Occupational exposure to incidental nanoparticles: a review on control banding

M Sousa 1, 2, P Arezes 1 and F Silva 1, 3

1 ALGORITMI Research Center, School of Engineering, University of Minho, Portugal
2 CATIM – Technological Center for the Metal Working Industry, Portugal
3 CTCV – Technological Center for Ceramic and Glass, Portugal

Email: marta.sousa@catim.pt

Abstract. As the integration of nanomaterials in our lives evolves, these materials become more noticeable and so do the concerns about the associated risks. Handling engineered nanomaterials (ENM) increases these concerns and has been leading to multiple studies about how to assess the risk of exposure to these materials. In the meanwhile, many workers are not conscious that they are exposed to nanomaterials, since some are unintentionally released in workplaces, during industrial activities, for example. The exact approach to be taken to study this exposure risk is far from being fully established and unanimously accepted. Choosing a quantitative approach can lead to more consistent results, but it requires expert’s knowledge and proper equipment. A qualitative methodology may be less expensive and time consuming. Control Banding (CB) is an example of a qualitative approach, frequently used to manage the risk of exposure to engineered nanomaterials. But while numerous authors and organizations are focused on risk management of ENM, is the exposure to incidental nanomaterials being neglected? If not, how is this being managed? The purpose of this work was to review different CB approaches for occupational risk management of nanomaterials and to highlight its application for the specific case of incidental nanoparticles. Using two databases for the literature review and after some data analysis, the results of this work allowed to clarify the tendency to apply CB methodologies to ENM risk management research and also the opportunity of applying such approach to incidental nanomaterials.

1. Introduction

In 2011, a definition of nanomaterial (NM) was published in the Official Journal of the European Union, stating that it is “a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50 % or more of the particles in the number size distribution, one or more external dimensions is in the size range 1 nm-100 nm” [1].

Natural nanomaterials have been present in our planet for billions of years, playing important roles in the Earth’s system and evolution. Meanwhile humankind emerged and evolved and so did the anthropogenic nanomaterials, both incidental and manufactured. The first ones have been produced unintentionally by humans over the years, since the beginning of humanity. On the other hand, manufactured nanomaterials (MNM) are not even a century old, since the first products started been made in the 40s of the 20th century. Even nowadays incidental NM are in fact more abundant than engineered ones [2].
This notion that nanomaterials are so diverse, are practically everywhere and cannot be seen, rises concerns about safety. Deliberately working with engineered nanomaterials, increases this conscience and has been leading to multiple studies about assessing and managing the associated risk factors. However, many workers are not aware of the presence and much less of the risks associated with unintentional NM including nanoparticles produced, for example, during industrial activities.

Many questions are yet to be answered regarding the best occupational risk management frameworks for nanomaterials. It is known that using the traditional industrial hygiene approach is still not an adequate option, since most information required is unknown or not available. Quantitative methodologies may be a good option, although they may require using highly specialized measurement techniques and equipment, which is usually expensive, and also expert knowledge. Therefore, a qualitative approach may nowadays be more suitable for occupational risk management, as these usually require less investment and can be also used by non-experts. Control Banding (CB) is an example of these qualitative approaches.

In 2016, Erbis et al. published a review regarding the emerging research trends and methods to study the risk of nanomaterials related to safety, health and the environment [3]. In this publication, strengths and limitations of five risk analysis methodologies are highlighted: Monte Carlo Simulation Models, Bayesian Methods, Multicriteria Decision Making, Decision Tree Analysis and Control Banding. Although Monte Carlo Simulation can be used in occupational environments to determine the mean value concentration and Decision trees can help study the possible hazard scenarios in workstations, Control Banding is pointed out as the approach that can deliver better endorsement for work-related safety measures. Besides, this article mentions strong and weak points of CB, such as being useful for small to medium-sized enterprises and being able to suggest ways to reduce exposure in workplaces; and, on the other hand, requiring expert opinion, accurate exposure data and providing static control instead of dynamic control measures [3]. With its advantages and disadvantages, Control Banding has been frequently used for studying the risk of exposure to NM, particularly to engineered nanomaterials [4]. And regardless its limitations, at first sight, it is adequate for studies in occupational environments and may even be suitable for incidental nanomaterials.

The purpose of this paper was to review the different CB approaches for occupational risk management of nanomaterials and to highlight its application for incidental nanomaterials, namely nanoparticles.

2. Methods

2.1. Literature review

Aiming to review the pertinence of Control Banding approaches to manage the occupational risk of exposure to nanomaterials, especially incidental ones, a literature review was conducted on scientific articles using the following databases: Scopus, from Elsevier, and Web of Science, produced by the Institute for Scientific Information and currently maintained by Clarivate Analytics. The research was conducted in order to find documents covering the terms "Control banding", "risk assessment" or "risk management", "occupational exposure" and "nanomaterials" or "nanoparticles". As a result, 59 records were identified in the database search.

Studies were then selected based on exclusion criteria. Firstly, book chapters, notes and technical reports were excluded, as well as documents not written in English. Then, articles were excluded if the complete document was not available online. Also, duplicate articles were excluded and considered as only one document. The fourth and last criterion was the exclusion of studies not focused on nanomaterial’s occupational exposure and Control Banding approaches.

There was no search limitation regarding publication period, so the results included papers published between 2008 and 2020. After applying the inclusion criteria, 35 articles were considered eligible.
2.2. Literature analysis

Apart from the title, author(s) and Journal, the following data were gathered from each selected reference: 1) publication year; 2) keywords; 3) objective of the study; 4) type of document (scientific article, review or conference paper); 5) type of nanomaterials under study (engineered nanomaterials, incidental nanomaterials or both); 6) type of approach (qualitative or qualitative and quantitative); 7) Method used for risk assessment/management (documents using more than one method were considered more than once). All of these data were analysed and a critical literature review was conducted.

3. Results and discussion

The results of the current review consisted of a compilation and analysis of 35 eligible publications regarding CB approaches to manage the occupational risk of exposure to nanomaterials, in the last 12 years, as presented in Figure 1. The publications include 20 scientific articles, 8 literature reviews and 7 conference papers.

![Figure 1 – Number of eligible publications.](image)

3.1. Qualitative and quantitative approaches

The data collected suggests that CB approach in 18 documents is purely qualitative, although quantitative concepts are introduced in 17 articles. As mentioned by Levin et al. [5] control banding methodologies do not provide quantitative data; instead the result is qualitative, based on quantitative and qualitative inputs and modelling, depending on the method used. However, it is feasible to combine these methods with quantitative approaches. Analysing the tendency by year, in the past 6 years it is possible to recognize that the integration of quantitative concepts combined with CB is becoming more popular (Figure 2).

Among the 17 publications that combine these two concepts is the one published by Bouhoule et al., in which the authors applied two CB methodologies and also used measurement instruments, to assess the risk during laboratory tests with carbon black and Multi-Walled Carbon Nanotubes (MWCNT) [6]. The authors used a condensation particle counter (CPC), a scanning mobility nanoparticle sizer (SMPS), a portative particle counter DiscMini and a mini particle sampler (MPS) to characterize the particles by Transmission Electron Microscopy (TEM). Their qualitative approach was based on the application of
CB NanoTool 2.0 and Stoffenmanager Nano. Results of this study showed that both qualitative and quantitative methods lead to the same outcome for carbon black (medium risk level). Regarding MWCNT the results are not that consistent as CB Nanotool and Stoffenmanager Nano assigned the highest risk, while measurements of particles number revealed very low concentrations during tests and that almost no MWCNT fibre was detected.

![Figure 2](image)

**Figure 2** – Number of eligible publications per year, considering the type of approach (fully qualitative or qualitative and quantitative).

Another study used the same qualitative methodologies and a Condensation Particle Counter (CPC), in this case to assess the risk of exposure to TiO$_2$ nanoparticles in a research laboratory [7]. The results obtained in the direct-reading equipment and using the CB Nanotool 1.0 were aligned as both indicated a low risk level. Stoffenmanager Nano presented a higher risk level, overestimating the risk. As mentioned by the authors of the study, combining qualitative and quantitative measures can help to reduce the overall uncertainty and to maintain a precautionary approach.

In 2019, a quantitative validation of CB Nanotool 2.0 was presented by its own authors [8]. This qualitative tool was applied to 20 activities performed at a research laboratory, as well as air monitoring for a qualitative study. The following equipment were used: Ultrafine Particle Counter, scanning mobility nanoparticle sizer (SMPS), filter sampling using a 2 -mm filter with a cyclone and/or filter sampling using a 37 mm closed-face cassette (CFC) sampler. In another laboratory 8 activities were also studied qualitative and quantitatively, using a Condensation Particle Counter (CPC), an Aerosol Spectrometer and filter sampling with 25 mm filters used in open-face configuration for microscopic analysis. From the 28 studied activities, 8 revealed qualitative results equal to quantitative ones. For the other 20 the risk was overestimated by CB Nanotool when comparing to strictly quantitative results.

### 3.2. Engineered and incidental nanomaterials

Regarding the type of nanomaterials under study, most publications focus on engineered nanomaterials (32 out of 35). Besides these publications, Gridelet et al. suggests a new control banding method applicable for industrial implementation for all powders [9] and Lamon et al. present a review on grouping frameworks aimed at identifying hazard classes, mentioning articles that consider both ENM and incidental nanomaterials [10]. Only one document shows a study dedicated exclusively to the exposure to incidental nanomaterials [11]. In this study, Huang, Li, & Li, applied CB Nanotool 2.0 to incidental nanoparticles, generated in a thermal spraying process. It is mentioned by the authors that the various metal nanoparticles generated during the process have different composition, which affects some important toxicological factors considered in CB Nanotool. Plus, many characteristics of incidental nanomaterials and parent materials are not known. Therefore, when scoring severity, some factors were
classified as “unknown” such as carcinogenicity, reproductive toxicity, mutagenicity, dermal toxicity, asthmagen and surface chemistry.

The result of the application of CB Nanotool 2.0 to this case study was an overall risk level of 3 out of 4 (4 being the highest risk level), meaning containment is the recommended control measure. Authors consider this result coherent.

3.3. Different Control Banding methodologies

The control banding methods for risk assessment mentioned and/or applied in the 35 publications designated in this review are diverse, as showed in Figure 3.

![Figure 3 – Control banding methods mentioned/used per publication.](image)

A total of 24 publications apply or at least mention Control Banding Nanotool (CB Nanotool). This tool was developed by Paik et al. in 2008 aiming to assess and control the risk of exposure to nanoparticles of nanotechnology researchers at the Lawrence Livermore National Laboratory (California, United States of America), keeping a qualitative approach [12]. One year after, it was adapted by Zalk et al., that reduced the maximum points in the severity scale, presenting CB Nanotool 2.0 [13].

The concept of this method is to assign a severity score and a probability score (each corresponding to one axis), allowing the risk level to be determined using a four-by-four matrix. Severity is determined scoring 13 different factors related with properties of the nanomaterial under study (including physicochemical ones) and of its parent material, indicating the ability of particles to affect human health. The sum of all the points assigned to these 13 factors is the final score for severity. On the other hand, probability final score is given by sum of the results of 5 factors that are scored considering the interaction between the worker and the engineered nanomaterials under study (assessing the potential exposure) [14].

Knowing the final score of severity and probability and matching them with the correspondent band, it is possible to determine the risk level (RL), using the matrix present in Figure 4. Each RL corresponds to a control band, meaning that RL 1 requires general ventilation; RL 2 demands fume hoods or local exhaust ventilation; RL 3, requires containment; and RL 4 suggests seeking specialist advice [12].
Probability

| Severity          | Extremely Unlikely [0 - 25] | Less Likely [26 - 50] | Likely [51 - 75] | Probable [76 - 100] |
|-------------------|------------------------------|-----------------------|-------------------|---------------------|
| Very High [76 - 100] | RL 3                         | RL 3                  | RL 4              | RL 4               |
| High [51 – 75]    | RL 2                         | RL 2                  | RL 3              | RL 4               |
| Medium [26 – 50]  | RL 1                         | RL 1                  | RL 2              | RL 3               |
| Low [0 - 25]      | RL 1                         | RL 1                  | RL 1              | RL 2               |

**Figure 4** – CB Nanotool risk level matrix based on Paik et al. [12], in which RL 1 corresponds to general ventilation; RL 2 to fume hoods or local exhaust ventilation; RL 3 to containment; and RL 4 to seeking specialist advice.

As mentioned before, among the articles studied in the present review, most mention and/or apply CB Nanotool, focusing ENM. However, Huang et al. applied CB Nanotool 2.0 to incidental nanoparticles, generated in a thermal spraying process [11]. Allowing the classification of “unknown” in certain parameters, makes CB Nanotool eligible to assess the risk of exposure to incidental nanoparticles. Nonetheless, this literature review shows that this is not common practice. Another advantage of this tool is that it can be used by professionals and non-professionals [14], although it is recommended to involve an expert [15], which may be an advantage while studying incidental NM. Another reason to consider this tool as appropriate for being eventually adapted to assess the risk of incidental nanomaterials, is that it is suitable for industrial environments, were many incidental nanomaterials are found and represent risk to workers exposed [16].

Other methods were found to be used when studying occupational exposure to ENM, as demonstrated in Figure 3. For example, **Stoffenmanager Nano**, created in The Netherlands, was mentioned in 15 articles analysed in the present review. This tool intends to be used by non-experts [15] and its online version allows a comfortable solution when quantitative assessment is not feasible [17]. Its authors claim that this qualitative risk assessment method features health risks associated with the exposure to manufactured nano-objects and it helps defining control measures. It is emphasized that information on shape and size of the manufactured nano-objects is fundamental to appropriately classify hazards, a detail that can exclude its suitability to assess the risk of exposure to incidental nanomaterials [18].

Stoffenmanager Nano defines five hazard bands (considering hazardous properties of the nano-object such as particle diameter and length, solubility, morphology, bioavailability, among others; parent material characteristics may also be considered) and four exposure bands (considering nine modifying factors as, for example personal behaviour, substance emission potential and surface contamination), allowing the user to determine the risk priority band using the risk matrix presented in Figure 5. There are three risk prioritisation bands, 1 having the highest priority and 3 the lowest [18].
**Figure 5** – Stoffenmanager Nano risk priority band matrix adapted from Duuren-Stuurman et al. [18] in which 1 corresponds to high priority; 2 to medium priority; and 3 to low priority.

CB Tool from French Agency for Food, Environmental and Occupational Health & Safety method (ANSES) and NanoSafer were both mentioned in 10 articles studied in the present review, showing that these control banding methods are also highlighted when assessing the risk of occupational exposure to nanomaterials.

The French Agency for Food, Environmental and Occupational Health & Safety created a CB Tool, hereinafter called ANSES, aiming the development of a CB tool suitable for small and large enterprises, allowing them to evaluate the occupational risk of exposure to manufactured nanomaterials [19]. It proposes a 5-hazard band classification, based on physicochemical and toxicological properties of the nanomaterial, and a 4-exposure band classification, specified according to the nanomaterial emission potential. The control band of each case study is defined by using the matrix presented in Figure 6, that can vary from CB1 (natural or mechanical general ventilation) to CB5 (full containment and expert advice).

**Figure 6** – ANSES control bands based on Riediker et al. [19] in which CB1 corresponds to natural or mechanical general ventilation; CB 2 to local ventilation; CB 3 to enclosed ventilation; CB 4 to full containment; and CB 5 to full containment and review by a specialist required.
NanoSafer is described by its authors as a control banding and risk management online tool designed for small and medium-sized enterprises working with manufactured nanomaterials [20]. It was developed by Denmark’s National Research Center for the Working Environment. Relying on technical information sheets and safety data sheets of the material to collect physical and toxicological data (water solubility for example) and other information about the bulk analogue compound, it is possible to determine the hazard band score. This can be difficult (or even impossible) data to collect when discussing incidental NM, so an adaptation of this method would be necessary to study these materials, particularly in input data.

This method proposes 4 hazard bands and 5 exposure bands. This last one is estimated considering the principles of the source-to-receptor model described in Schneider et al. [21]. Finally, based on the matrix presented in Figure 7, the risk level is determinate, ranging from RL1 (low hazard and low exposure potential) to RL5 (high hazard and/or moderate to very high exposure potential).

![Figure 7](image)

**Figure 7** – NanoSafer risk levels based on Jensen et al. [20] in which RL5 corresponds to high hazard and/or moderate to very high exposure potential and RL1 to low hazard and low exposure potential.

The **Precautionary Matrix for Synthetic Nanomaterials** was developed by the Swiss Federal Office of Public Health and the Federal Office for the Environment, in 2008, and it has been revised into its current version 3.1 [22]. It assesses the risk by combining hazard and exposure potential in a single score [15] and adds a new element in comparison to other CB tools created so far: it aims the protection of not only employees but also consumers and the environment during the life cycle of nanomaterials [22]. Nevertheless, it is focused in the prevention of exposure to engineered nanomaterials [14], not mentioning its possible applicability to incidental ones.

The Precautionary Matrix for Synthetic Nanomaterials allows the user to differentiate the risks and opportunities related to the nanomaterial in two different categories – Class A or Class B, as shown in Figure 8. According to Dimou & Emond [14], it requires expertise to ensure accurate interpretation of the results.
The nanospecific need for action for the considered materials, products and applications can be rated as low and does not need further clarification.

Nanospecific action is needed. Existing measures should be reviewed, further clarification undertaken and, if necessary, measures to reduce the risk associated with development, manufacturing, use and disposal implemented in the interests of precaution.

**Figure 8** – Nanospecific action requirement based on Höck et al. [22].

The IVAM Guidance [23] was created to deliver a guidance to work safely with ENM and nanoproducts. This method is based on a stepwise decision tree, consisting in 8 steps. At the fifth step a control approach band for activity is already selected, based on 3 hazard bands and 3 exposure bands according to the matrix presented in Figure 9. In this decision matrix, A is the lowest risk having as suggested measure applying sufficient (room) ventilation, if needed local exhaust ventilation and/or containment of the emission source and use appropriate personal protective equipment; B means that according to the hierarchic Occupational Hygienic Strategy, the technical and organizational feasible protective measures are evaluated on their economic feasibility. Control measures will be based on this evaluation; and C means the hierarchic Occupational Hygienic Strategy will be strictly applied and all protective measures that are both technically and organizationally feasible will be implemented.

| Score | Classification | Significance |
|-------|----------------|--------------|
| [0 – 20] | A | The nanospecific need for action for the considered materials, products and applications can be rated as low and does not need further clarification |
| > 20 | B | Nanospecific action is needed. Existing measures should be reviewed, further clarification undertaken and, if necessary, measures to reduce the risk associated with development, manufacturing, use and disposal implemented in the interests of precaution. |

### Description of the hazard category for nanoproduct

| Hazard category 1: (water) soluble nanoparticles | Hazard category 2: Synthetic, persistent nanomaterials (non-fibrous) | Hazard category 3: Fibrous, non-soluble nanomaterials for which asbestos like properties cannot be ruled out |
|-----------------------------------------------|-------------------------------------------------|--------------------------------------------------|
| **Exposure category I:** Emission of free nanoparticles minimized due to working in full containment | A | A |
| **Exposure category II:** Emission of nanoparticles (1-100 nm) embedded in a larger solid or liquid matrix (100 nm - 100 µm) is possible | A | B |
| **Exposure category III:** Emission of primary nanoparticles (1-100 nm) is possible | A | C |

**Figure 9** – The IVAM Guidance decision matrix based on Cornelissen et al. [23].
IVAM Guidance was mentioned in 8 articles from the selection of this review and, probably because of its 8 steps so well outlined for ENM and nanoproducts, not applied to incidental nanomaterials.

Finally, the decision tree of the Ecole Polytechnique Fédérale de Lausanne (EPFL) was mentioned in 4 articles from the present review [24], [25]. This method consists in a decision tree for research laboratories producing and using ENM, so the main concept may be by itself an impediment to use this tool to assess the risk of incidental nanoparticles present in industrial workplaces. Summarizing, this decision tree method allows the classification of the risk in three different levels between Nano1 (low) to Nano3 (high), each one of them with associated control measures proposed by the method [17].

4. Conclusions

This review provided an overview on different Control Banding approaches for occupational risk assessment of nanomaterials, showing the clear tendency to apply these methods to study engineered nanomaterials. Nevertheless, considering the abundance of incidental nanomaterials and their potential exposure risks, namely in workplaces, this review intended to highlight this approach application for incidental nanomaterials.

Besides showing various Control Banding methods, the results of the current review show that although some of these CB tools have potential of being used for managing the risk of exposure to incidental nanomaterials, so far it is not common to use such approach. Most authors of the tools highlight the fact that their purpose is to protect workers against consequences of exposure to manufactured nanomaterials, meaning that if these methods are ever used to incidental ones, an adaptation will be needed for most (if not all) of them.

Extensive changes would be necessary to adapt methods like IVAM Guidance, decision tree of the EPFL, ANSES and the Precautionary Matrix for Synthetic Nanomaterials, to incidental nanomaterials, since their approach is clearly outlined for ENM and lacks flexibility for a different application. On the contrary, CB Nanotool does not require much adaptation for incidental nanomaterials, as it allows the user to classify factors as “unknown”, making it suitable for this purpose. Other tools, like Stoffenmanager Nano and NanoSafer, may eventually be suitable for incidental nanomaterials, but this application would require several modifications, especially on their inputs as some of them are not easily obtained for incidental materials (for example shape, solubility and toxicological data).

Screening the characteristics of the different CB methods mentioned in this review, the major challenge to use either of them to incidental nanomaterials is most likely the input data, as there are no safety materials datasheets available or information accessible through literature review. Additionally, inputs for exposure bands require data related to the emission, which is more challenging to for incidental nanomaterials than for engineered nanomaterials. Therefore, scoring the parameters for hazard and exposure bands may be a difficult obstacle to overcome.

Nevertheless, as a qualitative approach, Control Banding concept has great potential when applied to nanomaterials, including incidental ones, and there is, therefore, an opportunity to explore and improve this approach to manage the risk of exposure to incidental nanomaterials.

References

[1] European Commission. 2011. Commission Recommendation of 18 October 2011 on the definition of nanomaterial. Off. J. Eur. Union. L 275/38, 38–40.
[2] Hochella M F, Mogk D W, Ranville J, Allen I C, Luther G W, Marr L C, … Yang Y. 2019. Natural, incidental, and engineered nanomaterials and their impacts on the Earth system. Science. 363 (6434).
[3] Erbis S, Ok Z, Isaacs J A, Benneyan J C and Kamarthi S. 2016., Review of Research Trends and Methods in Nano Environmental, Health, and Safety Risk Analysis. Risk Anal. 36 (8), 1644–1665.
[4] Wu W Te, Liao H Y, Chung Y T, Li W F, Tsou T C, Li L A, … Liou S H. 2014. Effect of nanoparticles exposure on fractional exhaled nitric Oxide(FENO) in workers exposed to
nanomaterials. *Int. J. Mol. Sci.*, **15**(1), 878–894.

[5] Levin M, Rojas E, Vanhala E, Vippola M, Ligouri B, Kling K I, … Jensen K A. 2015. Influence of relative humidity and physical load during storage on dustiness of inorganic nanomaterials: implications for testing and risk assessment. *J. Nanoparticle Res.* **17**(8), 1–13.

[6] Bouhouille E, Sinaba T, Laruelle R, Dalle M, Aguerre-Chariol O, Breulet H, and Le Bihan O. 2019. Occupational risk assessment during explosion severity tests of carbon black and MWCNT in a laboratory. *J. Phys. Conf. Ser.* **1323**(1).

[7] Silva F, Arezes P, and Swuste P. 2015. Risk assessment in a research laboratory during sol-gel synthesis of nano-TiO2. *Saf. Sci.* **80**, 201–212.

[8] Zalk D M, Paik S Y, and Chase W D. 2019. A Quantitative Validation of the Control Banding Nanotool. *Ann. Work Expo. Heal.* **63**(8), 898–917.

[9] Gridlelet L, Delbecq P, Hervé L, Boissolle P, Fleury D, Kowal S, and Fayet G. 2015. Proposal of a new risk assessment method for the handling of powders and nanomaterials. *Ind. Health.* **53**(1), 56–68.

[10] Lamon L, Aschberger K, Asturiol D, Richarz A, and Worth A. 2019. Grouping of nanomaterials to read-across hazard endpoints: a review. *Nanotoxicology.* **13**(1), 100–118.

[11] Huang H, Li H, and Li X. 2016. Physicochemical Characteristics of Dust Particles in HVOF Spraying and Occupational Hazards: Case Study in a Chinese Company. *J. Therm. Spray Technol.* **25**(5), 971–981.

[12] Paik S Y, Zalk D M, and Swuste P. 2008. Application of a pilot control banding tool for risk level assessment and control of nanoparticle exposures. *Ann. Occup. Hyg.* **52**(6), 419–428.

[13] Zalk D M, Paik S Y, and Swuste P. 2009. Evaluating the Control Banding Nanotool: a qualitative risk assessment method for controlling nanoparticle exposures. *J. Nanoparticle Res.* **11**(7), 1685–1704.

[14] Dimou K and Emond C. 2017. Nanomaterials, and Occupational Health and Safety - A Literature Review about Control Banding and a Semi-Quantitative Method Proposed for Hazard Assessment. *J. Phys. Conf. Ser.* **838**(1), 2017.

[15] Brouwer D H. 2012. Control banding approaches for nanomaterials. *Ann. Occup. Hyg.* **56**(5), 506–514.

[16] Juric A, Meldrum R, and Liberda E N. 2015. Achieving Control of Occupational Exposures to Engineered Nanomaterials. *J. Occup. Environ. Hyg.* **12**(8), 501–508.

[17] Silva F, Sousa S P B, Arezes P, Swuste P, Ribeiro M C S, and Baptista J S. 2015. Qualitative risk assessment during polymer mortar test specimens preparation - Methods comparison. *J. Phys. Conf. Ser.* **617**(1).

[18] Van Duuren-Stuurman B, Vink S R, Verbiest K J M, Heussen H G A, Brouwer D H, Kroese D E D, … Fransman W. 2012. Stoffenmanager nano version 1.0: Aweb-based tool for risk prioritization of airborne manufactured nano objects. *Ann. Occup. Hyg.* **56**(5), 525–541.

[19] Riediker M, Ostiguy C, Trioloet C, Troisfontaine P, Vernez D, Bourdel G, … Cadène A. 2012. Development of a control banding tool for nanomaterials. *J. Nanomater.* **2012**.

[20] Jensen K, Saber A, Kristensen H, Koponen I, Ligouri B, and Wallin H. 2014. NanoSafer vs 1.1 - Nanomaterial risk assessment using first order modeling. 6th Int. Symp. Nanotechnology, *Occup. Environ. Heal.*, 22–23.

[21] Schneider T, Brouwer D H, Koponen I K, Jensen K A, Fransman W, Van Duuren-Stuurman B, … Tielemans E. 2011. Conceptual model for assessment of inhalation exposure to manufactured nanoparticles. *J. Expo. Sci. Environ. Epidemiol.* **21**(5), 450–463

[22] Höck J, Behra R, Bergamin L, Bourqui-Pittet M, Bosshard C, Epprecht T, … Studer C. 2018. Guidelines on the Precautionary Matrix for Synthetic Nanomaterials. *Fed. Off. Public Heal. FOPHFederal Off. Environ.*, 1–46.

[23] Cornelissen I R, Jongeneelen F, Van Broekhuizen P, and Van Broekhuizen F. 2011. Guidance working safely with nanomaterials and nanoproducts, the guide for employers and employees. 1–17.
[24] Groso A, Petri-Fink A, Magrez A, Riediker M, and Meyer T. 2010. Management of nanomaterials safety in research environment. *Part. Fibre Toxicol.* 7 (1), 40.

[25] Groso A, Petri-Fink A, Rothen-Rutishauser B, Hofmann H, and Meyer T. 2016. Engineered nanomaterials: Toward effective safety management in research laboratories. *J. Nanobiotechnology.* 14 (1), 1–18.