchical phases of approach, described in Figure 8, consists of:

1. *Workplace general safety analysis*: evaluation of workplace condition in terms of shell, services and interior spaces of premises containing workplaces and their not-operative content, energy qualification, performance limits, necessary to verify the actual consistency with the intended use; this phase should be associated to the activation of the *General Support Services,* technical and organizational response in respect to the relevant general and specific sector regulations, in order to achieve the correct quantification of the damage. General Support Services cover a series of contingency plans (general to the structure/area/department) associated with resources (in terms of teams and dedicated equipment, including communication systems) for their coordination and management.
2. *OS&H analysis of working activities*: starting from the compliance with the conditions defined in the previous phase, every activity in terms of workers and equipment is analysed, with the goal to assess the exposure of each worker to the total number of Hazard Factors, systematically identified by means of the available H.I techniques – the Job Safety Analysis (JSA) can be considered as a reference technique.
3. *Quality Management*: the last step towards the adoption of an OS&H Management Systems, intended to establish, document, implement, and continually improve the OS&H policy, in compliance with the Italian Law D.Lgs. 81/08 art.30 and the ISO 45001:2018 standard.

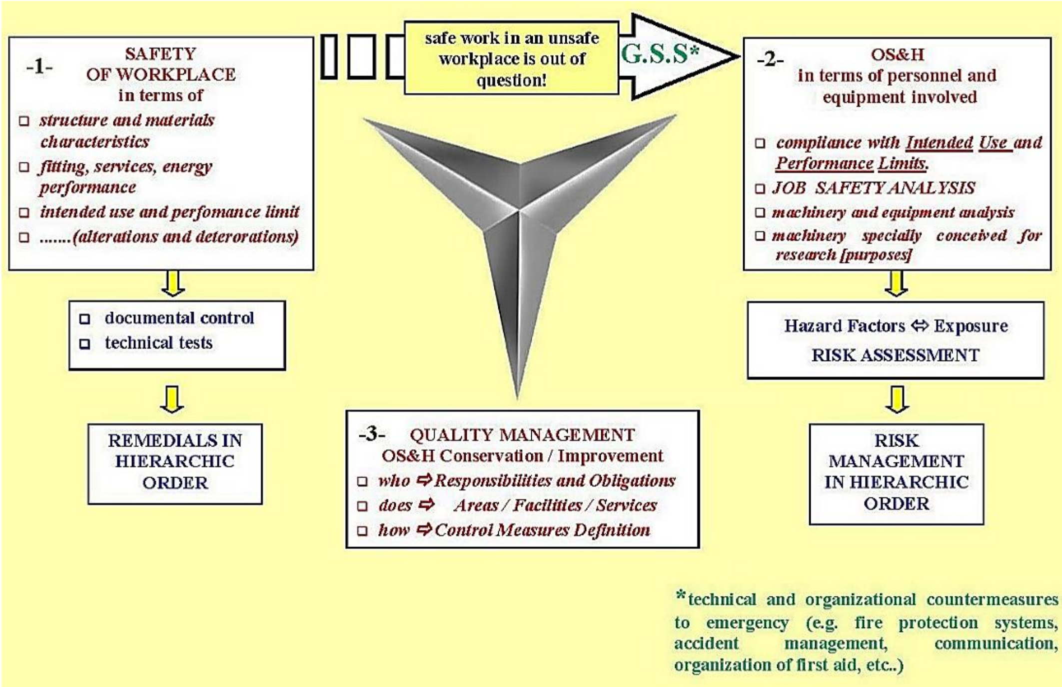


Figure 8 PoliTo – UniTo Guideline hierarchical phases

4.2 The Guideline sub-phases

Sub-phases of the PoliTo-UniTo Guideline, consistent with the Guideline principles, i.e. systematic, complete and formalizable (originally from Center for Chemical Process Safety, 1992), had been already developed to support the work of the analysts (skilled technicians) to address special OS&H problems typical of the universities, giving also an important contribution to the dissemination of the Culture of Safety (De Cillis et al., 2017 b). Both the Guideline and the sub-phases passed a thorough validation process of extended field tests aimed to verify both feasibility and exhaustiveness in different real situations before their approval and dissemination. As an example, some achieved technical and organizational improvements, from the already implemented sub-phases, concern:

a) the establishing of a well-defined systemic flow of information, and roles and responsibilities definition, providing a chain of responsibilities and information links for normal and emergency situations (Borchiellini et al., 2013); this includes also the definition of the organizational and social aspects necessary to support the people covered by the Guideline in the correct adoption and practical implementation of innovations introduced by the Guideline and its sub-phases,
b) the identification of the Hazard Factors related to the different working phases and to the used equipment and machinery, the elimination/minimization of risks and quantification of residual risks through the Job Safety Analysis technique (Patrucco et al., 2010), analysis of risks due to interference through the Functional Volumes method (Labagnara et al., 2016),

c) the compliance verification of equipment to Safety requirements (in particular machinery and equipment for research) and dedicated corrective / supplementary actions where necessary (Maida, 2015).

The present research work covers the development and validation of special sub-phases -operational tools in line with the Guideline principles- following the Guideline hierarchical phases of approach: starting from the analysis of possible OS&H problems peculiar of the workplaces, to the subsequent identification of criticalities related to the working activities performed in those workplaces. A special study, mostly matter of the workplace safety analysis, deals with the health problems due to the residual presence of ACMs in large public facilities and universities. In detail, the approaches developed and validated as part of the present research work address three main questions:

1. *OS&H criticalities due to the workplace problems, in terms of structure, fittings, intended use, performance limits,*
2. *quality of exposure data and representativeness of the workers' exposure models,*
3. *Occupational Health problems related to asbestos residual presence,*

making available special operational means to manage such criticalities.

The following comprehensive Outlines describe the research methodology, based on a metrological rigour and system quality, adopted for each sub-phase developing, including the principles of the Guideline mainly involved in the process.

Outline 1

Sub-phase 1 of the Guideline: workplace general safety	
Question 1	Assessment and management, in System Quality, of workplace OS&H criticalities, in terms of structure, fittings, intended use, performance limits;
Approach solution	Workplace safety analysis through a rigorous method to support the H.I. phase, with the possibility to derive special Checklists, for each investigated environment, to support the conservative management of the Safety level reached; *Note:* the technique can be implemented in Quality (e.g. by using Image analysis techniques)
☆ *Principles*	**A.** Well-defined systemic flow of information, and clear and unambiguous definition of responsibilities and obligations of each figure involved in OS&H system, **C.** Three hierarchical phases of approach: ***C.1.*** *Workplace general Safety and General Support Services;* ***C.3.*** *Management in System Quality.*
Approach validation	Approach tested on workplaces with different characteristics and intended use.

Outline 2

Sub-phase 2 of the Guideline: OS&H analysis of working activities	
Question 2a	Checking of the metrological state of the measuring equipment conditioning the quality of the recorded measures, input data for the exposure models;
Question 2b	Achieving an actual representativeness of workers' exposure models in the analysed working scenario;
Approach solution	- Approach based on intermediate calibration checks to verify the metrological characteristics of the measuring equipment; - Careful design of measuring campaigns and correct data interpretation to define exposure models actually representative of the exposure scenarios, on which the occupational physician could base the health surveillance programs;
✰ *Principles*	**A.** Well-defined systemic flow of information, and clear and unambiguous definition of responsibilities and obligations of each figure involved in OS&H system; **B.** Reference to a well-established methodology of Risk numerical quantification based of the adoption of the PR; **C.** Three hierarchical phases of approach: ***C.2**. Working activities analysis: Job Safety Analysis - JSA (equipment included) and interferences management;* ***C.3.** Management in System Quality.*
Approach validation	Approach tested on airborne particulate measures and occupational noise data.

Outline 3

Asbestos sub-phase of the Guideline	
Question 3	Assessing and managing the widespread residual presence of ACMs in large public facilities and universities, and related potential risks for health of people involved;
Approach solution	Rigorous classification of the workplaces depending on the asbestos Hazard modes, resulting Risk Assessment and Management criteria, improved through approaches based on investigation techniques of proven effectiveness, already topic of the sub-phase 1, and Image Analysis techniques;
☆ *Principles*	**A.** Well-defined systemic flow of information, and clear and unambiguous definition of responsibilities and obligations of each figure involved in OS&H system; **B.** Reference to a well-established methodology of Risk numerical quantification based of the adoption of the PR; **C.** Three hierarchical phases of approach: ***C.1.*** *Workplace general Safety and General Support Services;* ***C.3.*** *Management in System Quality.*
Approach validation	Method tested in real workplaces characterized by criticalities due to the presence of ACMs enclosures.

The following sections of the present Thesis discuss the development and tested results of the introduced Guideline sub-phases; the activity can be considered still ongoing, since the detection of further criticalities requires the drawing up of additional specific sub-phases.

Chapter 5

Guideline sub-phase: workplace general safety analysis

Research question 1*: how to achieve a systematic, complete and formalizable safety analysis, and the following management in System Quality, of the workplace?*

5.1 Workplaces general safety analysis, early step of the Hazard Identification phase

OS&H Risks Assessment and Management is a particularly demanding task: the European Directives, and the derived Italian regulations, stress the importance of a pro-active approach, the only able to reach effective results. To simply focus on localized situations, and carry out a hasty survey cannot ensure a systematic evaluation of the operating contexts in complex facilities such as the research universities, where the most serious criticalities are of difficult identification.

The PhD research work has contributed to improve the Guideline sub-phase especially devoted to the workplaces general safety analysis, aimed to ensure a sufficient detail in the previously mentioned situations. The developed approach is based on an original modification, for OS&H Risk Assessment and Management, of some Forensic Investigations techniques for a thorough H.I. on shell, services and interior spaces of premises containing workplaces, and on their not-operative content (Borchiellini et al., 2016).

OS&H Risk Analysis involves the identification of Hazards in a system and the evaluation of possible scenarios leading to unwanted consequences. As discussed in Section 2.2 and clarified by the GAH approach (flow chart in Figure 2) an effective H.I. is the key point for a careful Risk Assessment and Management process. Risk analysis relies on a structured and systematic approach, starting from the Hazard and Exposure Identification phase, characterized by the largest potential for errors due to a poor identification of hazardous agents/materials characterizing the process. This phase is also a basic part of the Quality Management of process and systems (hence, the revision of H.I. process when system changes occur should never be underestimated). The correct definition of the exposure model for each worker involved in the system depends firstly on a correct H.I.: obviously, in the case of undetected or underestimated Hazard Factors, the result is an incomplete Risk Analysis misleading the Risk Assessment and Management phases.

In order to develop an effective H.I., it is essential to investigate the following aspects:

1st: shell, services and interior spaces of facilities containing workplaces and their not-operative content, obviously pre-conditioning both the OS&H conditions and the selection of prevention measures for ordinary and emergency situations;

2nd: the productive activities at the workplaces, which should be designed and organized in coherence with the above.

The adopted approach should comply with the basic requirements of H.I. (Center for Chemical Process Safety, 2008). In particular:

a. the analysis of the process variables and deviations should lead to design tailored solutions also including the emergency aspects;
b. an analysis based on a logic sequence of functional discretization of the system in key points minimizes the risk of missing some Hazard Factors;
c. the logical breaking up of every complex operation into a number of basic activities enables a thorough understanding of the system criticalities;
d. finally, an unbiased, systematically updated documental/technical information sharing is of pivotal importance for "historical memory" of the analysis approach and results along the time, and to satisfy the exigence of a Systemic Information System, open to the decision makers and safety staff.

Points b. and c. cover both the technological aspects (e.g. a combination of machines constituting a production line) and the total duration of productive operations aimed to complete a complex operation (e.g. Work Breakdown Structure, tasks and sub-tasks in a Gantt Chart). Moreover, where the target is the Safety analysis of shell, services and interior spaces of premises containing workplaces and their not-operative content, the approach suggested in point b. becomes of particular relevance.

5.2 Original modification of the Forensic Investigation techniques: Canvassing

An exhaustive H.I., coherent with a scientific approach, should start from a thorough analysis -based on real evidences- of the safety characteristics of shell, services and interior spaces of premises containing workplaces and their not-operative content, in absence of production and workers, to avoid interferences with the analysis. The diagram in Figure 9 summarizes the procedure and final result, including the possibility to derive Checklists usable for subsequent checks on the state of conservation of the achieved Safety level (conservative management) by personnel not particularly skilled in OS&H (*).

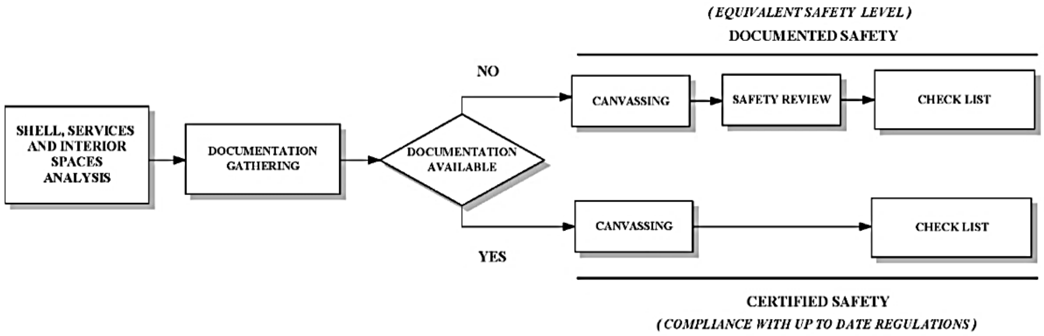


Figure 9 Procedure and results of the workplace general analysis approach

(*) Concept borrowed from a different context

The concept derives from a research on OS&H in highway maintenance yards: for the systematic and thorough yard Safety inspections, personnel not particularly skilled in OS&H -*Fellow Supervisors*- supports the Coordinator for safety and health matters at the project execution stage in the routine activities, giving an important contribution in optimizing the Coordinator activities. The frequent and long-lasting systematic presence of Fellow Evaluators at the yard can contribute to a substantial improvement, in terms of increased attention to OS&H problems and responsibilities, continuous cooperation on the safety aspects, and in more general terms, wide spreading of the Culture of Safety (Borchiellini et al., 2017).

On the base of this considerations, it was evaluated the possible use of the techniques, typical of the Forensic Science, to improve the completeness of the analysis in the OS&H Hazard Investigation phase. The main search modes for evidence gathering typically used in the forensic investigations (International Association of Chiefs of Police and the Federal Law Enforcement Training Center, 2010 and Miller, 2011), consist of functional volumes discretization methods (Tab. 6) and techniques as guidance on how the site investigation should be performed (Tab. 7). Both the goals are clearly coherent with the basic requirements of H.I.

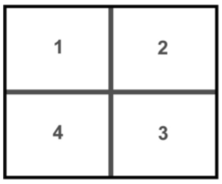
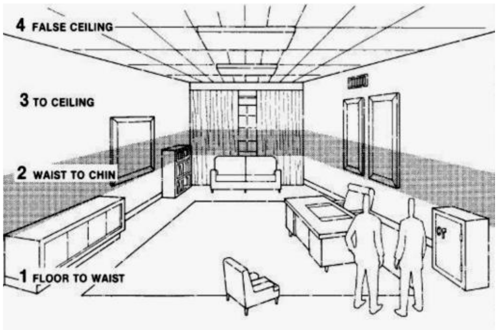
Target	Technique	Description
Volume discretization	***Zone search***	The area to be searched is divided into zones or sectors. For a thorough search, each person is assigned to one sector. The sectors can be searched by another team member, if necessary. 
	Zone elevation search	Kind of search used where evidence may be on the walls or in the ceiling. Only one elevation zone should be checked at a time. 

Table 6 Main forensic volumes discretization methods

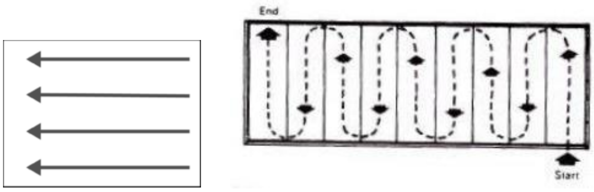
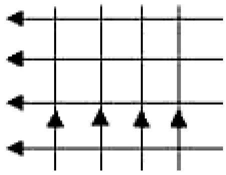
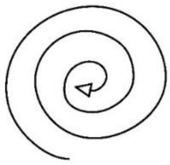
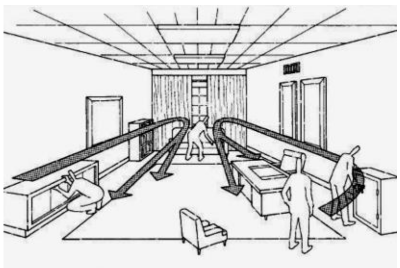
Target	Technique	Description
Investigation mode (way of looking for)	***Lane search***	Staff will stand in one long line and move forward together to avoid missing areas. Stakes and string can also be used to create “lanes” for which each member of the team would be responsible. When a suspected piece of evidence is located, the Team Leader is informed before any action.  *Strip (left) and Wavy line (right) search*
	Grid search	Similar to a strip search, the investigation is performed by completing a lane search in one direction and then completing a lane search in the perpendicular direction. This is the most thorough search technique because the same area is searched twice by a grid pattern format. 
	Spiral search	Spiral search involves a spiral inward or outward from a crime scene. For crime scene, a practical disadvantage with outward spiral searches is the evidence may be destroyed as the searchers move to the centre of the crime scene area to begin their outward search. 
	Overlapping search	The Team Leader should observe and supervise the search, while other team members perform the investigation of the area. With an overlapping search items are unlikely to be missed. 

Table 7 Main forensic investigation modes

Having acknowledged the potential of Forensic Investigation techniques, a preliminary study was carried out on special adjustments - known as “*Canvassing*”- to make them fully fit to improve the completeness of the H.I.

phase, on shell, services and interior spaces of premises containing workplaces and their not-operative content (equipment included [3]), in particular taking into account the following aspects:

1. *the target is the* H.I.*, not the reconstruction of the dynamic of unwanted events;*
2. *the search should start from available documentation;*
3. *the selection of the most suitable Canvassing technique depends on the typology of working environment also in terms of spatial configuration, furniture and operative context.*

Regarding the point 2, in the case of buildings of old construction, for which no exhaustive documentation is available, the H.I. can be supported e.g. by a Safety Review approach, in coherence with the suggestions of the PoliTo-UniTo Guideline.

In the OS&H context, special combination of volume discretization and way-of-looking-for techniques, taking advantage of the most useful peculiarities of each technique, can contribute to make exhaustive the analysis. This is clear in the case of the *Zone Elevation Search*: the method could be used as reference technique in each combination, since it allows extending the search to the volume in compliance with the investigation needs. For OS&H purposes, the Zone Elevation Search technique was improved in two original combinations: the *Zone Split 3D* and *the Zone Elevation Split*.

Zone Split 3D is essential to distinguish in the same environment sub-zones characterized by parameters that require a homogeneous approach. A Zone Split 3D preliminary discretization, based on well-founded assumptions, can simplify each volume to be searched and avoids errors due to subjectivity, slapdash or bureaucratic decisions. Correct results can be:

- the division of a large settlement in independent modules, each of them in certified or equivalent safety for fire emergencies;
- the division of each module in floors, and not by intended use (workshops, offices, etc.), the latter neglecting the layout and conditioning of general fittings and technical-organizational countermeasures to emergency, and the possible interference criticalities.

Zone Elevation Split is used for the discretization of the volume to be searched. The use of some reference points and landmarks is strongly recommended, since it facilitates both the spatial discretization and the recording of points of interest. The availability of computer assisted geo-referencing image processing techniques, explained in the Section 7.3.2, based on image adjustment algorithms of the images digitizing elaborations, can be very useful both for the investigation results documentation and the sharing phases.

[3] In this particular case the term "equipment" includes any machine, apparatus, tool or system, forming complex machines, equipment and components necessary for the implementation of a production process, destined to be used at work (Italian D.Lgs. 81/08 s.m.s. art. 69 lett.a.) also including machinery specially designed and constructed for the purpose of research.

Finally, the selection of the most suitable method to carry out the site investigation depends on a number of factors of difficult standardization, such as the geometrical characteristics of the investigated volume, the presence of fittings, equipment, furniture, etc.

5.3 Approach validation in different workplaces

A number of in situ tests were performed in offices, classrooms, laboratories and workshops at Politecnico di Torino, selected as pilot sites representing typical working environments, to practically verify the real user-friendliness and the effectiveness of the proposed evolution of the Forensic Investigation techniques.

As an example, Table 8 summarizes the implementation and results of the Canvassing on a workshop, and some considerations concerning the benefits/limits of each discretization and way-of-look-for technique. The results of the Canvassing approach on other investigated working environments (offices, research laboratories, classrooms) are available in Appendix 5.

Site: **WORKSHOPS**

Image of one of the investigated workshops

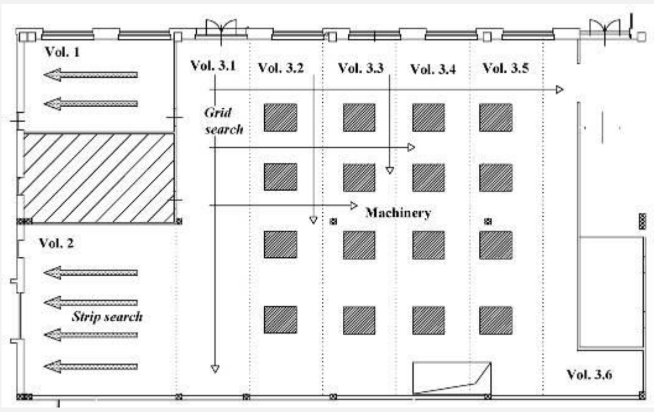
Discretization: the *Zone Split 3D* results necessary both to reduce the extent of the investigation area, especially in crammed volumes, and to isolate, where possible, zone assigned to different uses (e.g. office, storage, etc.). The discretization of the search volume will be the more effective if the sub-volumes are identified according to pre-defined criteria based on their characteristics. Similarly, to previous pilot sites, the analysis requires a *Zone Elevation Split.*

⇨ *Suggested discretization:* ***Zone Split 3D + Zone Elevation Split***

Search modes: the well-organized layout of the different workstations suggests the implementation of the *Grid Search* in the machinery area, and the *Strip Search* in the storage zone and in the office.
In presence of limited and clear spaces, resulting from *Zone Split 3D* application, it can become advantageous to substitute the *Grid Search*, too expensive for these situations with a *Strip Search*, simple and effective.

⇨ *Suggested search modes:* ***Grid and Strip searches***

The method at a glance



Layout of a workshop

Graphical discretization of the workshop

Special benefit of the method

Points of interest

Considerations: Typically, the workshop shows a lot of criticalities related to special activities, machinery, fittings and tools, sometimes worsened if the working areas are narrow and crowded. As result of the in situ test, a combination of *Zone Split 3D* and *Zone Elevation Split* becomes necessary to reduce the volume to be searched.

Table 8 Result of the in situ test on workshop

5.4 In closing

With reference to *Research question 1 (how to achieve a systematic, complete and formalizable safety analysis, and following management in System Quality, of the workplace?)*, the tests performed demonstrated that the Forensic Investigation based approach can support the H.I., making possible some suggestions on their useful contribution in the workplaces safety analysis, and on the logistic and operative parameters somehow conditioning the selection of the most suitable technique.

Thanks to the good results achieved, these techniques can be considered effective, appreciably rigorous; the following positive aspects of Canvassing can be highlighted:

a. *in OS&H field, Canvassing is particularly suitable for the analysis of shell, services and interior spaces of facilities containing workplaces, and on their not-operative content: in absence of production and workers, to avoid interferences and alteration of the boundary conditions;*
b. *the analysis is independent of the nature of the critical issues and their subsequent management, and therefore can be defined "aseptic";*
c. *the use of Canvassing avoids incurring errors due to the judgment subjectivity of the analyst, who may act in accordance with his own preconceived and possibly misleading Attention Index criteria;*
d. *Canvassing makes possible a thorough spatial referencing of the results, the detail depending on the quality and suitability of the storage and sharing systems available (in the case of Politecnico di Torino, which has efficient and constantly updated systems, this will provide a considerable advantage); then, they ensure the repeatability of the analysis in controlled conditions;*
e. *Canvassing enables to derive Checklists usable for subsequent checks on the state of conservation of the achieved Safety level, which can be carried out by not particularly expert operators (in the case of the Politecnico di Torino typically the Safety Advisors headed by the various Departments and Units).*

Table 9 provides some suggestions on the main logistic and operative parameters which can condition the selection of the most suitable Canvassing to be adopted in different scenarios.

Logistic Parameters	*Skills, Information and Resources*	❑ documented site layout; ❑ skilled OS&H analysts; ❑ analysts assistants; ❑ experts in surveying techniques; ❑ time spent on the analysis; ………………
	Tools	❑ support devices and tools (e.g. professional camera, markers, Electronic Distance Meter); ❑ tools to delimit volumes (landmarks, stakes and strings); …………
Operative Parameters	*Working environment layout*	❑ site dimensions and characteristics; ❑ presence of machinery and furniture; ❑ possibility of freely circulating the site; ………………
	Common services and fittings	❑ complex plants; ❑ devoted fittings of machineries; ……………
	Particular situations	❑ false ceiling; ❑ enclosures; ❑ special volumes covered by security regulations ………..

Table 9 Main aspects conditioning the selection of the Canvassing

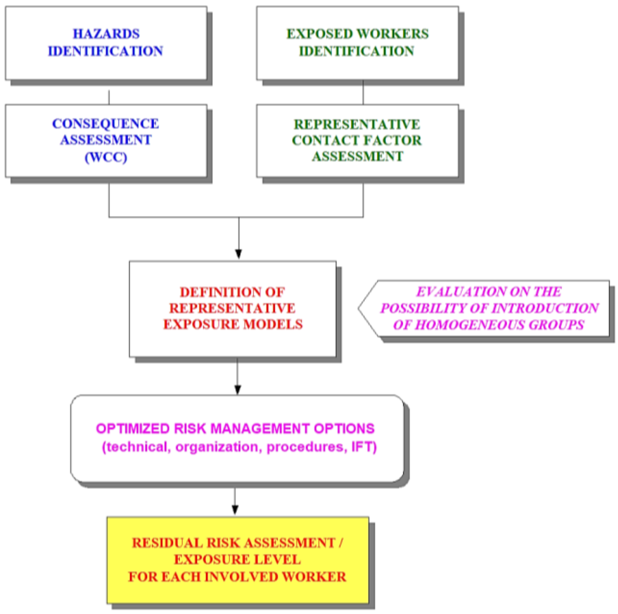
The completeness and repeatability of the suggested approach contributes to enhance, from the very first step, the effectiveness of the relevant sub-phase of the Guideline, providing a significant contribution to the diffusion of the Culture of Safety, in a synergic cooperation of all the people involved.

Chapter 6

Guideline sub-phase: OS&H analysis of working activities

6.1 Hazard Factors quantification for effective workers' exposure models

Where an effective workplaces general safety analysis was performed and criticalities/non-compliances managed, a careful OS&H analysis of working activities is fundamental in the Risk Assessment and Management process. To reach a reliable Risk Assessment it is necessary the quantification of each Hazard Factor, the identification of workers exposed, the definition of the exposure duration and the evaluation of the consequences. All these parameters, properly assessed, define the exposure model of workers to the Hazard Factors, as summarized in Table 10: the flow chart clarifies the box "*workers' exposure model definition*" in point three of the flow diagram suggested by the GAH (see Section 2.2, Figure 2).



Definition of exposure models: a method that combines all the hazardous elements with the Contact Factor of involved workers, in order to define their own exposure situation to each Hazard. Taking into account the approach for the risk quantification (Table 3 in Section 2.2), in presence of more than one Hazard Factors and workers operating in various departments, to correctly quantify the Risk is necessary to

1. know if actually different Hazard Factors are present;
2. assess the Contact Factor of each worker to one or more Hazard Factors;
3. define ED (WCC) that can be associated with each Hazard Factor;
4. if ED or FC are $\neq 0$ which actions should be implemented to reach $PR \leq 1$.

Then for each worker, it is possible to calculate:

$$RL_1 = \sum_{i=0}^{n} [(FC_i \cdot ED_i) \cdot P_i]$$

Bearing in mind that the Risk Assessment target is a correct assessment of the risk for each worker, the introduction of homogeneous exposure groups could be a correct idea, but really thorny, since sometimes heavily misleading if not previously and carefully verified.

Table 10 Workers' exposure model

Moreover, the flow chart in Table 10 gives rise an important consideration about the definition of workers' exposure models: *the need of a synergic activity between OS&H technicians and occupational physician*.

As an example, considering the exposure of workers to airborne pollutant (the Hazard Factor), as stated by the D.Lgs. 81/08, hazardous pollutant must be identified and quantified in the Safety document, and the collected data compared with the Threshold Limit Value – TLV or Occupational Exposure Level – OEL, where available ([4]). TLVs represent the main indicator to prevent the onset of a

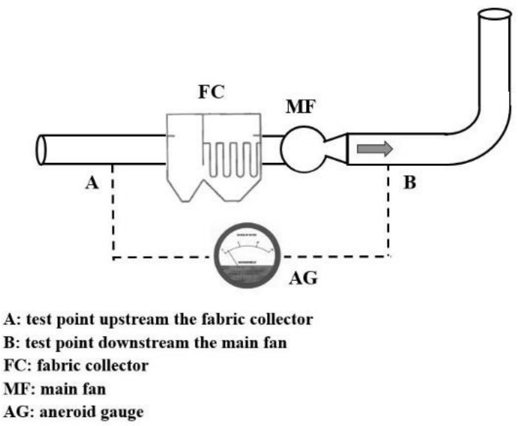
[4] TLV is a reserved term of the American Conference of Governmental Industrial Hygienists (American Conference of Governmental Industrial Hygienist, 2018); for EU Countries: Occupational Exposure Levels - OELs (European Directive 98/24/EC).

work-related pathology. TLVs for chemical substances and physical agents exist; in particular, for chemicals three typologies of limits are defined (American Conference of Governmental Industrial Hygienist, 2018):

1) *TLV-TWA time-weighted average*: average exposure based on a 8-hour workday, and a 40-hour workweek work schedule;
2) *TLV-STEL short-term exposure limit*: 15-minute TWA exposure that should not be exceeded at any time during a workday, and should occur no more than four times per a day, with at least 60 minutes successive exposure;
3) *TLV-C ceiling limit*: absolute exposure limit that should not be exceeded at any time.

The compliance with the TLV-STEL and TLV-C could be easier to achieve since the recommendation of behaviours is stricter, because the suggestion is clear and well defined. The problem can rise in the case of TLV-TWA, a value fluctuating without control, measured just in a long time exposure, during which the peaks of concentration are not always known.

In a situation as simplified in Table 11 (Patrucco et al., 2017), the concentration of the pollutant in the working environment grows until the limit of the activation of the mitigation system (in the case a ventilation system), but the exposure of the worker(s) would be quantified using the Time Weighted Average limit, ignoring the transition between an acceptable value of pollutant concentration and the peak.

<table>
<tr>
<td>Sketch of the final segment of the involved ventilation system</td>
<td>


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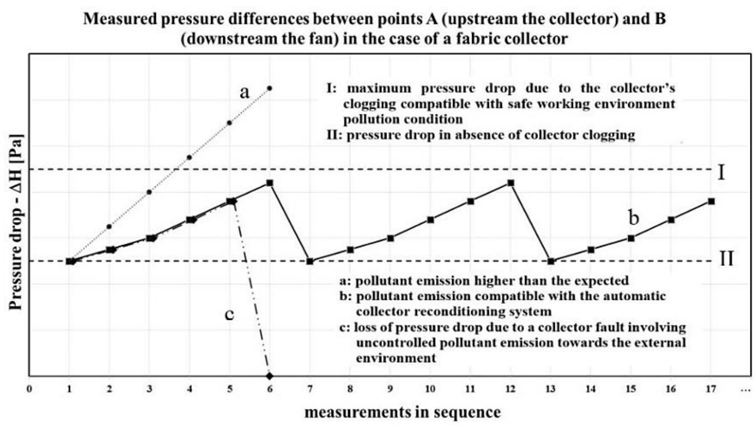
<tr>
<td>System’s efficiency monitoring</td>
<td>


</td>
</tr>
</table>

Table 11 Simplified airborne pollutant management system

In such a situation, the intervention of the occupational physician from the first phases of the process could avoid gaps in the assessment or underestimation of the consequences of exposure on workers' health. The example makes clear the importance of a necessary synergy between technicians and occupational physician. Therefore, occupational physician should take on the role of a "global consultant" who, on the basis of specialized notions, cooperates with the technical staff in the definition of workers' exposure model, to further reduce the number of accidents and occupational diseases.

At the light of these considerations, the evident relevance of a correct quantification of Hazard Factors in the assessment of the actual workers' exposure conditions, has motivated the development and testing of an operational tool of the Guideline –resulting in the specific sub-phase - especially aimed to optimize and improve the definition of workers' exposure models, acting on:

- the management of the measuring equipment, in terms of metrological confirmations, to ensure the quality of exposure data gathered;
- a precise measuring campaigns design, and a correct interpretation of the achieved exposure data, specific for chemical agents, with the possibility to adopt the same approach for the exposure assessment to different Hazard Factors (e.g. physical agents).

6.2 Approach 1: System Quality in measuring processes and equipment setup

***Research question 2a**: how to ensure that the measuring processes fulfil the necessary metrological requirements, providing exposure data quality?*

6.2.1 Metrological requirements of the measuring systems

The research work, developed on the basis of Bisio et al., 2016, focuses on the setup and management of the measuring equipment and on its pivotal importance for OS&H Risk Assessment, with the main goal to ensure both maximum data accuracy and economic sustainability.

The result of any analytical process depends on input variables, which could have a critical impact on the result of the measurement; only a preventive management of such parameters can reduce the influence on the outcome of the measuring process. The suitability of the equipment should result from a metrological confirmation process, involving the identification, with a frequency of monitoring adequate to every special situation, of Key Performance Indicators of the equipment operative conditions effectiveness and efficiency, taken into account the OS&H criticalities and the overall management costs. The UNI EN ISO 10012:2004 Standard for the "*Measurement management systems - Requirements for measurement processes and measuring equipment*" can be an important reference for the rationalization in the management of equipment, covering the *effectiveness* (equipment suitability for the use) and *efficiency* (time & money savings in the equipment management).

Where the definition of workers' exposure conditions are involved, the measuring process quality lays at the very base of an effective OS&H Risk Assessment, upon which correct decision making processes can lead to an effective Prevention. As shown in Figure 10, the Sampling and Analysis "bones" of the Cause and Effect – Ishikawa diagram (Center for Chemical Process Safety, 2008) include the main causes conditioning the result quality in the measurement of an air dispersed pollutant concentration at a workplace.

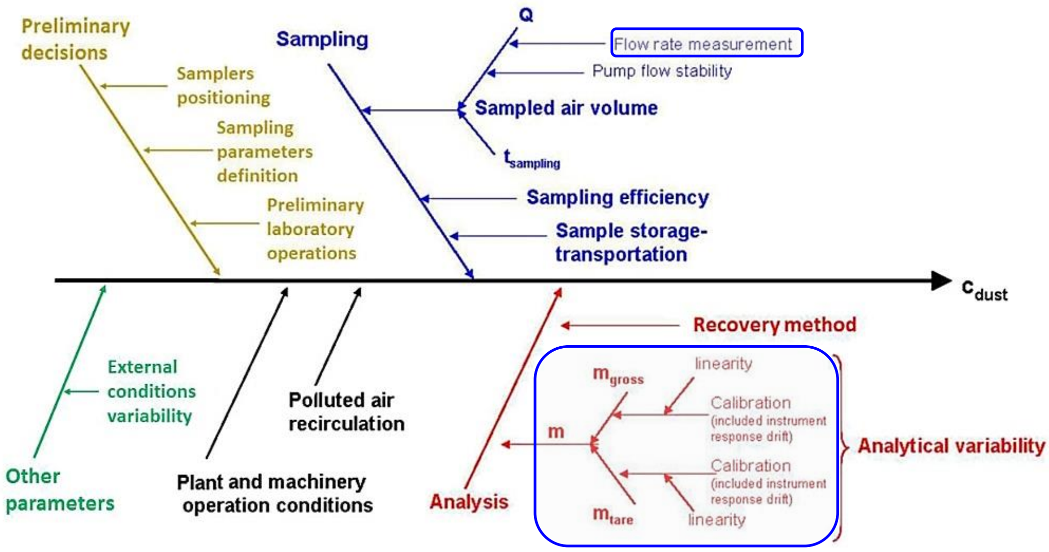


Figure 10 The Ishikawa diagram on the causes of uncertainties affecting the measure of the concentration of airborne dust.

The measuring system can consist of one or more components, more or less complex, generally simplified as a measurement chain from the sensor to the transducer. Each element in the chain provides a measure of a particular quantity by the sensor, which measures the measurand (the quantity to be measured) up to the transducer, which shows to the operator, or records, the measured value. Both the measurand and each *influence quantity* ([5]) (measured by the components of the measurement chain and potentially affecting the relation between the indication and the measurement result) should have a specific calibration ([6]) and metrological traceability (International Laboratory Accreditation Cooperation, 2007). To ensure the traceability of the result, the calibration of every single quantity in the measurement chain would be necessary, with measurement

[5] *Influence Quantity*: quantity that, in a direct measurement, does not affect the quantity that is actually measured, but affects the relation between the indication and the measurement result (JCGM 200:2012).

[6] *Calibration*: the operation that, under specified conditions, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties, and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication (JCGM 200:2012).

standards of known values, traceable and with an uncertainty ([7]) negligible with respect to the measurand uncertainty. Usually, the manufacturer performs these calibrations and traceability tests during the initial set up and check of the measuring system. Measuring equipment calibration is the first step to achieve a *metrological confirmation*: to guarantee the suitability of a Measuring Equipment of known Metrological Characteristics – MCME for the intended use, in particular when the equipment condition can influence the final results, it is necessary to prove, through a confirmation procedure, the fulfilment of the Customer Metrological Requirement - CMR. The definition of a proper confirmation interval, ensuring also the approach efficiency, can take advantage of the concepts of the process statistical control, through the monitoring, with an adequate frequency and use of quality indexes, of some significant parameters identified on the basis of a preliminary Risk Assessment. The calibration frequency and calibration checks should be based upon experience and literature suggestions (e.g. Unichim manuals series 177, covering the calibration of some influence quantities, usually monitored by the manufacturer in the initial installation phase, or during the Instrument Performance Verification - IPV inspections).

A different approach to calibration and traceability is of common use in testing laboratories, which often adopt indirect methods. There, the calibration of a measuring system is carried out recording the relation between the transducer indications in correspondence of known values of the measurand, specified by primary measurement standards or otherwise determined by means of a measuring procedure with negligible uncertainty.

In the practice the verification of calibration effectiveness for the influence quantities in the measuring chain, can however be of difficult implementation, mainly due to costs, use, maintenance and conservation problems.

The MCME and CMRs are input data for the metrological conformation process; in particular, the CMRs are conditioned by the special target and context of the measurement (Tab. 12):

Typology	Control method	Example
Qualitative measurement (presence/absence)	Validation of the actual measurement on a product, providing information on the process quality	Drawings with values, dimensions and tolerances
Quantitative measurement (numerical verification)	Verification of the method used for the measurement (testing process / method)	✓ information on the testing method ✓ measurements of known characteristics on reference materials during the different testing process phases

Table 12 General aspects of Customer Metrological Requirements

[7] *Uncertainty (of measurement):* parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand (JCGM 200:2012)

The MCME are intrinsic of the measuring devices, in terms of

a) architectural features, typical of the system and conditioning the achievable performances (e.g. readiness, resolution, sensitivity, etc.),

b) characteristics, derived from the equipment architectural features, which make possible the use for measurements on objects external to the system itself (testing object or measurement standard).

6.2.2 Metrological confirmation of measuring equipment

The metrological confirmation process (Fig. 11) deals with the measuring systems suitability for each intended use, and consists of the MCME verification, the calibration of the measuring equipment, the comparison of the calibration results with the necessary metrological requirements, and the final decision on the metrological confirmation (positive/negative).

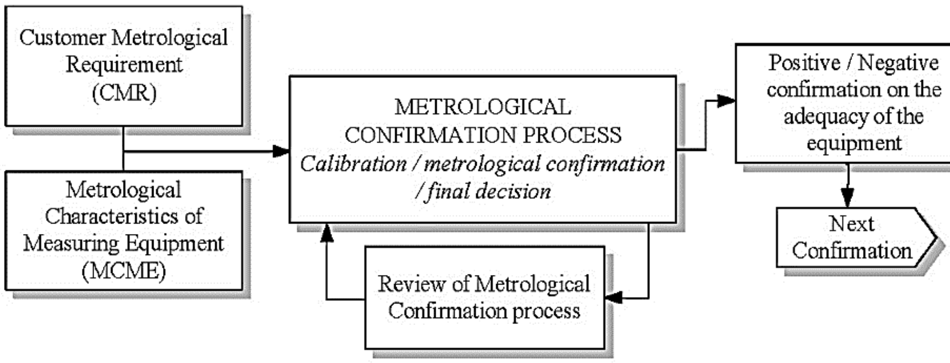


Figure 11 Metrological confirmation process

The measuring systems management should comply with the UNI EN ISO 10012:2004 Standard in terms of:

1. preliminary definition of a process aimed to guarantee the equipment suitability for the intended use and time span (*metrological confirmation interval*);
2. review of the measuring process to ensure: a) constant performance quality of the measuring systems along the time, and b) progressive reduction of required resources *(measuring process efficiency*).

The metrological confirmation interval is the time between two consecutive confirmations, established taking into account the following aspects:

1. the measuring systems should provide performances adequate to the measuring requirements along the time;
2. the risk related to inadequate results should always be kept to acceptable levels (Risk Analysis);
3. qualified personnel should periodically verify the activity;
4. the overall management costs should be acceptable.

The selection of the metrological confirmation interval depends essentially on the intrinsic features of the measuring instruments, and on the typology/frequency of their calibration. In the case of equipment requiring periodic calibration, the monitoring of significant instrumental parameters (MCME) through suitable tools can provide *intermediate calibration checks* and guarantees the metrological confirmation. Hence, the identification and regular monitoring of the MCME ensure the correct functioning of the equipment, and reduce the necessary resources, thus improving the *process efficiency*. Such "indicators" should be easily measurable even by personnel not particularly qualified, but familiar with the equipment. The selection of the characteristics to be monitored and the related monitoring frequencies should be based on the preventive assessment of the criticality of such characteristics and on their impact on the final result, a task which necessitates of a thorough Risk Analyses.

Risk analysis for measuring processes

The basics on Risk Assessment and Management, refined for the OS&H analysis, as summarized in Table 3, can be conveniently adapted to the Risks Analysis for any measuring and metrological confirmation process. In the case of measuring processes, the method for the analysis of the risks compromising the quality of measures should mainly consider:

Hazard Identification: identification of factors which, taking advantage of a system vulnerability, could potentially cause alteration both on the intrinsic characteristics of equipment and on the calibration, resulting in loss of metrological confirmation of the measuring system, and consequent non-compliance with the CMRs;

Vulnerability: Hazard Factors impacting on the measuring process through a system vulnerability can compromise the results quality; it is fundamental to eliminate/minimize every vulnerability of the system to impede disturbances on the measuring process;

Likelihood: this concept is strictly linked to each Hazard Factor in terms of measurement scenarios and typology of Hazard; in the case of the architectural features of measuring devices, the components failure rates can be useful to evaluate the frequency of occurrence of the unwanted event (component failure);

Damage severity: in the case, inadequacy of the equipment to comply with the CMRs (due to loss of metrological confirmation of the measuring equipment): a measuring process, out of the metrological requirements, could cause "tangible" damages (e.g. economic losses) or "intangible" (e.g. Organization's image damage).

In the case of measurements aimed to define the workers' exposure to a specific Hazard Factor (e.g. air dispersed pollutants in workplaces), tangible damages become particularly critical. An under estimation of the Hazard Factor (e.g. actual pollutant concentration) implies the ineffectiveness of the resulting Risk Assessment and Management, whilst an over estimation of it involves both critical errors in the Risk Assessment and misdirected investments.

The implementation of this approach to each specific measuring scenario makes possible an in-depth Risk Assessment and Risks hierarchy definition, related to each Hazard Factor, stating the consequences on the result deriving from the occurrence of the specific unwanted event. However, the complexity to achieve an in-depth Risk Assessment, involving a measuring process, makes difficult the consequent Risk Management focused on the evaluation of the most suitable prevention and protection solutions aimed to ensure the compliance of the measures to the CMR. With reference to metrological confirmation aspects, therefore, it is evident the very close link between Risk Management and Measuring Process Management. The implementation of Risk Analysis to measuring processes relates to:

- *the operational Risk*: execution of an analytical process by means of a measuring equipment in incorrect state of metrological confirmation;
- *the final purpose of measuring process results*: impact on OS&H Risk Assessment and Management (e.g. measurement aimed to workers' exposure models definition), effect on strategic risks, risks related to contracts and regulations, image damage, financial risks, etc.

The quality on the OS&H Risk Analysis is strictly bound to the diverse typology, complexity and criticality of the measuring equipment. Table 13 summarizes a possible classification in homogeneous groups of the measuring equipment in relation to the metrological confirmation.

Group	Definition	Description
A	**High** impact equipment	Complex instruments and computerized systems that *need the status of metrological confirmation* process. It is necessary to consider the intended use and the required performances, according to the indication of testing methods. The complexity of the metrological confirmation activities could requires experts support (AA, HPLC, spectrometer, …).
B	**Medium** impact equipment	Equipment that measure or monitor physical quantities, and, therefore, *require metrological confirmation*. The user, to comply the laboratory demand, specifies the requirements. The compliance is defined within metrological confirmation procedures, which meet the intended uses (scales, pH-meters, variable volume pipettes, thermometers, pumps, thermostats, thermostatic baths…).
C	**Low** impact equipment	Standard equipment not used for measuring and consequently *not subjected to metrological confirmation*. Generally, their correct management could be set up on the observance of manufacturer specifications and their monitoring during the use (magnetic stirrers, homogenizers/mixers, centrifuges, ultrasonic baths, refrigerators, etc.).

Table 13 Possible measuring equipment classification

The risks arising by a lacking or improper check of measuring equipment are:

a) instability of the instrumental response resulting in unacceptable variability of analytical results;
b) substantial stability of the instrumental response, but inaccuracy of the obtained results, due to systematic errors, not directly proportional to the investigated quantity, that becomes noticeable only in specific operating conditions.

The possibility to reveal these deviations depends on the correct selection of MCME, and on the acceptability criteria established during the validation procedure: with a sufficient number of available data for a statistical validation, the approach provides information on the presence of identifiable causes of variability. An accurate definition of the variability limits of the measuring process for the most significant parameters, describing the correct state of metrological confirmation of the equipment, is essential.

Approach based on Control Charts and Process Capability indexes

When the same method defines the acceptability limits of the calibration and metrological confirmations, it should refer to these "guide values": if data fall outside the Control Limits, some correction on the cause becomes necessary, to bring again the measurement within the acceptability limits. An adequate number of data on the control of the guide characteristic makes possible the systematic removal of the causes determining the falling out of limits: a continuous improvement aimed at the removal of abnormal situations, to bring / keep the measuring process under statistical control (ISO 7870-2:2013 "Shewhart control charts"). The result is a process accomplishing the statistical control, predictable in terms of capability to comply with the specifications, and requiring a reduced number/frequency (i.e. total time) of verifications (Juran and Godfrey, 1999*)*.

Control charts are simple tools to verify the statistical control of the process. The statistical control verification enables the Process Capability analysis i.e. process conformity with Specification Limits through Process Capability indexes (Tab. 14).

C_p – *Process Capability index* $C_p = \frac{(ULS - LLS)}{6\sigma}$	*ULS = Upper Limit of Specification;* *LLS = Lower Limit of Specification;*
C_{pk} – *Shifted Capability index* $C_{pk} = \min\left(\frac{ULS - \mu}{3\sigma}, \frac{\mu - LLS}{3\sigma}\right)$	σ *= standard deviation or natural capacity of the process;* μ *= mean of the process (nominal value of the specification).*

Table 14 Process Capability indexes

Values for C_p and C_{pk} indexes higher than 1 indicate that the Specification Limits range includes the three process standard deviations either side of the mean (Porter and Oakland, 1990).

6.2.3 Approach validation: measuring equipment for airborne particulate concentration measurements

The approach was tested on the measuring process to quantify, through personal samplings, the airborne respirable dust concentration for the definition of the workers' exposure. The characteristics of measurement devices and the organization of the sampling campaign were preliminarily defined with particular reference to the pollutant criticality (from no-fibrogenic reaction in the lungs, to carcinogenicity), the working activity pattern(s), and the boundary environmental parameters. The discussion of the measurement campaign results is based on suitable techniques to ensure the representativeness of the final assumptions (Leidel et al., 1977, Tuggle, 1982), but obviously, the quality of the whole process depends on the quality of the input data. The quantification of the workers' exposure to airborne particulate consists of two consecutive operations, according to the Unichim 2010:2011 method:

Sampling phase: by means of a flow-controlled pump, the required air volume is drawn through a personal sampler ([8]) containing a micro pore filter, which collects the airborne dust;

Laboratory analysis phase: to determine the quantity/nature of the collected pollutant. The filter is weighted before and after sampling by means of an analytical scale, to determine the mass of the collected dust. A preliminary conditioning of the filter in a special conditioning cabinet makes comparable the humidity content of the filter before and after the sampling.

Considering in particular the flow-controlled pump and the analytical scale (Fig. 12), the definition of a proper metrological confirmation interval is essential to ensure the metrological confirmation state of measuring instruments during the use, and the measuring process efficiency. Consequently, the constant level of performance of the measuring systems along the time is proved, with also a progressive reduction of the involved resources and related costs.

Figure 12 Personal sampling line (left), analytical scale in the climatic cabinet (right)

[8] *Flow-controlled pump* and *personal sampler* are both defined in UNI EN ISO 13137:2015 standard

Analytical balance

The used analytical balance (model Scaltec SBC 21 capable of weight to an accuracy of five digits, i.e. 10 μg) for gravimetric analysis belongs to the B Group (see Tab. 13), and requires metrological confirmation arising from calibration and intermediate checks, possible by means of measurements of a standard mass. The mass measurement is the significant instrumental parameter to monitor, to verify along the time that the gathered measures:

1) belong to the normal distribution (*natural variability* due to only chance causes of variations),
2) remain inside the specification limits interval (metrological requirement – CMR).

A gradual increase of the interval between two consecutive confirmations should take into account the critical OS&H purposes of measuring process results, in terms of potential under/over estimation of the actual pollutant concentration, in addition to the efficacy and efficiency of the process. The variability in the measurement results of two-milligram mass, certified reference weight traceable to International Standards (Fig. 13), monitored through Mean Control Charts, and the evaluation of quality indexes (Process Capability index - C_p and Shifted Capability index - C_{pk}), provides evidence of statistical control and Capability of the measuring process.

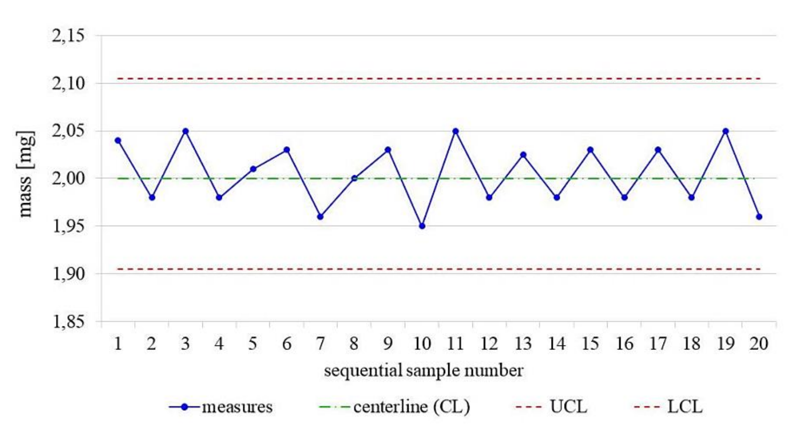
Figure 13 Class E1 set of reference masses, compliant with ISO 15767:2009 standard - the red box indicates the two-milligrams mass used

According to the developed approach, assuming fulfilled the initial steps of the metrological confirmation process, in particular the selection of an analytical balance of proper metrological characteristics and its calibration, the intermediate calibration check phases, ensuring the metrological confirmation of the analytical scale, are summarized below:

Phase 1. *Statistical control of the process:* the Mean Control Chart (Tab. 15) proves the statistical control of the process, in relation to the Control Limits (Upper Control Limits – UCL and Lower Control Limits - LCL) and Centre Line – CL, defined by the general model:

$UCL = \mu + 3\sigma, LCL = \mu - 3\sigma, CL = \mu$

where μ is the mean of the sample statistic, and σ the standard deviation of the sample (each value is the mean of ten mass measurements).



μ = 2,00

σ = 0,033

UCL = 2,10

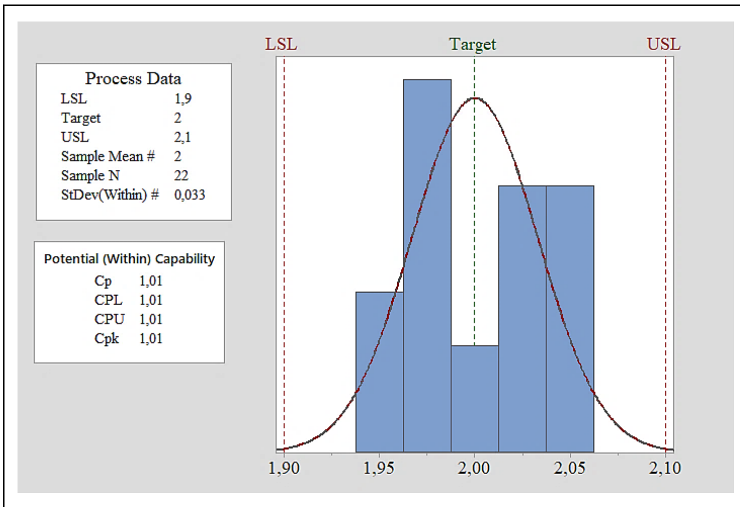
CL = 2,00

LCL = 1,90

Table 15 Mass measurements Mean Control Chart

The Control Chart shows that no points fall out of the Control Limits: no tendency due to systematic causes of errors is evident, the process should be affected by only chance causes of variation, i.e. the process is in statistical control. In addition to the control chart, other statistic tools (e.g. Normality Tests) can be used to verify the absence of systematic components in the data: e.g. to improve the scale of the analysis, tests can be performed on data residuals, resulting from the subtraction of the mean of the sample to each value.

Phase 2. *Process Capability:* since the process appears in statistical control, it is possible to check the process conformity with Specification Limits (i.e. Process Capability). In this case, the Specification Limits are selected according to the analytical variability on gravimetric measurements, consistent with the gravimetric analysis of respirable dust in workplaces (based on indications of ISO 15767:2009 standard and Unichim 2010:2011 method). The Specification Limits have been set to ± 5% of the results of the standard mass measurements. Table 16 describes the Capability analysis on the mass measuring process, showing the distribution of data within the Specification Limits interval: the quality indexes, greater than 1, confirm the compliance with the Specification Limits.



Specification Limits:

USL (+ 5%) = 2,10

LSL (- 5%) = 1,90

Table 16 Mass measurements conformity with the Specification Limits (Minitab ®)

The result of the two-phases approach implementation, providing the intermediate calibration check, confirms that the analytical scale is in correct metrological confirmation condition and it is completely capable to ensure the required performances.

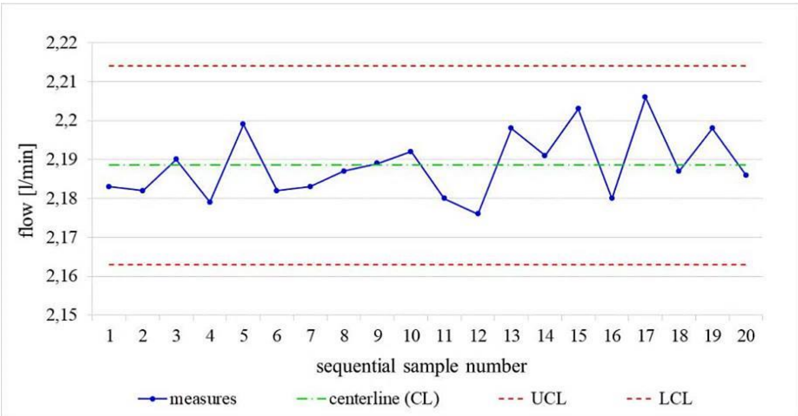
Sampling device

Airflow is the significant instrumental parameter to monitor for the flow-controlled pump (B Group - Tab. 13) used for the personal samplings. In particular, the 2,2 l/min airflow, needed to get the required particle size cut (0,2 ÷ 10 μm: aerodynamic equivalent diameter for respirable particulate - UNI EN 481:1994), represents the guide value. A Gilibrator-2 System primary calibrator, equipped with a high-flow cell, connected to the flow-controlled pump, enabled to record a sample of airflow measures. Particular care was devoted to the boundary conditions on which the instruments guarantee the metrological requirements, i.e. humidity, pressure and pressure drop, temperature. The metrological confirmation of personal flow-controlled pump results from the two phases of intermediate calibration check:

Phase 1. *Statistical control of the process*: according to the general model for the statistical control of the process:

$UCL = \mu + 3\sigma, LCL = \mu - 3\sigma, CL = \mu$

the Mean Control Chart (Tab. 17) shows that no points (each value is the mean of ten airflow measures) fall out the Control Limits and no tendency appears. Data should be affected by only the natural variability (normal distribution): the process is in statistical control.



μ = 2,19

σ = 0,01

UCL= 2,21

CL= 2,19

LCL= 2,16

Table 17 Airflow measures Mean Control Chart

Phase 2. *Process capability:* the outcome of the Mean Control Chart enables the verification of the Process Capability; in this case, the Specification Limits (equal to ± 5% of set airflow) are suggested by the Unichim 2010:2011 method *"Samples collected with an airflow outside the specification limits interval have to be discarded"*. The graph in Table 18 shows as the normal distribution of airflow measures is included in the Specification Limits interval; the relevant values of indexes C_p and C_{pk} (both of them greater than 1) confirm that measuring process can be considered capable.

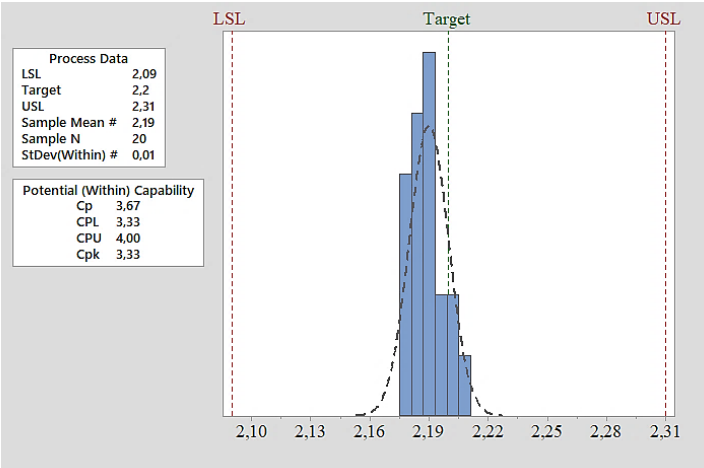
	*Specification limits:* *USL (+ 5%) = 2,31* *LSL (- 5%) = 2,09*

Table 18 Airflow measurements conformity with the Specification Limits (Minitab ®)

The reduced dispersion of airflow data is also explainable by the compensation flow system inside the flow-controlled pump, which provides an automatic adjustment of the airflow range (± 2%) in different backpressure conditions.

The flow-controlled pump is capable to ensure the required performances, being in metrological confirmation condition, as confirmed by the intermediate calibration check.

6.3. Approach 2: representativeness of the measurements results

Research question 2b*: how to gather exposure data actually representative of the specific working scenario, in particular for complex contexts?*

6.3.1. Representativeness of workers' exposure models

The sub-part of the Guideline especially developed for the OS&H analysis of working activities deals with a key issue for the Occupational Risk Assessment and Management: the representativeness of the exposure measurements results (Bisio et al., 2017). A correct assessment of the exposure conditions of workers, essential for an effective Occupational Risk Assessment, is a difficult and demanding task, and a very large number of accidents and occupational diseases are due to the underestimation of risks resulting from an incorrect or incomplete understanding of measurement results or a poorly designed measuring campaign. On the other hand, the overestimation of the risk associated with a Hazard Factor can generate an equally serious error in the organization of the Risk Management, as well as misdirected investment of the available economic resources.

As already discussed, the OS&H issues and the measuring processes of Hazard Factors are strictly linked: the protection of safety and health of workers requires the definition of exposure models based on the quantification of Hazard Factors. The models in particular should be based on:

1. the identification of the exposed workers (only apparently an easy task in complex scenario such as the research universities);
2. the analysis of the exposure way, frequency and duration;
3. measuring processes aimed to effectively characterize, with the necessary detail, the Hazard Factors (physical, chemical, biological) which can compromise the workers' safety and health;
4. statistical criteria suitable to ensure the representativeness of the achieved measurement results, essential to make comparisons with the limit values suggested by Safety regulations, standards and good practices.

Steps 1 and 2 represent the target of the measuring campaigns design; the risk analyst should devote special care on the preliminary examination of the activity, to obtain all the information necessary to define a measuring program suitable to provide -in each special situation under exam- correct data on the workers' exposure to the investigated Hazard Factors. The last two steps are pivotal to ensure that the measurement results, thanks to their quality, detail and statistical representativeness, can be correctly used as reliable input data for the assessment of the actual workers' exposure scenario, and its comparison with the limit values suggested by Safety regulations, effectively supporting the decision making process on control design if necessary.

Unlike what happens in other engineering fields, in the case of OS&H Risk Assessment some difficulties arise from a very large variability of internal and external parameters conditioning the measurements, and limit values in some cases (e.g. carcinogenic dust pollution, asbestos, silica, etc.) very restrictive or tend to zero, i.e. near to the instrumental sensitivity.

The developed method makes possible an effective assessment of workers' exposure to factors compromising their safety and health, in particular to chemical agents; however, the way of thinking at the base of the approach can be effectively implemented to manage risks related to different Hazards (e.g. physical agents – the method testing on occupational noise data gave good results as well). The approach is based on two key stages:

- a careful and well-planned quantification of specific factors resulting in data (measuring process results) that accurately represent the actual working scenario (*first level of representativeness*);
- a suitable data processing, aimed to ensure the usability of the measurement results in terms of outliers presence, belonging statistical distribution and statistical representativeness of samples (*second level of representativeness*), necessary conditions to compare the exposure data with the Safety regulations, standards and good practices.

6.3.2. The two-representativeness levels approach

Measuring campaign design ⇨ first level of representativeness

The planning of a series of measurements aimed to assess the workers' exposure to Hazard Factors requires a thorough knowledge of the working context and of the activities performed, in terms of boundary conditions, processes, materials, workers' tasks, etc. In general, the assessment of workers' exposure conditions, and in particular the measurement campaign design, can result the more challenging the more variable is the activity to monitor. A correct approach to design a measuring campaign should be based on the basic H.I. (e.g. Job Safety Analysis) principles: consequently, it is important to break up macro-working tasks in sub operations, to achieve a better resolution on the involved parameters (materials, emission sources, workers shift, etc.).

Information for a careful measuring campaign design

The preliminary information, fundamental to carry out a careful design of a measurement campaign for OS&H purposes, should cover:

1. *the definition of measurement target*: identification of spatial distribution of pollutants in the working environment, evaluation of the characteristics of emission sources, workers' exposure assessment, etc.; according to the measurement target, it is possible to define the quantity (e.g. airborne pollutant concentration, characterization of typologies of airborne fibres, quantification of sound pressure level, etc.) to be measured: usually the time weighted average, upon which to base the average exposure assessment, but additional information (maximum or minimum values, time history, etc.) is sometimes necessary;
2. *thorough examination of the activity*, in terms of handled materials and substances, operations (review of the production processes, work patterns, hazard sources), equipment, adopted techniques and technologies, possible presence of simultaneous processes, workplaces locations and operating conditions (e.g. fixed position or variable operating conditions) necessary to identify the permanence time of workers in the different areas;
3. *the analysis of typology and maintenance level (efficiency) of existing measures* to control the Hazard Factors (engineering -e.g. airborne dust collection systems- administrative, organizational, etc.);
4. *information on work shifts* (tasks associated with each job), number of workers per shift, shift duration and rest periods, and, where possible, identification of homogeneous groups of workers.

An in-depth analysis of working context makes it possible to design a measuring campaign tailored for each scenario by:

- selecting the measurements typology for the measurand: if direct measurements are not possible, the selection should cover both the sampling (e.g. in the case of airborne samplings, choice between personal or area samplings) and analysis (e.g. gravimetric or microscopy analyses) phases;
- selecting the measurements typology or recording techniques for the internal/external parameters potentially affecting the measurand evaluation results (e.g. production characteristics and fluctuations, microclimatic and general boundary conditions, etc.);
- defining characteristics, layout and setup (e.g. sampling duration) of all the measuring equipment: every equipment should comply with the metrological requirements.

A measuring process designed and performed following the above-discussed criteria makes possible to gather data actually representative (*first level of representativeness*) of the working context under exam.

Analysis of the measurement results ⇨ second level of representativeness

Key point of the exposure data processing/interpretation is the statistical approach adopted to relate the measures (input for the workers' exposure models) with the suitable threshold limit values, through the implementation of representativeness tests.

OTL-Tuggle (Tuggle, 1982) and Leidel & Busch (Leidel et al., 1977) tests are some of statistical methods widely used for measures interpretation, also in presence of a limited number of input data. These statistical methods allow to compare the measures with the limit values suggested by Safety regulations, and to draw conclusions about the minimum number of required measures, according to the dispersion value of data, to achieve an acceptable estimate of the exposure situation during the considered time span (typically a work shift).

The developed model considers a well-structured logic flow for an effective data analysis and interpretation, starting from a preliminary general examination of the overall data, to the final data representativeness evaluation.

Since the collection of measures of the same quantity (in this case the Hazard Factor) is equivalent to draw a sample from the statistical population representing the phenomenon, the usability of exposure measures needs of some preliminary steps. The definition of uncertainty affecting each measure, the potential outliers check, and the confirmation of statistical representativeness of the sample versus their origin population necessarily should be part of the final data interpretation. The statistical nature of the approach, at the base of the developed method, makes the process the more robust the higher is the number of available measures.

The initial bird's-eye analysis of data should consider the information collected during the measuring phase (or sampling in the case of indirect measurements), in order to evaluate the measures' trend vs the expected values, and possibly make decision on potential anomalous values.

A careful uncertainty evaluation should quantify the variability due to different factors (e.g. equipment preparation, sampling, sample storage and transportation, laboratory analysis, etc.), affecting each value (Barbato et la. 2013).

Uncertainty evaluation

The general document-guide for the uncertainty evaluation is the JCGM 100:2008 *Evaluation of measurement data – Guide to the expression of uncertainty in measurement - GUM*. The document provides definitions, terms and concepts pertaining to metrology, the "science of measurement and its application". According to the JCGM 100:2008 document, some technical standards make available information on the expanded uncertainty determination in the case of specific measurements. Among these, the UNI EN 482:2015 indicates the procedure to determine a careful expanded uncertainty in the case of chemical agents measurements:

- measurand definition;
- identification of all the possible sources of uncertainty;
- random sampling uncertainty (u_{s_r}), and non-random sampling uncertainty ($u_{s_{nr}}$) quantification;
- random analytical uncertainty (u_{a_r}), and non-random analytical uncertainty ($u_{a_{nr}}$) quantification;
- combined standard random uncertainty (u_{c_r}), and combined standard non-random uncertainty ($u_{c_{nr}}$) computation according to eq. 1 and eq. 2:

$$u_{c_r} = \sqrt{{u_{s_r}}^2 + {u_{a_r}}^2} \quad \text{(eq. 1)} \qquad u_{c_{nr}} = \sqrt{{u_{s_{nr}}}^2 + {u_{a_{nr}}}^2} \quad \text{(eq. 2)}$$

- combined expanded uncertainty (u_c) resulting from eq. 3:

$$u_c = \sqrt{{u_{c_r}}^2 + {u_{cn_r}}^2} \quad \text{(eq. 3)}$$

- expanded uncertainty (U), using a coverage factor k = 2 (on the basis of the level of confidence required) as suggested by the quoted UNI EN 482:2015 standard, calculated according to eq. 4:

$$\mathrm{U} = 2 \cdot \mathrm{u_c} \quad \text{(eq. 4).}$$

The identification of all the uncertainty sources makes possible the quantification of the standard uncertainty ([9]), and the resulting final definition of the expanded uncertainty ([10]), necessary to make decision about the acceptance of each measure ([11]). In the case of gravimetric determination of airborne pollutant concentrations, the technical standard Unichim 2010:2011 method provides guidance on the uncertainty assessment as result from an appropriate combination of the specific phases variability.

[9] *Standard uncertainty:* uncertainty of the result of a measurement expressed as a standard deviation (JCGM 100:2008)

[10] *Expanded uncertainty*: quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand (JCGM 100:2008)

[11] The expanded uncertainty of each measure can be considered as decision making to accept or exclude that measure.

The availability of the expanded uncertainty and the resulting decision about the usability of each measure enable the analysis of anomalous values.

Outliers, data distant from other observations, should be identified since they could condition the assumptions of a statistical test, e.g. belonging to a normal distribution for a sample, but can also provide useful information on the causes of input data anomalies.

Outliers evaluation methods

The assessment of these extreme values can be possible by means of formal or informal methods:

- *Formal methods* (e.g. Generalized Extreme Studentized Deviate -ESD, Kurtosis statistics, and Dixon test applicable to normal distributed samples), usually requiring test statistics based on the distribution assumptions, permit determining if extreme values are outliers of the distribution.
- *Informal methods* (or outlier-labelling methods), such as Standard Deviation and Boxplot, generally are used as screening devices before conducting formal tests. These kind of tests generate an interval or criterion, based on location and scale parameters for the outliers' detection instead of hypothesis testing; any observation beyond the interval or criterion is considered as outlier. Although the labelling methods are usually simple to use, some observations outside the interval may turn out to be falsely identified outliers after a formal test when the outliers are defined as the only observations that deviate from the assumed distribution.

In the case of occupational exposure measures, we should refer to "*potential outliers*", since anomalous data can be due also to particular activities, expected or not, which contribute (increasing) to the workers' exposure, and should be considered. Hence, the assessment on the usability of potential outliers in the interpretation of measurement results becomes fundamental. Therefore, a careful monitoring of all samplings operations becomes essential: recording each significant information during the sampling operations, integrated with additional details from employers, workers designated for prevention and protection, etc., makes possible to identify the possible causes (operational) of anomalous data. Provided that the preliminary laboratory operations comply with the quality standards, potential outliers devoid of work or production related explanations could be reasonably due to errors in the sampling stage.

The sample "filtered" from measures evaluated unusable in the uncertainty and/or outliers' analysis can be subject to representativeness check, to verify if it is representative of its belonging origin population, i.e. it maintains the characteristics of the same population (*second level of representativeness*).

Verification of the statistical representativeness of the sample

Since data can fit the belonging population distribution with different correlation degrees, it is recommended to estimate the correlation level by using the available statistic tests (e.g. χ^2 test) to verify the necessary condition to implement the representativeness test.

A *high correlation level* enables the implementation of statistical tests for representativeness.

An *acceptable correlation degree* suggests that the sample has an approximate fitting with its belonging distribution due to anomalous values, not rejected during the tests to identify the potential outliers. The odd data should be combined with explanatory information, examined during the potential outliers' research process. Such information should influence the decision whether implement the statistical tests for representativeness on the whole sample, or separate the anomalous and "normal" values and process them independently; this means that belonging verifications for the origin population distribution should be carried out for both the two different data sets.

In presence of a *low correlation level,* the sample does not belong to the origin population distribution and the selected statistical test for representativeness simply cannot be applied, since one of the necessary condition is not verified.

The final exposure data interpretation, based on the statistical comparison of the "cleaned" sample with the threshold limit values, can be performed by means of statistical representativeness tests (e.g. OTL-Tuggle, Leidel & Busch, etc.) usually adopted for measures interpretation also in the presence of a reduced sample size.

The described approach was tested, step by step, in the design and realization of measurement campaigns of airborne dust concentration and occupational noise, and consequent statistical interpretation of achieved data.

6.3.3. Approach validation: airborne particulate concentration data

The first approach validation involved a sample of airborne dust concentration measures (Table 19 shows the complete dataset) in respirable fraction, gathered through the same devices (personal flow-controlled pumps and analytical balance) used to test the System Quality in measuring processes approach (discussed in Section 6.2). The sampling/analysis campaign was carried out in a university working environment characterized by fixed operating position and almost constant pollutant concentration (Bisio et al., 2018). The reduced sample size conditioned the selection of suitable tests for the analysis step.

The usable methods apply to normally distributed data, therefore, since the airborne particulate concentration measures are described by lognormal distribution, a log transformation of such data could be necessary in some steps of the analysis.

n. measure	1	2	3	4	5	6	7	8
C [mg/m^3]	***0,065***	***0,007***	***0,007***	***0,111***	***0,229***	***0,079***	***0,209***	***0,170***
n. measure	9	10	11	12	13	14	15	16
C [mg/m^3]	***0,085***	***0,059***	***0,052***	***0,269***	***0,052***	***0,020***	***0,052***	***0,058***

Table 19 Dataset of the airborne dust concentration

The expanded uncertainty (U), affecting each concentration measure has been determined in conformity with the suggestions of the Unichim 2010:2011 method (eq. 5).

$U = u_c \cdot k = u_c \cdot t_{p=0,95}$ (eq. 5)

where u_c is the combined standard uncertainty ([12]), k is the coverage factor related to the t-Student variable, and 95% likelihood level. The preliminary uncertainty calculation ensured the usability of all dataset, since every uncertainty value resulted in compliance with the reference standard.

The preliminary analysis of the sample pointed out three values as potential outliers. In particular, the measures n. 2, 3 and 12 appear far from the mean value of the sample (0,095 [mg/m^3]): some considerations on the nature and origin of these values were therefore necessary. Boxplot and Standard Deviation method, informal tests, made possible the initial screening on potential outliers. The outcome of Boxplot on whole sample was not able to identify outliers (Fig. 14).

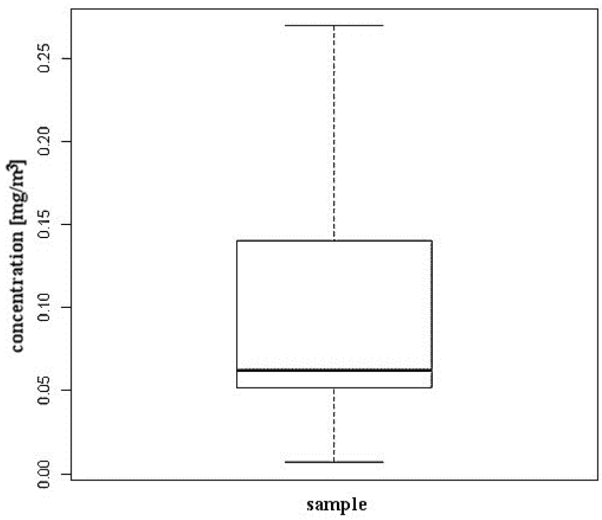


Figure 14 Boxplot of the data set

The Standard Deviation method entails that observations outside the $\bar{x} \pm SD$ interval (where $\bar{x}$ is the sample Mean and SD the Standard Deviation) may be considered as outliers. The method, under the necessary condition of data belonging normal distribution, was applied on the log-transformed measures.

The method gave negative response on the outliers' presence, since all values fell into the $\bar{x} \pm 3 \cdot SD$ interval (including approximately the 99,7% of the data).

[12] The *combined standard uncertainty* is an estimated standard deviation characterizing the dispersion of the values that could reasonably be attributed to the measurand *y* (JCGM 100:2008)

The modified Z-score test (Iglewicz and Hoaglin, 1993) was selected to confirm the results of the previous informal tests instead of the original Z-score test, since the latter could be misleading on small samples size due to the conditioning of a few, or even a single, extreme value. To avoid this problem, the Median ($\tilde{x}$) and the Median Absolute Deviation – MAD replace respectively the Mean and Standard Deviation of the sample. The modified Z-score test implies calculating and assessing the absolute M_i value (eq. 6); if the resulting value is greater than 3,5 the measure can be labelled as potential outliers.

$$M_i = \frac{0{,}6745 \cdot (x_i - \tilde{x})}{MAD} \quad \text{(eq. 6)}$$

The test identified only the measure n. 12 (0,269 [mg/m^3] value) as potential outlier, since the related Z-score (equal to 4,3) exceeds the reference value.

The adopted informal tests, as preliminary screening, gave discordant results, making necessary the implementation of formal tests to make decision. Among the available formal tests, the Generalized ESD test (Rosner, 1983) was considered appropriate (according to the sample size and data belonging distribution) to detect one or more outliers in a univariate data set that follows an approximately normal distribution. Generalized ESD is essentially a Grubbs test (Grubbs, 1969) applied sequentially, and requires only the specification of an upper bound for the suspected number of outliers. The method is based on the test statistics (eq. 7):

$$R_i = \frac{max_i\,|x_i - \bar{x}|}{s} \quad \text{(eq. 7)}$$

where $\bar{x}$ and s are respectively the sample Mean and Standard Deviation. The test requires to remove the value that maximizes the difference $|x_i - \bar{x}|$ and then to recalculate the same test statistic R_i with $(n - 1)$ observations, repeating the process until r observations have been removed, resulting in r test statistics ($R_1, R_2, \ldots, R_r$). The number of outliers is determined by finding the largest i such that $R_i > \lambda_i$, where λ_i are critical values determined by (eq. 8):

$$\lambda_i = \frac{(n-i)\cdot t_{p,n-i-1}}{\sqrt{\left(n-i-1+t^2_{p,n-i-1}\right)\cdot(n-i+1)}} \quad i = 1,2,3,\ldots,r \quad \text{(eq. 8)}$$

where, n is the sample size, and $t_{p,v}$ is a coefficient deriving from the t-Student distribution with ν degrees of freedom. The method is applied under the hypothesis that up to four anomalous values, supposed in the preliminary data survey, can be potential outliers; the log-transformed values are input data for test. For each of the four potential outliers the condition $R_i > \lambda_i$ is never verified (Tab. 20) at the 5 % significance level ([13]). Hence, none of the odd values can be classified as outlier.

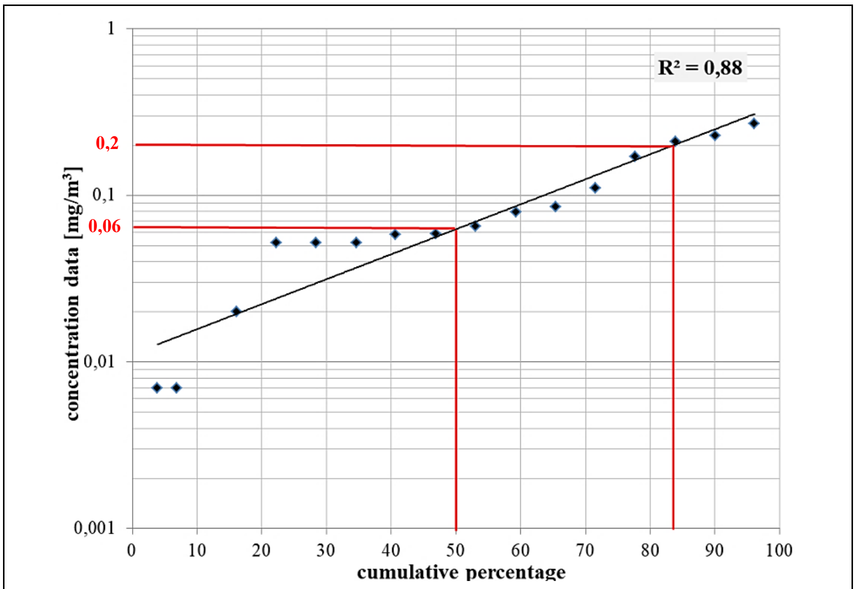
[13] The significance level, α, defines the sensitivity of the test. A value of α = 0,05 means that we inadvertently reject the null hypothesis 5% of the times when it is in fact true. This is also called 1° kind error. The choice of α is somewhat arbitrary, although in practice values of 0,1, 0,05, and 0,01 are commonly used.

Potential outlier	Potential outlier (log-transformed)	n. of outlier (i)	Test statistic R_i value	Critical value λ_i (5% sign. level)
0,007	-2,155	1	2,0079	2,5857
0,007	-2,155	2	2,4499	2,5483
0,020	-1,699	3	1,9933	2,5073
0,269	-0,570	4	1,6833	2,4620

Table 20 Generalized ESD results tested for up to four outliers

The results of different tests on the collected airborne dust concentration measures show that no value can be considered as outlier: the all data seems belonging to the same population. Since the lognormal distribution of the sample (or the normal distribution of the log-transformed data sample) represents the condition to be verified before the implementation of representativeness tests, the achieved data can be analysed through goodness fit tests.

The log-probability diagram (method proposed also by technical standard UNI EN 689:2018) is a simple method to check the lognormal distribution of the airborne particulate concentration data. The concentration values and the corresponding cumulative percentages are plotted on the log-probability diagram (x-axis: cumulative percentage - y-axis: measured values). The alignment of the points on the diagram (Fig. 15) confirms the log-normality hypothesis for the sample. The Geometric Mean (50% cumulative size) and the Geometric Standard Deviation, completely defining the lognormal distribution, can be determined directly from the log-probability plot:



Geometric Mean = 0,062 mg/m³

Geometric Standard Deviation $= \frac{84\%}{50\%} = \frac{0,2}{0,062} = 3,2$

Figure 15 Data set log-probability diagram

As results from the test, data fit the lognormal distribution with a high correlation coefficient (R^2 = 0,88): the sample is statistically representative of its population.

In addition, the Shapiro - Wilk test (Shapiro and Wilk, 1965), suitable to evaluate the supposed normality of a complete data set, also for small sample sizes (n < 20), was applied to validate the log-probability diagram result. The method, implemented on the log-transformed data (supposed normally distributed), is based on the W statistic test (eq. 9):

$$W = \frac{\left(\sum_{i=1}^{n} a_i \cdot x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad \text{(eq. 9)}$$

where, $x_{(i)}$ are the ordered sample values ($x_{(1)}$ is the smallest) and a_i are constants generated from the Mean, Variance and Covariance of the order statistics of a *n* size sample from a normal distribution.

The calculated W value resulted equal to 0,898. The comparison between the calculated W value and the percentage point of the W test for the specific sample size (n=16), available in the document "An Analysis of Variance Test for Normality" (Shapiro and Wilk, 1965), gave positive response: (log-transformed) data belong to a normal distribution with a 95% confidence level, since the W value falls within the 0,05 and 0,10 significance levels interval (Tab. 21).

Percentage points of the W test									
n (sample size)	*Significance level*								
	0,01	*0,02*	*0,05*	*0,10*	*0,50*	*0,90*	*0,95*	*0,98*	*0,99*
16	***0,844***	***0,863***	***0,887***	***0,906***	***0,952***	***0,976***	***0,981***	***0,985***	***0,987***

Table 21 Shapiro - Wilk test: Percentage points of the W test

The established sample statistical representativeness matches with the output of HISTAT data processing software (Tab. 22). The software, distributed by the American Industrial Hygiene Association - AIHA, is a simple Excel application able to provide useful information on exposure statistics, goodness of fit tests, and graphs exposure data.

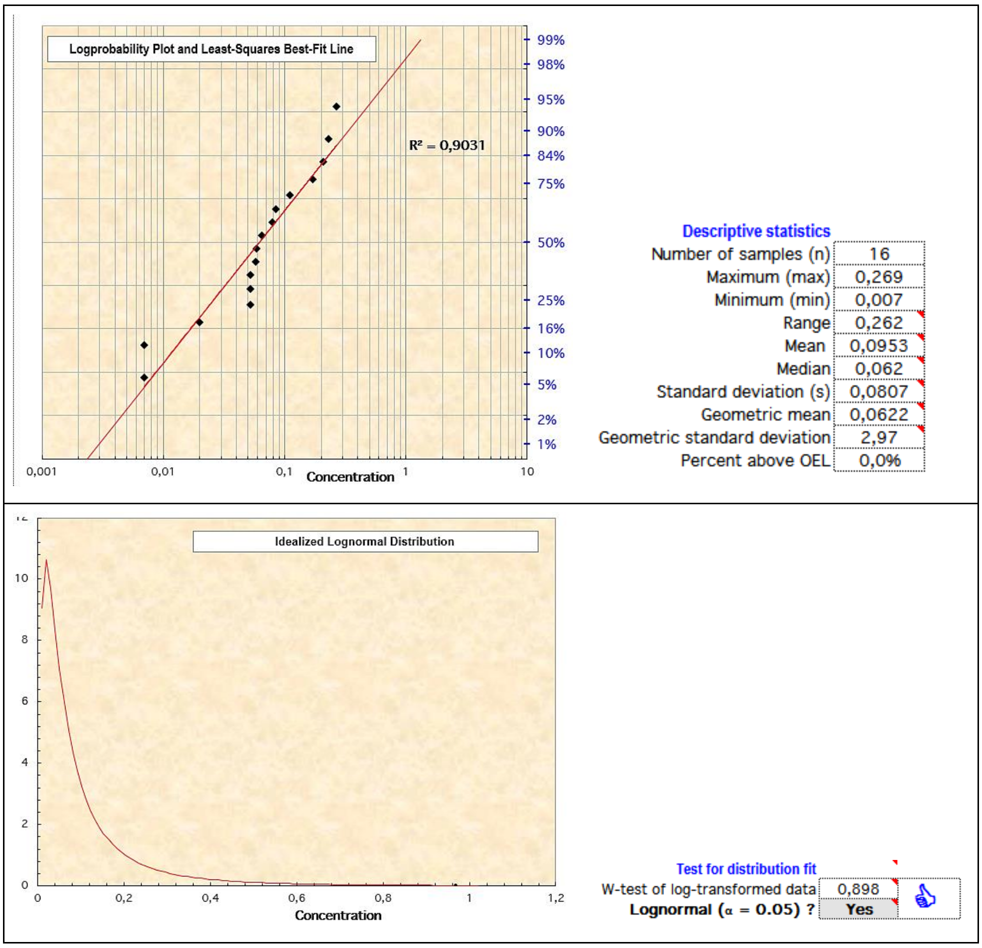


Table 22 HISTAT results on the dataset

Given that the confirmed statistical representativeness of the sample by two tests, all the recorded measures belong surely to the lognormal distribution. The final phase of the measures interpretation is possible: the sample can be related to the exposure limits from Safety regulations, through the available representativeness tests (e.g. Tuggle test, Leidel & Busch test, etc.), to get information about the compliance / not compliance of the analysed workers' exposure situation.

In this case, the Tuggle tests was selected to perform the analysis. The method is based on statistical One-sided Tolerance Limits – OTL. Since the necessary condition for the implementation of the OTL procedure (and of the deriving Tuggle method as well) is the normal distribution data, the method is applied on the log-transformed data. According to the OTL test, the Tuggle method requires to define parameters which describe an "acceptable" situation, as, summarized in Table 23:

- **p**: percentage of exceeding of the statistically acceptable exposure reference value: it represents, as reasonable condition, the acceptability of a working environment in which the concentration values, greater than the reference value, are not more than 5% of the total of the measures;
- **γ**: confidence level of one-sided tolerance test; a confidence level equal to 95% (1-p) means that, with a 95% likelihood, all the measures over time can assume values less than the reference limit value;
- **K**: represents values defining the limit for an *acceptable* workplace (compliance with the relevant limit value, e.g. TLV);
- **K'**: represents values defining the limit for an *unacceptable* workplace (limit value exceeded);
- **Z**: represents the uncertainty area, between K and K', and indications on the trend of test statistic for an increase of the sample size (n) become available.

Table 23 Parameters for Tuggle test

After the first three independent measurements (minimum sample size required by the method), data are processed for testing, according to the steps described in Table 24.

Step 1	$PR_i = \frac{x_i}{TLV}$ ⇨ $\log PR_i = y_i$ *(x_i = measured value;* *TLV = Threshold Limit Value)*
Step 2	$\bar{y} = \frac{1}{n} \cdot \sum_{1}^{n} y_i$ *(n= sample size)*
Step 3	$s_y = \sqrt{\frac{\sum_1^n (y_i - \bar{y})^2}{n-1}}$
Step 4	$Test\ Statistic = \frac{\log(TLV) - \bar{y}}{s_y}$

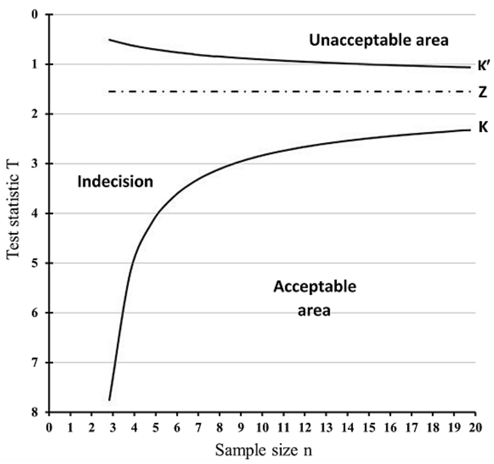


Table 24 Tuggle test phases (left) and chart (right)

The method is implemented on relative measures (see Step 1) resulting from the ratio between the measured data and the reference value (the ratio is known as *Pollution Ratio - PR*). Working on relative data, some benefits in the method implementation are achievable, first of all the increased resolution of the analysis (comparable to analyse data residuals).

In our case, being the analysis intended to get information on the workers' exposure to PNOS (Particulates Not Otherwise Specified) in respirable fraction, the proper 3 mg/m^3 Threshold Limit Value (American Conference of Governmental Industrial Hygienist, 2018) was selected as term of reference (denominator) for the PR computation.

The log-transformation of the normalized sample (PR values) makes fulfilled the necessary condition of the method, i.e. its belonging to the normal distribution, enabling the calculation of the Mean ($\bar{y}$) and the Standard Deviation (S_y). These parameters permit the computation of the Test Statistic, as reported in Step 4. Test Statistic can be considered the parameter that truly relates the measures with the limit value. The process described in Table 24 is performed starting from three data, increasing the sample size until the reaching of a decision area on the graph, providing information useful for the evaluation of the exposure condition in the context under exam. The minimum number of measures to achieve an actually representative exposure situation (in compliance with the reference limit) can be identified on the x-axis of the first point certainly included in the acceptable area, on the chart.

Table 25 displays the result of the method applied in three consecutive phases (Test 1, Test 2 and Test 3), increasing the sample size.

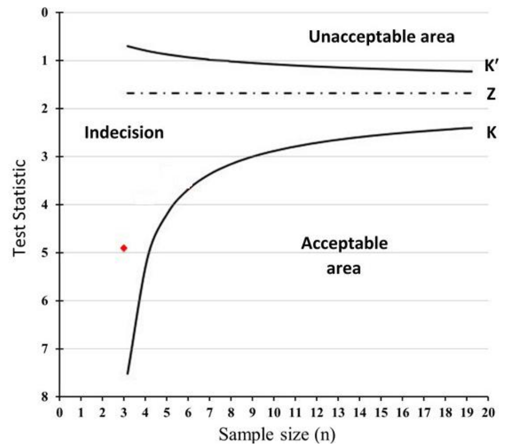
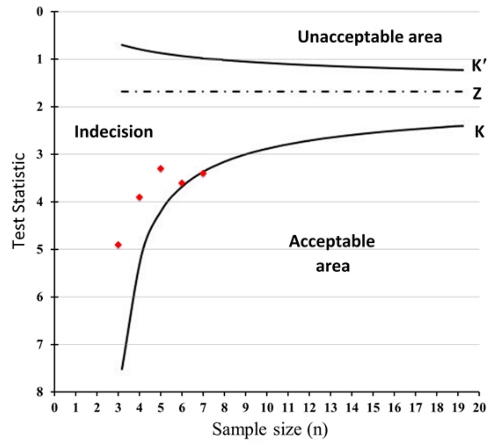
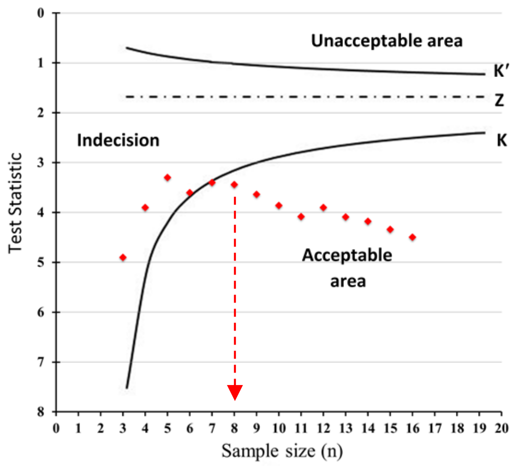
Test 1, carried out on a size sample consisting of *three* measures, does not permit to make decision on the compliance with the reference limit (3 mg/m^3): identified point fall in the uncertainty area.	
Test 2, performed with a *seven* measures sample size, results borderline with acceptable area: an additional increase of sample size is required.	
Test 3, in the considered context, *eight* was the minimum number of measures necessary to assess the exposure condition: points fall into the acceptable area, therefore, with eight data, it is possible to get important information about the workers' exposure.	

Table 25 Tuggle test implementation phases

As results from the tested approach, an exposure situation, even if related to a working environment with a theoretically constant pollutant concentration, should be verified at least by three initial measurements, as suggested also by the British Occupational Hygiene Society, EN 689:2018 standard, and French Regulations.

6.3.4. Approach validation: occupational noise data

As preliminary test, the approach was adopted to support the assessment of the exposure condition to occupational noise of people involved in laboratory activities. The method was implemented on a sample of twenty measures (A-weighted equivalent sound level - Leq(A) as specified in eq. 10, modified from Malchaire and Piette, 1997), characterized by low variability (controlled Standard Deviation), recorded in a university laboratory (Bronuzzi et al., 2018).

$$L_{Aeq,T} = 10\ \log\frac{1}{n} \cdot \left(\sum_{i=1}^{n} 10^{\frac{L_{Aeq,t}}{10}}\right) \quad \text{(eq. 10)}$$

where

T = total measuring duration (typical work shift);

t = measuring duration of each measure (15 - 20 min.);

n = number of measures;

$L_{Aeq,t}$ *= Sound Equivalent Level of each measure;*

$L_{Aeq,T}$ *= overall Sound Equivalent Level.*

As result from the first stage of the approach, the overall sample (20 measures, as result from the uncertainty evaluation) devoid of outliers, well fits to the normal distribution (according to the scientific literature, occupational noise data in not too complex scenarios, can be described by the normal distribution (Malchaire and Piette, 1997). Tuggle method was selected to relate the sample with the reference values.

Unlike for the airborne particulate, the occupational noise risk assessment considers three reference levels: Lower Action Limit – LAL, Upper Action Limit – UAL, and Occupational Exposure Limit – OEL (2003/10/EC Directive). The implementation of the Tuggle method, originally modified to process noise data, makes possible the definition of the minimum sample size to compare, in a statistical approach, the noise values with the exposure reference values, taking into account the confidence interval selected and the power of the test. The Tuggle representativeness test needs of some modifications of the method used in the previous analysis (airborne dust), in particular involving two steps:

- *Step 1:* no log-transformation of the PR, in this case ratio between measures and *Reference Level – RL* (to choose among the Action limits and the Occupational Exposure limit) is needed, since data are normally distributed;
- *Step 4:* in the Test Statistic formula, the selected limit value is not log-transformed, since it belongs to the same (normal) distribution of measured values.

Moreover, a scale factor (*C*) was introduced to compensate for the different ratio - measured values/reference level - existing in the cases of airborne particulate and noise. Table 26 shows the modified Tuggle approach, implemented in three consecutive phases increasing the sample size, using as RL the Lower and Upper Action Limits and the Exposure Limit Value, step by step. Test 1 was performed with a 3-measures sample size (minimum condition for the applicability of the method); Test 2 with a 10 data sample size; Test 3 using the complete set of measures (20 data).

Step 1	$PR_i = \frac{x_i}{RL} \Rightarrow PR_i = y_i$ *(x_i = measured value; RL = Reference Level)*
Step 2	$\bar{y} = \frac{1}{n} \cdot \sum_1^n y_i$ *(n= sample size)*
Step 3	$s_y = \sqrt{\frac{\sum_1^n (y_i - \bar{y})^2}{n-1}}$
Step 4	$Test\ Statistic = C \cdot \left(\frac{RL - \bar{y}}{s_y}\right)$

Table 26 Modified Tuggle test

As results from Figure 16, Test 1 does not permit to make decision on the compliance with the three reference limits: identified points fall in the uncertainty area. Test 2 results borderline with acceptable area, in the case of a 87 dB RL (OEL) and of a 85 dB RL (Upper Action Limit); an additional increase of sample size is required, especially considering the Lower Action Limit (80 dB). Finally, the complete sample does not allow to establish the compliance with the Action Limits also using the OEL as reference value: the Test Statistic trend remains in a borderline condition with acceptable area; the sample size is insufficient to define clearly the workers' exposure situation.

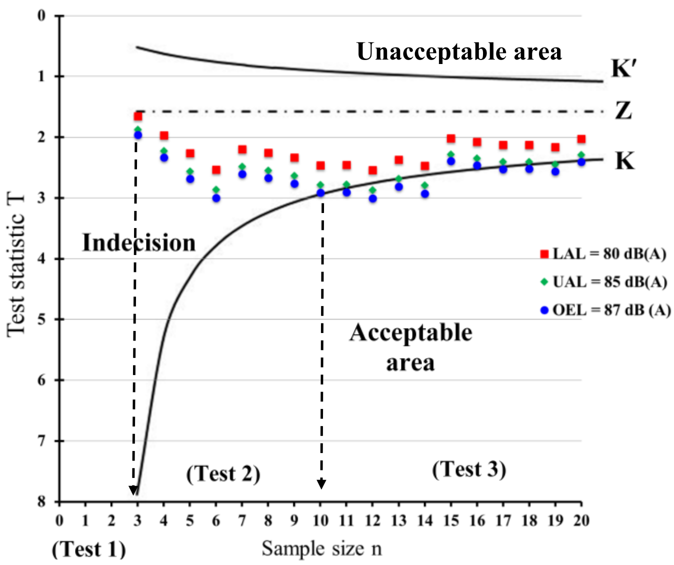


Figure 16 Tuggle test results on noise data

The performed tests proved the effectiveness and suitability of the proposed representativeness analysis techniques, the completeness and comprehensiveness of the results in a real case, and the consistency with the EN standards and regulations on the strategies of the pollutant assessment (noise included) at the workplaces.

The need for a careful monitoring during the measurement campaign is confirmed: the deriving considerations may be essential for the interpretation of the measurement results. This aspect becomes very important where, such as in the case of airborne dust pollution evaluation, the concentration values result from separate phases (sampling and subsequent laboratory analysis).

6.4. In closing

An effective implementation of the sub-phase of the Guideline especially devoted to the OS&H analysis of working activities can rely on the results of the developed approach on a) the system quality in measuring systems setup and b) the workers' exposure models representativeness.

With reference to *Research question 2a (how to ensure that the measuring processes fulfil the necessary metrological requirements, providing exposure data quality?)* the research on measuring equipment setup confirmed that if a measuring process remains under statistical control along the time, the equipment calibration could be postponed to important maintenance interventions, or when the equipment performances will no longer be adequate to the analytical requirements of the specific analysis. In such a condition, a compromise between the correct Risk Management and the process efficiency guarantees the metrological requirements and then the regular performance quality of the measuring systems.

In the case of measuring systems involved in OS&H Risk Assessment, the quality of data is fundamental, since the measurement results are essential decision-making tools both in the definition of workers' exposure models and in the selection of technical and work organization prevention solutions. Therefore, the use of suitable measuring systems for the intended use, in terms of correct metrological confirmation condition, and the appropriate metrological confirmation interval become of pivotal importance. The sub-phase approach 1 makes available a manageable and effective method based on the process statistical control and Capability analysis tools (i.e. Control Charts and Process Capability indexes), to perform intermediate calibration checks ensuring both the management in System Quality and the correct metrological confirmation of the used equipment.

With reference to *Research question 2b (how to gather exposure data actually representative of the specific working scenario, in particular for complex contexts?),* it is necessary to consider that incorrect or incomplete understanding of measurement results or poorly designed measuring campaigns are the main cause of lacking assessment of the exposure conditions of workers, resulting in an incorrect Risk Assessment.

The developed sub-phase approach 2 of the Guideline, based on two representativeness levels, introduces formalized techniques leading to a rigorous design and manage of the measuring campaigns, and to obtain actual exposure models founded on data truly representative of the analysed working context, essential also for the occupational physicians to define the health surveillance program of workers. However, in the definition of representative workers' exposure models, the enhancement possible through the implementation of the sub-phase criteria should be combined with a careful estimation of the exposure duration (or Contact Factor) to each Hazard Factor.

Given the encouraging results of the performed tests, the developed sub-phase of PoliTo-UniTo Guideline can be considered an effective tool, available for the analysts, to improve the effectiveness of the workers' exposure assessment, in a metrological and scientific rigour, and in system quality approach, arising from the logical consistency of principles established in the Guideline.

Chapter 7

Special asbestos sub-phase of the PoliTo – UniTo Guideline

7.1 The asbestos sub-phase approach

Research question 3: *how can be effectively assessed and managed, in System Quality, the risks related to the still widespread presence of residual ACMs in large public facilities and universities?*

The residual presence of critical components (i.e. ACMs) still represents one of the main criticalities for the OS&H in many large public facilities (Lee and Van Orden, 2007). The verified carcinogenicity of all varieties of asbestos was at the base of the ban of these materials in 55 Countries, according to the International Ban Asbestos Secretariat. Due to the remarkable number of uses of asbestos in the past, from the beginning of last century, and in particular from the end of WWII, to the official ban in 1992 (Italian Law n. 257 of 27 march 1992), several materials, products and structural elements containing asbestos are still present in shell, systems and interior spaces of settlements containing workplaces, and in work equipment, in buildings, public facilities and universities.

The analysis of workplace safety condition, in terms of structure, materials, plants, artefacts, and work equipment, essential to verify the absence of such critical components or to manage the existing ones, is crucial for a thorough identification of the all ACMs and resulting careful Risk Assessment and Management.

The Italian Ministerial Decree September 6^{th} 1994 (D.M. 06/09/94) regulates the aspects related to the presence of ACMs in public facilities, and in particular provides general information on the assessment and management of the related risks.

The PhD research work has contributed to develop and validate a special sub-phase of the PoliTo-UniTo Guideline focusing on the risk of exposure to air-dispersed respirable asbestos fibres. The asbestos sub-phase, consistent with the Guideline principles, is based on the results of a research sub-project, and covers different scenarios ranging from a confirmed absence of ACMs, to the various Hazard modes, from Dormant, to Armed, to Active, according to the OSHA definitions (Occupational Safety and Health Administration, 1991):

- *Dormant:* the situation presents a potential hazard, but no people, property, or environment is currently affected;
- *Armed:* people, property, or environment are in potential harm's way;
- *Active:* a harmful incident involving the hazard has actually occurred.

A basic point of the asbestos sub-phase approach is that no undue exposure to asbestos fibres in common work environments is acceptable; hence, consistently with what suggested by Health and Safety Authority - HSA (2013), the asbestos sub-phase distinguishes between:

- *'Non-friable asbestos'*, material containing asbestos that is resistant to mild abrasion and damage, and less likely to release inhalable fibres (labelled as *compact matrix* in the asbestos sub-phase of the Guideline);
- *'Friable asbestos'*, an ACM is less resistant to mild abrasion or damage and more likely to release inhalable fibres.

Moreover, the sub-phase shares the statement "*If ACMs are in good condition and left undisturbed, it is unlikely that airborne asbestos will be released into the air, and therefore the risk to health is extremely low. It is usually safer to leave it and review its condition over time. However, if the asbestos or ACM has deteriorated, been disturbed, or if asbestos-contaminated dust is present, the likelihood that airborne asbestos fibres will be released into the air is increased*".

On these basis, the asbestos sub-phase provides:

a. univocal criteria for a strict classification of workplaces in categories well defined in terms of asbestos Hazard modes;

b. a reliable and well-tested reference for the H.I. phase both in shell, systems and interior spaces, and in work equipment, in terms of presence and conservation conditions of the ACMs and their sealing/enclosures;

c. a reliable reference on the Risk Assessment and Management for the prevention of occupational illness from exposure to respirable asbestos fibres of people at work in universities and large public facilities.

The essential parts of the asbestos sub-phase of the Guideline

Point a. Univocal criteria for workplaces classification

The univocal criteria for rigorous workplaces classification in categories well defined in terms of asbestos Hazard modes considers five possible criticality levels. Table 27 summarizes the 5 classes of ascription of the building areas suspect for presence of ACMs, the classification of each area resulting from a thorough H.I. process. The outcome of the first inspection in every area requires systematic confirmation, since the ACMs and sealing/enclosure status can worsen along the time, compromising the initial assumption.

Nature of Hazard	Criticality	Criticality Level
Absent	*the ACMs absence, resulting from documents analysis, is confirmed by in situ surveys;*	White
Dormant	*confirmed ACMs presence exclusively in a persisting situation of compact matrix in good conservation conditions, rigorously sealed/enclosed;*	Green
Armed - 1 *transition to active status is proven unlikely*	*confirmed ACMs presence exclusively in compact matrix in good conservation conditions, located in areas out of common reach and not subject to stress actions potentially causing degradation effects;*	Yellow
Armed - 2 *transition to active status without notice is possible*	*confirmed ACMs presence exclusively in compact matrix in good conservation conditions or sealed/enclosed, but exposed to stress actions potentially causing degradation effects;*	Red
Active	*confirmed ACMs presence in friable matrix, and/or deteriorated sealing/enclosure.*	Black

Table 27 Classes of ascription of the areas depending on the Hazard mode

Point b. Reliable and well-tested reference for the H.I.

For a reliable and well-tested reference for the H.I. phase both in shell, systems and interior spaces, and in work equipment, in terms of presence and conservation conditions of the ACMs and their sealing/enclosures, a first rough distinction between areas can be based on a *document search.*

The document search should be performed through the analysis of the building original project and of the additional documents on structural modifications, improvements and maintenances, gathering all the available information about the presence and location of artefacts potentially or surely containing asbestos. Special care should be devoted to the identification of the possible presence of mobile artefacts/equipment, through an inventory check. However, if the document search does not allow to exclude with certainty the presence of ACMs, the area should be included in the *H.I. program special for ACMs*.

On this matter, the asbestos sub-phase of the Guideline suggests an approach based on the Canvassing (ad hoc modified Forensic Investigation technique already discussed in Section 5.2), able to ensure a thorough Hazard Investigation and an objective reference to assess any worsening of the situation over the time. The H.I. program special for ACMs makes possible systematic surveys of the workplaces through:

1. the selection of the part of the building to examine (external or internal);
2. the definition of the modus operandi for environmental or technological units (UNI 8290:1981): external (facade sections, roofs, etc.) or internal (interior spaces, shared areas, etc.);

3. the implementation of the Canvassing to perform a deepened and thorough analysis of the area; as resulted from the approach validation, the Canvassing resulted particularly suitable for the analysis, devoid of errors due to the judgment subjectivity of the analyst, of shell, services and interior spaces of settlements containing workplaces, and of their not-operative content; on this basis, also the collection of material samples for subsequent laboratory analysis (consistent with the D.M. 06/09/94) becomes exhaustive; moreover the technique can make possible a thorough spatial referencing of the results, ensuring the repeatability of the analysis in conditions under control; at this regard, a photographic documentation gathering of the identified artefacts assumes great importance both to document the investigation results and to provide useful information for the Quality Management phase;
4. the resulting updated mapping ([14]) of the identified ACMs and/or sealing/enclosures: the results of the systematic H.I. program special for ACMs enable the validation and/or integration of the artefacts preliminary mapping, resulting from the document search.

Point c. Reliable reference on the Risk Assessment and Management

According to the different classes of ascription in Table 27, the Risk Assessment and Quality Management for the prevention of occupational illness from exposure to respirable asbestos fibres of people at work in universities and large public facilities, needs of different criteria.

Table 28 summarizes the management principles of the different classified areas, established on the basis of the general Quality requirement: more so in the case of asbestos, a record should be available of activities and results, based on documents on the area, fittings and equipment history, updated mapping, measurement results, collected and processed photographic documentation, involved activities and procedures, etc.

[14] Updated mapping refers to the areas classification based on the criticality levels observed at the time of the survey: mapping is a dynamic tool that evolves a) following the remediation work, b) depending on the management of the conservation conditions of artefacts in compact matrix, c) depending on the progress of knowledge about the presence of other typologies of artefacts not currently suspect.

Area Criticality level of ascription	OS&H Management criteria
White	*every artefact/material introduced into the area should be labelled asbestos free to preserve the safe condition;*
Green	*the green level needs systematic confirmation: this entails thorough inspections (NOTE 1) of the artefacts conservation conditions, periodically <u>and</u> <u>when</u> <u>necessary</u>, i.e. in response to occurrences potentially causing alterations of artefacts or sealing/enclosures (e.g. vibrations from natural causes or human activities, plumbing leakages,...);*
Yellow	*more so in this case, a systematic confirmation is necessary: in addition to the green area confirmation criteria, any modification in the use of the areas potentially compromising the clause "out of common reach and not subject to stress actions potentially causing degradation effects" should be considered, and special procedures defined for routine and exceptional activities in the whole yellow area. Such procedures, based on special risk analysis, should ensure no modifications in the Hazard Factor conditions, and in no case cover activities directly involving the ACM or jeopardizing their sealing/enclosure (NOTE 2);*
Red	*any access into the red area of people covered by the Guideline is prohibited prior to the area reclassification through asbestos removal or sealing/enclosure (only licensed contractors are entitled to operate into the red area);*
Black	*the black condition, involving asbestos removal or sealing/enclosure, is not covered by the Guideline: only licensed contractors are entitled to operate into the area.*
(NOTE 1) independent from the area classification, inspection activities should be carried out in safe conditions according to the OS&H general and special regulations; *(NOTE 2) such activities pertain exclusively to the management of black areas, not covered by the Guideline.*	

Table 28 Management approaches for the different categorized areas

In particular the status of Green and Yellow classified areas (respectively Dormant, or Armed with proven unlikely transition to active status) is the most difficult to confirm: consistent with the D.M. 06/09/94, thorough visual inspections of the artefacts conditions, supported by airborne fibres concentration measurements, are necessary. Indeed, the same Decree suggests the possibility to adopt two criteria: 1. exam of the surficial condition of artefacts to detect possible deteriorations resulting in airborne fibres release, 2. indoor airborne fibres concentration measurements, specifying that the airborne measurements alone cannot be a valid criterion to detect the possible fibres release from the pre-identified ACMs deterioration.

The demanding confirmation in particular for Green and Yellow categorized areas motivated the two following parts of the research work (summarized in the Outline 3a and 3b) developed to evaluate which kind of information can be obtained from airborne concentration measurements for the workplaces classification and periodic confirmation of the categorized areas, and to improve the visual inspections, introducing Image Analysis techniques.

Outline 3a

Asbestos sub-phase of the Guideline: the role of the airborne measurements	
Question 3a	Investigation on the possibility to obtain a prompt identification of the ACMs even slight alteration by means of indoor airborne measurements;
Approach solution	study on the possibility to detect very low concentrations through the increase of the method sensitivity, selecting a peculiar sampling context, adopting a special sampling and analysis strategy, and implementing an approach for the data interpretation characterized by a well-defined logical (metrology-based) structure;
Approach validation	approach tested involving a Yellow classified area and ACMs removal operations.

Outline 3b

Asbestos sub-phase of the Guideline: the Image Analysis	
Question 3b	Overcoming the limits of the visual inspection due to: a) a limited quality in the deriving documentation, b) the unsatisfactory detail in the comparison of the AMCs and sealing/enclosures status along the time, and the eventual subjectivity in the evaluation;
Approach solution	implementation of computer assisted image processing and interpretation techniques to support the inspection activities providing a documented history of each ACM conditions along the time, both in small and large scale;
Approach validation	approach tested in a Yellow classified workplace.

7.2 Special research for the asbestos sub-phase of the Guideline: the role of the airborne measurements

Research sub-question 3a: *what is the actual contribution of the airborne fibres measurements both in the initial workplaces classification and their periodic confirmation?*

In line with the D.M. 06/09/94, indoor air dispersed asbestos fibres measurements could periodically contribute to confirm the good compactness conditions of the pre-identified ACMs, along the time. In no other situation the environmental pollution measures are needed, since the presence of deteriorated (or easily degradable) asbestos containing artefacts, or damaged sealing/enclosure, pertains to a scenario where the area involved, already classified in Red or Black categories, is no more considered a workplace (except for the licensed contractors entitled to operate into the areas).

The same Decree specifies that the airborne measurement alone cannot be a valid criterion to detect the possible ACMs degradation. Therefore, the evaluation of the role, the contribution and the effectiveness of airborne measurements in the identification of incipient degradations of asbestos containing products in good conditions, is important to determine whether the airborne measurements could be included in the H.I. program special for ACMs (as collateral supporting tool) and in the areas Quality management criteria.

Even more given the common, but not exhaustive, practice to monitor the artefacts condition evaluating the airborne fibres concentrations collected by occasional airborne fibres samplings, assuming questionably a direct correlation between pollution and ACMs conditions, without any considerations on factors affecting the indoor pollution, mainly in terms of boundary conditions. Such an approach can be debated since it is affected by different criticalities and difficulties:

1. the collection of a limited number of indoor asbestos airborne fibres measures inside the areas containing ACMs can provide only a “snapshot” of the pollution in a limited time span;
2. the extent of possible fibres release due to incipient artefacts deterioration results in an increase of concentration barely measureable (comparable with the outdoor background), as confirmed by some research works on the evaluation of fibres release from artefacts subject to stress condition (Paustenbach et al., 2004); therefore, the indoor pollution variability due to artefacts degradation can be heavily conditioned by the outdoor concentrations fluctuations (e.g. outdoor pollution variability);
3. the method uncertainty (sampling and analysis) should be carefully defined: in some cases (e.g. in the Phase Contrast Microscopy - PCM analysis) the measure expanded uncertainty becomes important and comparable to the numerical value of the measured concentration (National Health and Safety

Commission, 2005); the decision making becomes then difficult, in particular in very low concentration conditions;

4. according to the approach discussed in Section 6.3.2, every method, intended to get information from the relation between data samples and reference values (e.g. to correlate an indoor pollution situation with reference outdoor pollutant concentrations, or to define a workers' exposure situation compliance with limit values), needs to comply with a careful and well-planned measuring process and a suitable data interpretation.

Hence, a presumed prompt identification of the ACMs even slight alteration by means of indoor airborne measurements presents not negligible lacks.

The target of the study entails the possibility to detect very low quantities: hence the method sensitivity was increased selecting a peculiar sampling context, adopting a special sampling/analysis strategy, and implementing an approach, for the data interpretation, characterized by a well-defined logical (metrology-based) structure (Fargione et al., 2019).

7.2.1 The sampling/measuring strategy

The context designated to perform the measurement campaigns pertains to window fixtures removal operations due to the presence of asbestos in sealant mastic, in some university environments at Politecnico (Fig. 17). The removal yard, involving consecutively different parts of buildings, e.g. single floors, can reproduce a context of ongoing degradation of materials containing limited amount of asbestos. The situation is certainly worse, and most critical (just think to the mechanical stresses on the window fixtures due to the removal operations) than a context where ACMs in compact matrix, located in areas out of common reach, are not subject to stress actions potentially causing degradation effects ([15]) – Yellow class of ascription. Therefore, the selected sampling context could contribute to overcome the problems related to barely detectable airborne fibres concentrations thanks to the mechanical wearing actions on artefacts producing potentially higher fibres releases.

Figure 17 Sampling context and detail of window fixtures to remove

[15] Mechanical actions on the ACMs due to working/operational causes (e.g. maintenance or cleaning activities) are managed through a careful design of both the intended use and allowed activities (see classification requirements).

In this context, the sampling campaign was designed and carried out on a special strategy based on sessions of three simultaneous (matching starting sampling times) indoor/outdoor samplings, involving three different areas at a time:

1. the remediation working area (indoor environment), labelled as *area A;*
2. an indoor nearby area (*area B*) with the same criticalities (i.e. window fixtures with asbestos containing mastics to be successively removed);
3. the external environment (*area C*) close to the removal yard.

The identification of each zone typology by a specific letter simplified also the management of sampling operations, tagging the used membranes with the same letter of the relevant sampling area, together with the progressive number of sampling session (Figure 18 shows the membranes used in the first sampling session).

Figure 18 First sampling session filters

The concurrent indoor/outdoor measurements can provide useful information to evaluate the potential effect of external pollution on the indoor measurements, considering that the expected indoor fibres concentrations could be comparable with the outdoor ones. The entire sampling campaign lasted from October 2016 to May 2017, in six “ordinary” and some others “special” sampling stages.

The sampling phase and location of the sampling stations were organized taking into account the parameters conditioning the quality of measures (e.g. microclimatic conditions in the three different sampling areas) and the peculiarities of pollutant, in particular the negligible aerodynamic resistance of fibres. Table 29 summarizes the layout adopted for the sampling sessions; as an example, the described layout refers to the sampling performed on September 29th 2016.

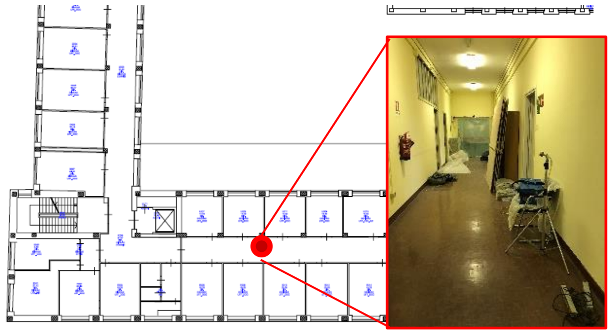
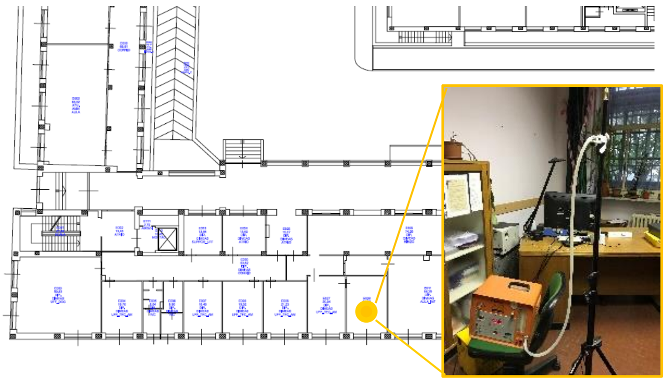
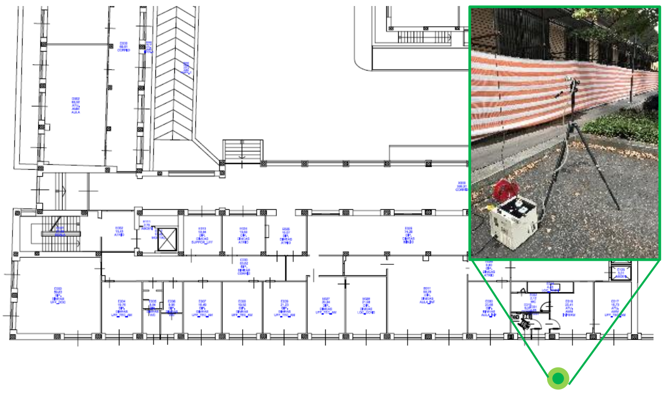
<table>
<tr><th colspan="2">Location of flow-controlled pump: indoor-working / area A (first floor)</th></tr>
<tr><td>The sampling device (Zambelli 5000 model) was positioned at the midpoint of the working area (area A), since that location was considered representative of the whole yard area pollution.</td><td></td></tr>
<tr><th colspan="2">Location of flow-controlled pump: indoor-not working / area B (ground floor)</th></tr>
<tr><td>The second sampling device (Zambelli ZB2 model) was placed in the middle of the area B; the central position was considered suitable to collect efficiently the indoor pollutant potentially present.</td><td></td></tr>
<tr><th colspan="2">Location of flow-controlled pump: outdoor / area C (ground floor)</th></tr>
<tr><td>The third sampling device (Tecora Bravo R model), for the outdoor sampling, was positioned outside (area C) nearby the working area to measure the background fibre concentration, to provide reference values of the external pollution in the area close to the removal yard.</td><td></td></tr>
</table>

Table 29 Layout of the simultaneous samplings

Inside the *area A,* the access of people, sampling operator included, to the working zone (Red classified area) is not allowed until the completion of the removal operations; this implies the impossibility to monitor the sampling operations. In such a context the use of monitoring devices (e.g. 360° cameras in Figure 19) able to capture 360° images of the area surrounding the sampling flow-controlled pump can be useful. The use of compact and rugged cameras, mounted on the used pumps, makes possible both an image recording and a remote control monitoring, to verify that the sampling device remains in the designated location for the all sampling duration, and to get information about possible occurrences causing anomalous data (e.g. particular operations producing higher fibres release).

Figure 19 Example of 360° camera suitable for the sampling operations monitoring

The three simultaneous samplings were carried out using three high-flow area sampling devices (the flow-controlled pumps), compliant with UNI EN ISO 13137:2015 standard, equipped with open face samplers ([16]) (Tab. 30).

Sampling area	**Area A**	**Area B**	**Area C**
Sampling devices	 *Zambelli 5000*	 *Zambelli ZB2*	 *Tecora Bravo R*
Sampler	Open face samplers, positioned approx. 1,5 meters above the floor, using Mixed Cellulose Ester – MCE filters (47 mm diameter, 0,8 µm pore size)	 	

Table 30 Sampling equipment used in the measuring campaign

According to the System Quality in measuring processes and equipment setup, discussed in Section 6.2, the used sampling equipment and the analytical instruments fulfil the metrological confirmation condition, ensuring the quality of the results. Moreover, the three flow-controlled pumps were calibrated by means of a flowmeter before and after each sampling session to verify the flowrate within the required interval: ± 5% of the set flowrate (UNI EN ISO 13137: 2015).

[16] *Sampler*: device for separating chemical and/or biological agents from the surrounding air (UNI EN ISO 13137:2015)

Increasing the method sensitivity - sampling

Regarding the sampling phase, the improvement to increase the method sensitivity concerned the sampled air volume: the minimum volume suggested by the D.M 06/09/94 (3000 litres) was increased to 5000 litres, drawn in 200 minutes (sampling duration) with a reference flowrate Q_{ref} = 25 l/min, maintaining unchanged the ratio flowrate/membrane surface (0,35 m/s, minimum capturing velocity required for SEM analyses).

The entire campaign was completed in six sampling sessions, resulting in 18 membranes to analyse. During the collection of the three concurrent samples, a multifunction measuring device monitored and recorded, every 30 minutes, the significant parameters potentially conditioning the sampling outcomes: temperature, pressure, relative humidity and air velocity and direction. The microclimatic data are required:

1. to correctly determine the concentration values; being the air density dependent on temperature and pressure, where necessary, the sampled air volume should be normalized (eq. 11) at normal temperature and pressure (T = 298 K and P = 1013 mbar according to the American Conference of Governmental Industrial Hygienist (2018);

$$\left(\frac{P \cdot V}{T}\right)_{normal\ condition} = \left(\frac{P^1 \cdot V^1}{T^1}\right)_{sampling\ condition} \quad \text{(eq. 11)}$$

2. to evaluate the outdoor concentration variability (relation between the outdoor measured concentration and the microclimatic condition at the time of the sampling);
3. to explain possible outliers within the dataset attributable to significant differences in microclimate conditions, in particular in terms of air velocity and direction.

The filters from sampling campaigns were analysed by a certified laboratory through a Scanning Electron Microscopy – SEM. The analytical method adopted conforms to the Italian regulation D.M. 06/09/94, Annex 2: the analysis was carried out by means of a Hitachi TM 3000 SEM, equipped with SwiftED 3000 device for micro-analysis, working at 2000x magnification, with 15 kV acceleration voltage. The respirable fibres (complying the geometric requirements: length greater than 5 µm, cross dimension smaller than 3 µm, and length / diameter ratio equal to or greater than 3:1, American Conference of Governmental Industrial Hygienist, 2018) were definitely recognized as asbestos fibres through the elemental analysis.

Increasing the method sensitivity – laboratory analysis

As for the sampling phase, one of the analytical parameters was improved to increase the method sensitivity. In particular, a larger filter section (1,27 mm^2), resulting from 400 reading fields of 0,0032 mm^2 area, was analysed with an increase of approx. 22% of the routine value suggested by the already quoted D.M. 06/09/94.

7.2.2 The method implementation - data analysis

To draw some considerations about the results of the above-described measuring strategy based on the comparison of the simultaneous concentration measures, the approach implementation followed three consecutive steps:
1. *determination of the airborne fibres concentration and method detection limit*;
2. *measuring uncertainty evaluation*;
3. *data interpretation*.

1. Airborne fibres concentration and Limit of Detection

The starting point is the definition of the *mathematical model* (eq. 12) to calculate the airborne fibres concentration from the samplings and analysis parameters (Tab. 31).

Concentration mathematical model:

$$\boldsymbol{C}\,[\boldsymbol{ff/l}] = \frac{\boldsymbol{N_f} * \boldsymbol{A}}{\boldsymbol{N_c} * \boldsymbol{a} * (\boldsymbol{Q} * \boldsymbol{t})} \qquad (\text{eq. } 12)$$

where:
- ***N_f*** *is the number of fibres detected in the analysed section of membrane*;
- ***A*** *is the effective area of the filter [mm^2]*;
- ***N_c*** *is the number of reading fields*;
- ***a*** *is the area of each reading field [mm^2]*;
- ***Q*** *is the flowrate of the flow-controlled pump [l/min]*;
- ***t*** *is the sampling duration [min]*.

Multiplying **Q** and **t** results in the sampling volume (**V**) referred to the normal conditions.

Table 31 Airborne fibres concentration formula and parameters

Table 32 shows the "nominal" values of the parameters, set in sampling and analysis stages, except for the variable N_f whose value changes depending on the analytical results.

Parameters and "nominal" values					
N_f *[ff]*	***A*** *[mm^2]* ([17])	***N_c*** *[n.]*	***a*** *[mm^2]*	***Q*** *[l/min]*	***t*** *[min]*
x	962,1	400	0,0032	25	200

Table 32 Values of parameters

The mathematical model in eq. 12 lays at the basis of the calculation of the *Limit of Detection – LoD* of the method, which specifies the smallest detectable quantity achievable by the used method, as expressed in Table 33. Equation 13 shows as the number of fibres count (N_f) is replaced by the upper limit of the 95% confidence interval of a zero fibres count, due to the Poisson distribution of fibres on the filter.

[17] The 962,1 mm^2 effective area of the filter exposed to the airflow results from the 35 mm mean effective diameter of the used membranes.

In the case of SEM analysis, the LoD is defined as the numerical asbestos fibres concentration below which, with the 95% probability, the real concentration shall lie when no asbestos fibres are detected during the analysis (UNI EN ISO 16000-7:2018 standard). Hence, this limit shall be determined for each single analysis, and in the case of no fibre count, the outcome of the analysis will denote "*below the LoD*".

LoD formula: $$LoD = \frac{UCL * A}{N_c * a * (Q * t)} \quad \text{(eq. 13)}$$ In general, the 95% confidence interval of a measurement, as function of the number of asbestos fibres counted, can be obtained from the two equations (eq. 14 and eq. 15): $$x_{UCL} = d * \left[1 - \left(\frac{1}{9 * d}\right) + z * \sqrt{\left(\frac{1}{9 * d}\right)}\right]^3 \quad \text{(eq. 14)}$$ $$x_{LCL} = x * \left[1 - \left(\frac{1}{9 * x}\right) - z * \sqrt{\left(\frac{1}{9 * x}\right)}\right]^3 \quad \text{(eq. 15)}$$ where x is the fibre count, d = (x + 1) and z = 1,960 the standard normal deviate for the two-sided limits at the 95% probability level. The same data are available in Table 3 of the UNI EN ISO 16000-7:2018 standard. The considered 95% confidence interval of a zero fibre count ranges from 0 [ff], Lower Confidence Limit – LCL to 3,69 [ff], Upper Confidence Limit – UCL.

Table 33 Limit of Detection and Confidence Limits

At the light of these considerations, taking into account the "nominal" values of parameters (Tab. 32) the LoD of the developed method results (eq. 16):

$$\boldsymbol{LoD} = \frac{\mathbf{3{,}69}\,[\boldsymbol{ff}] * \mathbf{962}\,[\boldsymbol{mm^2}]}{\mathbf{400} * \mathbf{0{,}0032}\,[\boldsymbol{mm^2}] * \left(\mathbf{25}\left[\frac{\boldsymbol{l}}{\boldsymbol{min}}\right] * \mathbf{200}\,[\boldsymbol{min}]\right)} = \mathbf{0{,}56}\,[\boldsymbol{ff/l}] \quad \text{(eq. 16)}$$

The SEM analysis of the 18 membranes, from the six "ordinary" samplings, resulted in *no asbestos fibres detection* (only few artificial or organic fibres were identified): laboratory reports gave concentration values below the LoD (*conc. < 0,56 [ff/l]*) for the all membranes analysed. Appendix 6 provides a report summarizing the result of the laboratory analysis, including information on the fibres count, the UCL and the airborne fibres concentrations.

No background fibres were detected in the field blank ([18]) analysis, proving the absence of membrane contamination.

To verify the possibility of getting a higher fibres count, through a further reduction of the LoD, four additional samplings were carried out following an alternative procedure based on an additional increase of the sampled air volume up to 10.000 litres, using the same membrane for two consecutive samplings of

[18] *Field blanks* are filters which has been taken to the sampling site, opened, and then closed; they are used to determine whether contamination can have occurred during the field handling of the cassettes (UNI EN ISO 16000-7:2008)

the usual 200 minutes sampling duration. The inlet airflow was monitored systematically to verify the minimum capturing velocity required (0,35 m/s in the case of SEM analysis), taking into account the increased aerodynamic resistance due to the progressive filter obstruction.

2. Measuring uncertainty assessment

The measuring processes aimed to define pollutant airborne concentrations (or in general to quantify the Hazard Factors) should take into account some important issues about sources of variability conditioning the measurements. Specifically, the study of the uncertainty due to different factors (e.g. equipment preparation, sampling, sample storage and transportation, laboratory analysis, etc., see Figure 10 discussed in Section 6.2.1) is pivotal to reduce the final expanded uncertainty affecting the measures (Barbato et al., 2013).

Even if, as suggested by literature, in the case of low fibres counts, the intrinsic uncertainty due to the statistical Poisson distribution of fibres on the filters surface can make negligible the contribution of the remaining uncertainty sources, the experimental nature of the sampling and analytical method adopted made necessary to investigate whether the adjustments aimed to increase the sensitivity of the method introduce significant variability causes. Based on the principles of statistical methods in design, production and verification processes, the analysis was planned in three steps:

1. evaluation of *a-priori uncertainty* of the analytical method (predicted variability obtained by combining the various uncertainty components that characterize the measurement);
2. *a-posteriori assessment of uncertainty* of the method implementation, using measured data accurately processed to identify systematic effects/tendencies, outliers, etc.;
3. *conclusion* about the three set of concurrent measures in terms of both values and experimentally observed variability.

Table 34 summarizes the methods (statistic - Type A and non-statistic - Type B) for the uncertainty evaluation of the involved parameters in eq. 12.

Parameters	Uncertainty evaluation method
Q and ***t***	The parameters could be easily measured several times and then their relevant uncertainty managed through the statistical analysis of a series of observations (Type A evaluation of uncertainty feasible).
a and N_c	The parameters can be hardly measured, in particular the reading field area depends on the characteristics and settings of the used microscope: the uncertainty should be evaluated mainly by Type B method using a-priori information (Type A evaluation difficult).
A	The effective area of the membrane can be measured several time, but also managed with a priori information (e.g. caliper uncertainty as declared by the supplier).
N_f	The fibres count is affected by the uncertainty intrinsic to the filter method, due to the Poisson distribution of fibres on the filter.

Table 34 Uncertainty evaluation of the different parameters

Typically, the a-priori uncertainty is a preliminary evaluation of the method variability, to perform before any measurement, and is based on the knowledge of influence factors producing uncertainty contributions.

The three simultaneous samplings strategy results comparable to *three distinct processes*, carried out by means of comparable sampling equipment (with their own metrological characteristics – MCME) and same analytical instrument. The a-priori uncertainty assessment should provide indication on:

1. the predicted variability associated to each of the three processes;
2. the ranking of the uncertainty contributions, useful to make decisions about the sources to act upon to reduce the expanded uncertainty in the method implementation, identifying the most critical factors;
3. the effect of such decisions (point 2) in the terms of expanded uncertainty reduction.

The knowledge of sampling and analysis activity/equipment made possible the identification of the uncertainties sources for each parameter, as summarized in Table 35.

Parameters	Uncertainty source
N_f	- *Poisson distribution* of fibres on the membrane - *Resolution* (two possible detection situations: 1 or half a fibre)
A	- *Caliper uncertainty* (zero error) - *Reproducibility* (variability of replicated measurements in different conditions) - *Reading uncertainty*
N_c	- *Bias* (due to the operator distraction, interruption and restart of the analysis, etc.)
a	- *Micrometre calibration*
Q	- *Reproducibility* - *Resolution* (sampling equipment characteristic) - *Accuracy* (sampling equipment characteristic)
t	- *Reproducibility* - *Resolution* (chronometer characteristic) - *Accuracy* (chronometer characteristic)
NOTE: the following definitions of the terms used in the table are drawn from JCGM 200:2012: ***Resolution****:* smallest change in a quantity being measured that causes a perceptible change in the corresponding indication; ***Reproducibility****:* measurement precision under reproducibility conditions of measurement (condition of measurement, out of a set of conditions that includes different locations, operators, measuring systems, and replicate measurements on the same or similar objects); ***Bias****:* estimate of a systematic measurement error; ***Accuracy*** *([19]):* closeness of agreement between a measured quantity value and a true quantity value of a measurand.	

Table 35 Parameters and their relevant variability sources

The uncertainty contributions were estimated by the Procedure for Uncertainty MAnagement - PUMA method: non-statistical information were transformed in statistical characteristics in terms of Variance, to be composed with statistical information assessing the relevant statistical distribution, e.g. rectangular or triangular, for passing to Variance.

A Excel based spreadsheet, briefly described in Appendix 7, made possible to quantify the expanded uncertainty by setting the “nominal” values of the parameters and their estimated variability. According to the analytical results (i.e. no fibres counted in the “ordinary” samplings filters), the measurement uncertainty was evaluated by replacing the fibres count parameter (N_f) with the 95% Upper Confidence Limit for a zero fibres count (3,69 [ff]).

Table 36, drawn from the used spreadsheet, clarifies, for the three situations, the parameters, the uncertainty sources and their estimated values.

[19] For the purpose of this research work, we still refer to the term accuracy, even if the last updates of International Vocabulary of Metrology – VIM introduced some amendments on the term.

area A

Factor x_j			Statistical					Not statistical	
Symbol	Value	Remarks	U_j	P_{dj}	ν_{dj}	k_{dj}	s_j	a_j	k_a
Nf	3,7E+00	Poisson distr	1,4E-01	95%	100	2,0	7,1E-02		3
		resolution		95%	100	2,0	0,0E+00	5,0E-01	3
A	9,6E+02	caliper uncertainty (zero)		95%	100	2,0	0,0E+00	1,0E-02	3
		reproducibility		95%	100	2,0	0,0E+00	3,0E-02	3
		reading uncertainty		95%	100	2,0	0,0E+00	5,0E-01	3
Nc	4,0E+02	bias		95%	100	2,0	0,0E+00	2,0E+00	3
a	3,2E-03	microm calibr		95%	100	2,0	0,0E+00	1,0E-04	3
Q_{IW}	2,5E+01	reproducibility		95%	100	2,0	0,0E+00	5,0E-01	3
		resolution		95%	100	2,0	0,0E+00	1,0E-01	3
		accuracy		95%	100	2,0	0,0E+00	7,0E-01	3
t	2,0E+02	accuracy		95%	100	2,0	0,0E+00	4,0E-02	3
		reproducibility		95%	100	2,0	0,0E+00	2,5E-02	3
		resolution		95%	100	2,0	0,0E+00	8,3E-03	3
y = C	**0,55**	**[ff/l]**							

area B

Factor x_j			Statistical					Not statistical	
Symbol	Value	Remarks	U_j	P_{dj}	ν_{dj}	k_{dj}	s_j	a_j	k_a
Nf	3,7E+00	Poisson distr	1,4E-01	95%	100	2,0	7,1E-02		3
		resolution		95%	100	2,0	0,0E+00	5,0E-01	3
A	9,6E+02	caliper uncertanty (zero)		95%	100	2,0	0,0E+00	1,0E-02	3
		reproducibility		95%	100	2,0	0,0E+00	3,0E-02	3
		reading uncertainty		95%	100	2,0	0,0E+00	5,0E-01	3
Nc	4,0E+02	bias		95%	100	2,0	0,0E+00	2,0E+00	3
a	3,2E-03	microm calibr		95%	100	2,0	0,0E+00	1,0E-04	3
Q_{INW}	2,5E+01	reproducibility		95%	100	2,0	0,0E+00	3,0E-01	3
		resolution		95%	100	2,0	0,0E+00	2,0E-01	3
		accuracy		95%	100	2,0	0,0E+00	4,0E-01	3
t	2,0E+02	accuracy		95%	100	2,0	0,0E+00	4,0E-02	3
		reproducibility		95%	100	2,0	0,0E+00	2,5E-02	3
		resolution		95%	100	2,0	0,0E+00	8,3E-03	3
y = C	**0,55**	**[ff/l]**							

area C

Factor x_j			Statistical					Not statistical	
Symbol	Value	Remarks	U_j	P_{dj}	ν_{dj}	k_{dj}	s_j	a_j	k_a
Nf	3,7E+00	Poisson distr	1,4E-01	95%	100	2,0	7,1E-02		3
		resolution		95%	100	2,0	0,0E+00	5,0E-01	3
A	9,6E+02	caliper uncertanty (zero)		95%	100	2,0	0,0E+00	1,0E-02	3
		reproducibility		95%	100	2,0	0,0E+00	3,0E-02	3
		reading uncertainty		95%	100	2,0	0,0E+00	5,0E-01	3
Nc	4,0E+02	bias		95%	100	2,0	0,0E+00	2,0E+00	3
a	3,2E-03	microm calibr		95%	100	2,0	0,0E+00	1,0E-04	3
Q_{OU}	2,5E+01	reproducibility		95%	100	2,0	0,0E+00	4,0E-01	3
		resolution		95%	100	2,0	0,0E+00	1,0E-01	3
		accuracy		95%	100	2,0	0,0E+00	6,0E-01	3
t	2,0E+02	accuracy		95%	100	2,0	0,0E+00	4,0E-02	3
		reproducibility		95%	100	2,0	0,0E+00	2,5E-02	3
		resolution		95%	100	2,0	0,0E+00	8,3E-03	3
y = C	**0,55**	**[ff/l]**							

Table 36 Parameters, values and uncertainty sources in the three situations

The PUMA method, adopted to perform the a-priori uncertainty analysis, pointed out that the variability sources of the three processes resulted equivalent ("*Non statistical - a_j*" column in Table 36), except for the flow-controlled pumps: the three used devices, even having very similar characteristics, differed for producer and model.

The predicted variability, achieved from the a-priori uncertainty calculation sheets, resulted similar for the three measuring processes/conditions (Tab. 37).

A-priori uncertainty results			
	area A	**area B**	**area C**
Confidence level	0,95	0,95	0,95
Coverage factor (t-Student)	2	2	2
Expanded uncertainty U(y)	**0,093 ff/l**	**0,092 ff/l**	**0,092 ff/l**

Table 37 A priori expanded uncertainty in the three situations

Table 37 shows as the implementation of the adopted sampling and analytical strategy implies an approx. 18% variability range for the minimum detectable concentration (0,56 ff/l) in the three analysed situations.

The main contributions to such a variability emerge from the ranking of the standard uncertainty $u_i^2(y)$ values, namely the values of the estimated variances associated with the output y (concentration) generated by the estimated variance associated with each input estimate x_i. The standard uncertainties appear almost in the same ranking between the three situations (Tab. 38): the fibres count represents the first important contribution to the final combined standard uncertainty $u_c(y)$.

area A					area B			area C		
Factor x_j					Factor x_j			Factor x_j		
Symbol	Value	Remarks	$u_j^2(y)$	Rank	Symbol	$u_j^2(y)$	Rank	Symbol	$u_j^2(y)$	Rank
Nf	3,7E+00	Poisson distr	1,1E-04	2	**Nf**	1,1E-04	2	**Nf**	1,1E-04	2
		resolution	1,9E-03	1		1,9E-03	1		1,9E-03	1
A	9,6E+02	caliper uncertainty (zero)	1,1E-11	13	**A**	1,1E-11	13	**A**	1,1E-11	13
		reproducibility	1,0E-10	12		1,0E-10	12		1,0E-10	12
		reading uncertainty	2,8E-08	8		2,8E-08	8		2,8E-08	8
Nc	4,0E+02	bias	2,6E-06	6	**Nc**	2,6E-06	7	**Nc**	2,6E-06	6
a	3,2E-03	microm calibr	1,0E-04	3	**a**	1,0E-04	3	**a**	1,0E-04	3
Q_{IW}	2,5E+01	reproducibility	4,1E-05	5	**Q_{INW}**	1,5E-05	5	**Q_{OU}**	2,6E-05	5
		resolution	1,6E-06	7		6,6E-06	6		1,6E-06	7
		accuracy	8,0E-05	4		2,6E-05	4		5,9E-05	4
t	2,0E+02	accuracy	4,1E-09	9	**t**	4,1E-09	9	**t**	4,1E-09	9
		reproducibility	1,6E-09	10		1,6E-09	10		1,6E-09	10
		resolution	1,8E-10	11		1,8E-10	11		1,8E-10	11

Table 38 Ranking of the standard uncertainties in the three situations

The result confirms the importance of hierarchical ordering of variability sources as key decision tool for the allocation of resources for samplings, analysis and measuring devices. The results of a-priori uncertainty analysis make possible some significant considerations:

1. the original modifications implemented to increase the method sensitivity (i.e. higher air volume sampled and larger filter area analysed) did not introduce significant uncertainties sources;
2. the three measuring systems (samplings and analysis) shown a comparable degree of variability; the uncertainty related to fibres count (resolution and Poisson distribution) remained the major uncertainty cause.

In the same situation, assuming a higher fibres counts, the ranking would change and other uncertainty sources would become significant (Tab. 39) making necessary the second step of the uncertainty analysis: the *a-posteriori* evaluation phase.

Factor x_j				
Symbol	Value	Remarks	$u_j^2(y)$	Rank
Nf	2,0E+01	Poisson distr	1,1E-04	5
		resolution	1,9E-03	3
A	9,6E+02	caliper uncertainty (zero)	3,3E-10	13
		reproducibility	2,9E-09	12
		reading uncertainty	8,1E-07	8
Nc	4,0E+02	bias	7,5E-05	6
a	3,2E-03	microm calibr	2,9E-03	1
Q_{IW}	2,5E+01	reproducibility	1,2E-03	4
		resolution	4,8E-05	7
		accuracy	2,4E-03	2
t	2,0E+02	accuracy	1,2E-07	9
		reproducibility	4,7E-08	10
		resolution	5,2E-09	11

Indoor work situation, assuming a higher fibres count (20 fibres): changed ranking of the variability sources.

Table 39 Uncertainty sources ranking, in the high fibres count hypothesis

The principle at the basis of the a-posteriori uncertainty method implies the replacement of the estimated variability contributions (achieved by PUMA method) with uncertainty values statistically defined, in order to achieve the expanded uncertainty in the specific operating conditions.

Having suitable data available, the method entails: 1) the data analysis through descriptive statistic techniques to identify possible systematic effects, 2) the outliers identification and removal, 3) the verification of normal distribution of "cleaned" sample of data. The process, implemented on measured data of each parameter evaluable by the Type A method, makes available the Standard Deviation of the sample due to only random effects. This figure replaces the corresponding a-priori estimated variability: the a-priori uncertainty evaluation turns in the a-posteriori one, providing the effective variability of measures in operative conditions. The comparison between the two analysis makes possible to understand if the measurement system is functioning properly.

Making reference to the hypothesis described in Table 39, the reading field area (a) and the flowrate (Q) would produce the most significant variability on the final result of the measuring process. The gathering of a number of measures of those parameters in operative condition, where possible, (e.g. flowrate data recorded during the sampling operations) provides the required input data for the uncertainty statistical determination.

In the case under exam, the a-posteriori analysis would be ineffective owing to a) the preponderance of variability related to N_f over the remaining uncertainty sources, b) the difficulty to collect data on the third source (the reading field area), and c) the reduced contribution of the remaining sources ([20]).

3. Data interpretation

The accurate calculation of the concentration values in the three considered contexts, together with the associated variability range for each measure, makes possible a reliable data interpretation phase.

[20] in the case of a-posteriori uncertainty calculation, it is necessary to consider also the uncertainty contribution of the measuring devices for temperature and pressure determination, needed in particular to normalize the sampled volume, whilst these uncertainty contributions are not introduced in the a-priori uncertainty evaluations, since the variability related to flowrate is estimated on the basis of non-statistical information (e.g. samplers characteristics).

The interpretation of the indoor airborne fibres concentration measures (sample drawn from its belonging statistical population) through their comparison with reference values, e.g. the outdoor data, should be managed in an overall control strategy based on statistical representativeness criteria using relative input data, i.e. suitable ratios (PRs): the approach discussed in Section 6.3.2 can be effectively adopted to this purpose. However, the implementation of such an approach, designed to assess workers' exposure, needs of adjustments to make the method suitable for the statistical comparison of datasets representative of different pollution situations (e.g. indoor working pollution and outdoor concentration measures).

The availability and typology of the datasets guide the adaptation of the method; the following criteria could be an input for further research developments:

1. *Indoor/outdoor data available* – the relation of suitable simultaneous indoor and outdoor measures makes necessary to replace the original PR with a specific measurements ratio (PR_{ext}) between the situation in areas where ACMs have been identified, but no activities involving emission are present, or situations where some activities can be expected to cause asbestos fibres release, and the common environment pollution ([21]), as expressed by eq. 17, taking carefully into account that weather conditions could restrict the ability to collect satisfactory air samples.

$$PR_{ext} = \frac{\textit{concentration in the indoor polluted area}}{\textit{concentration in external nearby area}} \quad \text{(eq. 17)}$$

2. *Indoor data available only* – in contexts where no reference values (e.g. outdoor data) are available, a special pollution index (PR_{LD}) can be determined involving the method LoD (eq. 18). Modifying the LoD parameters, in particular the confidence level of the filters method (Poisson distribution), the index can be adapted to each measuring context.

$$PR_{LD} = \frac{x_i}{LoD_i} \quad \text{(eq. 18)}$$

The PR_{LD} can be comparable to a kind of concentration values normalization, maintaining the belonging statistical distribution of samples.

3. *Indoor/outdoor data below the LoD* – the approaches in point 2 and 3 could be impractical where data to be compared result below the LoD. In this case, it would be necessary to develop focused methods starting from the already available researches on relevant topics, e.g. the exposure estimation in presence of no detectable values (Murray et al., 2001).

According to the approach, the criterion in point 1 would be implemented to analyse our airborne concentration measures, however the lack of usable data (all

[21] It is important to verify that in adjacent area no potential asbestos fibre sources are present

the concentration values below the LoD of the method) invalidated this step of the analysis.

The result of the above-discussed approach confirms that, even during the window fixtures removal, the measurements in the operating area did not put into evidence a significant environmental pollution.

A preliminary bird's-eye analysis of concentration data from different scenarios (Tab. 40 and 41), in terms of asbestos characteristics and quantities, and typologies of operation performed, enables to refine the conclusions drawn from the above described study.

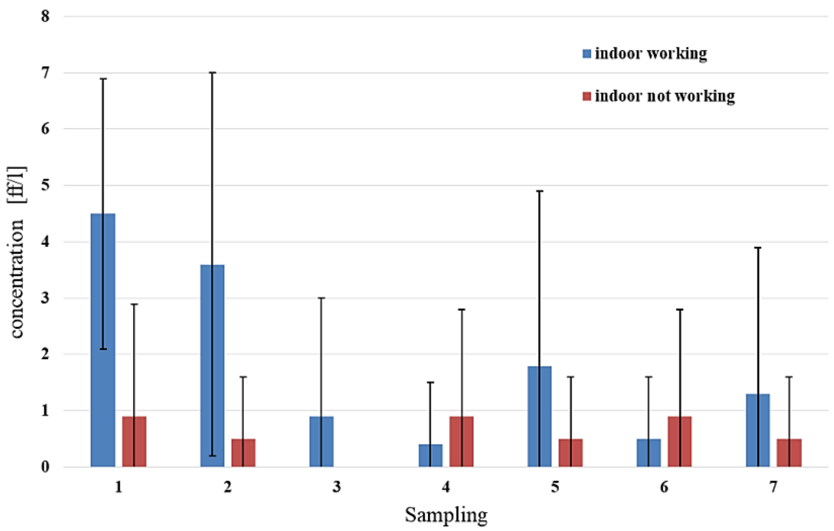
Context description
Indoor artefacts removal Removal of insulating layers containing friable asbestos, placed under the flooring in some indoor environments.
Airborne fibres concentration data

Data refer to indoor samplings involving both working and not working areas; laboratory analyses were performed through PCM (data supplied by the licensed contractor tasked to the removal operations). As a preliminary analysis, a simple graphical comparison between the two sets of indoor measures, including correctly the uncertainty intervals, shows: 1) low concentration values (lower than 5 ff/l – PCM analysis), and 2) overlapping uncertainty intervals in all the couple of measures, therefore it is not possible to make any remark about the potential increase of pollution owing to the asbestos removal operation.

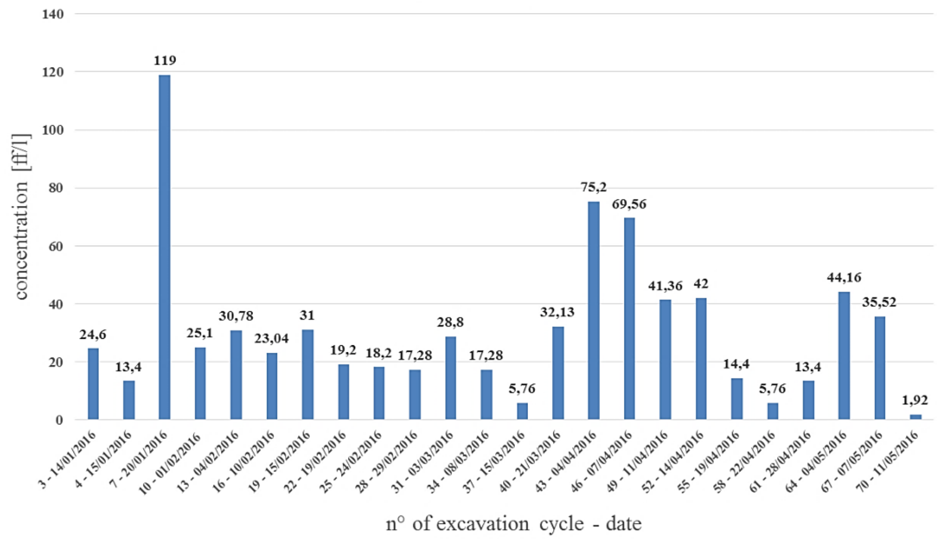
Table 40 Data on removal operations of friable asbestos

Context description

Tunnelling operations

Tunnel excavation in asbestos containing rock masses.

Airborne fibres concentration data



Data result from samplings performed in the excavation area (Poma and Puma, 2016), in proximity of the face (only indoor measures are available): the concentration values are determined by SEM analysis. The values appear certainly high and in some cases close (or higher) to the technical threshold limit (100 ff/l).

In this case, simultaneous indoor/outdoor measurements could be effective: the raising of indoor pollutant concentration attributable to the excavation activities, revealing the tunnel driving crossing an asbestos containing zone, could be detected by identifying significant gaps between indoor / outdoor concentrations.

Table 41 Data on tunnelling operations in asbestos containing rock mass

In conclusion, the airborne measurements demonstrate to be still ineffective to detect fibres releases from friable asbestos handlings, except in the case of operations involving high mechanical stresses on asbestos (e.g. tunnel excavations), where those kind of measurements can become an useful tool. Clearly these situations are very far from the target of the study.

The research proved the negligible contribution of airborne measurements in the identification of possible pollution deriving from the ACMs handling/stressing: no useful information are achievable through airborne fibres measurements, where no massive emissions are caused by stressing actions on friable ACMs. Therefore, the airborne fibres monitoring cannot provide useful contribution in the H.I. program special for ACMs neither in the classified areas Quality management: every effort should be directed towards the enhancement of periodic visual inspection, through innovative supporting technical solutions.

7.3 Special research for the asbestos sub-phase of the Guideline: the Image Analysis

Research sub-question 3b: *how can be the visual inspections improved, overcoming their limits and providing an effective tool for asbestos sub-phase of the Guideline?*

The result of the previous study confirms that the visual evaluation of the ACMs conservation conditions represents the main tool at disposal of the asbestos sub-phase of the Guideline, for the H.I. phase and the classified workplaces confirmation, within the Risk Assessment and Management in System Quality. However a visual inspection approach can present clear limits both in the first H.I. phase and in the following inspections aimed to verify the ACMs and sealing/enclosures status: a) a limited quality in the deriving documentation, b) the unsatisfactory detail in the comparison of the AMCs and sealing/enclosures status along the time, and the eventual subjectivity in that evaluation.

This part of the research work discusses the substantial improvement achievable thanks to the use of *Image Analysis* techniques, both in ACMs H.I., and ACMs and sealing/enclosures status confirmation along the time, in terms of documentation for the identified ACMs, resulting in a kind of *Identity Card* for each artefact, and in terms of reduction of subjectivity in the decision making process, making more detailed the comparison of the ACMs conditions along the time. The implementation of Image Analysis techniques follows a logical flow of three different steps:

1. Data acquisition *The data acquisition is designed depending on the target of the Image Analysis, and performed using equipment, and setting their significant parameters, to record images with the required characteristics in terms of data typology (e.g. digital images or clouds of points), resolution, etc. Where geo-referencing operations are needed, the data acquisition phase includes markers positioning for a reference system setup.*
2. Image processing *The image processing covers different procedures, including the measurements network adjustment for the reference system definition, if required, the image geo-referencing and the operations necessary to undistort digital images (e.g. minimizing the optical and perspective distortions due to both the used optical element and the perspective visual). Image processing makes the digital images suitable for the data interpretation stage.*
3. Information gathering from the automatic/assisted image interpretation *The image analysis procedures aim to gather only the "important" information from the image(s) under exam (Russ, 2002), through a wide range of algorithms (Radke et al., 2005) used to prepare images for different purposes (e.g. the identification and count of features in an image, or the evaluation of the radiometric content differences between couples of images).*

7.3.1 Image Analysis special for the asbestos sub-phase of the Guideline

Some special Image Analysis techniques, involving laser-scanner acquisitions of the investigated areas, and high-resolution digital images of the identified points of interests (ACMs and/or sealing/enclosures), were introduced in the asbestos sub-phase of the Guideline.

The techniques provide different improvement levels both in the H.I. and Risk Assessment and Management, in particular in Green and Yellow categorized areas (Tab. 42).

Modus Operandi	
1. 3D Base model	*3D Base model is the initial acquisition, performed by means of a laser-scanner technique, of digitalized information on the investigated area, necessary for a detailed high quality "snap-shot", and to fix a permanent reference system for the future acquisitions vs pre-positioned markers (more than one acquisition can be necessary, to include critical points located in blind zones). The initial acquisition can conveniently take place during the Canvassing phase;*
2. Global analysis	*The Global analysis, based on the computer aided comparison of the global laser-scanner acquisitions of the same area gathered at different times and geo referenced in the system defined in the 3D Base model, can point out coarse modifications in the area (structural modifications, equipment, furniture etc.);*
3. Local analysis	*The local analysis entails the collection of high-resolution digital images of critical points of particular interest, identified through the documentary analysis and Canvassing investigation. So, the first set of high resolution images should be collected at the end of the Canvassing investigation, as soon as a permanent local reference system is set up. Thanks to the high resolution, it is then possible to point out in detail localized changes in size, conditions and shape of artefacts or sealing/enclosures down to millimetre scale.*

Table 42 Modus operandi for the Image Analysis implementation

The approach, set according to the above described work flow, aims to join good effectiveness and resources saving, in terms of equipment, staff and knowledge.

1. Global analysis by Light Detection and Ranging - LiDAR

Data acquisition phase - The LiDAR technique can acquire clouds of 3D points, each point containing four information: the three point coordinates X, Y and Z, and the reflectance value. For a realistic view, the cloud of points can be coloured with Red Green Blue - RGB images. The Global analysis is carried out using these clouds of points as input data, still maintaining the quality of information (Laser scanner acquisitions made possible to have multi-purposes data, i.e. clouds of points at different resolution levels, with the possibility to draw reduced resolution data still maintaining the required information, but more manageable).

Cloud processing phase - Clouds of points are not affected by optical and perspective distortions, making unnecessary preliminary image processing.

Information gathering phase - The information gathering, supported by special software (e.g. CloudCompare ®), derives from accurate superimposing of the clouds of points of the investigated area, recorded at different times. A preliminary adjustment of the position of the markers is required for the comparison of multi-temporal clouds of points.

2. Image Analysis on high resolution digital images – Local analysis

Data acquisition phase - The acquisition of high-resolution digital images of every ACMs identified for the Local analysis should be carried out keeping unchanged the shooting parameters, in particular the focal length. The markers of the local reference system are necessary for the image processing procedure, namely for the perspective deformation recovery.

Image processing phase - The quality of digital images depends on the quality of the used lens; the image distortions must be adjusted, in particular when pictures are involved in precise measurements processes. Moreover, in the case of accurate images superimposing, the perspective deformations due to the different shooting perspective should be recovered. Preliminarily to the Local analysis, both in radiometric and geometrical approach, a careful image processing is pivotal both to correct the image distortions through lens calibration, and to recover the perspective deformations, using the equations of the homography.

Information gathering phase - Both *radiometric differences*, and *geometrical* analysis techniques can be implemented to perform the assisted image interpretation. The *radiometric differences* approach performs the comparison of the radiometric content of each couple of corresponding pixels of the images to compare, geo referenced in the same local reference system. The *geometrical analysis* is based on precision measuring operations on the images (e.g. measurements of length, areas or pixels coordinates): a variation of these features between the compared images, covering the part of the object under investigation, can be representative of an alteration of the artefact conditions.

7.3.2 Approach validation: Image Analysis on a Yellow classified area

Test site details

The Image Analysis approach was tested to verify its effectiveness in the Canvassing of a Yellow classified area, characterized by the presence of an enclosure, near to the ceiling, segregating insulated pipes. In the Hazard Identification/in situ surveys phase, the Canvassing made possible the detection, and photographic documentation, of both an ongoing discontinuity (*1° point of interest*) between the enclosure panel and the side walls, potentially invalidating the effectiveness of the enclosure, and a discontinuity on the wall (*2° point of* *interest*) not directly related to the enclosure, but potentially starting point of further cracks that may involve the enclosure (Tab. 43).

1° point of interest	2° point of interest
 *Detail of the discontinuity in the ceiling enclosure-walls junction*	 *Fracture on the wall*

Table 43 Identified points of interest in the testing area

Test equipment and shooting project

According to the identified Modus Operandi (Tab. 42), high-performances equipment were selected to increase the sensitivity of the method.

During the inspections, carried out from October 2015 (preliminary inspection on the test area) to April 2017, three sets of high-resolution digital images and LiDAR acquisitions were recorded using a Nikon D800E high-resolution reflex camera and a CAM2 Focus 3D laser scanner (Fig. 20).

Figure 20 CAM2 Focus 3D laser scanner

The Nikon D800E high-resolution reflex camera (Full Frame – FF sensor with 36 x 10^6 pixels) was assumed as an effective device, suitable to capture digital images with the required resolution for the Local analysis. The camera was equipped with AF-S NIKKOR 24-70mm f/2.8G ED lens, used with 50 mm fixed focal length (Tab. 44).

High-resolution camera	
 *Nikon D800E*	 *AF-S NIKKOR 24-70mm f/2.8G ED*
Camera characteristics	
Model: D800E	*Sensor resolution*: 7379 x 4919
Effective megapixels - MPx: 36,30	*Max. image resolution*: 7360 x 4912
Total megapixels: 36,80	*Pixel pitch*: 4,87 µm
Sensor size: 35,9 x 24 mm	*Pixel area*: 23,7 μm^2
Sensor type: Complementary Metal–Oxide–Semiconductor - CMOS	

Table 44 Camera used for the Local analysis

The Nikon D800E camera, together with a well-designed photographic shooting project (Tab. 45), including modifiable (e.g. focal length) and fixed (e.g. camera resolution and sensor dimension) parameters, made possible to capture images with the quality required by the Local analysis.

Shooting project		
Shooting parameters	Resolution MPx	**36**
	Focal (mm in the used format)	**50**
	Shooting distance (m)	**3**
Camera parameters	a side of the sensor (mm)	**24**
	b side of the sensor (mm)	**36**
	a side of the sensor (px)	**4899**
	b side of the sensor (px)	**7348**
	Dim px (mm)	**0,0049**
	Dim px (µm)	**4,90**
Ground coverage	Mean scale 1:	**60**
	GSD (mm)	**0,3**
	Side a (m)	**1,4**
	Side b (m)	**2,2**

Table 45 Shooting project for the Local analysis

The Ground Sample Distance – GSD, namely the ground coverage of the sensor pixel, is the distance between pixel centres measured on the object (Tab. 46). This important parameter gives information about the minimum detail detectable on the image (or the minimum alteration detectable of the shot object), depending on the pixel dimension, the shooting distance and the focal length (eq. 19).

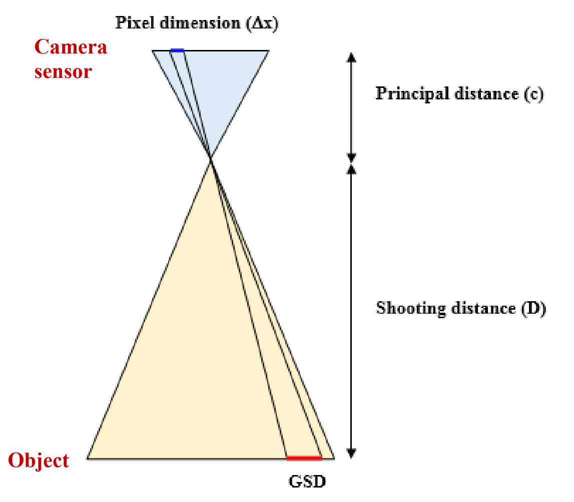
 	Ground Sample distance: $GSD = \frac{D}{c} \cdot \Delta x$ (eq. 19) where Δx is the pixels dimension (square elements), resulting from the sensor dimension and number of pixels, c is the focal length, D is the distance between the principal point and the object.

Table 46 Ground Sample Distance

In line with the quoted shooting project, keeping fixed both the 50 mm focal length and the shooting distance (3 m is a reasonable distance between the camera kept by a standing operator and the identified point of interest) a 0,3 mm length on the object represents the minimum detectable change (the GSD is a geometric characteristics that can be considered devoid of uncertainty component).

Test period

The inspections were planned taking into account the window fixtures replacement operations, involving consecutively both the Yellow test area and the nearby areas: the removal operations and the mechanical stresses on the identified points of interest represent useful information to interpret the results of the Image Analysis for the Local Analysis.

The data recording started in May 5th 2015 (first step of image shooting) at the end of the Canvassing investigation: the first set of high-resolution images of the identified points of interest, shot by the selected Nikon D800E high-resolution camera, provided the zero condition for the Local analysis. At the same time, the poor results of a preliminary test with a special camera - iStar 360° model, guided the choice towards the use of the CAM2 Focus 3D laser scanner to perform the next data gathering for the 3D Base model and the Global analysis.

The second step of image shooting was carried out during the inspection in December 14th 2016. At that time, the planned window fixtures removal and replacement works inside the testing area, were accomplished.

During the inspection of the April 26th 2017 (third step of image shooting), some high-resolution digital images and laser scanner acquisitions were gathered. The date of the inspection was selected according to the conclusion of window fixtures replacement operation involving nearby areas. The activity could have further stressed the identified points of interest, therefore it was decided to capture a set of images after the conclusion of the work.

As result of this process, three complete and consecutive sets of acquisitions, for both the General and Local analysis, were available.

Data processing for the Global analysis

According to the discussed approach, the first step of the areas Quality Management is a general analysis performed geo-referencing and superimposing the laser scanner acquisitions to the 3D Base model.

Figure 21 shows a screenshot of the 3D Base model of the tests area.

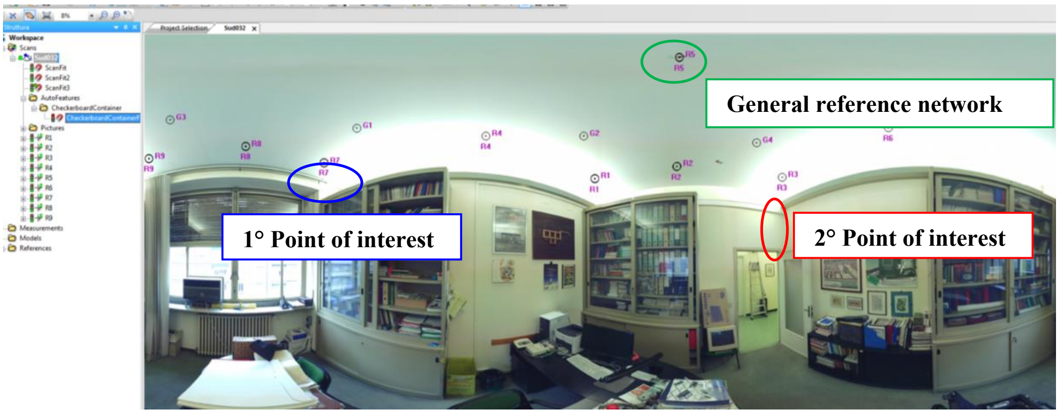


Figure 21 3D Base model of the test area, reference system, and points of interest location

A set of nine markers (red and white) and four checkpoints (yellow and white) specifically positioned on the ceiling of the test area (Fig. 22 left) made available a permanent reference system for the laser scanner acquisitions geo-referencing. The measurements network adjustment for the reference system definition with the Least Square method (Fig. 22 right), needed to compare the multi-temporal clouds of points, resulted from a series of mutual distances measurements between the markers and checkpoints processed by MicroSurvey StarNet ® software; the network adjustment reduced to 1 mm the maximum uncertainty of the markers position, both in X and Y coordinates, providing an increased accuracy in the superimposing operations.

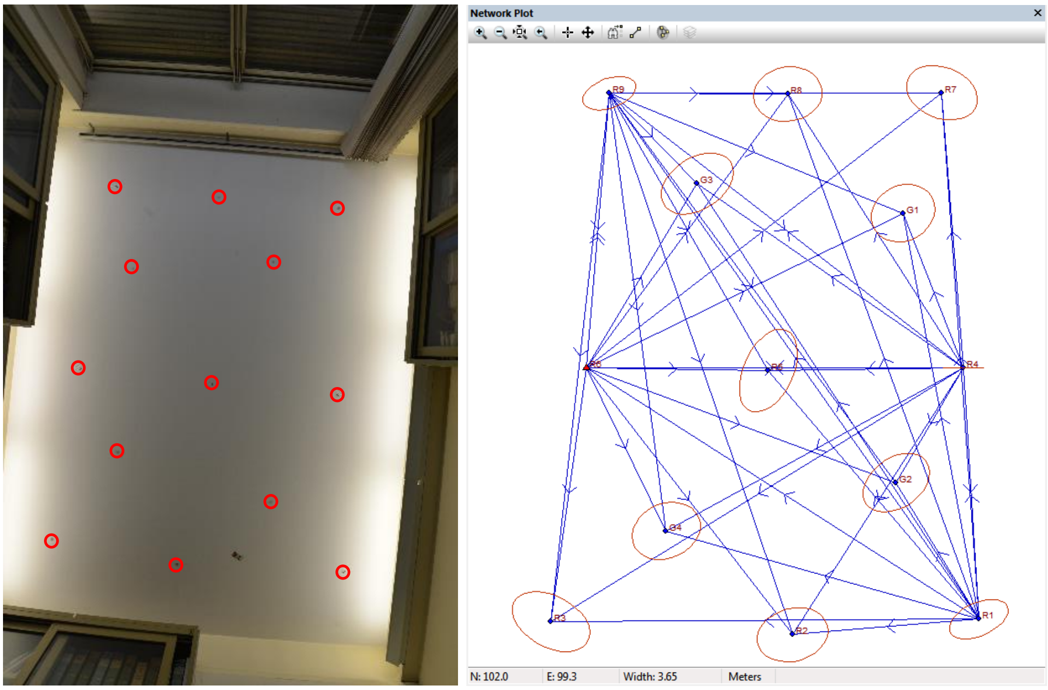


Figure 22 Reference system – circles evidence the markers and checkpoints (left), Least Square network adjustment with error ellipses (right)

The Global Analysis did not underline coarse modifications occurred during the time interval between the first and the last acquisition.

Data processing for the Local analysis

The Local Analysis tests involved the crack on the wall - *2° point of interest*: the flatness characteristics of the surface where the crack is located simplifies the image processing procedure.

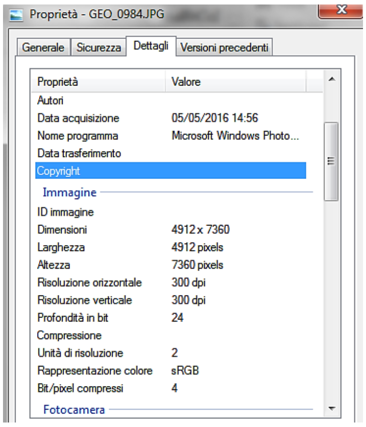
The approach requires to select, adjust and compare three high-resolution digital images of the same point of interest with comparable characteristics, captured in different times. Three sets of images of the crack are available: Table 47 summarizes some information about each images collection.

1st set	*Image shooting date*: May 5th 2016 *Files names*: from GEO_0979.JPG to GEO_0986.JPG *Note*: planned window fixtures replacement works not carried out yet.	
2nd set	*Image shooting date*: December 14th 2016 *Files names*: from GEO_1289.JPG to GEO_1293.JPG *Note*: planned window fixtures replacement works completed.	
3rd set	*Image shooting date*: April 26th 2017 *Files names*: GEO_2552.JPG and GEO_2564.JPG *Note*: planned window fixtures replacement works completed in nearby areas.	

Table 47 Information about the three sets of images

The three selected images within the sets of data show comparable features in terms of geometrical resolution (300 dot per inch – dpi), focal length 48 ÷ 50 mm, and focal ratio ([22]) f/4 ÷ f/3 (Tab. 48). Some different features, e.g. the exposure times (1/40, 1/60 and 1/160 sec) and the ISO sensitivity (ISO 250, 500 e 800) do not affect the analysis, in terms of dimensional image interpretation.

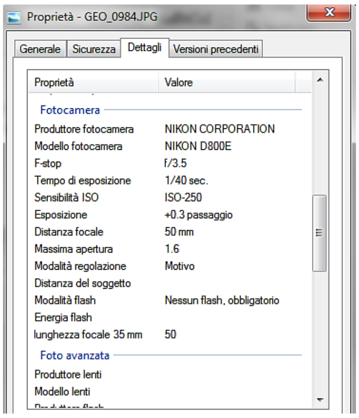
Image GEO_0984.JPG



Proprietà - GEO_0984.JPG

Generale | Sicurezza | Dettagli | Versioni precedenti

Proprietà	Valore
Autori	
Data acquisizione	05/05/2016 14:56
Nome programma	Microsoft Windows Photo...
Data trasferimento	
Copyright	
Immagine	
ID immagine	
Dimensioni	4912 x 7360
Larghezza	4912 pixels
Altezza	7360 pixels
Risoluzione orizzontale	300 dpi
Risoluzione verticale	300 dpi
Profondità in bit	24
Compressione	
Unità di risoluzione	2
Rappresentazione colore	sRGB
Bit/pixel compressi	4
Fotocamera	

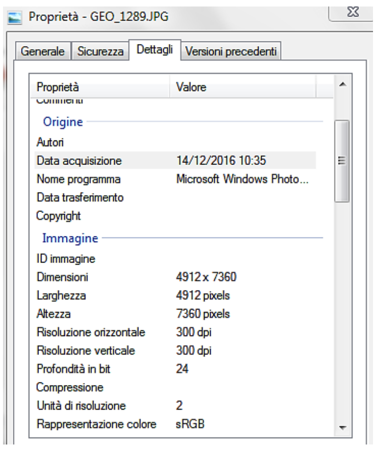


Proprietà - GEO_0984.JPG

Generale | Sicurezza | Dettagli | Versioni precedenti

Proprietà	Valore
Fotocamera	
Produttore fotocamera	NIKON CORPORATION
Modello fotocamera	NIKON D800E
F-stop	f/3.5
Tempo di esposizione	1/40 sec.
Sensibilità ISO	ISO-250
Esposizione	+0.3 passaggio
Distanza focale	50 mm
Massima apertura	1.6
Modalità regolazione	Motivo
Distanza del soggetto	
Modalità flash	Nessun flash, obbligatorio
Energia flash	
lunghezza focale 35 mm	50
Foto avanzata	
Produttore lenti	
Modello lenti	

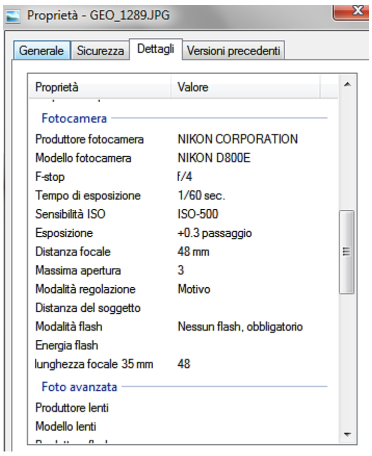
Image GEO_1289.JPG



Proprietà - GEO_1289.JPG

Generale | Sicurezza | Dettagli | Versioni precedenti

Proprietà	Valore
Origine	
Autori	
Data acquisizione	14/12/2016 10:35
Nome programma	Microsoft Windows Photo...
Data trasferimento	
Copyright	
Immagine	
ID immagine	
Dimensioni	4912 x 7360
Larghezza	4912 pixels
Altezza	7360 pixels
Risoluzione orizzontale	300 dpi
Risoluzione verticale	300 dpi
Profondità in bit	24
Compressione	
Unità di risoluzione	2
Rappresentazione colore	sRGB

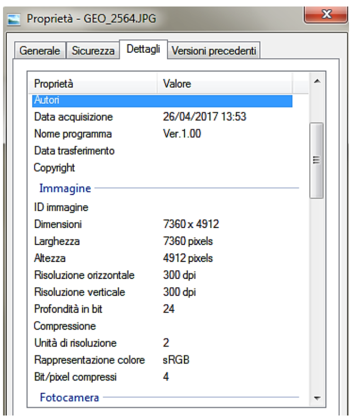


Proprietà - GEO_1289.JPG

Generale | Sicurezza | Dettagli | Versioni precedenti

Proprietà	Valore
Fotocamera	
Produttore fotocamera	NIKON CORPORATION
Modello fotocamera	NIKON D800E
F-stop	f/4
Tempo di esposizione	1/60 sec.
Sensibilità ISO	ISO-500
Esposizione	+0.3 passaggio
Distanza focale	48 mm
Massima apertura	3
Modalità regolazione	Motivo
Distanza del soggetto	
Modalità flash	Nessun flash, obbligatorio
Energia flash	
lunghezza focale 35 mm	48
Foto avanzata	
Produttore lenti	
Modello lenti	

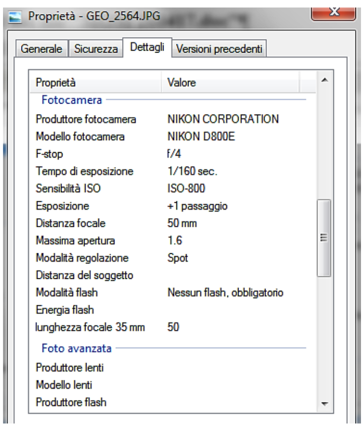
Image GEO_2564.JPG



Proprietà - GEO_2564.JPG

Generale | Sicurezza | Dettagli | Versioni precedenti

Proprietà	Valore
Autori	
Data acquisizione	26/04/2017 13:53
Nome programma	Ver.1.00
Data trasferimento	
Copyright	
Immagine	
ID immagine	
Dimensioni	7360 x 4912
Larghezza	7360 pixels
Altezza	4912 pixels
Risoluzione orizzontale	300 dpi
Risoluzione verticale	300 dpi
Profondità in bit	24
Compressione	
Unità di risoluzione	2
Rappresentazione colore	sRGB
Bit/pixel compressi	4
Fotocamera	



Proprietà - GEO_2564.JPG

Generale | Sicurezza | Dettagli | Versioni precedenti

Proprietà	Valore
Fotocamera	
Produttore fotocamera	NIKON CORPORATION
Modello fotocamera	NIKON D800E
F-stop	f/4
Tempo di esposizione	1/160 sec.
Sensibilità ISO	ISO-800
Esposizione	+1 passaggio
Distanza focale	50 mm
Massima apertura	1.6
Modalità regolazione	Spot
Distanza del soggetto	
Modalità flash	Nessun flash, obbligatorio
Energia flash	
lunghezza focale 35 mm	50
Foto avanzata	
Produttore lenti	
Modello lenti	
Produttore flash	

Table 48 Characteristics of the selected images

[22] Focal ratio or F-stop is the ratio of the system's focal length to the diameter of the entrance pupil or reciprocal of the relative aperture

Image processing: distortion correction

Some automatic lens calibration software, e.g. Agisoft Lens ®, make possible to estimate the non-linear distortion coefficients necessary to correct the image distortion. Agisoft Lens ® determines the calibration parameters from a calibration pattern provided by the software, i.e. a set of images of a chessboard of known geometry taken from different perspectives (Tab. 49).

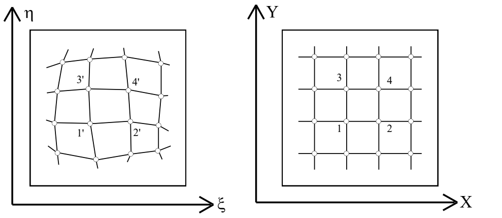
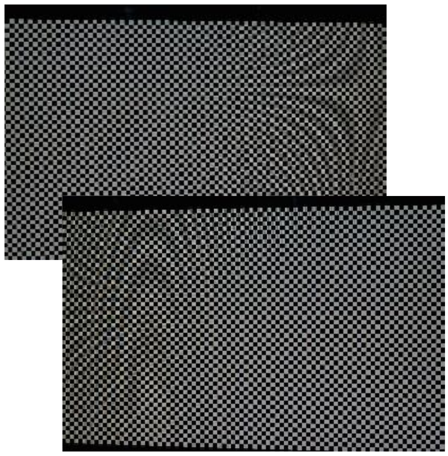
Distortion coefficients	Chessboards
 - *f* - focal length, in pixels; - *cx* - X coordinate of the principal point; - *cy* - Y coordinate of the principal point; - *K1, K2, K3, K4* - radial distortion coefficients in the Brown's model; - *P1, P2, P3, P4* - tangential distortion coefficients in the Brown's model; - *B1, B2* - affinity and non-orthogonality (skew) coefficients.	

Table 49 Distortion coefficients and chessboard for the lens calibration

Processing the chessboard pictures shot by means of the Nikon D800E camera fitted with Nikkor 24-70 mm f/2.8 lens, used with 50 mm focal, the software made available the required coefficients (only for radial distortions, since the tangential ones resulted negligible); Figure 23 shows the output of the software.

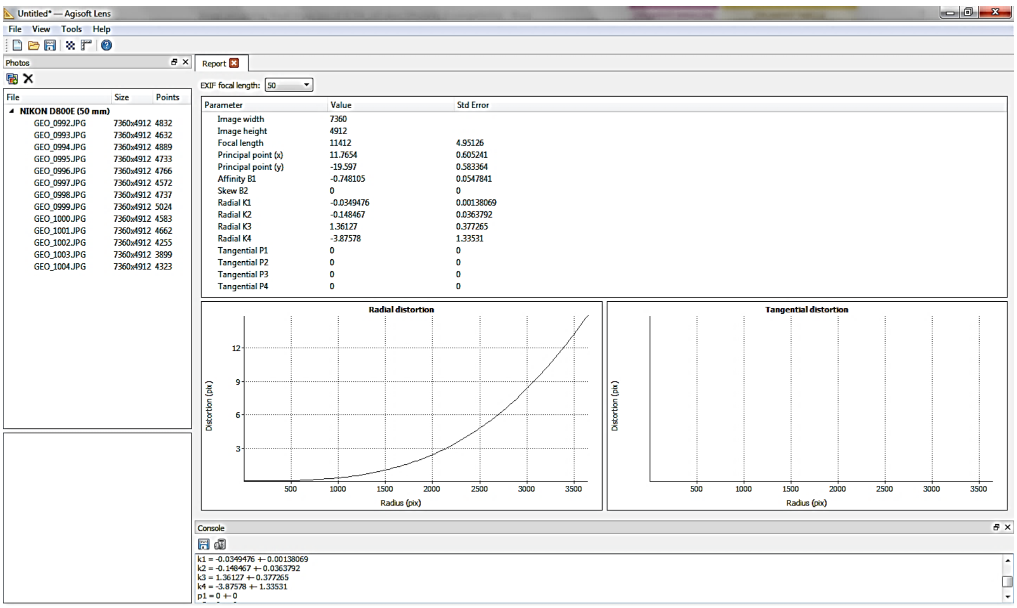


Figure 23 Agisoft Lens ® calibration document

The images undistortion procedure, possible by means of different software, e.g. StereoCad Menci software ®, can require a preliminary conversion of the calibration document (file extension .xml) in special extension files (.cvc), since software such as StereoCad ® requires .cvc file as input data. In this case, the necessary transformation was obtained by an algorithm developed in Matlab MathWorks ®: Table 50 shows the content of the original (.xml) and converted (.cvc) files.

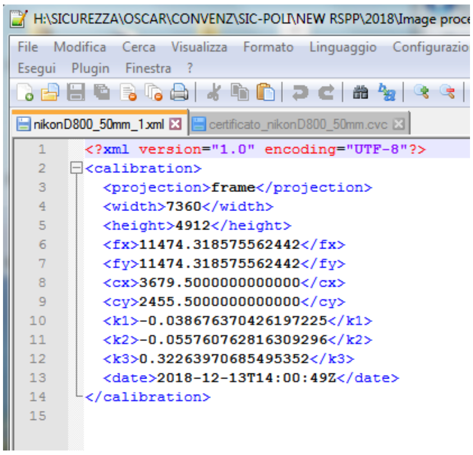
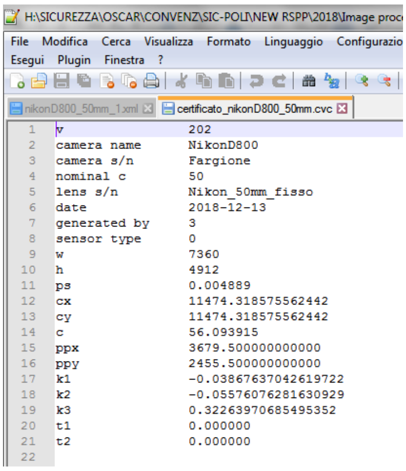
<table>
<tr><th>Agisoft Lens calibration data</th><th>StereoCad file input</th></tr>
<tr><td>
H:\SICUREZZA\OSCAR\CONVENZ\SIC-POLI\NEW RSPP\2018\Image proc
nikonD800_50mm_1.xml
<?xml version="1.0" encoding="UTF-8"?>
<calibration>
<projection>frame</projection>
<width>7360</width>
<height>4912</height>
<fx>11474.318575562442</fx>
<fy>11474.318575562442</fy>
<cx>3679.500000000000</cx>
<cy>2455.500000000000</cy>
<k1>-0.038676370426197225</k1>
<k2>-0.055760762816309296</k2>
<k3>0.32263970685495352</k3>
<date>2018-12-13T14:00:49Z</date>
</calibration></td><td>
H:\SICUREZZA\OSCAR\CONVENZ\SIC-POLI\NEW RSPP\2018\Image proc
certificato_nikonD800_50mm.cvc
v 202
camera name NikonD800
camera s/n Fargione
nominal c 50
lens s/n Nikon_50mm_fisso
date 2018-12-13
generated by 3
sensor type 0
w 7360
h 4912
ps 0.004889
cx 11474.318575562442
cy 11474.318575562442
c 56.093915
ppx 3679.500000000000
ppy 2455.500000000000
k1 -0.0386763704261972
k2 -0.0557607628163092
k3 0.32263970685495352
t1 0.000000
t2 0.000000</td></tr>
<tr><td colspan="2">With reference to the converted file:
- ps is the pixel size
- c is the focal length in millimetres
- cx and cy are the focal in pixels
- ppx and ppy are the principal point coordinates in pixel
- k1, k2, k3 are the parameters of the characteristic curve necessary to adjust the distortion through the equation $\delta r = k_1 r^3 + k_2 r^5 + k_3 r^7 + \cdots$(eq. 20)</td></tr>
</table>

Table 50 Original and converted calibration data

Thanks to the information in the .cvc file, the software produces three undistorted images (.TIFF).

An algorithm, developed in Matlab MathWorks ® to detect radiometric content differences between images for Local analysis purpose, makes possible to display the differences between the original and undistorted pictures.

As an example, Figure 24 shows the result of the comparison between the original GEO_0984.JPG image and its undistorted version: in the centre of the figure no differences appear (black colour corresponds to zero value pixels), moving towards the edge of the image, some un-matching pixels (coloured pixels containing other than zero values) highlight observable radial distortions – increasing from the centre to the edges of the picture.

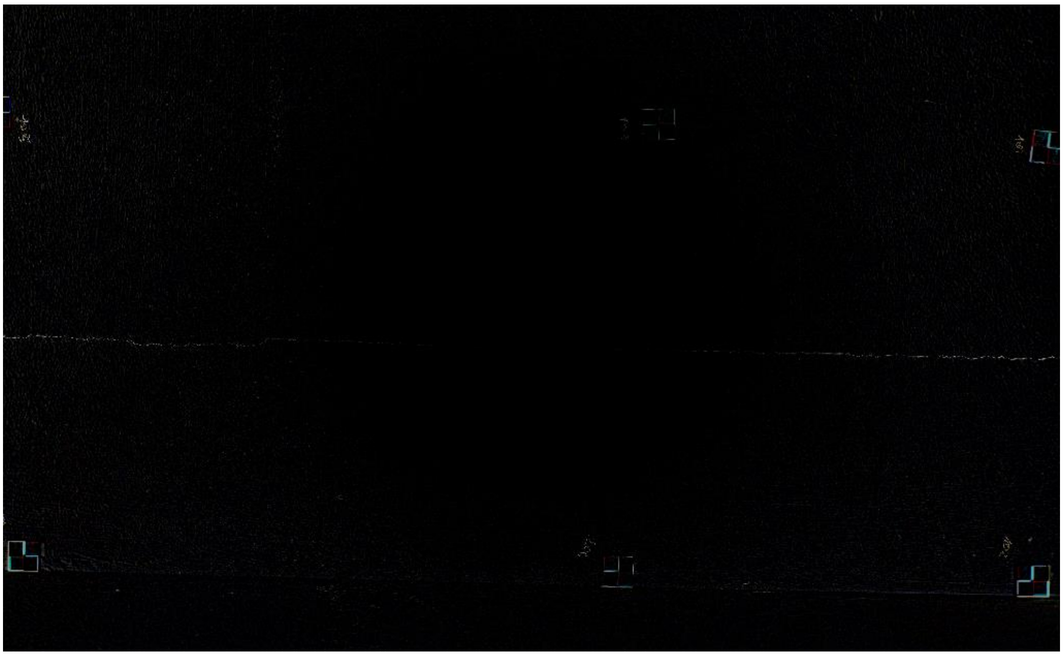


Figure 24 Difference between original and undistorted image

Figure 25 shows a magnification of the upper right corner of the image in Figure 24: data tips show the image coordinates (in pixels) and the content of the selected pixels in RGB bands: values other than zero identify un-matching pixels due to distortion.

Figure 25 Magnification of part of the Fig. 24 and pixels information

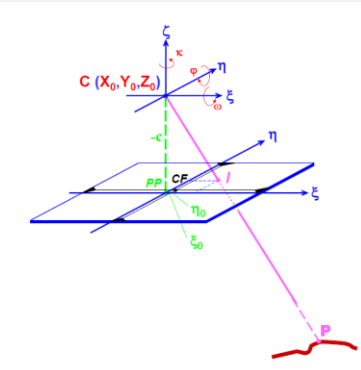
Image processing: perspective deformation recovery

The perspective deformation recovery, implemented on the undistorted images from the previous stage, needs of points of known coordinates in a defined reference system. Points could be directly identified, or specifically positioned (local markers), on the photographed object.

The estimate of the eight homography coefficients, possible with a minimum of four points of known coordinates, enables the perspective deformation adjustment.

The adjusted image is obtained implementing the homography equations to each pixel of the original image, to relocate the pixels in the correct position and to resample their radiometric content. This process needs both the object and image coordinates of each marker. The relation object/image depends on nine parameters, describing:

- the *external orientation*: camera position in the space, including three translations and three rotations components (Fig. 26)



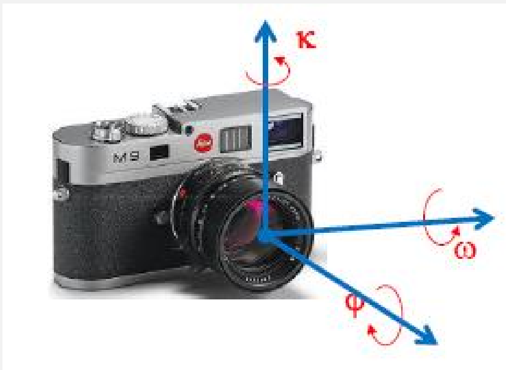
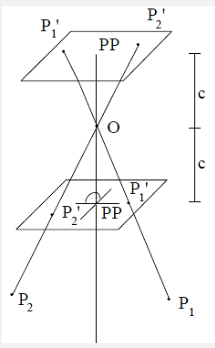


Figure 26 External orientation

- the *internal orientation:* parameters describing the internal geometry of the camera: Principal Point – PP coordinates (ξ_0, η_0) and principal distance/focal length (Fig. 27)



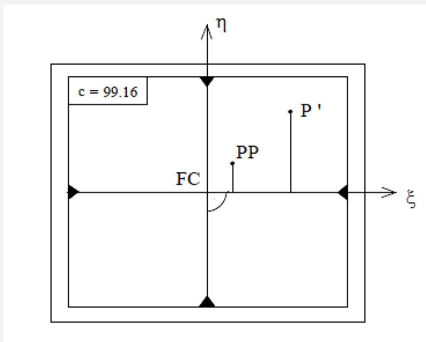
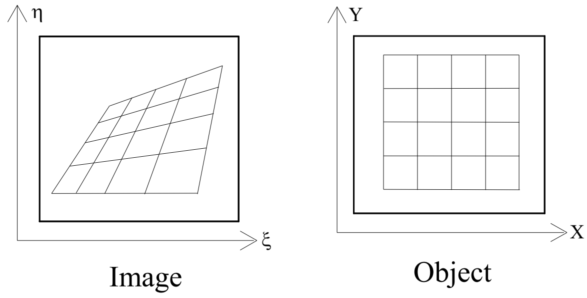


Figure 27 Internal orientation

The flatness characteristic of the chosen point of interest simplifies the perspective deformation adjustment, which can be modelled through the general homography equations at eight parameters (eq. 21 and 22 in Table 51), instead of the nine parameters necessary in the case of 3D objects. These equations give the relation between object and image.



$$X = \frac{a_1\xi + a_2\eta + a_3}{c_1\xi + c_2\eta + 1} \quad \text{(eq. 21)}$$

$$Y = \frac{b_1\xi + b_2\eta + b_3}{c_1\xi + c_2\eta + 1} \quad \text{(eq. 22)}$$

Where:

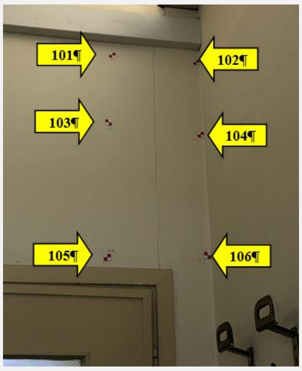
- (X,Y) object coordinates
- (ξ, η) image coordinates
- (a_1, a_2, a_3, b_1, b_2, b_3, c_1, c_2) eight homography parameters

Table 51 Homography formulas

On the basis of the image (ξ, η) and object (X,Y) coordinates of the six local markers (constituting the local reference system), specially positioned close to the wall discontinuity (Tab. 52), the eight parameters can be determined by software, e.g. RDF ®.

The precision required by the approach made necessary the measurements network adjustment for the local reference system definition, before the perspective deformation correction, to obtain precise object coordinates minimizing the uncertainty related to each marker position. Table 52 shows the markers labels and their mutual distances needed to adjust the network.

Local reference system



Marker A	Marker B	Mutual distances [m]	Marker A	Marker B	Mutual distances [m]
101	102	**0,286**	102	106	**0,681**
101	103	**0,254**	103	104	**0,300**
101	104	**0,397**	103	105	**0,442**
101	105	**0,695**	103	106	**0,520**
101	106	**0,738**	104	105	**0,517**
102	103	**0,254**	104	106	**0,405**
102	104	**0,275**	105	106	**0,300**
102	105	**0,756**			

Table 52 Mutual distances between local markers

The measurements network adjustment was performed through MicroSurvey StarNet ® software, selecting the 103 marker as origin of the local reference system. The first attempt underlined some error ellipses too large (in both the axes). The analysis of residuals gave indications about the possible cause of the problem: among the adjusted distance observations, the measure between markers 102 and 103 showed a too large residual, probably due to an error in the measurement. Excluding that measure from the network adjustment, the error ellipses came back to acceptable dimensions. Table 53 displays the adjusted local reference system and the precise markers coordinates.

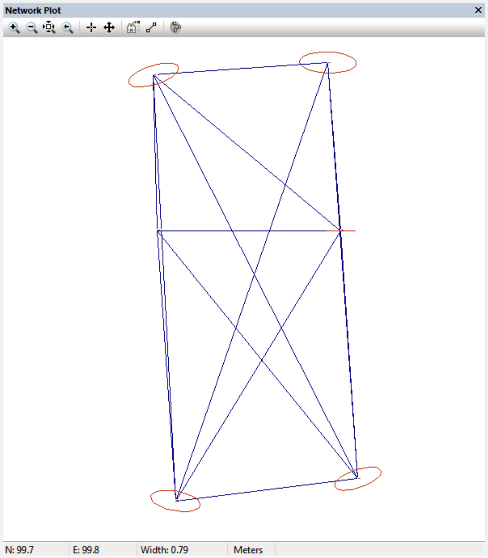
<table>
<tr><th>Adjusted reference system</th><th colspan="3">Adjusted object coordinates [m]</th></tr>
<tr><td rowspan="8">
</td><td>Station</td><td>X</td><td>Y</td></tr>
<tr><td>103</td><td>100,000</td><td>100,000</td></tr>
<tr><td>101</td><td>99,994</td><td>100,254</td></tr>
<tr><td>102</td><td>100,279</td><td>100,274</td></tr>
<tr><td>104</td><td>100,299</td><td>100,000</td></tr>
<tr><td>105</td><td>100,030</td><td>99,560</td></tr>
<tr><td>106</td><td>100,327</td><td>99,596</td></tr>
<tr><td colspan="3">Maximum Standard Deviation in X,Y = 1,8 mm</td></tr>
</table>

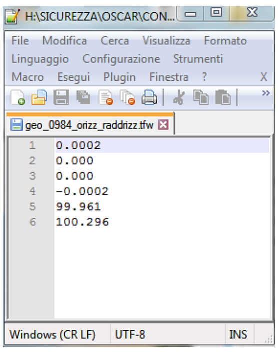
Table 53 Adjusted local reference system

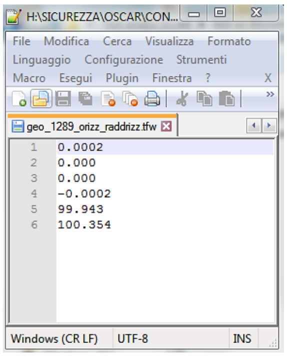
RDF ® software determines the parameters of the homography equation, having both the adjusted object coordinates of the local markers as input data, and the corresponding image coordinates, recorded by collimating each markers centre on the image. On the base of these parameters, the image is re-sampled by setting a bilinear resampling method and a pixel dimension close to the calculated GSD (0,3 mm according to the shooting project): the final resulting picture is corrected from the perspective deformations.

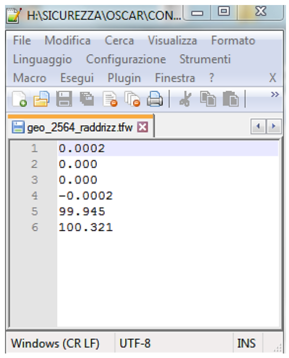
Affine transformation

The geometrical approach for the Local analysis, based on precision measurements, requires the availability of the object coordinates directly on the image. Therefore, an affine transformation (eq. 23 and eq. 24 in Table 54) is necessary to convert the image system coordinate (ξ, η) in cartographic system coordinates (Est, Nord). The “image geo-referencing” option, available in RDF ® software menu, enables to save the six parameters for the affine transformation in .TFW files, to associate to the relevant .TIFF image. Table 54 shows the content of the .TFW file of the three adjusted images, and the affine transformation formula.

Affine transformation parameters and formula







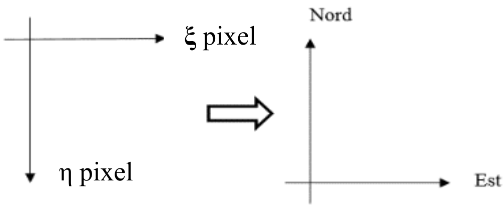


Image coordinates (ξ,η) ⇨ *Cartographic coordinates (E,N)*

$Est = A * \xi + C * \eta + E$ (eq. 23)

$Nord = B * \xi + D * \eta + F$ (eq. 24)

Meaning of the six parameters of equation 23 and 24 (in bracket numbers indicating the parameters in .TFW files):

- *A (1) and D (4)*: scale of the image, pixels dimension;
- *B (2) and C (3)*: skew factor (zero values, since the image is still resampled);
- *E (5) and F (6)*: translation of the system origin (from the upper left corner).

Table 54 Affine transformation parameters for the three images

Uploading both the .TIFF and .TFW files in software e.g. AutoCad Autodesk ® or similar, the object coordinates become available directly on the image (Fig. 28), and special operations, e.g. precision measurements, are possible.

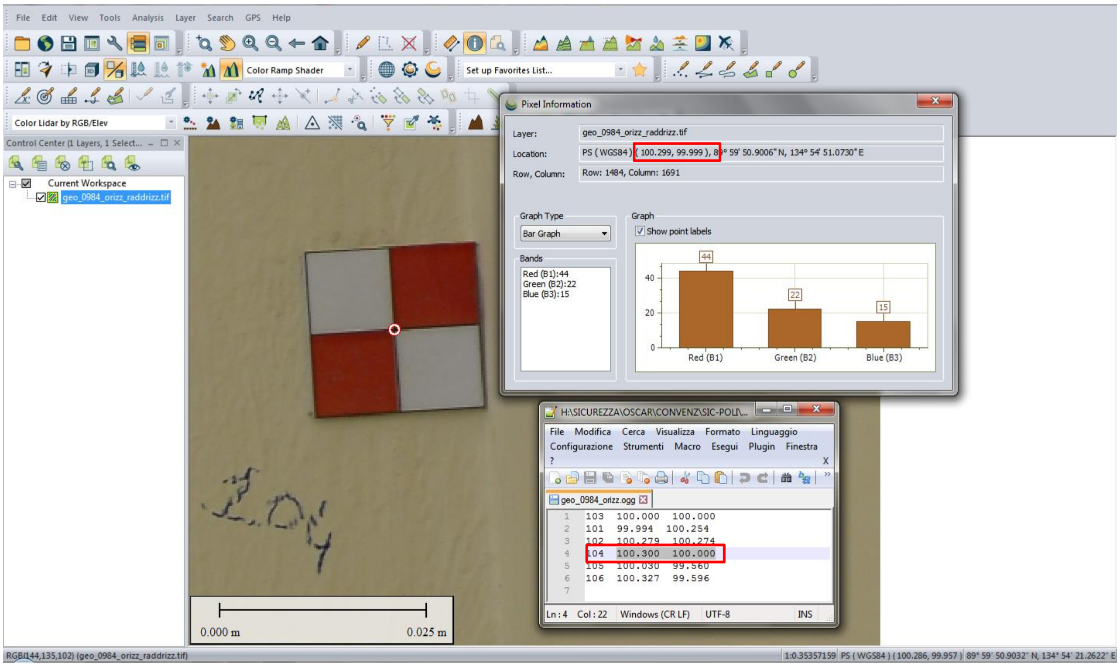


Figure 28 Object coordinates available on the image GEO_0984

Information gathering: the Identity Card of the point of interest

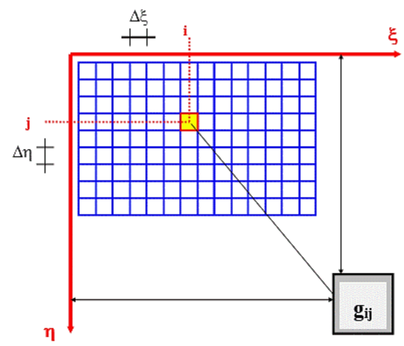
Finalized the preliminary Image processing, the adjustment of the mutual distances for the local reference system definition, and the coordinates affine transformation, the three images of the crack can be included in the quoted *Identity Card* of the point of interest (Fig. 29), and analysed in two consecutive steps according to the timeline of images acquisition.

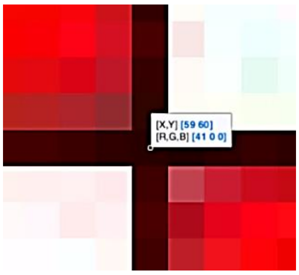
	Image 1	***Image 2***	***Image 3***
Shooting date	May 5th 2016	December 14th 2016	April 26th 2017
Original file	GEO_0984.JPG	GEO_1289.JPG	GEO_2564.JPG
Adjusted file *(optical and perspective deformations recovered)*	geo_0984_orizz_raddrizz ⇩ 	geo_1289_orizz_raddrizz ⇩ 	geo_2564_raddrizz ⇩ 
Note	Planned window fixtures replacement not yet carried out.	Planned window fixtures replacement completed into the area.	Planned window fixtures replacement completed in nearby areas.

Figure 29 Identity Card of the 2° point of interest

Information gathering: the radiometric difference analysis

The assisted image interpretation by radiometric difference method can be considered as a subtraction between two matrices. Digital images, indeed, are matrixes where the photographic content is recorded in numbers. Each infinitesimal element of the image (pixel, not further divisible) contains a number (or numbers) representing the radiometry of the portion of image involved. In true colour images, the radiometry of a pixel is represented by three integers (ranging from 0 to 255) expressing the saturation of the main three bands (RGB); this representation requires three bytes for each pixel. Each pixel is uniquely identified by two integers that represent the row and column position of the element within the matrix (Tab. 55).





247	249	205	50	255	245	245
250	254	213	72	249	247	238
228	218	191	53	255	251	230
182	173	146	48	255	255	250
66	58	46	41	34	45	54
255	255	255	62	192	201	203
255	255	255	73	173	230	255
255	251	255	64	190	242	254
247	241	255	80	179	227	250

Table 55 Digital image as matrix of numbers

The principle at the base of the analysis is the identification of differences between couples of images, subtracting (images subtraction) each element of the first matrix (image 1) to the corresponding element belonging to the second matrix (image 2). The finding of differences in some pixels content reveals that, during the image taking, different reflectance values were recorded by the elementary parts of the camera sensor, or physical pixels ([23]), due to different surficial conditions of the object photographed in steady light conditions.

Practically the images subtraction was performed through an original Matlab MathWorks ® algorithm: after the initial conversion of the RGB images to grayscale, the algorithm enables a kind of images orthorectification needed, for an accurate superimposing. The algorithm outcome is a "*difference-image*" (matrix of differences): the Local analysis is based on two possible interpretations of such an image:

1. totally black *difference-image* - all zero values in the matrix of differences: perfect matching of two successive pictures and their pixels content; no detectable surficial modifications of the point of interest occurred in the timespan between the two images shooting;
2. *difference-image* with coloured parts - values other than zero in the matrix of differences: some parts of the compared pictures differ, and differences are

[23] Physical pixels - photodetector: smallest light-sensitive element of the sensor.

localizable in the coloured portions of the *difference-image*; if the coloured area includes the point of interest, or to part of it, some alterations of its conservation conditions occurred (e.g. modification in shape of the wall discontinuity).

The method was implemented to compare the three chosen pictures of the wall crack, in two consecutive steps, according to the timeline of images acquisition. Table 56 shows the first couple of adjusted images to compare: *geo_0984_orizz_raddrizz* (image 1) and *geo_1289_orizz_raddrizz* (image 2), converted in grayscale and orthorectified.

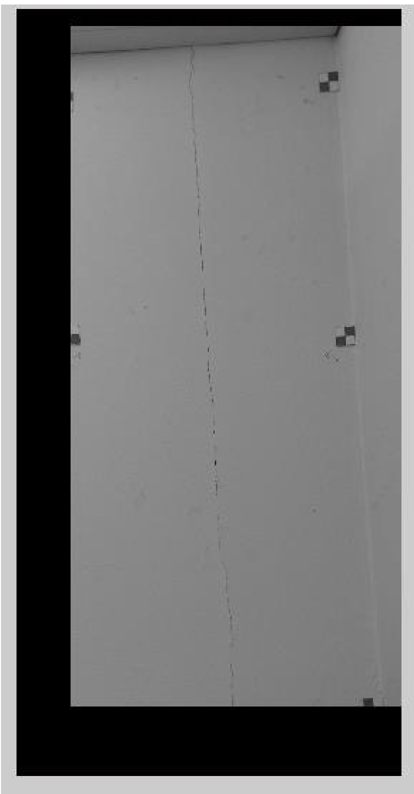
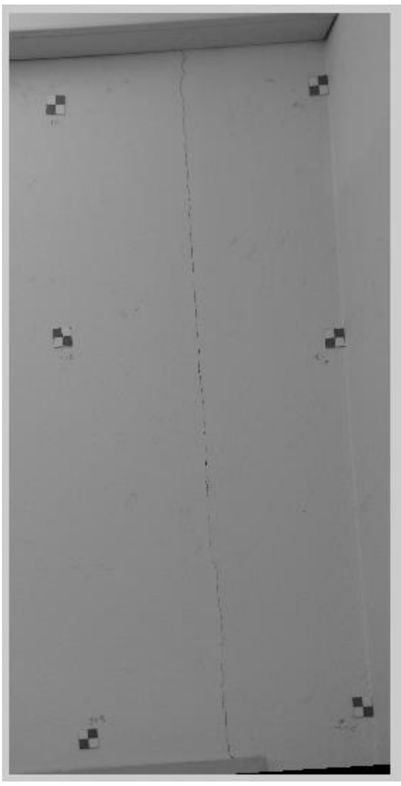
	
geo_0984_orizz_raddrizz (image 1)	geo_1289_orizz_raddrizz (image 2)

Table 56 First couple of orthorectified grayscale images of the point of interest in Identity Card of Fig. 29

Table 57 (left) shows the *difference-image* resulting from the subtraction of image 1 and image 2: the white coloured pixels include the most of the point of interest area; the right part of Table 57 displays an in high detail of such an area.

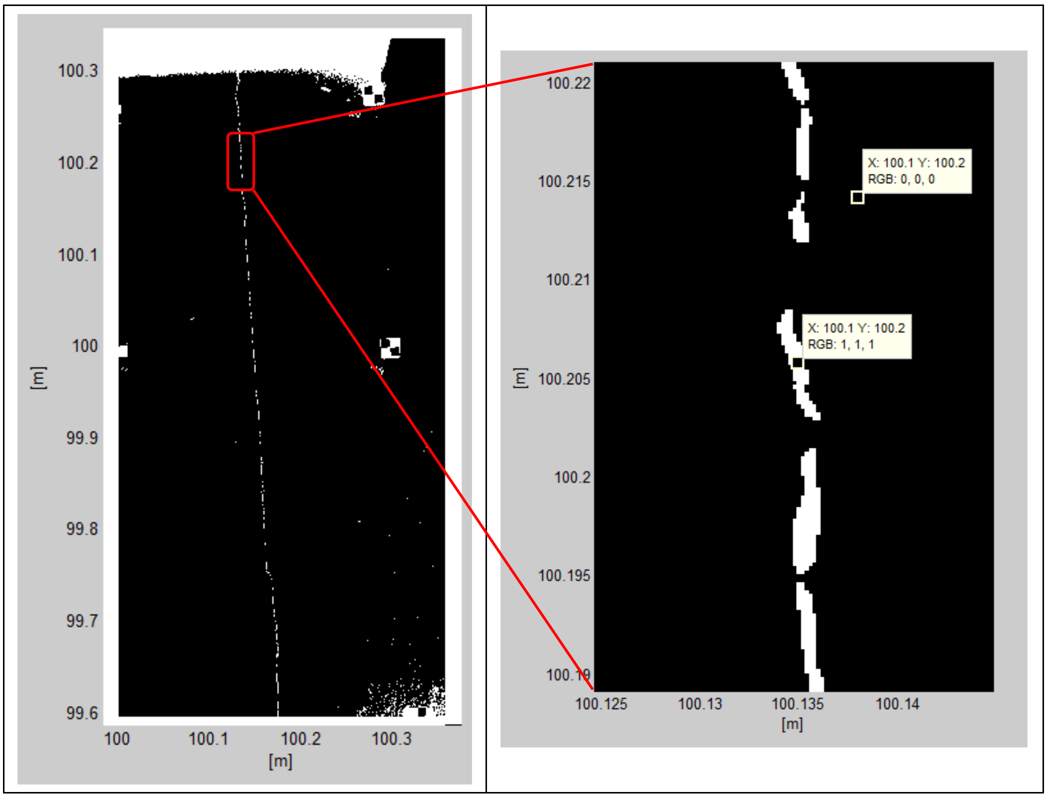


Table 57 Radiometric difference-image resulting from image 1 / image 2 subtraction

The grayscale and orthorectified images *geo_1289_orizz_raddrizz* (image 2) and *geo_2564_raddrizz* (image 3) for the second step of the analysis are shown in Table 58.

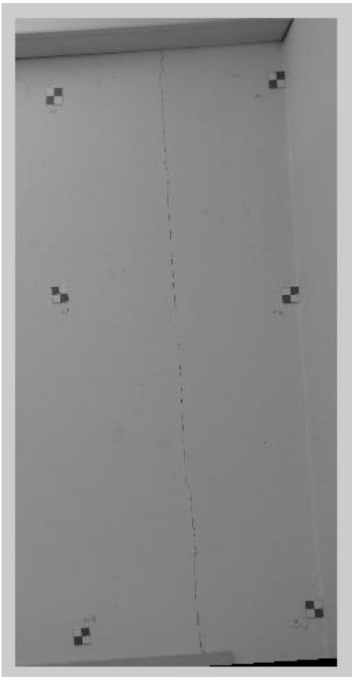
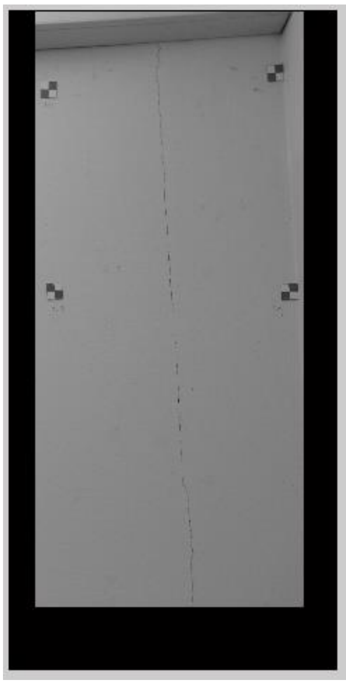
	
geo_1289_orizz_raddrizz (image 2)	geo_2564_raddrizz (image 3)

Table 58 Second couple of orthorectified grayscale images of the point of interest in Identity Card of Fig. 29

Table 59 shows the result of the subtraction between image 2 and images 3.

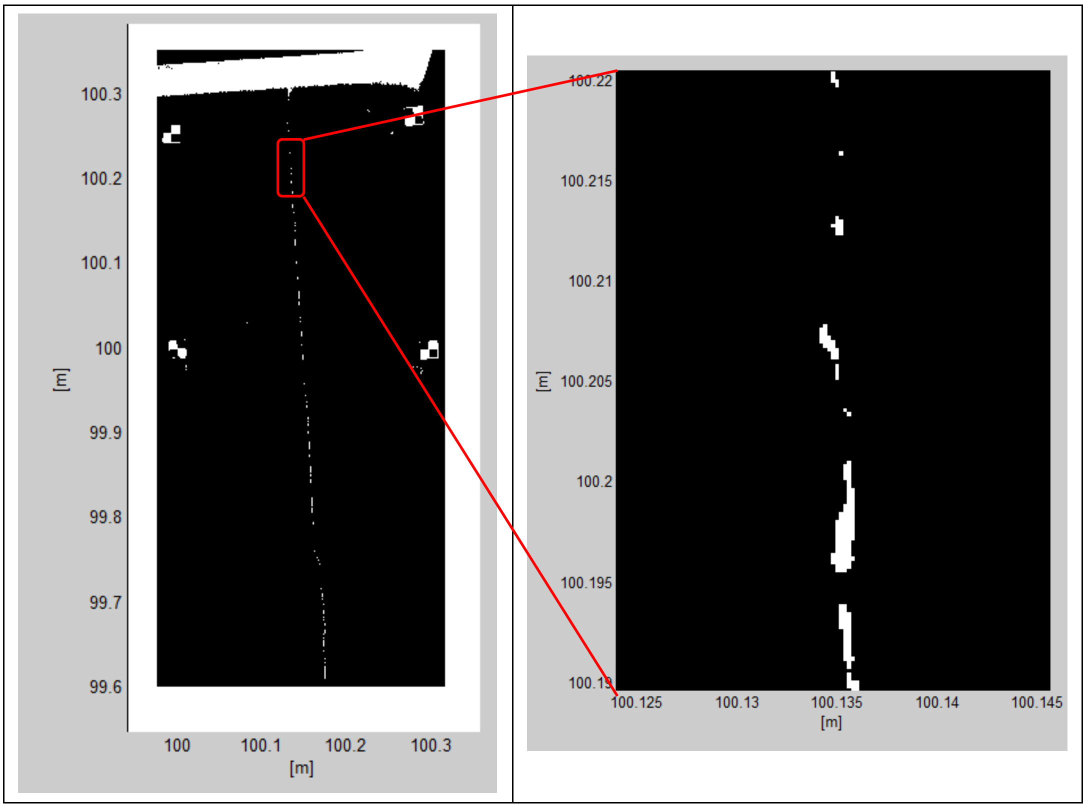


Table 59 Radiometric difference-image resulting from image 2 / image 3 subtraction

As shown in the right part of both Table 57 and Table 59 (result of the analysis in high detail), zero difference values between the corresponding pixels of the two recorded images result in a black representation, i.e. in no detectable modification of the point of interest in the timespan between the shooting of the two images, whilst the coloured parts correspond to un-matching pixels of the input images, and provide evidence of alterations in the point of interest conditions.

The extent of the white coloured area involving the wall discontinuity, resulting from the comparison of image 1 and image 2, denotes a significant alteration, (most likely imperceptible through a simple visual analysis), occurred between May 2016 and December 2016. The alteration of the crack is probably due to structural mechanical stresses during the window fixtures replacement works.

The *difference-image* resulting from the subtraction of image 2 and image 3 shows a very reduced coloured area involving the crack: the deterioration, occurred during the second time interval between December 2016 to April 2017, is certainly less important than the alteration occurred during the first timespan considered; this is also clear comparing the analysis in high detail in the right part of Tables 57 and 59 involving the portion of the crack.

Information gathering: the geometrical analysis

The *geometrical analysis* approach can be performed through precision measurements on the *difference-image* or directly on the adjusted images:

- *measurements on the difference-image*: the same Matlab MathWorks ® algorithm used for the radiometric difference analysis makes possible to load the affine transformation parameters: precise measurements can be therefore carried out on the resulting *difference-image* thanks to the availability of the object coordinates which enables the measurements of the extent of the point of interest changes occurred over the time;
- *measurements on the images*: based on the comparison of geometrical quantities, e.g. areas or lengths, defined on the first image with the same quantities on the other pictures; differences between such quantities, involving the part of the image reproducing the wall discontinuity, are attributable to alterations, i.e. crack propagation or enlargement.

According to the first approach, direct measurements of the point of interest modifications, in length and width, can be performed on the resulting *difference-image,* thanks to the object coordinates availability with an accuracy in the range of 1 mm, and to the 0,3 mm GSD resulting from the selected shooting project.

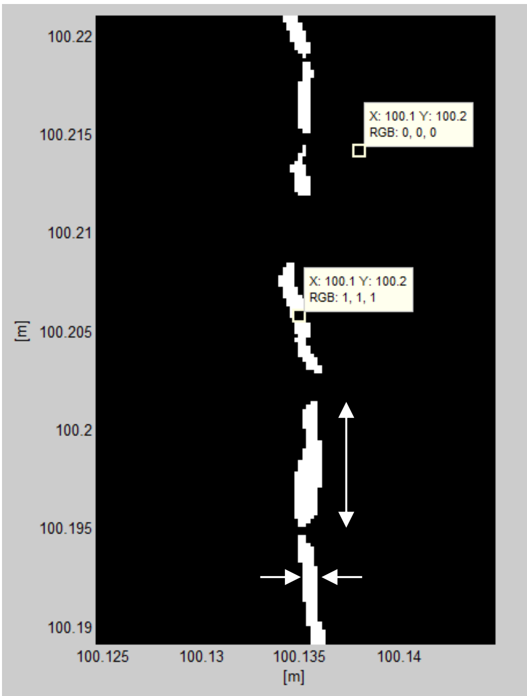


Figure 30 Example of measurements on the difference-image in Tab. 57

The extent of the white coloured area involving the wall discontinuity denotes a measurable alteration: enlargements more than 1 mm can be measured on the *difference-image*.

According to the second approach as an alternative method, preliminary tests were carried out by using special software, e.g. Global Mapper Blue Marble Geographics ®. Contemporarily opening the three adjusted images (Fig. 31), it is possible a preliminary evaluation of the effectiveness of the image processing, by turning on and off the overlapped images (as layers), and verifying the good match of the markers position on the three overlapped images.

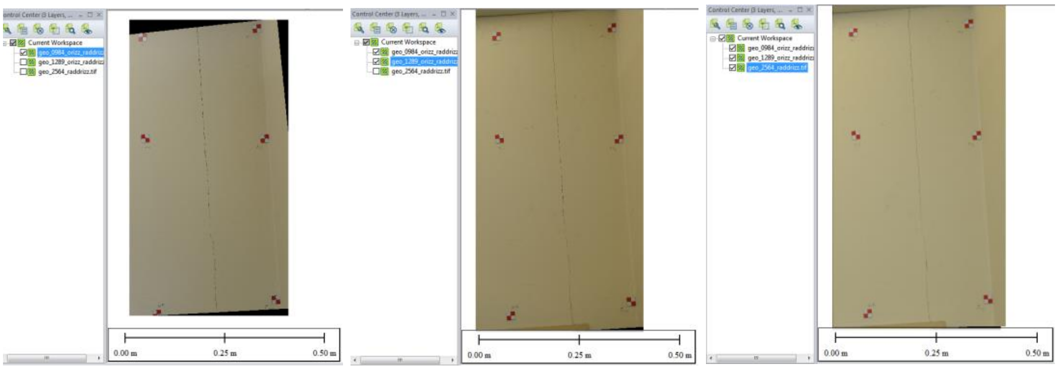


Figure 31 The three adjusted images overlapped

A more accurate evaluation is possible using the available *digitizer tool*, able to create or modify vector features. A vector feature of points collimated in the central pixel of markers on the image 1, makes possible to verify the correct matching in the other two overlapped images (Fig. 32).

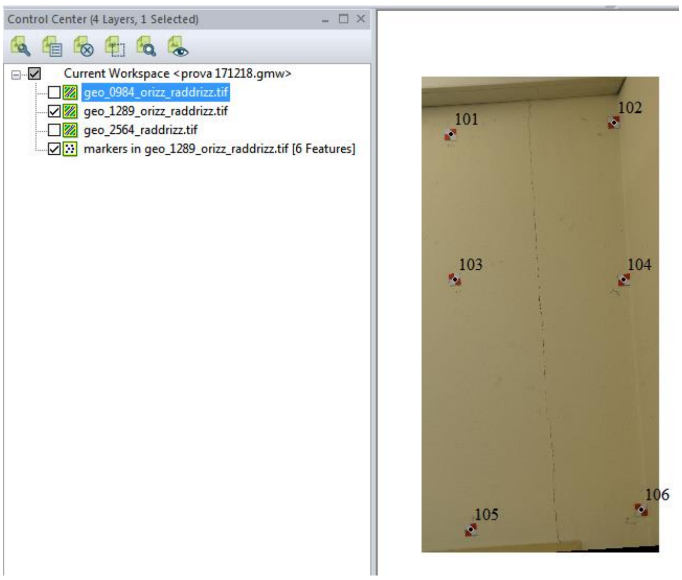


Figure 32 Vector feature of markers position

The same digitizer tool was used to carry out a preliminary test to analyse the potential alteration of the point of interest. In particular, the procedure implemented consisted in the opening of the image 1, and the drawing of a vector area, by following the entire discontinuity shape. The *pixel information tool* is a useful support for the selection of pixels on the edge of the crack: depending on the pixel RGB content, it is possible to make decision about including or not the involved pixel in the vector area under construction. Figure 33 shows the vector area making process, including the pixel information analysis.

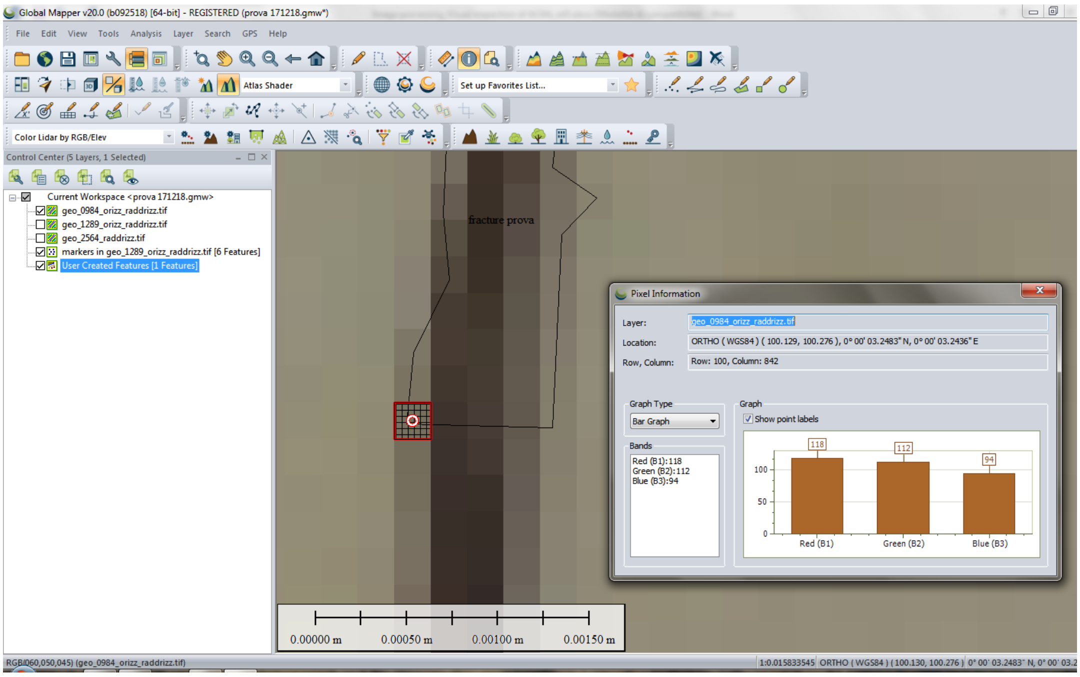


Figure 33 Vector area construction on the first image

The vector area, drawn tracing the shape of the discontinuity on the image 1, become the frame of reference for the other two images. Keeping turned on the vector area, and switching alternatively the other pictures, the potential discontinuity alterations are easy to detect by looking for section of the image under analysis where vector area does not overlap perfectly with the discontinuity.

7.4 In closing

In the frame of PoliTo-UniTo Guideline, the still present high criticality due to the residual presence of asbestos containing artefacts in many public facilities motivated the development of the special asbestos sub-phase of the Guideline.

To achieve an effective Risk Assessment and Management in System Quality, the asbestos sub-phase makes available univocal criteria for a strict classification of workplaces in well-defined categories in terms of asbestos Hazard modes, a reliable reference for the H.I. phase based on the well-tested Canvassing, and management criteria of the different classified areas, established on the base of the general Quality requirement.

With reference to *Research sub-question 3a (what is the actual contribution of the airborne fibres measurements both in the initial workplaces classification and their periodic confirmation?*), a special study, performed to identify the role of airborne fibres measurements in the H.I. and Risk Assessment and Management of Green and Yellow classified areas, confirmed that airborne measurements cannot give useful information where no massive emissions are caused by stressing actions on friable ACMs. Also accidental damages, involving a high but occasional and short-term emissions, are not detectable. To increase the possibility to detected pollution due to artefacts deterioration, some improvements on the method were adopted, in terms of sampling and analysis strategy and samplings locations. However, these adjustments did not give appreciable outcomes:

- all the measures resulted below the method LoD; no evaluation was possible about the pollution levels in the three typologies of sampling areas, neither considerations on the indoor fibres release attributable to the ACMs degradation or effects of the outdoor pollution were achievable;
- the attempt to force the increasing of the sampled air volume till to 10.000 l, did not give appreciable results. However, such a high volume causes difficulties in the analytical stage (e.g. problems in filters reading due to the membrane overload), as well as problems in the samplings management (e.g. the handling of a membrane already used in the previous sampling);
- the main uncertainty contribution of the concentration measures remained related to the fibres count, also considering the adopted strategy;
- due to the lacking of usable data, a careful statistical comparison between the three sets of measures through suitable representativeness tests resulted unfeasible.

Therefore no useful contribution for the initial workplaces classification, neither for their periodic confirmation, can derive from airborne fibres measurements.

With reference to *Research sub-question 3b (how can be the visual inspections improved, overcoming their limits and providing an effective tool for asbestos sub-phase of the Guideline?*), the implementation of computer assisted image processing and interpretation techniques into the asbestos sub-phase of the Guideline to support the inspection activities -in particular in Green and Yellow classified areas- provides a documented history of the artefacts conditions along the time, both in small and large scale, the latter making available Identity Cards of the points of interest, and results in substantial improvements in the Quality Management of Occupational Safety in these areas. Table 59 summarizes the main improvements and the possible future developments of the approach.

Improvements in the Hazard Identification and Risk Assessment and Management made possible by the introduction of Image Analysis techniques for the ACMs status and sealing/enclosures conditions, in Green and Yellow areas.	
The common approach, based on inspectors' subjective judgment, can result in not exhaustive Hazard mode and Risk Assessment, and inspections scheduling.	The introduction of an Image Analysis approach in the asbestos sub-phase of the Guideline makes possible the following improvements
a) poor completeness, in particular when Checklists are used (see comments in the Canvassing chapter);	**a)** *the* ***3D Base model*** *makes available a complete – event if rough– documentation of the Canvassing results in the area; it is moreover possible to implement into the 3D Base model geo referenced information on the positions where ACMs are present;*
b) modifications in the layout of services, systems and interior spaces containing workplaces and working equipment can remain not completely noticed by a coarse inspection;	**b)** *the* ***3D Base model*** *provides an effective tool for the comparison of the general area conditions along the time, both for direct evaluations by the people charged of the inspections, and for more detailed comparisons, supported by computer-assisted image analysis –***Global Analysis***- of the sequence of acquisitions;*
c) poor results in terms of recognition and assessment of changes in the ACMs or sealing/enclosures conditions along the time;	**c)** ***Local Analysis*** *makes possible to directly point out in detail localized changes in size, conditions and shape of ACMs, artefacts or sealing/enclosures: this is of great help to confirm or modify, on a not subjective base, the area classification (in particular from Yellow to Red);*
d) possible -even unacceptable- delay between critical modifications in ACMs or sealing/enclosures status, and the inspections.	**d)** *the use of permanent camera systems (in particular for Local Analysis of critical points of interest) and data loggers can ensure a monitoring of the status of ACMs and sealing/enclosures at predefined intervals and/or on remote demand, and setup in real time alarms where significant modifications occur, independent from the schedule of inspections.*

Table 60 Improvements in the H.I. and Risk Assessment and Management made possible by the introduction of Image Analysis techniques in the asbestos sub-part of the Guideline

Discussion and conclusion

The Occupational Risk Assessment and Management appears is a particularly complex task in the case of research universities, due to a number of typical problems, involving different aspects both of organizational nature and related to the special activities carried out, requiring tailored approaches.

As discussed, a special research work developed as part of a formal collaboration between PoliTo and UniTo, within *The General Safety Issues and Goals in Turin Universities – TGSIGTU* project, made possible the issuing of the PoliTo - UniTo Guideline for the Occupational Risk Assessment and Management of employees, students and people involved in the research university, encouraged since 2008 by Politecnico di Torino and Universita' degli Studi di Torino, and officially quoted as basic reference in 2015.

The research work presented in this PhD Thesis makes available systematic, complete and formalized instruments –the Guideline sub-phases- for a correct and effective Occupational Risk Assessment and Quality Management in public structures and in particular in research universities in the frame of PoliTo-UniTo Guideline. The validation of each developed sub-phase proves the OS&H improvements and benefits achievable.

The *sub-phase of the Guideline special to manage the workplace general safety*, based on the Canvassing, has proven an organized and complete method to support both a systematic H.I. phase and a Quality Management within the workplace general safety analysis.

The several in-situ tests, involving different working environments, pointed out the effectiveness, completeness and repeatability of the method in the identification of OS&H criticalities related to shell, services and interior spaces of premises containing workplaces, and on their not-operative content.

Given the sheer sizes and criticalities of large public facilities (universities included), the task of the skilled technicians is already assisted by the sub-phases, but it is evident that, in the conservative management of Safety level achieved, the highly qualified technicians would be under employed, also from an economic point of view. An effective solution (already adopted in different context, e.g. safety management in construction sites) is to benefit from the availability of less qualified personnel that could be more frequently present on the field. Therefore, the final result of the Canvassing analysis and the management organization, carried out by skilled technicians, can be put into practice also by means of the preparation of tailored Checklists, usable by local staff. This solution gives an additional benefit: thanks to their frequent interventions, local staff can also call for a greater awareness on the OS&H aspects than in the case of inevitably less frequent inspections by skilled technicians.

The *sub-phase of the Guideline special for the OS&H analysis of working activities* represents an effective tool, characterized by metrological and scientific rigour and in system quality approach, to improve the effectiveness of the workers' exposure assessment, thanks to approaches aimed to increase the quality of exposure data gathered, to design precise measuring campaigns, and achieve a correct interpretation of the exposure data, in particular for chemical agents.

The approach based on the process statistical control and Capability analysis tools (i.e. Control Charts and Process Capability indexes) enables to perform intermediate calibration checks of measuring systems involved in OS&H Risk Assessment: the use of measuring systems in correct metrological confirmation condition, verified by appropriate metrological confirmation intervals become of pivotal importance to gather high quality exposure data. The measurement results, for OS&H purposes, are essential decision-making tools both in the definition of workers' exposure models and in the selection of technical and work organization prevention solutions, therefore the data quality is a pivotal requirement.

The following part of the *sub-phase of the Guideline special for the OS&H analysis of working activities* makes available a rigorous approach, based on two levels of representativeness, to achieve a correct assessment of the exposure conditions of workers.

The approach, through both a rigorously design and manage of measuring campaigns and a statistical-based data interpretation, makes possible the achievement of data actually representative of the working context (1^{st} level of representativeness), and the optimization of the measuring campaigns to collect actually usable data (2^{nd} level of representativeness), making effective the workers exposure model definition, and therefore the resulting Risk Assessment and Management in a Quality approach, overcoming problems due to over/underestimation of risks resulting from an incorrect or incomplete understanding of measurement results or a poorly designed measuring campaign.

The *special asbestos sub-phase of the Guideline* has proved an effective approach to assess and manage, in System Quality, the risks related to the still widespread presence of residual ACMs in large public facilities and universities. The asbestos sub-phase of the effective and well tested Guideline for Occupational Safety in Universities and large public facilities, results from a multidisciplinary research study aimed to provide a reliable reference for the Assessment and Quality Management of Risk of exposure to air-dispersed respirable asbestos fibers, covering the definition of the correct approaches in scenarios from confirmed absence of ACM, to the various Hazard modes, from Dormant, to Armed, to Active. The target is obtainable through some key points:

a. univocal criteria for a strict classification of workplaces in categories well defined in terms of asbestos Hazard modes;

b. a reliable and well-tested reference for the H.I. phase both in shell, systems and interior spaces, and in work equipment, in terms of presence and conservation conditions of the ACMs and their sealing/enclosures;

c. a reliable reference on the Risk Assessment and Management for the prevention of occupational illness from exposure to respirable asbestos fibres of people at work in universities and large public facilities.

As part of the asbestos sub-phase of the Guideline, a special study was carried out to evaluate the actual contribution of the airborne fibres measurements in the asbestos sub-phase approach, in particular in terms of initial workplaces classification and their periodic confirmation.

On the basis of the achieved results in a rigorous metrological approach, it is confirmed the impossibility to characterize the environments containing ACMs on the basis of airborne fibres concentration measurements, since, taken into account the uncertainty values related to such determinations, the concentrations result hardly comparable with the measures collected in areas with verified presence of ACMs without ongoing stresses, or in outdoor environments close to the abovementioned areas. Very different is the situation in operative contexts where the quantities of asbestos containing materials and the involved stressing actions cause important pollution levels.

Hence, according to the D.M.06/09/94 indications, the importance of rigorous direct inspections is confirmed, both to localize ACMs in compact matrix (Hazard Factor dormant), and to identify transition situations from Dormant to Active Hazard Factor. Such a result cannot be achieved by means of airborne fibres measurements, except in the case of important fibres releases.

Verified that the airborne fibers concentration measurements cannot provide useful information where no massive emissions are caused by stressing actions on friable ACMs, the asbestos sub-phase improvements focused on the set up of rigorous instrumental techniques to support the direct investigations, reducing the impact of judgment subjectivity, thanks to the implementation of formalized methodologies of Canvassing, based on assisted image interpretation techniques.

As demonstrated by direct in situ tests, the implementation of Image Analysis techniques into the Canvassing, recommended approach for a reliable Hazard

Identification and asbestos Hazard mode confirmation along the time, is feasible and makes possible substantial improvements in the investigations results, directly in terms of detail, reliability and repeatability, and in general for the overall quality of the investigations and decision making processes.

Such an approach could result also beneficial where implemented in refurbishing works involving civil and industrial buildings, thanks to the possibility to achieve an improved exhaustiveness of the operations and a documented effectiveness of the intervention performed.

Asides from the direct results here discussed, further developments in the implementation of Image Analysis techniques for the Assessment and Management of Occupational risks nowadays possible will substantially contribute to the transition of OS&H from approaches still conditioned by the subjective judgment of a human observer, or relying on poorly effective techniques, to methods more consistent with the evolution of the production systems towards checks and controls from remote, with high digitalization and automation levels.

In conclusion, the Guideline and the developed sub-phases, consistent in every single step and phase with both the regulatory requirements, can be considered a rigorously structured and carefully tested reference -in terms of effectiveness and practical feasibility- both for the introduced general analysis principles and for the risk assessment and management models discussed in the sub sections intended to special aspects typical of the research universities. A side benefit -certainly not negligible- is that the method can help to promote the spreading of the Culture of Safety.

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Appendix 1

TU Delft OS&H approach

VISITING ACTIVITY REPORT - DELFT UNIVERSITY OF TECHNOLOGY

(based also on ISO 45001 Standard - Occupational Health and Safety management systems)

PhD candidate: Paolo Fargione

Location	**Tutor(s)/ reference person**
Delft (NL)	Drs. ing. D. Dick Hoeneveld (Researcher in the Safety and Security Science section at the Faculty of Technology, Policy and Management)

Institution typology - details
TECHNISCHE UNIVERSITEIT DELFT - DELFT UNIVERSITY OF TECHNOLOGY (the largest and oldest Dutch public technological university: eight faculties and numerous research institutes) **Faculty:** TECHNOLOGY, POLICY AND MANAGEMENT **Department:** VALUES, TECHNOLOGY AND INNOVATION **Section:** SAFETY & SECURITY SCIENCE

1 GENERAL APPROACH FOR RISK MANAGEMENT

1.1 National enforcement of European Directives – Reference normative

National legislation

- *Working Conditions Act*

  General provisions for employers and employees how to deal with occupational safety and health, for example to have a written OSH-policy or a risk inventory. The Act gives certain powers to the Inspectorate-SZW, for example to force the employer to stop the work.

- *Working Condition Decree*

  This Decree covers a wide range of specific occupational health and safety topics, such as provisions on work places, dangerous substances, noise, vibrations etc.

- *The Working Conditions Regulation*

  Very specific provisions which are changing relatively fast. For example the occupational exposure limit for dangerous substances.

University legislation

- *Occupational Health and Safety Catalogue of the Association of Universities in the Netherlands (VSNU)*
- *TU Delft additional internal safety regulations*

  TU Delft regularly strives to improve the safety of its staff beyond the level prescribed by working conditions legislation. Such additional OS&H regulations, requiring the agreement of the Works Council, concern e.g. the establishment of the HSE department (number of employees, quality, etc.), the emergency response organization, work-stress surveys, the appointment of prevention officers, internal regulations on working with hazardous materials, lasers, the selection of the risk assessment method, etc.

- *USHA document* (English Universities Safety and Health Association)

  Some sections of the document regarding the approach for risk assessment are used in The Netherland Universities.

The Labour Inspectorate (Arbeidsinspectie) (or Inspection Service of the Ministry of Social Affairs and Employment (I-SZW)), verifies whether TU Delft complies with legislation on health and safety at work. The Inspection Service proceeds from the laws and regulations of the Working Conditions Act and the Occupational Health and Safety Catalogue.

1.2 Understanding the organization and its context

OS&H policy and related OS&H objectives

Working condition

Working conditions refers to all conditions during working hours, i.e. all working conditions at and during work. For the specifics of the working conditions policy, the Occupational Health and Safety Catalogue of the Association of Universities in the Netherlands (VSNU) is adopted where possible. The policy aims to create optimal working conditions, in a pleasant and above all safe working and learning environment for students and staff.

To create optimal working conditions in terms of health, working conditions legislation in place, as well as supplementary regulations that have been agreed with the Works Council.

These laws and regulations cover a wide range of factors, such as workload and working with chemical substances. These factors are approached from the perspective of safety and security. Working conditions are a matter of safety, while security covers security-related aspects.

In accordance with the Works Councils Act, the staff members, represented by the Works Council, have the right of approval with regard to the working conditions policy. Therefore the Executive Board and the Works Council consult regularly on HSE, usually in the form of a regular consultation between the HSE Manager and the Safety, Health, Welfare and Environment (VGWM) Committee of the Works Council.

Safety and environmental issues are an agenda item in the formal meetings between deans and local employee representation. At the level of the Works Council, an HSE committee discusses safety policy with the Executive Board.

The working conditions policy is supported by the Health, Safety and Environment (HSE) department. This department consists of the following units:

- University health services doctors;
- University social services;
- HSE advisers, who are responsible for issuing expert advice to the management, the line officers, individual staff members, students and the Works Council.

Moreover, a number of Health, Safety and Environment Advisers (also known in Dutch as Arbo Milieu adviseurs - AMas, or Department Safety Officers - DSO) with specific expertise, support the working condition policy and ensure that line officers, individual staff members and students receive adequate advice. A HSE Adviser is available for each unit. Most HSE Advisers are also Health and Safety Officers. But a transition is in progress, from the HSE advisor model to a more decentralized prevention officer model.

According to the Working Conditions Act, students have the same rights as staff members with regard to working conditions (apart from work related stress), insofar as those students carry out similar work to that carried out in professional practice. Working conditions legislation provides a number of exceptions with regard to students in terms of well-being. These exceptions can be found in the Working Conditions Act and the Working Conditions Decree.

To ensure that staff members can work as safely and healthily as possible, the Working Conditions Act requires a safe working situation and stipulates that staff members behave in a safe manner. To this end, the

Act sets requirements with regard to policy, prevention of accidents and occupational disease, cooperation between employers and employees (Works Council), information and instruction and health and safety support. The Health and Safety Officer plays a supporting role in this respect. This officer also helps to draw up and implement the Hazard Identification and Risk Assessment (RI&E). (*source: working condition policy and legislation*)

1.3 .Organizational roles, responsibilities and authorities

TU Delft is organized in faculties and departments. The departments are actually the core of the university. The faculty is merely the organizational construction to maintain controllability within the university. Only some faculties have sections (e.g. Safety and Security Science section in TPM faculty).

Officers with line-responsibility are appointed with a responsibility for Safety and the environment; these line managers are mainly the deans of the faculties and complex managers of general buildings. The deans have, if necessary, assigned their responsibility to their subordinates: the Heads of department who are supported by their section leaders and Area supervisors / laboratory managers. Faculties with clear chemical or physical risks have a Safety Committee in which employees discuss Safety aspects with management

The dean is responsible for the safety mission per faculty and to put a vision into practice. Each faculty has its own safety profile and the approach can therefore differ. The Integral Safety department ensures that the faculties coordinate their approach.

TU Delft consists of various management units: faculties or managements. Complex managers take care of managing the buildings. If the building belongs to a faculty, then the complex manager is (almost) always the dean.

The complex manager is responsible for the management and therefore also for the safety of the people:

- students
- staff members
- others, such as visitors and (sub) contractors

The complex manager is responsible for creating a safe study and working environment, both physically and socially safe; but he cannot do this alone, which is why more parties are involved in the organization of safety faculty (source *TU Delft Integral Safety Program – Pocketbook*)

The model based on five tiers of management, described in the document *USHA Leadership and management of health and safety in higher education institutions,* is identified as guideline to ensure good health and safety management in Dutch universities

HASMAP8 (Health and Safety Management Profile) is a management standard developed for use in HEIs by USHA and has been endorsed by UCEA as a scheme for measuring health and safety management performance within Higher Education (Plan – do – check – act approach for each of the 5 tiers).

1.4 Figures involved in OS&H

The following parties are involved for each faculty:

- Complex manager
- Dean / director
- Faculty secretary
- Integral Safety Manager (MIV)
- Marketing & Communication (M&C)
- Health and Environmental Advisor (AMa) - Health, Safety and Environment (HSE) Advisers , also known in Dutch as Arbo Milieu adviseurs - AMas, or Department Safety Officers – DSO. Most HSE Advisers are also Health and Safety officers: in the near future, this task (HSE officer) will be transferred to decentral workers (Prevention Officers) (source *Working environment policy and*

legislation)
- Facility Manager (FM)
- Faculty ICT Manager (FIM'er)
- Company emergency services (BHV)

A good coordination between all these parties is possible through the Platform Integrale Veiligheid (PIV) – Integral Safety Platform where these parties can exchange information and advice about safety issues and bottlenecks.

The in-house emergency services (BHV) is a separate group among the parties involved. These are employees who have registered to act as company emergency responders in addition to their normal responsibilities and have followed a training course for this purpose. The BHV has an important role in the first-line response in incidents. Company emergency services are required by law. The employer is responsible for having and maintaining a quantitative and good quality BHV. (source *TU Delft Integral Safety Program - Pocketbook*)

HSE Advisers

All faculties and support services are advised by HSE advisers. They have contact with the managers and area supervisors / laboratory managers. HSE advisers also monitor the environmental and safety performance (purchasing, waste, analysis and energy figures and incidents). This is increasingly happening with automated systems (Lab Servant).

Periodically the HSE advisors keep workplace inspections together with the supervisors: there is no separate section for inspections; inspections are carried out by the supervisors and coordinated by the HSE officers. Monitoring of deadlines and follow-up of improvement actions takes place via the Inspection System (Lab Servant – Inspection module). HSE advisor also manages the environmental permit for the campus, the permit for Logistics & Environment and the permit for Sports & Culture. The regulations attached to the environmental license are monitored via the Licensing Management System (VMS, part of the Lab Servant). One of the HSE advisors has as a specific task, the periodic environmental consultation with the competent authority.

General Radiation expert

The environmental permit of the Reactor Institute (RID) is handled by the General Radiation expert.

For ionizing radiation a General Radiation Expert is appointed together with a Radiation Protection Service (SBD) and a network of local supervisors at the faculties. Radiological work is only allowed after admission to register, vocational training and experiment permission.

For lasers there is a network of local laser supervisors and laser workers at the faculties. Laser work is only allowed after inclusion in a register (part Lab Servant), vocational training and experiment permission (Laser Safety Report). All lasers are included in a central register (part Lab Servant).

Biological Safety Officer

A Biological Safety Officer (BVF) is appointed for biological safety. Biological work is only allowed after admission to a register and a test. For handling biological agents (yeasts, fungi, bacteria viruses, etc.), TU Delft has specific permits. The researchers have an automated decision support system (Biosafety module, part of the Lab Servant) to take the proper safety decisions when dealing with genetically modified material and biological agents. The Biosafety module also monitors compliance with the permit regulations and keeps an inventory of agents.

Integral Safety Manager

The Integral Safety manager (Manager IV) ensures that the faculties and support services comply with the laws and regulations and internal agreements; the Manager IV also maintains contact with the police and fire brigade. (*source: Description of the management organization for safety and environment at TU Delft doc from Hoeneveld*)

Safety & Security Institute DSyS

Among the figures involved in the OS&H the Safety & Security Institute – DSyS is a scientific institute developing special Safety and Security topics. DSyS acts as an information source in the field of safety and security, carrying out research and develops methods and techniques aimed at quantifying safety issues and optimizing general and design solutions.

DSyS brings together scientists from more than thirty different TU Delft chairs. This enables DSyS to provide high-quality research capacity to national and international consortia and networks on a wide range of topics, such as occupational safety, safe transport, robots, remote sensing, drones and aerial surveillance, shipping and aviation safety, storage and logistics, forensics, terrorist threat to critical infrastructures and the design of safe cities.

1.5 Risk Assessment and Management approach

- Hazard identification (on-going and proactive process) and assessment of risks and opportunities ([1])

In general, the approach for Risk Assessment adopted in TU Delft follows the USHA method. USHA is the (British) Universities Safety and Health Association, that promotes safety and health in higher education ensuring the wellbeing of university staff, students and visitors. The first 4 sections of the USHA document (Management and responsibilities, using a management system approach to manage health and safety in research, Safety culture, Risk assessment) represent a reference for The Netherlands Universities (the approach is not applied all in the way suggested in the USHA document).

In research (and teaching) activities risks are methodically estimated per experiment or series of experiments, via the Safety Reporting System (specific module of the online tool Lab Servant system - see Research Activities section) and measures taken on the basis of the occupational hygiene strategy. The special system supports the risk assessments before commencing new experiments.

The approach to assess and manage risks related to the research activities entails a close link between:

- substances, materials, equipment needed, but also byproducts and waste,
- the researcher (s) who performs the experiment and his information level on Safety,
- the processes involved, failures and deviations included,
- the structures and laboratories to be used.

All these aspects are connected (and the relevant information crossed) in the Lab Servant system through specific modules:

in the experiment design the researcher enters, in the online system, all the relevant information about substances, equipment, processes etc. he needs to use in the experiment; these data are linked with the Inventory and Equipment modules, special databases about all the chemicals, gases, biological and equipment present in the University: substances database contains a number of data e.g. presence, quantity, storage

[1] The organization shall establish, implement and maintain a process(es) to assess:
a) opportunities to enhance OH&S performance, while taking into account:
1) opportunities to adapt work, work organization and work environment to workers;
2) opportunities to eliminate hazards and reduce OH&S risks;
3) planned changes to the organization, its policies, processes or its activities;
b) opportunities for improving the OH&S management system.

location – faculty, lab, etc., potential hazards; in the equipment database information about use, calibration, periodic maintenance and available reference material (instruction manuals, fault recording, log books, etc.) are available. (WHAT). In the first step the researcher inserts also the location of the experimental units (labs needed) (WHERE), a description of the experiment, some flow charts of the processes and indications on failure and exceptional conditions and emergency (HOW). The laboratories are equipped with the technical measures to prevent the risks related to the specific research active ty. The authorization for the researcher to work safely in the specific area is provided through the Instruction & Test (I&T) module, linked to the access policy also for new and existing staff, students and contractors. The researcher receives information and instruction, and must then answer to a questions list. The questions cover safety issues present in the area (e.g. laboratory) where he will be working. If he passes the test, the workflow engine initiates the subsequent steps and informs the candidate. All results are stored in the central database. The researcher is not permitted to enter any defined risk area or laboratory until they have passed the test (WHO).

All laboratories and workshops where hazardous substances are used, are equipped with adequate technical safety provisions. These safety provisions are kept in good condition by the university and are professionally operated by the user. Employees have sufficient safety competence for the job and have access to good information services. This is devoted to recruitment, annual performance appraisals, staff development and work consultation.

The supervisors / lecturers supervise the maintenance of safety competence among their staff / students and, if necessary, instruct them and themselves: student starting to work in laboratories have to attend the basic course on safety, and researchers a more specific one. (*source: Description of the management organization for safety and environment at TU Delft doc from Hoeneveld*)

Risk Management: information and instruction / access policy

Contracted third parties are contractually obliged to meet safety requirements of the TU Delft. They must learn the safety instructions related to their job on first entry; this knowledge is then tested and the score is linked to the person and stored in a web database (Lab Servant, Introduction & Test - I&T section). Obtaining the test is conditional for being allowed to carry out work.

BSc students must learn the safety instructions related to the lab's in their study program. Again, <u>the knowledge level is tested and the score is stored in their student file</u>. Passing the test is a condition to be admitted to the practical.

New employees receive a general safety instruction on first entry and, if necessary, specific instructions such as safe handling of chemicals. This knowledge level is also tested and the score is linked to the person and stored in the web database. Passing the test is a prerequisite for performing risky work; only then will their campus card be activated for the relevant lab.

Risk Management: chemicals storage and waste

TU Delft has a chemical / gas ordering system with just-in-time deliveries; the storage capacity within the faculties is deliberately kept small; therefore only limited storage of chemicals takes place at the faculties. The chemicals registration takes place via the ordering system, right down to the laboratory. The system also supplies safety information during the order, which is the right moment to (re)consider the necessity. For hazardous substances, permission from a manager is mandatory. The system is part of the Lab Servant (*Inventory* is integral part of the order system for chemicals, within the Lab Servant).

Logistics & Environment (L&M) coordinates waste collection, monitors this and is responsible for the collection of industrial and hazardous waste, up to each laboratory.

1.6 Emergency preparedness and response

TU Delft has a large decentralized first response organization (BHV) organization (about 500 people) that is deployed in the event of a disaster. The BHV is organized at a building level and is under the responsibility of the dean or complex manager. The TU Delft Emergency Response Plan describes the preconditions of the emergency response, including the improvement cycle. (*source: Description of the management organization* *for safety and environment at TU Delft doc from Hoeneveld*)

The emergency team has various roles and responsibilities, including assisting victims after an incident, alerting the appropriate parties on location, seeing to evacuation, if necessary, and initial control of fire.

The BHV system is a good example of an integral approach to safety within an organization. The deans/complex managers (at local level) and the Executive Board (at central level) are responsible for the organization and operation of the BHV system. The head of BHV is appointed by the dean/complex manager of a building. The HSE advisers for a building complex are responsible for the local in-house emergency response (BHV) policy, while the Safety and Security Manager is in charge of supervision on behalf of the Executive Board and is the director in the event of major.

Depending on the seriousness/extent of the accident or emergency, it is possible to contact an in-house emergency response team member, via Service Desk if necessary, or approach an in-house emergency response team member who can be identified by a white/green sign beside their office. In the case of serious event immediately dialing the emergency numbers you will be connected to the *TU Delft emergency control center*. In the case of fire you can also activate the manual fire alarm which can be found beside all fire hose reels. Your alarm will be sent directly to the fire service.

A special ongoing research work aims to evaluate the impact of the access rights of the indoor spaces during an emergency evacuation (see Research Activities section)

1.7 (Safety) performance evaluation

Laboratories and other areas at the University are inspected on a regular basis to check compliance with safety regulations. The Inspection module in the Lab Servant system is a useful instrument for making inspection rounds and recording the results. Within the module, tasks resulting from inspection rounds are assigned to the relevant persons. The progress of the tasks to be carried out and measures to be taken are monitored in a digital Action Plan.

1.8 Improvement

TU Delft has an incident and accident analysis protocol, and an own database where accidents and near misses are recorded. At this moment the only faculty of Applied Science uses the Prisma method to analyze near misses and unsafe situations; this method it is not a general tool for the TU Delft. The scientific validity of the method is disputable and its wider use within the university is most unlikely. Officially a system, based on the Knowledge Management approach in relation with the organizational learning (https://link.springer.com/chapter/10.1007/978-1-4471-1480-2_10), developed a long time ago together with Safety & Security Science is used, but selection of a new system is planned. Below the incident report form currently used, it will be replaced by a new form in the next future.

TU Delft
Technische Universiteit Delft

APPLIED SCIENCES REPORT FORM FOR ACCIDENTS, INCIDENTS AND BHV SERVICES

(for accidents, near-accidents, incidents, hazardous situations, environmental incidents and use of services of the BHV team (in-house emergency response))

I. Details of person reporting the incident (filling in the form)

Name: .... Telephone: ....
Management unit: .... Department: ....
Signature: .... Date: ....

II. Type of report

☐ Pager	☐ Accident (phone the Occupational Health and Safety Advisor (AMa))	☐ Health problem	☐ Evacuation YES / NO
☐ By telephone	☐ Gas	☐ Hazardous situation	☐ Other ....
☐ Orally	☐ Fire	☐ False/unnecessary alarm	☐ Number of BHV team members ....

III. Description of the incident

Which activities were being carried out and what happened? (Include documents where necessary)

....
....
....

IV. Details of the incident

Date of incident: .... Time of incident: ....
Area/location: ....
Nature of injury/damage: .... Location of injury: ....
Resume duties within 24 hours?: .... Temporary/permanent injury: ....
Medical treatment; ....
☐ No ☐ FIRST AID ☐ Hospital outpatient clinic ☐ Hospital admission ☐ GP

V. Details of the injured party

Name: Mr/Miss/Mrs/Ms .... Date of birth (D/M/Y): / /
Address: .... Telephone: ....
☐ TU Delft staff ☐ Student ☐ Company staff ☐Visitor ☐Passer-by
Department/research group/company name: ....
Company address: ....
Name of superior: .... Telephone: ....

☐ *BHV team notifies the Occupational Health and Safety Advisor (AMa) in the event of an accident or evacuation.*
☐ *Person reporting the incident submits the fully completed form to the Department Safety Officer (DSO) and AMa.*

Versie: 17 mei 2010

2 SAFETY DOCUMENTATION

The whole information about hazards, risks, prevention and protection measures, are recorded and available in the Lab Servant system. For simple experiments, a summary of the Risk Assessment and Management is available in the Safety Assessment Sheets, usually located and properly displayed in the laboratories where the experiments are carried out. Complex experiments require the Safety Report System tool to assess and manage the related risks; the Safety Report obtained will automatically be saved in the database of the system, where it can be retrieved by the search engine. Below the Safety Assessment Sheet form (in the case for the experiment performed in the 3mE faculty laboratories):

TUDelft	Delft University of Technology Faculty of Material, Maritime and Materials Engineering (3mE)	3mE

"Safety Assessment Sheet"

Author:	Name Author	phone TU	
(Name supervisor)	room #	private	
Area Supervisor:	Name Area Supervisor	phone TU	
	room #	private	

Description of experiment:

Temperature (°C)		Pressure (bar)	

Hazardous materials and solvents	Dangerous properties	MAC	Halogen rich/poor	Acid /base	Phase

Measures

How to act in case of emergency

Approval of the area supervisor

Name supervisor		Date	Valid until:
Signature			

Double click to fill in grey areas – Hit F1 for info after selection – Add manually further data after printing to complete form

3 RESEARCH ACTIVITIES

Research works aimed to contribute to the improvements of OS&H in the Institute

3.1. Emergency response innovation

Using the combined LADM-IndoorGML model to support building evacuation

The research work aims to improve the emergency response, addressing the impact of the access rights of the indoor spaces during an emergency evacuation, by employing the conceptual model of LADM-IndoorGML, that defines the accessibility of the indoor spaces based on the rights, restrictions, and responsibilities of the user of the indoor space.

During an incident, many people that are located in indoor environments require emergency evacuation (defined as a critical movement of people from a dangerous area due to the risk or an incident of a tragic event).

In crisis situation the perception of the indoor environment, which differs from person to person, play a critical role in the evacuation. Also the access rights of the indoor spaces are different from those rights (and restrictions) during normal times. They may positively impact the movements of the people during the evacuation by providing suggestions for shorter/ better route.

The access rights of the indoor spaces will be affected by the crisis event and this needs to be modelled explicitly (and before crisis situation). Actually, the rights / restrictions persons have on spaces is time dependent: normal operation hours, outside normal operation hours (e.g. during night time in case of a University building) or during crisis times. These actual / valid rights and restrictions will affect the movement / accessibility of the users to reach the nearest emergency exits or the safe zone.

For this reason, different scenarios have to be developed to study the impact of the accessibilities for different types of users, also through a 3D model of an educational building, supported by a real data for all spaces from the facility management department such as departments information, sections, groups of users (visitors, employees, and students), and public/private spaces, etc. and a real evacuation exercise.

3.2. Intercultural safety

Safety and internationalisation, missing the link?

The available data on students nationality (according to US data, more than one third of the PhD degrees in science and engineering and nearly half of the MSc diplomas are awarded to foreign students, equivalent data are available from the EU and Australia) underline that the world internationalizes rapidly and research institutes are the frontrunners. According to the mainstream intercultural literature, the multicultural organizations are sensitive for different perceptions on rules and regulations, and cultural differences could cause safety problems in the laboratories (language problems, non-verbal misunderstandings).

The research work discusses on the relevance of an intercultural focus on lab-safety at research institutes and to strengthen research capability.

3.3. TU Delft Integral Safety Program

(Un) Safety has many facets: unsafe work situations, undesirable behavior, theft and the risks of hazardous substances. Sometimes even destruction, violence, fire, very rapid burning and detonation or a crisis. Identifying risks and taking measures in every faculty building is therefore important.

Various professionals from the departments of HSE, FM and ICT security, with Safety and Security as key player, are committed to ensuring that students and staff can count on a pleasant and above all safe working and learning environment. As Safety and Security is a responsibility of a number of divisions, and cooperation takes place both internally and externally, we can speak of integral Safety and Security.

3.4. Lab Servant system

Lab Servant is an online tool, partially developed by TU Delft, that enables researchers to take optimum measures to protect their own Health and Safety and that of others, while minimizing delays and modifications to their research. It simplifies the work of researchers and support staff, and ensures the compliance with the extensive Dutch legislation on Health, Safety and the Environment. In the future the system will be adopted by even more Dutch universities, so that the system can be continuously improved and upgraded thanks to the adjustments (involving different research fields) suggested by the universities.

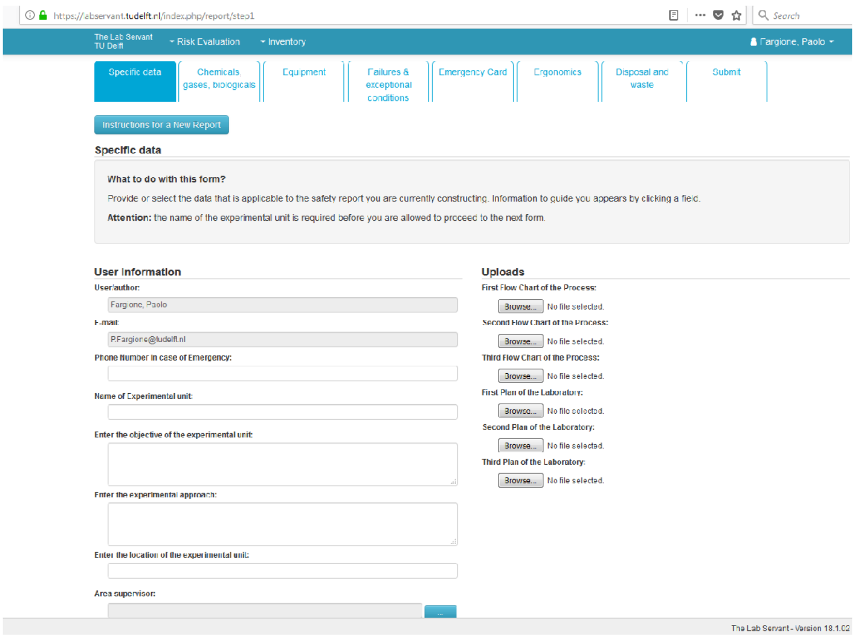
The fundamental idea of the Lab Servant is to put responsibility for Safety in the line-management structure and to help researchers internalize the concept of safety.

The Lab Servant consists of several modules: Risk evaluation - Safety Report System, Biosafety, Human Research & Ethics, Instruction & Test (I&T), Inventory, Equipment, Inspection, Permit management, Environmental Management System, Laser Safety.

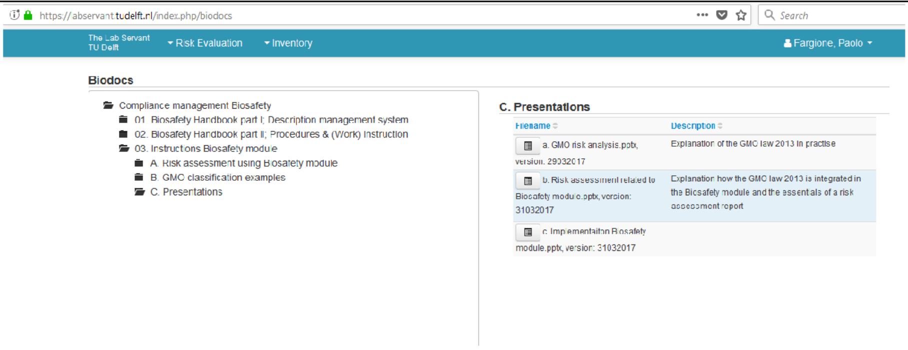
Most modules are designed for researchers and technicians. Other modules will be used by support staff who have responsibilities relating to Safety and the Environment, or by students and contractors to obtain safety instructions for example. Users of the system will gain understanding of the modules that are relevant for their own work. The system generates action lists and addresses these to the designated person. *(source Lab Servant general)*

Since all the information and the workflow related to the experiment that will be performed have to be recorded in the system, before the experiment starts, the Safety become one of the input design parameters (we can talk about a Prevention through Design applied to the experiments).

Below the screenshots of the Risk Evaluation module in Lab Servant, showing the sub modules to fill before starting a new experiment, and the Inventory module where information and instruction (in the form of document, presentations and videos) about the Biosafety are available:



Risk Evaluation module



Inventory module

The screenshots show only the Risk Evaluation and Inventory modules because I'm authorized to access to them only.

The Lab Servant provides current insight into:

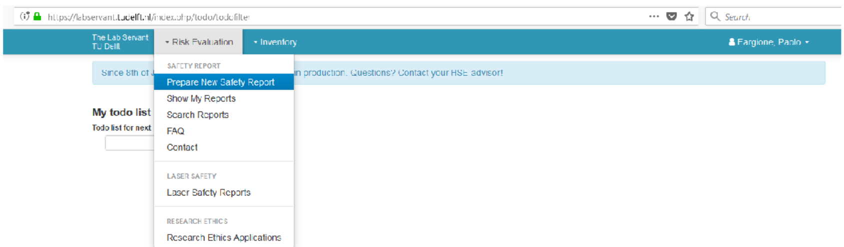
- the presence of hazardous substances and gases;
- the people who work with CMR substances and nanomaterials, including the conditions under which this takes place and the period in which the work is carried out;
- the status of the actions that are mandatory in the environmental permit;
- the status of the actions resulting from periodic safety inspections;
- all experiment setups that are in use, including detailed information, and the managers of the setups;
- all laser setups in use, including detailed information, and the administrators of the lasers;
- the people (own staff, students and third parties) who have received safety instructions;
- all officers who have a role in the safety organization;
- all equipment that - partly due to Safety - must be periodically maintained or inspected, including the lasers.

In the follow the Lab Servant modules closely linked to the OS&H in the research are briefly discussed:

Risk evaluation module - Safety Report System

This module is used for carrying out risk assessments before commencing new experiments, starting to experiment description, and reagents, solvents, gases, equipment etc. that will be used. On the base of these information it is possible to assess the hazard/risk level, and adopt the proper measures to minimize or eliminate risks. This process results in a <u>safety plan geared to the design of the experiment</u>. Through the workflow, the plan is submitted to the manager for approval (this can be regarded as the "work permit").

The preparation of a Safety Report is obligatory when an experimental unit is constructed or modified:



Risk Evaluation module – new Safety Report preparation

The aim of the Safety Report System - SRS is to prevent dangerous situations in laboratories. The SRS guides the researcher through the different hazards, and related risks, relevant for the experiment. A new report is composed for every new experiment.

Absolute safety, does not exist. However, this is no excuse to refrain from striving for absolute safety. A safety-oriented attitude of the personnel involved, remains crucial in achieving this goal; once again the role of the Culture of Safety is essential. The person who constructs or modifies the experimental unit has to write the Report. This can vary from student to professor. When more than one person is concerned, the main user should write the Report in mutual consultation.

Introduction & Test - I&T module

The Instruction & Test - I&T module is linked to the access policy for new and existing staff, students and contractors. They receive information and instruction, and must then answer questions. The questions are related to the risks of the area (e.g. laboratory) where the relevant person will be working. If the candidate passes the test, the workflow engine initiates the subsequent steps and informs the candidate. All results are stored in the central database. Candidates are not permitted to enter any defined risk area or laboratory until they have passed the test. When the candidate passes the test, the Area Supervisor receives an email informing him that the person is able to work safely in the specific laboratory. Then the supervisor informs the Service-point which upgrade the campus card of the candidate enabling the access to the laboratory.

Students, before starting to work in laboratories must attend to a basic course on Safety, a more specific course on Safety is available for researchers.

Inventory module - Ordering and Registration of (Bio)Chemicals

The module comprises an online order form. The online catalogues of the University's suppliers are linked to the module. The order form has a workflow to ensure that the order is submitted to the persons who are responsible for Safety and for the relevant project budget. The system is linked to Chemwatch (the subscription makes possible a direct connection with the Chemwatch database), which means that the properties of substances (hazard, precautionary measures) are displayed during ordering. When the order has been approved, it is forwarded to the supplier responsible for delivery to the TU Delft depot (Logistics & Environment). Depot staff then deliver the order to the work location.

When a researcher order chemical and biological products through Lab Servant, the stock level is updated. With just a simple click of the button, researchers can make selections and calculate totals for specific categories of substances.

Equipment module

Equipment requires management in terms of location of use, calibration, periodic maintenance and available reference material (instruction manuals, fault recording, log books, etc.). The Equipment module stores results of this type. The module has a workflow engine that generates task lists for the persons who are responsible for inspections and periodic testing.

Inspection module

Laboratories and other areas at the University are inspected on a regular basis to check compliance with safety regulations. The Inspection module is a useful instrument for making inspection rounds and recording the results. Within the module, tasks resulting from inspection rounds are assigned to the relevant persons. The progress of the tasks to be carried out and measures to be taken are monitored in a digital Action Plan.

4 ON SITE DIRECT INFORMATION On site direct information on the practical implementation of solutions for the Risks Management on the different working scenarios in the Institute, special research works outcomes included.
See Annexes

5 SPECIAL 3rd GENERATION APPROCHES (RESILIENCE – ANTIFRAGILITY)

Tutor approval
Name Drs. ing. D. Dick Hoeneveld
Date July 2018
Sign _______________

Appendix 2

TU Delft OS&H approach for research laboratories

VISITING ACTIVITY REPORT - DELFT UNIVERSITY OF TECHNOLOGY

OS&H ON SITE DIRECT INFORMATION FORM

PhD candidate: Paolo Fargione

Location	**Reference person**
Delft (NL)	Mr Peter Kohne Faculty Safety advisor

Working environment visited - details	
Institute: TECHNISCHE UNIVERSITEIT DELFT - DELFT UNIVERSITY OF TECHNOLOGY	TU Delft Delft University of Technology

Faculty: Mechanical, Maritime and Materials Engineering (3mE)

Department:

- ☐ BioMechanical Engineering
- ☐ Cognitive Robotics (CoR)
- ☐ Delft Center for Systems and Control
- ☐ Maritime and Transport Technology
- ☐ Materials Science and Engineering
- ☐ Precision and Microsystems Engineering (PME)
- ☑ Process & Energy

Working environment description:

- Laboratory for testing the fuel cells – P&E Open lab, Hall J
- Laboratory for the samples analysis - Analytical lab

1. PRELIMINARY INFORMATION

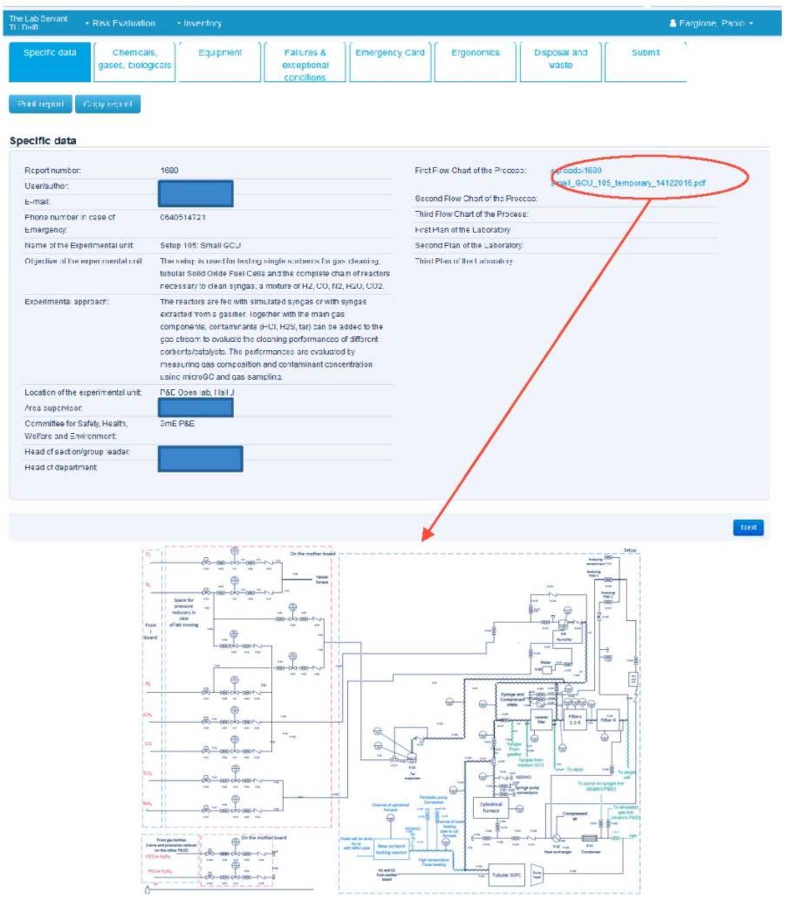
1.1 What: **Researches / experiments performed**

Among the numerous experiments carried out in the P&E Open lab, a specific experiment has been described, also thanks to the willingness of a PhD candidate:

Name of the Experimental unit: Setup 105 - Small GCU

Objective of the experimental unit: the setup is used for testing single sorbents for gas cleaning, tubular Solid Oxide Fuel Cells and the complete chain of reactors necessary to clean syngas, a mixture of H_2, CO, N_2, H_2O, CO_2.

Experimental approach: the reactors are fed with simulated syngas or with syngas extracted from a gasifier. Together with the main gas components, contaminants (HCl, H_2S, tar) can be added to the gas stream to evaluate the cleaning performances of different sorbents/catalysts. The performances are evaluated by measuring gas composition and contaminant concentration using micro Gas Chromatograph and gas sampling.



1.2 How: **Equipment and machinery**

- *New sorbent testing reactor* (electrically heated furnace where sorbents/catalysts are positioned for characterization).
- *Tubular Solid Oxide Fuel Cell – SOFC* (electrically heated furnace where tubular SOFCs are positioned for testing).
- *Cylindrical furnace* (electrically heated furnace where sorbents/catalysts are positioned for characterization).
- *Ceramic filter* (the reactor contains a ceramic filter used to filtrate particulate present in the gas).
- *Filters 1-2-3 and 4*
- *Condenser* (in the condenser the gas is partially dried).
- *Tar evaporator* (the tar evaporator is a glass container where the gas is passed and is saturated with the tar vapour).

1.3 How: **Hazardous substances**

The chemicals, gases or biological substances necessary for the experiment (listed in the following) are recorded, in the special "Chemicals, gases, biological" section in Risk Evaluation module of Lab Servant, with their own information sheet containing: CAS NR, substance name, quantity used (line supplied or quantity), nanoscale dimension, carcinogenic, mutagenic and reprotoxic effects, related hazards and precautions needed.

Hydrogen

Other substances used in the experiment:

Nitrogen, Oxygen, Carbon Dioxide, Carbon monoxide, Methane, Argon, Ammonia, Hydrogen Chloride, Hydrogen Sulfide, Acetic Acid, Hydroxyacetone, Furfural, Creosol, Isopropanol, Silica gel.

2. NOTE ON OS&H

GENERAL SUPPORT SERVICES (technical and organizational countermeasures to emergency – e.g. fire protection systems, accident management, communication, first aids organization, etc.)

P&E Open lab

Gas monitoring

In the lab, a number of sensors are located inside the setup area and near a cooling devices (close proximity where a leak would most likely occur and depending on the density of the gas and activity carried out), to detect gas leaks, gas releases, etc. Sensors are interfaced with the control unit; in the case of gas leakage detection, the control system interrupts the gas flow closing the electric valves, activates the alarm signals and boosts the local ventilation.

Gas sensors inside the setup and on the cooling devices – control system

Emergency team

A BHV station (pictures below) nearby the P&E Open lab is one of the main component of the General Support Services.

Detail of BHV equipment: PPE, gas detectors, initial control of fire equip.

The BHV team intervenes when an emergency situation occurs in the lab, e.g. gas leakages from the setup, setup ventilation failure, etc., according to three different emergency levels:

1) *First alarm level*: when visual and sound alarm signals activate, each person inside the laboratory must go out, closing the door behind;
2) *Second level alarm*: alarm level e.g. due to gas leakage, or setup ventilation stoppage. In the case of gas leakage, the gas flow is automatically stopped: the control unit, through the gas sensors, detect the leakage and activate the electric valves stopping the gas flow. The control unit activates in the case of setup ventilation interruption as well: through the airflow sensor the control unit identifies a flowrate decrease (or a no flow situation) and it stops the gas flow activating the alarm signals. The BHV team intervenes to support the laboratory staff evacuation;
3) *Third alarm level*: the entire area must be evacuated and the external fire brigade team intervene.

Analytical Lab

Inside the laboratory is available an eye wash shower station, to minimizing workplace injuries and protecting employees from chemicals and other hazardous materials unwanted contacts. A first-aid kit to manage the small wound is also present.

OCCUPATIONAL SAFETY & HEALTH

P&E Open lab

The information entered in the Safety Report of the experiment are:

Hazard Factors and precautions related to *equipment*:

- Temperature – Heat: some surfaces might get hot. It is suggested to wear heat-insulating gloves when operating on the hot parts of the system. Also, when removing/installing insulation material, it is suggested to wear laboratory gloves and a mask (similar to Aura 9322+ by 3M);
- Pressure vessel - Dangerous liquids: it is possible that contaminants (HCl, H_2S, tar) will also condense in the water of the condenser. When necessary, discharge the water in the appropriate location based on the contaminant used in the test.
- Pressure vessel - Dangerous gases and vapours: the tar in the tar evaporator is usually in the liquid or solid phase. It is suggested to fill the tar evaporator in a fume hood.

Hazard Factors and precautions related to *chemicals, gases, biological:*

- the hazards related to each substance are schematized according the Chemwatch platform:

The Safety Report proposed by the researcher was approved by the evaluators, and the resulting Safety Assessment Sheet approved by the Area supervisor.

The researcher is authorized to operate safely in the laboratory, since he passed the information and instruction online tests and his campus card was upgraded to acces to the laboratory.

Audits

According to the Quality Management, periodical internal audits verify the conservation of Safety level achieved.

Inspection, planned twice a year, are carried out by Safety advisor and Area supervisor. Special refresher meetings about safety are arranged two/three times a year.

SPECIAL PREVENTION (AND/OR PROTECTION) MEASURES (especially if resulting from special research works) In the follow some solutions to minimize the risks in the visited labs are described:

P&E Open lab

Prevention - Technical solutions

Reticulated gas system:

The gas (toxic, flammable, etc.) storage used in the experiments is located in a special area outside, protected from the weather (where gas cylinders are) and far from buildings. On the storage areas doors the Safety signage is present (UN number included, to identify the gas typology). Through fixed tubings the gases flow inside the laboratory; the tubings are connected with safe electric-valves inside the laboratory.

Gasses storage area and electric valves

Ventilation

The laboratory is equipped with general ventilation, to ensure the proper air changes, and localized ventilation involving the experiment setup and a fume hood, to minimize the exposure of researchers to the substances used. Possible ventilation failures, determining gas accumulations in the lab, is managed by the control unit through flowrate sensors positioned in the localized ventilation duct.

Flowrate sensor to detect possible failures in localized ventilation

Prevention - Procedures

Lab access

A common procedure to prevent risks in laboratories is based on the access policy (Lab Servant - Introduction

& Test module) involving many laboratories: candidates are not permitted to enter any defined risk area or laboratory until they have passed the test.

Setup modifications

The researcher who works on its experiment can make changes, adjustments, improvements on those setup parts and components he is able to modify (because he has got the needed tools). Modifications can include mechanical components, but no sensors or gas detectors. Also mechanical modifications of setup parts close sensors are not allowed. No electric components can be modified by the researchers; exclusively electrician are authorized to modify the electric fittings (also inside the setup). Therefore, if a researcher needs of a modification in electric part for research purpose, he asks to the electrician to execute the modification.

At the end of the mechanical setup adjustment, asking an opinion to technicians is a good rule.

Gas cylinder replacement

In the lab a gas cylinder (Argon) is present; the replacement of the empty cylinder is task of a special (special guest) team; nobody else is authorized to carry out that operation.

Failure and exceptional conditions

- Failure/condition: building / work area - interruption of facilities (power, water, pressurized air, etc.)

  Safety measure(s): in case of interrupted gas/compressed air supply, the setup should not be operated. In case the ventilation of the setup is not working the gas supply is automatically interrupted. In case of power failure, the gas supply will automatically be interrupted and the setup will naturally cool down.

- Failure/condition: work environment - (accidental) spill of water, chemicals etc., including environmental damage

  Safety measure(s): tar contained in the tar evaporator and water in the condenser should be disposed according to the laboratory procedures.

Emergency Card

Description of emergency shutdown: Do Not work with or on this setup without being fully informed on the hazards involved. Do consult with and obtain approval from the person responsible for the setup with respect to any activity involving it. Contact details are as follow: …… Use always appropriate personal protective equipment: helmet, safety glasses. Depending on the activity, use gloves, respiratory protection and lab coat. If the system does not stop automatically, press the emergency button, evacuate and inform the area supervisor. In case of local gas alarm (alarm on setup only) contact the author of this document or the area supervisor.

Prevention - Work organization

New setup installation

New staff or researchers who start to work at an experiment should ask advices to experienced personnel (such as researchers who already work to the project or specialists e.g. Laser Safety Officer), mainly for the setup preparation.

Working time

Researchers can work on their experiments during the working time of laboratory technicians. A special authorization is needed if a researcher want to work in laboratory in a time other than the above mentioned. In any case the main rule is "never be alone in the labs".

Safety meetings

Safety Awareness meetings are arranged four times a year. During the meetings the Safety Awareness meeting group meets and discusses about the improvement on Safety in the Department. During a meeting, that occurs four times year, a member of the group presents the Safety situation to Department people working on laboratories (technicians, students, professors, etc.).

Protection

As result from the Risk Assessment, adequate PPE are available in the laboratory, in particular gloves for hot surface contact protection and respirators to protect the respiratory tracts in the case of increase of gas concentration in the lab.

Respirators

Analytical Lab

Prevention - Technical solutions

Among the technical solution to minimize the risks in the analytical lab, the fume hoods allow the researchers to handle hazardous substances minimizing their exposure. Moreover, chemical substances are stored in the lab in special safety chemical cabinets ventilated and 90 minutes fire proof.

Cabinet for chemicals storage – fume hoods

Prevention - Procedures

The access policy is based on the access authorization after passing the information and instruction online tests. To access to the lab, it is mandatory to wear googles and lab coat; eating or drinking in the lab is forbidden. The procedures are summarized in the Safety signs board attached on the lab door.

Safety sign board on the lab door

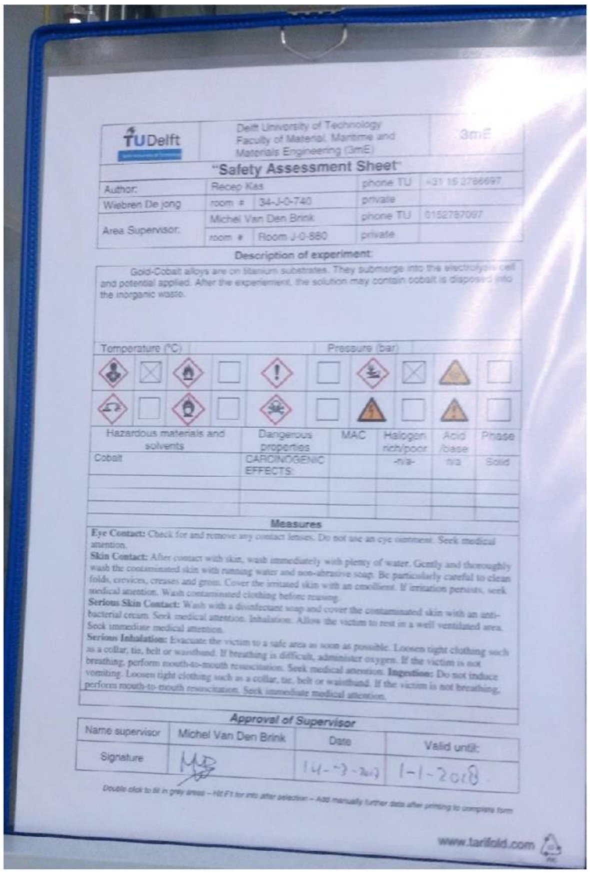
Prevention - Work organization

About the working time and the Safety awareness meeting the approach of the P&E Open lab is adopted.

Protection

To access to the laboratory is mandatory to wear the eye protection and the lab coat (PPEs available outside the laboratory)

3. SAFETY DOCUMENTATION
The whole information about hazards, risks, prevention and protection measures, are recorded and available in the Lab Servant system. The summary of the Risk Assessment and Management involving the activities in the Analytical Lab is available in the Safety Assessment Sheets (below), located and properly displayed in the laboratory.



Safety Assessment Sheet of the analytical labs

Tutor approval
Date July 2018

Appendix 3

University of Twente OS&H approach

PhD in Management, Production and Design | 2018

VISITING ACTIVITY REPORT - TWENTE UNIVERSITY

(based also on ISO 45001 Standard - Occupational Health and Safety management systems)

PhD candidate: Paolo Fargione

Location	**Tutor(s)/ reference person**
Enschede (NL)	**Dr. Alberto Martinetti** Assistant Professor in Maintenance Engineering Track Coordinator of Maintenance Engineering and Operations Specialization

Institution typology - details	
UNIVERSITY OF TWENTE (public research university located in Enschede, member of the 4TU - federation of four leading Dutch technical universities)	UNIVERSITY OF TWENTE.

1 GENERAL APPROACH FOR RISK MANAGEMENT

1.1 National enforcement of European Directives – Reference normative:

National legislation

- *Working Conditions Act*

  Working Conditions Act can be regarded as a framework for all the other working condition-related legislation. The Working Conditions Act includes provisions on: the employer's general duties, the employee's general duties, consultation duties (e.g. with the employee representation), duties towards experts (e.g. the relationship to a Health and Safety service), Labour Inspectorate legal possibilities (the Act gives certain powers to the Inspectorate-SZW, for example to force the employer to stop the work).

- *Working Condition Decree*

  More specific provisions have been laid down in the Working Conditions Decree, a so-called 'implementation decree'. This Decree covers a wide range of specific occupational health and safety topics, such as provisions on work places, dangerous substances, noise, vibrations etc.

- *The Working Conditions Regulation*

  Very specific provisions which are changing relatively fast. For example the Occupational Exposure Limit for dangerous substances.

University legislation

- *Occupational Health and Safety Catalogue of the Association of Universities in the Netherlands (VSNU)*

1.2 Understanding the organization and its context

OS&H policy and related OS&H objectives

According to the Working Conditions Act an employer is obliged to have a policy in place that minimizes the

1

risks for safety and health for the staff members as much as possible.

As the employer, the Executive Board of the University of Twente - UT is responsible for pursuing a proper health, safety and environment (HSE) policy.

The Health and Safety department ensures optimal support on all issues and duties with regard to working conditions, prevention and reintegration, radiation, genetically modified organisms (GMOs), emergency assistance (BHV) and sustainability. The target is to realize a safe, healthy and sustainable work and study environment and to make a positive contribution to the sustainable application of the staff members. This is possible through a close cooperation with the HSE (VGM in Dutch) coordinators at the faculties and services.

1.3 Organizational roles, responsibilities and authorities

The Executive Board –as formal employer– is ultimately responsible for safety, health, well-being and environment within the UT. This responsibility is mandated to the managers of the units (deans, research directors and heads of departments, faculty managers). They are mandated for the management of spaces that have been made available to their unit. In addition, the faculty manager is responsible for the unit-linked HSE care, of which emergency services - BHV is part. This responsibility implies, among other things, that the manager of the unit ensures that:

- ✓ a HSE coordinator is appointed;
- ✓ if necessary, a HSE committee is set up;
- ✓ an internal management structure and policy will be set up;
- ✓ in consultation with other units in the building, an emergency response organization is set up under the direction of a head of emergency response.

The deans and directors of the directorates and service centers are responsible for HSE at unit level. This includes emergency assistance (bedrijfshulpverlening - BHV). When several units, departments, faculties or third parties are housed in one building, the Executive Board appoints one of the deans/directors as contact person for Safety matters as well as a BHV team.

Regarding the assessment of risks in UT, the employer is permitted to perform the RI&E himself, but he is obliged to submit the written report to the Health and Safety service - HCC, that checks whether the analysis was conducted in a 'proper and systematic' manner and consequently draws up a validation statement.

The HCC holds consulting hours on the topic of working conditions, and performs the occupational health medical examination. The Health and Safety service is the unit to perform this examination. It is the employer who, on the basis of the RI&E and in consultation with each of the employees, decides which employees are to be examined and how often the periodical examination is to take place.

1.4 Figures involved in OS&H

As mentioned in the memorandum "Occupational health and safety at the UT: towards an optimal organization" the clarity about the tasks, powers and responsibilities within the Safety, Health and Environmental is fundamental.

At the UT various key figures have a specific task with regard to HSE:

- Executive Board;
- Dean / Service and Institute Director;
- Faculty managers
- Direct managers (e.g. department heads);
- Facility company;
- Policy officers Safety, Health and Environment - HR;
- Safety, Health and Environment coordinators of the units (VGMc);

- HSE contact persons departments / departments;
- Coordinator BHV UT;
- Heads of company emergency services (BHV);
- The Health and Safety Service (HCC).

In addition, there are special Safety supporting functions and services as:

- Coordinating radiation expert;
- Decentralized Responsible Radiation Experts;
- Biological safety officer;
- Laser safety officer;

1.5 Risk Assessment and Management approach

The UT has developed various preventive measures, based on the Hazard Identification and Risk Assessment, in order to ensure everyone a safe environment for work and study.

In the hazard identification and risk assessment (RI&E), the present and latent risks for the health and safety at the workplace and in the work environment are set down in writing. Every employer is compelled to have a current RI&E on file, combined with an action plan; employers and staff members structurally work together on safe and healthy working conditions.

Being the university a complex and dynamic environment, one comprehensive RI&E is insufficient; this is clear from the list of the topic involved in the UT Safety: hazardous substances, biological agents and GMOs, Safety information laboratory, Personal Protective Equipment, Electrical safety, machine safety and work equipment, radiation, increased pressure and protocol handling gas cylinders, vacuums, RPAS (Drones), new developments, refurbishments and renovations and Safety of third parties.

The preconditions, the minimal requirements and the frameworks that the execution and report of the RI&E has to meet are described in the Dutch Universities working conditions catalogue.

Risk Assessment in Laboratory experiments

The University of Twente has a range of laboratory areas (chemical, physical and biological, as well as for mechanical and electrical engineering) and workshops. Students and staff must be able to work there safely. As an example, for activities involving the use of hazardous substances the approach to the RI&E is described below:

The approach adopted by UT to perform a Risk Assessment involving hazardous substances focuses on the nature, extent and duration of the exposure of the staff member(s) to the hazardous substances and is based on the following steps:

1) Identification of the substance or mixture worked with (in the early, intermediate and end phase);
2) Data on the risks related to the substance or mixture, information available in GROS system (system for the registration of hazardous substances), in the supplier's security information sheet, etc.;
3) The nature of the activities performed, with different possibilities (e.g. processes take place in closely systems or in semi-closed systems involving substances which evaporate at 20 degree Celsius, etc.);
4) The way in which exposure can take place: exposure which would occur if no protective measures are taken (so-called potential exposure). This is possible through the description of the nature of the substance(s) used and the related hazards in solid, liquid or gas condition, taking into account any reinforcing effects that may occur during exposure to several substances (e.g. in combination with solvent, easy absorption via skin); investigation on which calamities may occur during the various steps of the process.
5) Information on the use of the substance or mixture, the storage location, knowledge of the staff involved.

6) Based on the identification of the above point, (groups of) staff can be designated who run a risk of being exposed (for example: scientific researchers, students and technicians).

7) Plan of action: state the measures to be taken to avoid exposure.

To ensure adequate assistance and maintenance activities, it is necessary to have information with regards to the nature of the activities in the laboratory and/or experiment room. The Safety Information Laboratory/Experiment Room form is required to be in the intended box outside the lab.

The Information card experiment, resulting from the RI&E, can be used to inform about risks related to the ongoing research. This card must be clearly visible during the experiment.

Duration experiment: Yes / NO	INFORMATIONCARD EXPERIMENT	Valid until:		
Reaction/Sort of experiment: (delete the symbols that are NOT applicable and also this text)		Risk-aspects	Y *)	Min/max
		*) tick if relevant		
		Pressure/vacuüm		
		High/low temperature		
		Moving parts		
		Electricity		
		For carcinogenic and reprotoxic substances, H-phrase 340,350,360, always should be considered whether replacing the substance with a less harmful alternative is possible. Because of the health risks, an additional risk assessment (RI&E) has to be made.		

Amount		HAZARDOUS SUBSTANCES					
gr.	mol	Name	CAS-nr	Vap.press (mbar)	Limit value (mg/m³)	H-phrase: nr + meaning	Waste-cat.

	Experimenter	VGM-C	Lab-supervisor	Safety measures: personal protection (besides lab coat and safety goggles), first aid, cleaning spills:
Name:				
Tel. Intern:				
Signature[1]:				
[1]Herewith I declare that I informed myself in a proper way about all the aspects of this experiment and that I have taken all the necessary measures to work safely according the rules of the UT. Lab-supervisor is only relevant for the facultyTNW.				
THIS FORM MUST BE PRESENT DURING THE EXPERIMENT				

Universiteit Twente, HR-2015-01

Information card – experiment-based (GHS) (Globally Harmonized System, abbreviated to GHS)

1.6 Emergency preparedness and response

According to the approach that everyone has to be involved to improve the safety level at the UT (Safety is an everybody task), different entities play a key role during an emergency at the University of Twente: the Emergency Response Team (ERT), the Security Service Desk (SSD), the Human Resource (HR) Management and visitors, students and personnel.

Special research focuses on the evaluation of the emergency response system, identifying the root causes of the deterioration of In Case of Emergency (ICE) performances (*see Research Activities section*)

1.7 Improvement

Within the opportunities for Safety improvement, to have an insight into unwanted situations (e.g. accidents) is essential. University of Twente has an own procedure for reporting accident, incident/near accident or dangerous situation. The procedure adopted by TU Twente mainly aims to find out the causes leading to the accident, incident/near miss or dangerous situation and to identify additional measures necessary to prevent a recurrence and improve the Risk Management.

The procedure applies to all members of staff, students, trainees, temporary staff and third parties (including guests) that are involved in an accident, incident/near accident or dangerous situation. The Safety, Health and Environment Coordinator of faculties and departments and the HR staff supervise the correct implementation of the procedure. Deans or Director of Operations and Department Directors are responsible for monitoring the procedure and ensuring that everyone is aware of the procedure.

In the follow a screenshot of the online-digital reporting form available in the *Reporting form (near) accident, (environmental) incident, dangerous situation UT* section.

2 RESEARCH ACTIVITIES

Research works aimed to contribute to the improvements of OS&H in the Institute

Emergency response in large public facilities: thoughts and reflections on the unique Dutch Campus University

The research studies aspects that influence the emergency response time within large public facilities in order to recommend improvements for responsible entities that warrant the safety within buildings of the University of Twente. Interviews were held with heads of these entities and the identified causes that could lead to deteriorations of the systems structured with the help of an Ishikawa diagram. The goal, methods and results of the research are discussed and recommendations to improve performance are made to help the responsible entities. The practical recommendations are based on continuous improvement philosophy and on the new concept of antifragility.

3 ON SITE DIRECT INFORMATION

Through visits in different laboratories (e.g. the DesignLab Workshop, Wind Tunnel) useful information on the practical implementation of solutions to manage risks are collected.

4 SPECIAL 3rd GENERATION APPROCHES (RESILIENCE – ANTIFRAGILITY)
Within the *Emergency response in large public facilities* research work, the Antifragility concept is used to make more robust the In Case of Emergency protocol: introducing mistakes and errors in the drills makes possible the ERT to face unexpected situations during the emergency.

Tutor approval
Name Dr. Alberto Martinetti
Date University of Twente, Enschede, 28th July 2018
Sign

Appendix 4

TNO OS&H approach

VISITING ACTIVITY REPORT – TNO

PhD candidate: Paolo Fargione

Location	Tutor(s)/ reference person
Den Haag (NL)	Drs. R. Remco Visser HSE advisor and HSE coordinator nationwide for TNO

Institution typology - details

TNO is an independent research organization for applied research, and it connects people and knowledge to create innovations that boost the competitive strength of industry and the well-being of society in a sustainable way.

TNO innovation for life

1 GENERAL APPROACH FOR RISK MANAGEMENT

1.1 National enforcement of European Directives – Reference normative:

National legislation

- *Working Conditions Act*

  General provisions for employers and employees how to deal with occupational safety and health, for example to have a written OSH-policy or a risk inventory. The Act gives certain powers to the Inspectorate-SZW, for example to force the employer to stop the work.

- *Working Condition Decree*

  This Decree covers a wide range of specific occupational health and safety topics, such as provisions on work places, dangerous substances, noise, vibrations etc.

- *The Working Conditions Regulation*

  Very specific provisions which are changing relatively fast. For example the occupational exposure limit for dangerous substances.

1.2 Organizational roles, responsibilities and authorities

TNO is organized in Research Units with their own research fields. The Units can be structured in one or more Departments (in total there are approx. 60 departments).

The Research Manager is responsible for S&H issues. Each Department has a Prevention Officer: usually he's a researcher with additional tasks on Safety.

1.3 Figures involved in OS&H

Prevention Officer, Research Manager, Room Manager, Head of Department, Project Leader.

1.4 Risk Assessment and Management approach

RISK ASSESSMENT

The approach adopted by TNO to manage Safety is based on two levels of Risk Assessment:

1. Base Risk Assessment – Base R.A.
2. Project Risk Assessment – Project R.A.

Base Risk Assessment

The Base R.A. focuses on the assessment of risks in specific working environments: buildings, offices, laboratories, etc. present in the TNO facilities. The evaluation is guided by question lists tailored to each typology of environment, therefore the content of the list for buildings is different from the offices and laboratories ones, but question lists are different also between laboratories.

The lists guiding the Risk Assessment for buildings contain questions about safety problems related to shell, services and interior spaces of settlements containing workplaces and their not-operative content.

The content of the offices question lists covers mainly problems related to video display terminals, work related stress, etc.

The Room Manager, having the better knowledge of the characteristics and details of the room he manages, Safety aspects included, is tasked to perform the Risk Assessment for his room: answering the question list he can be guided in performing the Base assessment of risks: a Laboratory Manager has a good understanding of substances, materials, equipment used and operations carried out in his laboratory, and according to the question lists he can evaluate the related risks. The Room Manager, during the Risk Assessment, can ask advices to the specialists (e.g. Laser Safety Officer) regarding peculiar Safety problems.

The Head of Department is responsible for the Base R.A.

Project Risk Assessment

The Project Leader, person who designs the research, knows deeply all the aspects involved in the project and related potential safety problems. Therefore in the design phase, the Project Leader carries out a Project Risk Assessment, also asking support to the Specialist Safety Officers for specific aspects e.g. laser. At project level the R.A. is more dynamic than the Base R.A., since it follows the project during its all development, and therefore it must be regularly updated.

The Prevention Officer helps the Project Leader in the assessment of risks (with the contribution of specialists). The final document is signed by:

- the Project Leader,
- the specialists who give their contribution because asked; each specialist signs for its part of the assessment, e.g. the Laser Safety Officer signs for its evaluation on lasers related risks,
- finally the Head of Department signs the document as well; he supervises the assessment of the different specialists and he can ask for clarifications through meetings to discuss about the specialists decisions and assessments.

A Project RI&E (Risk Inventory & Evaluation), resulting from the Risk assessment, is drawn up for each specific project, and it provides work instructions and preventive measures (*source: New staff information videos*)

RISK MANAGEMENT

Laboratories, and others areas, are equipped with adequate technical safety provisions identified thorough the Base R.A. However, the research project development could bring, in the working environments involved, risks not assessed in the Base R.A. It is the case of an experiment, within a research project, requiring the handling of carcinogenic substances in a laboratory where usually they are not used. The risk related to the

CMR materials is not assessed in the Base R.A. of the lab, but it is carefully evaluated in the Project R.A., and proper prevention measures to manage the risk are identified. The laboratory, before the project commences, must be equipped with the "additional" technical prevention measures to manage that risk.

The implementation of such an additional safety measures is responsibility and task of personnel (often technicians) who have significant knowledge of their working environments: frequently they are the Room Managers, the more qualified person to implement new technical solution for prevention in their rooms.

Risks prioritization

At *project level*, all the risks are managed: the Project Leader, according to the outcomes of the Risk Assessment, can decide to prioritize selecting the proper management solutions depending on the risk considered (in terms of seriousness of consequences, probability of occurrence, etc.). Instead a risks hierarchy is determined at *corporate level* in order to direct investments to solve first the high criticalities (e.g. 1. Stress, 2. CMR substances, 3. Working permits, 4. etc.).

Procedures

Regarding the working permits, procedures exist to manage the risks due to possible working interferences, e.g. in the case of staff belonging to external company working in TNO (e.g. the cleaning team, or maintenance technicians). Some of these procedures can be very complex, depending on the typologies of activities producing the possible interference: some operations follow the working plan (e.g. an equipment maintenance intervention, or the ordinary cleaning activities), some other ones often have no well-defined and rigid schedule (e.g. experiments and research activities).

(an example: it is necessary to prevent interference between the ventilation maintenance technician working on the lab roof, near a chimney, and a researcher who, at the same time, releases an hazardous gas through the chimney: the difficulty is that the researcher activity is not so rigid and well scheduled, and it can be sometimes unforecastable, and it is very different than an ordinary work).

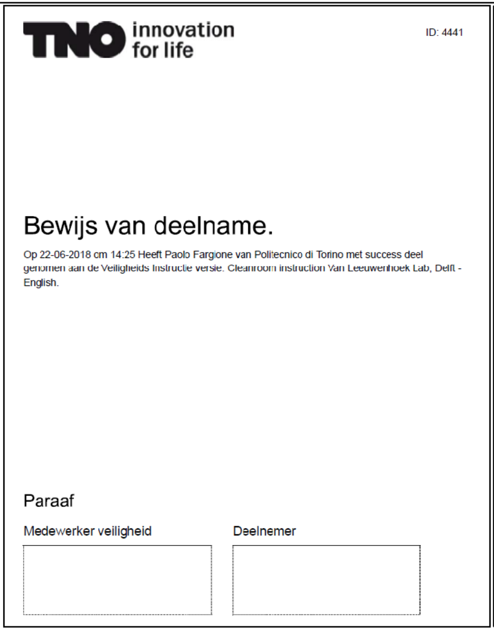
Many other procedures allow to manage the risks involved in external research work, among them the activities carried out in different companies, for measuring purposes, or outdoor – in field activities, e.g. the risks due to the Lyme disease due to the ticks.

Access policy - Information and instruction

The access in TNO buildings is regulated by the use of badges needed to open doors and access to areas. Different kind of badges are available, for employees and visitors, with diverse access authorizations.

A new employee, or a visitor, gains the pass when he/she has completed the information and instruction session required to enter in the specific area. According to authorization obtained, the badge is upgraded and to access in special areas (e.g. special cleanroom) become possible. (*source: New staff information videos*)

The basic level of information and instruction is available also in eLearning modules: accessing the TNO intranet, it is possible to attend eLearning courses about safety (and security) rules for the specific work and location. Each course is organized in section, including a brief question list, at the end of each section, concerning the topics previously discussed; correctly answering the questions allows to proceed to the next step. The result of the test is recorded (proving the occurred information) and a Certificate of Participation is sent to the candidate. Below two examples of the Certificate of Participation:



TNO innovation for life

ID: 4441

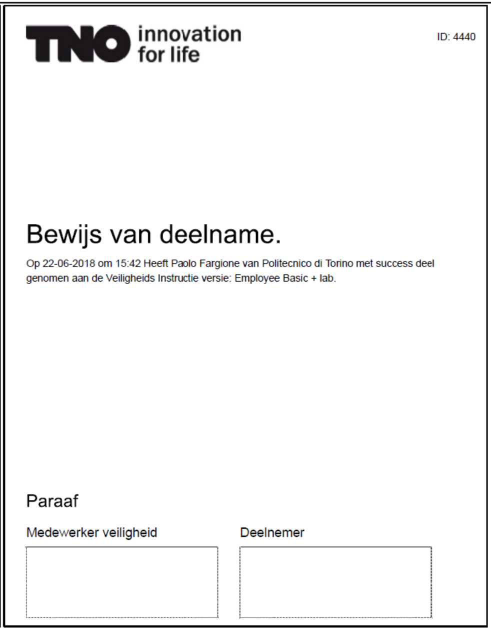
Bewijs van deelname.

Op 22-06-2018 om 14:25 Heeft Paolo Fargione van Politecnico di Torino met success deel genomen aan de Veiligheids Instructie versie: Cleanroom instruction Van Leeuwenhoek Lab, Delft - English.

Paraaf

Medewerker veiligheid

Deelnemer



TNO innovation for life

ID: 4440

Bewijs van deelname.

Op 22-06-2018 om 15:42 Heeft Paolo Fargione van Politecnico di Torino met success deel genomen aan de Veiligheids Instructie versie: Employee Basic + lab.

Paraaf

Medewerker veiligheid

Deelnemer

Certificate of Participation for the information and instruction on basic laboratory and cleanroom

1.5 Emergency preparedness and response

TNO has an in-house emergency response team as organizational component of the General Support Services to face emergency situations.

Laboratories are equipped with technical countermeasures to face the emergency situations in the labs, within the General Support Services: gas and fire detection systems, emergency buttons (in different colors for different purposes: from the emergency opening of possible blocked emergency doors to the general shutdown of the machinery and equipment working during the emergency), emergency showers and eyes washes, etc. (*source: New staff information videos*)

1.6 (Safety) Performance evaluation

A team of 40 auditors is tasked to perform internal audit in TNO laboratories; usually auditors (working in couples for each audit) are researchers from departments different than the one they audit.

1.7 Improvement

TNO has a notification system for registering accidents, incidents and unsafe situations in the field of first aid / safety and the environment.

The approach adopted by TNO to make the incident data useful for prevention purposes is based on the KPI (Key Performance Indicator) index. KPI index considers the percentage of incidents followed up correctly, - every quarter an overview is generated for the Balanced Scorecard. A correct follow up of incidents requires the following steps:

- assessment of the seriousness of the incident and the likelihood of a recurrence;
- taking action to repair any damage;
- investigation and announcement of the causes of the incident, both direct and indirect;
- planning, announcement and implementation preventive measures.

(*sources APPENDIX TO TNO ANNUAL REPORT 2015*) The incident analysis is performed case by case, and not based on the seriousness of consequences. In order to be able to correct for the number of employees within the organization, the safety indicators Lost Time Injury - LTI and Medical Treatment Case - MTC are also used. LTI indicates the number of accidents with absenteeism per 1.000.000 hours worked; MTC rate is the number of accidents with medical treatment per 1.000.000 hours worked.
2 SAFETY DOCUMENTATION
The approach adopted by TNO to manage the Safety in the research, based on two level of Risk Assessment (Base and Project), entails a lot of Safety documents: each department has a number of Base R.A. documents and a Project R.A. document for each Project.
3 RESEARCH ACTIVITIES Research works aimed to contribute to the improvements of OS&H in the Institute
Important researches on OS&H topics focus on the widespread Culture of Safety and the Safety Research: ❑ *Evidence of the benefits of a Culture of Prevention,* ❑ *Sustainable Safety,* ❑ *Challenges for future safety research.* *(Prof. Dr. Gerard Zwetsloot)*

4 ON SITE DIRECT INFORMATION	
Date and location	**Reference person**
10/07/2018 Delft (NL)	Walter Tuk Maintenance Coordinator Scientific equipment and Safety officer - TNO Space Systems Engineering

Working environment visited - details	TNO innovation for life
Research Unit: TNO Space Systems Engineering **Department:** /	

Working environment description and OS&H notes:

Laser laboratories: there are laboratories used to perform experiments requiring lasers. The experiment setups in these laboratories frequently changes according with the experiments and the projects. The main hazards and related risks in this environments are due to the use of lasers: several typologies of lasers, with different powers, can be used. Samples containing liquid with different evaporation characteristics are tested in some of these laboratories, therefore localized ventilation on the setup and gas sensors (also due to the use of nitrogen) are implemented.

During the use of lasers, a warning signal, outside the lab on the top of the lab door, warns about the ongoing hazard inside the laboratory: who accesses the lab have to wear the protection googles available. On the lab door a specific form reports the characteristics of laser (e.g. power and class) working at that time: these information are necessary also to select and wear the proper PPE (e.g. laser safety eyewear with appropriate protection level).

Semi cleanroom: it is a big room built two years ago specially designed to host a complex device;

Optic laboratories (for lenses) and *Mechanical laboratories:* these laboratories have hazard factors typical of the workshops. In optic laboratories the risks due to the use of special cleaning substances (necessary to reach a cleaning high level of lenses) are managed mainly through localized and general ventilation.

Cleaning laboratory: parts and components to be used in cleanrooms are treated with different levels of cleaning, through cold and hot water bath, dried in stoves, and sealed in containers. The different bath are not ventilated because the cleaning solution is water; some fume hood (or laminar hood) are used to temporary storage the cleaned components.

Vacuum device laboratory: it is a special environment where a vacuum device is used to test samples in special vacuum conditions. A main pipe, coming from the storage area positioned outside, feed the device inside the laboratory with hydrogen. The connection between the main pipe and the secondary ones (linked to the vacuum device) is enclosed in a special box where gas detectors are present, since the connection is a critical point of the hydrogen feeding system. The scope of the box is to isolate the volume potentially involved in a hydrogen leakage from the surrounding room. In the case of hydrogen leakage from the connection inside the box, the control system interrupt the flow, and the building is evacuated. Some hydrogen detectors are positioned on the lab roof to detect possible gas leakages inside the room.

EMERGENCY RESPONSE

In TNO Delft the in-house emergency service - BHV is one of the most important organizational component of the General Support Services. When an emergency occurs the BHV team, alerted by calling the emergency line, intervenes more rapid than the professional emergency services (fire brigade, ambulance, police,…). In the case of evacuation, the BHV team helps the people to leave the building, checks that everyone has left the building, and supervises the assembly point. (*source: New staff information videos*)

TNO Delft laboratories are equipped with special systems based on positioning sensors able to verify if, in case of evacuation, someone is still inside the building and in which area.

The visit on TNO Delft confirms as a lot of very different working environment are present: from the workshops to modify, arrange and adjust the mechanical components (through lathe, and others power tools), to a more sophisticated kind of workshop (e.g. the optical lab); from a laser labs to different levels of clean rooms. All these kind of environments requires a devoted Risk Assessment and Management both at Base and Project levels.

Tutor approval
Name Drs. R. Remco Visser
Date 13/9/2018
Sign

Appendix 5

Canvassing in-situ tests results

Site: **OFFICES**

Image of one of the investigated offices

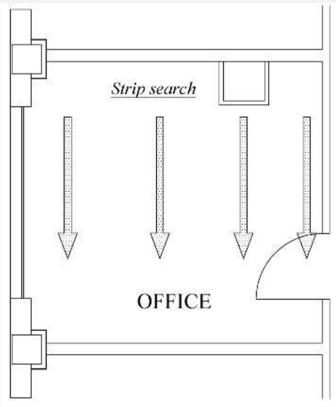
Discretization: the *Zone Elevation Split* proved to be of simple application, but the *Zone Split 3D* did not give special advantages, since the reduction of a homogeneous and limited volume into sub-volumes gave no more information.

⇨ *Suggested discretization:* ***Zone Elevation Split***

Search modes: the *Grid Search* results excessive: the search patterns result too dense. The same problems occur with the use of *Spiral Search*, more difficult for the presence of furniture. Hence, the best technique is the Strip Search.

⇨ *Suggested search modes*: ***Strip Search.***

The method at a glance



Layout of the office

Office discretization and search method

Special benefit of the method

Point of interest

Considerations: the *Zone Elevation Split + Strip Search* combines simple application and in-depth analysis of the area in a systematic way. This approach permits an effective Hazard Identification of some hidden potential criticalities.

Site: **RESEARCH LABORATORIES**

Image of one of the investigated laboratories

<u>Discretization</u>: the application of *Zone Split 3D* is necessary to separate the zone assigned to measuring equipment preparation, and results processing and archiving (Area A), from the laboratory area (Area B), characterized by different intended uses and criticalities; for each volume it is necessary a further discretization by means of the *Zone Elevation Split* technique.

⇨ *Suggested discretization:* ***Zone Split 3D + Zone Elevation Split***

<u>Search modes</u>:

Area A: this context results critical due to the presence of equipment, particular materials and tools. For these reasons:

- *Grid search* model is of difficult implementation due to some cramming of furniture;
- the application of *Wavy Line* search is problematic for encumbrance and tightness of the environment;
- *Overlapping Search* results too expensive also for the involved resources (the technique requires at least 3 operators).

Here, the *Spiral* or *Strip* searches allow to achieve a thorough analysis with good results.

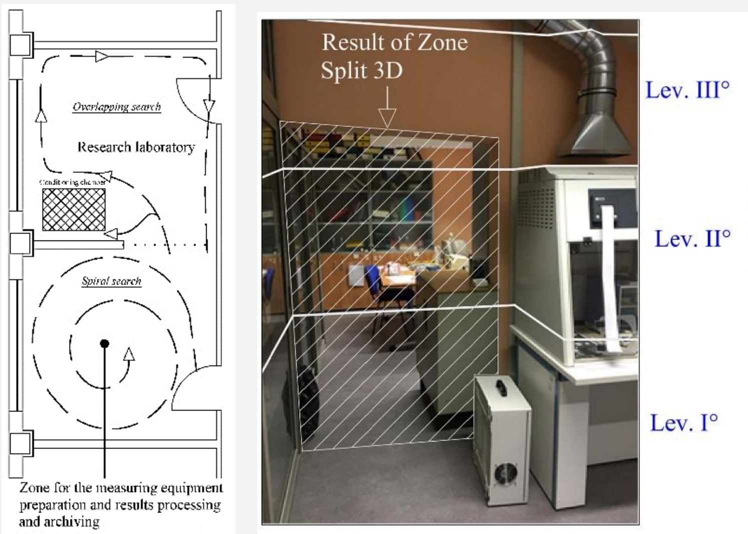
Area B:

- the application of the *Grid* and *Strip* searches can lead to loss of important pieces of information, e.g. due to the presence of critical hidden zones behind the various equipment;
- the use of *Wavy Line* search is difficult due to encumbrance problems and the tightness of the environment;

The *Overlapping search* can be the most suitable technique in such a complex scenario, since more operators perform the investigation of the whole environment. In such a way, Hazard Factors are unlikely to be missed.

Suggested search modes: ***Spiral or Strip for the Area A; Overlapping search for Area B***.

The method at a glance / Special benefit of the method



Layout of Lab. / Zone Split 3D result

Considerations:
the combination of the *Zone Elevation Split* and the *Overlapping Search* in such a complex contest permits multiple analysis of the potential criticalities, and reduces the possibilities of incompleteness of results: e.g. to overlap the same area by more than one operator reduces the risk of skipping some Hazard Factors.

Site: **CLASSROOMS**

Image of one of the investigated classrooms

<u>Discretization</u>: the *Zone Split 3D* results useful especially for the definition of homogenous volumes (desk zone, blackboard zone, etc.). In each identified volume, the *Zone Elevation Split* is applied. This combination ensures the completeness of the analysis.

⇨ *Suggested discretization:* ***Zone Split 3D + Zone Elevation Split***

<u>Search modes</u>:

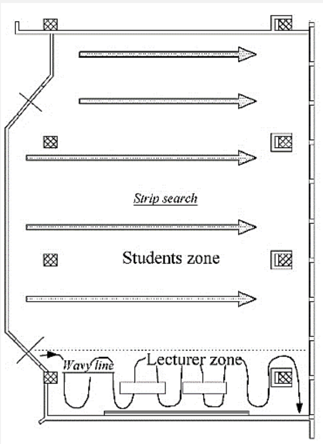
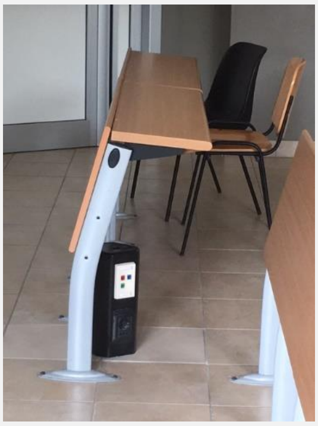
The search method depends on the specific configuration of each sub-volume previously identified.

Students' zone: the *Grid* and *Spiral* searches are poorly applicable due to particular desks layout. The *Strip Search* seems to be tailored for the students' zone, thanks to its suitability to the linear layout of the desks.

Lecturer zone: as in the desk zone, the *Strip Search* appears suitable. A good alternative could be the *Wavy Line Search,* due to the more complexity (in terms of devices and systems) of this volume if compared to the students' one.

In order to ensure the continuity in the analysis of the fittings, a *Strip Search* in the border areas could be useful; for the devoted analysis of identified plants and fittings a special Hazard Identification technique will then be used.

⇨ *Suggested search modes:* ***Strip search for the students' zone;***
Strip or Wavy Line search for the lecturer zone.

The method at a glance		**Special benefit of the method**
 *Layout of a classroom*	 *Classroom discretization in different floor levels*	 *Point of interest*

Considerations: the combination of *Zone Split 3D* and *Zone Elevation Split* permits to reduce the extent of the searched volume, and to select the investigation method, *Wavy line* or *Strip,* the most suitable to its characteristics. It is of pivotal importance to consider the possible variability of the classroom in terms of dimension and configuration. These aspects could influence the choice of a technique rather than another (e.g. in a small classroom the *Wavy Line* and *Zone Split 3D* do not provide any improvement for the Hazard Identification, and the *Zone Elevation Split* results sufficient).

Appendix 6

Outcomes of simultaneous measuring campaigns

Sampling		Membrane ID	Volume [litres]	Asbestos fibres counted	UCL (95% confidence level)	C [ff/l]
Ordinary samplings	1	A1	5000	0	3,69	< 0,56
		B1	5000	0	3,69	< 0,56
		C1	5000	0	3,69	< 0,56
	2	A2	5000	0	3,69	< 0,56
		B2	5000	0	3,69	< 0,56
		C2	5000	0	3,69	< 0,56
	3	A3	5000	0	3,69	< 0,56
		B3	5000	0	3,69	< 0,56
		C3	5000	0	3,69	< 0,56
	4	A4	5000	0	3,69	< 0,56
		B4	5000	0	3,69	< 0,56
		C4	5000	0	3,69	< 0,56
	5	A5	5000	0	3,69	< 0,56
		B5	5000	0	3,69	< 0,56
		C5	5000	0	3,69	< 0,56
	6	A6	5000	0	3,69	< 0,56
		B6	5000	0	3,69	< 0,56
		C6	5000	0	3,69	< 0,56
Special samplings	7 and 8	A7/8	10000	0	3,69	< 0,28
		B7/8	10000	0	3,69	< 0,28
		C7/8	10000	0	3,69	< 0,28
	A +	A PLUS	10000	1	-	0,08
	X	X	10000	0	3,69	< 0,28
	9 and 10	A9/10	10000	0	3,69	< 0,28
		B9/10	10000	0	3,69	< 0,28
		C9/10	10000	0	3,69	< 0,28
	OFFICE	OFFICE	10000	0	3,69	< 0,28
	11 and 12	A11/12	10000	0	3,69	< 0,28
		B11/12	10000	0	3,69	< 0,28
		C11/12	10000	0	3,69	< 0,28

Appendix 7

Excel spreadsheet for the a-priori uncertainty calculation

Factor x_j			Statistical					Not statistical		Assigned Parameters						
Symbol	Value	Remarks	U_j	P_{dj}	ν_{dj}	k_{dj}	s_j	a_j	k_a	ν_j	n_d	n_r	$u^2(x_j)$	$c_i=\Delta y/\Delta x$	$u_j^2(y)$	$u_j^4(y)/\nu_j$
Nf	3,7E+00	Poisson distr	1,4E-01	95%	100	2,0	7,1E-02		3	100	1	1	5,0E-03	1,5E-01	1,1E-04	1,3E-10
		resolution		95%	100	2,0	0,0E+00	5,0E-01	3	100	1	1	8,3E-02	1,5E-01	1,9E-03	3,5E-08
A	9,6E+02	caliper uncertainty (zero)		95%	100	2,0	0,0E+00	1,0E-02	3	100	1	1	3,3E-05	5,8E-04	1,1E-11	1,2E-24
		reproducibility		95%	100	2,0	0,0E+00	3,0E-02	3	30	1	1	3,0E-04	5,8E-04	1,0E-10	3,3E-22
		reading uncertainty		95%	100	2,0	0,0E+00	5,0E-01	3	30	1	1	8,3E-02	5,8E-04	2,8E-08	2,6E-17
Nc	4,0E+02	bias		95%	100	2,0	0,0E+00	2,0E+00	3	5	1	1	1,3E+00	-1,4E-03	2,6E-06	1,3E-12
a	3,2E-03	microm calibr		95%	100	2,0	0,0E+00	1,0E-04	3	100	1	1	3,3E-09	-1,7E+02	1,0E-04	1,0E-10
Q_{IW}	2,5E+01	reproducibility		95%	100	2,0	0,0E+00	5,0E-01	3	30	1	1	8,3E-02	-2,2E-02	4,1E-05	5,6E-11
		resolution		95%	100	2,0	0,0E+00	1,0E-01	3	100	1	1	3,3E-03	-2,2E-02	1,6E-06	2,7E-14
		accuracy		95%	100	2,0	0,0E+00	8,0E-01	3	30	1	1	2,1E-01	-2,2E-02	1,0E-04	3,7E-10
t	2,0E+02	accuracy		95%	100	2,0	0,0E+00	4,0E-02	3	30	1	1	5,3E-04	-2,8E-03	4,1E-09	5,6E-19
		reproducibility		95%	100	2,0	0,0E+00	2,5E-02	3	30	1	1	2,1E-04	-2,8E-03	1,6E-09	8,6E-20
		resolution		95%	100	2,0	0,0E+00	8,3E-03	3	100	1	1	2,3E-05	-2,8E-03	1,8E-10	3,1E-22
y = C	0,55	[ff/l]														
Remarks																

Variance of y, $u^2(y)$	2,2E-03	3,6E-08
standard uncertainty of y, $u(y)$	4,7E-02	
Degrees of freedom y, $\nu(y)$	139	
Confidence level	95%	
Coverage factor (t of Student)	2,0E+00	
Expanded uncertainty U(y)	9,4E-02	ff/l
Target uncertainty	5,6E-01	ff/l

Calcolus of sensitivity coefficient					
	Δx_i	$x_i+\Delta x_i$	$y+\Delta y$	Δy	$\Delta y/\Delta x$
Nf	7,06E-03	4E+00	6E-01	1,1E-03	1,5E-01
	2,89E-02	3E-02		-5,5E-01	#DIV/0!
A	5,87E-04	1E+03	5,5E-01	3,4E-07	5,8E-04
	1,73E-03	2E-03		-5,5E-01	#DIV/0!
	2,89E-02	3E-02		-5,5E-01	#DIV/0!
Nc	1,15E-01	4E+02	5,5E-01	-1,6E-04	-1,4E-03
a	5,77E-06	3E-03	5,5E-01	-1,0E-03	-1,7E+02
Q IW	2,89E-02	3E+01	5,5E-01	-6,4E-04	-2,2E-02
	5,77E-03	6E-03		-5,5E-01	#DIV/0!
	4,62E-02	5E-02		-5,5E-01	#DIV/0!
t	2,31E-03	2E+02	5,5E-01	-6,4E-06	-2,8E-03
	1,44E-03	1E-03		-5,5E-01	#DIV/0!
	4,79E-04	5E-04		-5,5E-01	#DIV/0!

Calculation steps

1) *Mathematical model definition*: the mathematical model involves a technical knowledge of the process for which the uncertainty is evaluated. From the management point of view it is necessary that JCGM 100:2008 conditions are fulfilled:

   - adequate linearity of the model in the variation range involved in uncertainty calculations (usually acceptable);

   - no correlation among independent variables (requires great attention in cooperation with the technical part);

   - avoid automatic compensation of factors. Compensation is usually valid at values level (values are nearly equal), not at variability level (if there is no correlation, variations of the two factors are independent, that is generally different).

2) Insertion in the column "Symbol" of the symbols of the variables contained in the mathematical model (one at a time);

3) Insertion in the column "Value" of the values of the variables contained in the mathematical model (note: also averages or nominal values can be used);

4) Insertion in the column "note" of all the factors affecting the relevant variable (one for each subsequent raw) and each useful information. In case of variables corresponding to measured quantities, in principle the metrological factors of bias, resolution, repeatability or reproducibility shall be considered;

5) Insertion of information of variability, statistical Type A, or non-statistical, Type B:

5.1) Sector for the statistical information (Type A) of variability (standard deviation s, standard uncertainty u, variance s^2, expanded uncertainty U) in column $\mathbf{S_i}$. The standard deviation can be obtained in different ways:

a1) obtained from experimental data by data analysis, cleaning as much as possible data from measurement accidents and systematic effects;

a2) obtained as variance s^2, when variance value is available;

a3) obtained from expanded uncertainty U received as external information (in case U was evaluated by yourself, you have directly s). Expanded uncertainty U should be given together with the relevant confidence level, to be inserted in column $\mathbf{P_{dj}}$ and degrees of freedom $\boldsymbol{\nu_{dj}}$, to be inserted in column $\boldsymbol{\nu_{dj}}$.

In case of accessory information on confidence level or degrees of freedom not available, it is possible to use the convectional values adopted in the metrological field, that is confidence level 95% and degrees of freedom 100. Excel automatically evaluates the coverage factor k (t-Student) and the relevant standard deviation

5.2) Insertion of information of Type B (non-statistic) variability in column $\mathbf{a_i}$ as half of the variability field.

To understand whether the available information regards the total field or directly half of variability field is important. In metrological field information on Uncertainty or maximum error should be given as half of the variability field, while in technology and quality total variability field is used.

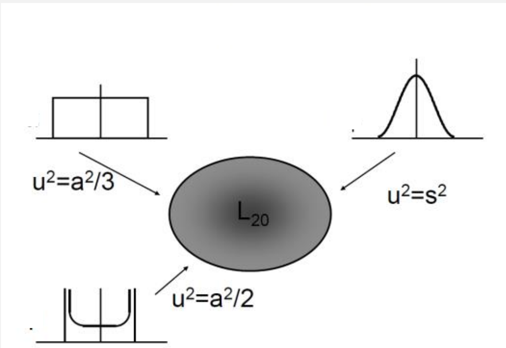
It is necessary to decide the type of statistical distribution to be associated and give in column $\mathbf{k_a}$ the relevant value 2, 3 or 6:

$$Half\ range\ a\ with\ S^2 = \frac{a^2}{k_a}$$

$$Uniform\ distribution\ S^2 = \frac{a^2}{3}$$

$$U - shape\ distribution\ S^2 = \frac{a^2}{2}$$

$$Triangular\ distribution\ S^2 = \frac{a^2}{6}$$



6) Insertion of the degrees of freedom pertaining to each factor in column $\boldsymbol{\nu_j}$ Note: in column $\boldsymbol{\nu_{dj}}$ connected with the information of U received, now you have to put the degrees of freedom you consider correct for the relevant factor, determined as follows:

- if know, from data calculations or information received, use the known number;

- if unknown, it is necessary to consider how believable is the variability information available: *very believable -> 100; believable -> 30; poorly believable -> 15*

In addition, when bias is involved and relevant degrees of freedom are not declared, as bias value is obtained by a calibration and standard specifications usually require few measurement for calibration, to be conservative 5 degrees of freedom are set;

7) Completing the column $\mathbf{n_d}$: consider carefully if the variability information used refers to single data or to the average of q data. In this last case put q in the column $\mathbf{n_d}$

8) Compile column $\mathbf{n_r}$: consider carefully if you will evaluate the uncertainty of single data or of the average of q data and if, for the factor considered, the conditions of the Central Limit Theorem (C.L.T.) are fulfilled. If so put q in the column $\mathbf{n_r}$

An efficient way for understanding if C.L.T. shall be applied to your q data consists in evaluating if the value of each of that data can be anywhere in the variability field declared; if so the average of your q data fall near the centre of variability interval and C.L.T. shall be applied.

9) Evaluation of sensitivity coefficients: sensitivity coefficients are the partial derivatives of the dependent variable against each of the independent variables, as the mathematical functions of the mathematical model can be very complicated, a table of numerical evaluation of sensitivity coefficients is available.

The table evaluate the incremental ratio and is nearly automatic, as it need only the calculation of the incremented value of the mathematical model putting at the place of the variable x_i considered its incremented value x_i+Dx_i

This can easily be done coping the formula in the formula line (therefore copied as text) pasting that text in each line where there is a variable (different factors of the same variable have the same value of derivative), putting the pointer in the formula line, so that the frames of the values used for calculation appear, and dragging the frame of the relevant variable xi to the incremented variable xi+Δxi. As a variable can be used by the mathematical model more than one time, repeat this operation until all frames are transferred to the incremented value. Copy the values of incremental ratios in the column of sensitivity coefficient for each variable and put them equal for each factor of the same variable.