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ORIGINAL ARTICLE

Comparative Risk Assessment of Tasks Involved with Nanomaterials Using NanoTool & Guidance Methods

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KEYWORDS

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ABSTRACT: Assessing the risks related to the advancement of science and technology has always been accompanied by many uncertainties. As a new field of science, nanotechnology faces numerous uncertainties concerning safety, health, and environmental aspects dealing with which requires a proper risk assessment. Accordingly, this study intended to assess the risk of tasks associated with nanomaterials comparatively, examining the risks in eighteen companies in Tehran. The two proposed risk-assessment methods for the activities involving nanomaterials (NanoTool and Guidance) assisted in assessing the risk of their tasks. The results were analyzed using SPSS.22 and the chi-square test and indicated the different outputs of the two methods despite being designed based on the control banding approach. These differences could be attributed to the different risk-assessment parameters that these methods considered. The statistical analysis results also showed no significant relationship between them. Given the large differences and insignificant association between risk assessment results, the guidance method was less effective than the nanotool method. However, straightforwardness and convivence of implementation in the workplace and various research environments make it a helpful method in initial evaluations.

INTRODUCTION

Nanotechnology emerged as a new field in science and technology less than half a century ago, and thus far, has proliferated and affected many scientific and technological sectors [1, 2]. The advent of nanotechnology has given a new life to different branches of science; various industries have developed new products with novel features and applications. Thus, economists consider nanotechnology one of the essential pillars of the future economy, with an estimated turnover of over 60 million dollars by the end of 2019 [3-5].

However, some papers working on nanomaterials' potential environmental and health repercussions have hindered

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nanotechnology's booming growth [2, 6]. Such papers were first published in the 1990s, focusing on this unfavored side of nanotechnology [7]. Since then, many have researched the different effects of nanomaterials on human health and the environment. Results have shown that nanomaterials can affect human health and the environment differently from larger-scale materials, even if they have the same chemical composition [8, 9]. Exposure to nanomaterials can occur in the environment, in the workplace, or after using nanomaterial-based products. Since company and laboratory staff dealing with nanotechnology are at the primary front of exposure to such substances, the risk assessment of their activities has received wide attention [10]. However, insufficient toxicological and exposure data concerning nanomaterials has ruled traditional occupational hygiene approaches out of risk assessment equations; Therefore, different institutions, organizations, universities, and researchers have designed and studied different risk assessment methods for the activities involving nanomaterials [11-13].

Among the proposed approaches for risk assessment of activities involving nanomaterials, the control banding approach has received more attention. Under this approach, various methods have been proposed for the risk assessment of nanomaterials: ANSES, NanoTool, Precautionary Matrix, Stoffenmanager Nano, NanoSafer, and Guidance [14].

In the group of methods mentioned above, the NanoTool method has become popular and has been used in many studies. It has also been suitably applied to assessing nanotechnology work environments [15, 16]. An initial version of this method was proposed in 2008 by Paik et al. [17] for risk prioritization and management in nanotechnology research environments; shortly after that, its adapted version (version 2.0), which was also suitable for use in the workplace, was published by Zalk et al. [18]. Another helpful method is Guidance, which, although not as popular as the NanoTool method and has not been widely used in nanotechnology research and work centers, can be valuable thanks to its similarity to chemical risk assessment methods and simplicity. Non-specialists can easily and quickly implement this method in the workplace.

Given the descriptions so far, this study assessed the risk of activities involving nanomaterials in nanotechnology companies in Tehran. In this study, each activity was assessed by the NanoTool and Guidance methods. Finally, the outputs of the methods were compared to evaluate the performance and select the more optimal method.

MATERIALS AND METHODS

This study was conducted in eighteen nanotechnology companies in Tehran in 2019. In this study, the main activity of each company was identified and assessed using the NanoTool and Guidance methods. Finally, the results of the assessments were compared.

NanoTool

At first, the severity band and the probability band for each activity are determined in this method. The severity score is the sum of the scores of fifteen factors, and eventually, severity falls into one of the “low,” “medium,” “high,” and “very high” bands, depending on the score. The probability score is the sum of the scores of the other five factors, and eventually, the probability falls into one of the “extremely unlikely,” “less likely,” “likely,” and “probable” bands, depending on the score. A matrix is used to determine the risk level. The severity and probability bands of each activity are put into this matrix, and the risk level is obtained (Tables 1 & 2). This method is fully explained by Zalk and Paik [19].

Guidance

In this method, the nanomaterials produced/consumed in each activity fall into one of these hazard bands based on their characteristics: 1, 2, or 3. Each activity also falls into one of the bands I, II, or III, based on the exposure possibility. Finally, the hazard band and the exposure band of each activity are put into the risk determination matrix, and the risk level (A, B, or C) is determined (Tables 1 & 2). This method is fully explained by Cornelissen et al. [20].

Statistical Analysis

The data were analyzed using SPSS.22. This study used the following descriptive statistics parameters: percentage, mean, standard deviation, and frequency distribution. Also, the chi-squared test was used to compare the results of the two methods.

Table 1. Characteristics of NanoTool and Guidance methods [21-24]

Characteristic / Method	Target population	Nanomaterials definition	Severity/ Hazard band	Probability/Exposure band	Risk level/Control band	Uncertainty
NanoTool	Workers; researchers	<100 nm	1 to 4 (Low, Medium, High, Very High)	1 to 4 (Extremely Unlikely, Less Likely, Likely, Probable)	1 to 4 (RL1, RL2, RL3, RL4)	Unknowns assigned 75% of maximum points
Guidance	Employers; employees	1-100 nm	1 to 3 (1, 2, 3)	1 to 3 (I, II, III)	1 to 3 (A, B, C)	Unknown

Table 2. Parameters used in allocation severity/hazard band and probability/exposure band by NanoTool and Guidance methods [21-23]

	Severity/Hazard band						Probability/Exposure band					
Parameters / Method	**size**	**Solubility (biopersistency, stability)**	**Surface chemistry/redox potential/reactivity**	**shape**	**toxicological profile of parent/bulk material**	**toxicological profile of nanomaterial**	**Frequency of exposure**	**Duration of exposure**	**Amount used or present**	**Type of process or dustiness**	**Physical form**	**Number of exposed employees**
NanoTool	+	+	+	+	+	+	+	+	+	+	o	+
Guidance	-	+	-	+	-	-	-	-	-	+	o	-

+: present in model design as an input parameter; -: not present in model design; o: not present in model design, but generally addressed by model or related guideline

RESULTS

The researchers investigated the main activities of each company and identified the activity descriptions, the type of nanomaterials, and engineering controls used to reduce exposure to nanomaterials were identified (Table 3).

The NanoTool method results revealed that 33.33% of the investigated activities had a very high-risk level (RL4), 44.44% had a high-risk level (RL3), and 22.22% had a medium risk level (RL2). The Guidance method results revealed that in 72.22% of the activities, the risk level was high (C), in 22.22%, it was medium (B), and in 5.55%, it was low (A). Table 4 summarizes the results of the survey of each activity using the two used methods.

In order to have a similar comparative basis, two bands of the "severity," "probability," and "controls" in the NanoTool method were merged: "probable" and "likely" in severity bands, "high" and "very high" in probability bands, and "RL3" and "RL4" in control bands were considered together. Therefore, like the Guidance method, the NanoTool method comprised three categories: low, medium, and high- in each group.

The results of the two methods were compared using the Chi-squared test. Comparison of severity & hazard groups, probability & exposure groups, and control band & risk level groups in the two methods indicated no significant relationship between them (Table 5).

Table 6 shows frequencies' differentiations of "low," "medium," and "high" groups for the two methods used.

Table 3. Description of the examined activities

Activity number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Scenario description	Production of cleaning products	producing Tin oxide nanoparticles from Tin-plated copper scrap	Working with metal nanomaterials	Working with Carbon Nanomaterials in the lab	Extraction and purification of sepiolite nanofibers	Working with metal nanoparticles in the lab	study on properties of metal and metal oxide nanoparticles	Working with metal and metal oxide nanomaterials in the lab	Preparing suspensions of solid powder of nanomaterials
Used nanomaterials	Carbon emulsion	SnO	Ag, Al	Carbon sheets	sepiolite nanofibers	Fe, Zn, Sn	Au, SiO_2	Ag, Cu, Ni, Fe_2O_3	ZnO
Activity classification	Working with Nanomaterials in Liquid Media	Handling nanoparticles in powder form	Handling nanoparticles in powder form	Handling nanoparticles in powder form	Handling nanoparticles in powder form	Working with Nanomaterials in Liquid Media	Handling nanoparticles in powder form	Handling nanoparticles in powder form	Handling nanoparticles in powder form
Current Engineering controls	General ventilation	Fume hoods or local exhaust ventilation	Fume hoods or local exhaust ventilation	Fume hoods or local exhaust ventilation	Fume hoods or local exhaust ventilation	General ventilation	General ventilation	General ventilation	Fume hoods or local exhaust ventilation
Activity number	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Scenario description	Research on manufacturing of metal and metal oxide nanomaterials	Production of herbal nanoparticles for use in cosmetic products	Production of lubricants (motor oils)	Production of car catalyst	Mixing CNTs and production nano-composites by the extruder	Electrostatic powder paint production	Synthesis of magnetic nanoparticles with/without polymer coating	Working with silver nanocloid	Synthesis of self-cleaning coatings
Used nanomaterials	MoO_2, NiO_2, Ag	Thyme nanoparticles	Diamond Nanoparticles	Pt	CNTs	SiO_2	Fe_3O_4	silver nanocloid	TiO_2
Activity classification	Generating nanomaterials	Generating nanomaterials	Handling nanoparticles in powder form	Handling nanoparticles in powder form	Handling nanoparticles in powder form	Handling nanoparticles in powder form	Generating nanomaterials	Working with Nanomaterials in Liquid Media	Working with Nanomaterials in Liquid Media
Current Engineering controls	Fume hoods or local exhaust ventilation	Fume hoods or local exhaust ventilation	Fume hoods or local exhaust ventilation	containment	Fume hoods or local exhaust ventilation	General ventilation	Fume hoods or local exhaust ventilation	Fume hoods or local exhaust ventilation	Fume hoods or local exhaust ventilation

Table 4. The results of assessing each activity using the NanoTool and Guidance methods

	Activity number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
NanoTool	**Severity band**	High	High	Very High	Very High	Very High	High	Medium	Very High	High	High	High	High	High	High	High	High	High	High
	Probability band	Likely	Likely	Probable	Likely	Likely	Likely	Likely	Likely	Less Likely	Less Likely	Likely	Likely	Likely	Likely	Probable	Likely	Less Likely	Probable
	Risk level/Control band	RL3	RL3	RL4	RL4	RL4	RL3	RL2	RL4	RL2	RL2	RL3	RL3	RL3	RL3	RL4	RL3	RL2	RL4
	Recommended Controls or Actions	C_3	C_3	C_4	C_4	C_4	C_3	C_2	C_4	C_2	C_2	C_3	C_3	C_3	C_3	C_4	C_3	C_2	C_4
	Upgrade Engineering Controls?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	Yes
Guidance	**Hazard band**	2	2	2	2	2	2	2	2	2	2	1	2	2	3	2	2	2	2
	Exposure band	III	III	III	III	II	III	III	II	III	III	III	III	III	III	III	III	II	II
	Risk level/Control band	C	C	C	C	B	C	C	B	C	C	A	C	C	C	C	C	B	B
	Recommended Controls or Actions	D_3	D_3	D_3	D_3	D_2	D_3	D_3	D_2	D_3	D_3	D_1	D_3	D_3	D_3	D_3	D_3	D_2	D_2
	Priority to take control measures	Highest	Highest	Highest	Highest	Medium	Highest	Highest	Medium	Highest	Highest	Lowest	Highest	Highest	Highest	Highest	Highest	Medium	Medium

C_1: General ventilation; C_2: Fume hoods or local exhaust ventilation; C_3: containment; C_4: Seek specialist advice; D_1: **Use the commonly used measures to control the exposure risks at the workplace that comply with legislation.** This implies: apply sufficient (room) ventilation, if needed, local exhaust ventilation and/or containment of the emission source, and use appropriate personal protective equipment. D_2: **Investigate extra measures that can reasonably be applied.** According to the Occupational Hygienic Strategy, the technical and organizational control measures are evaluated on their economic feasibility. Control measures will be based on this evaluation. D_3: **Apply the precautionary principle.** The Occupational Hygienic Strategy will be strictly applied, and all protective measures that are both technically and organizationally feasible will be implemented.

Table 5. contingency table of activity assessment using NanoTool and Guidance methods

basis of comparison	Method	Group Count (%)			Chi-squared statistic (df)	P-Value
		low	medium	high		
Severity/hazard band	NanoTool	0 (0.0%)	1 (5.6%)	17 (94.4%)	0.132 (2)	0.936
	Guidance	1 (5.6%)	16 (88.9%)	1 (5.6%)		
Probability/Exposure band	NanoTool	0 (0.0%)	3 (16.7%)	15 (83.3%)	0.257 (1)	0.612
	Guidance	0 (0.0%)	4 (22.2%)	14 (77.8%)		
Risk level/Control band	NanoTool	0 (0.0%)	4 (22.2%)	14 (77.8%)	0.309 (2)	0.857
	Guidance	1 (5.6%)	4 (22.2%)	13 (72.2%)		

Table 6. Frequency table for low, medium & high bands of the two used methods

basis of comparison	NanoTool	Guidance low	Guidance medium	Guidance high	Total
Severity/danger band	low	0	0	0	0
	medium	0	1	0	1
	high	1	15	1	17
Total		1	16	1	18
Probability/Exposure band	low	0	0	0	0
	medium	1	2	3	3
	high	3	12	15	15
Total		4	14	18	18
Risk level/Control band	low	0	0	0	0
	medium	0	1	3	4
	high	1	3	10	14
Total		1	4	13	18

DISCUSSION

Assessing the risks associated with technological advancement has always been problematic since the available studies focus on understanding the risks related to new technology are insufficient, researchers tend to use old-valid assumptions and methods, such as the proven methods, for assessing the risks for different chemicals, ambiguity, and confusing research results. Besides, inadequate equipment skills also have a critical part [25, 26]. Nanotechnology is at such a stage. The concurrent application and comparison of the proposed methods for risk assessment of the activities involving nanomaterials can positively reduce the uncertainties associated with these methods. Therefore, this study intended to assess the risk of nanomaterials based on the NanoTool and Guidance methods.

The differences between the results of NanoTool and Guidance methods (tables 4-6) were relatively predictable since these methods have different designs and the input parameters despite the same base (CB) (Tables 1 & 2). As Eastlake et al. [27] suggest, the differences between the parameters and the grouping systems of different risk assessment methods usually lead to differences in their results.

The results of the two methods in determining the severity/hazard group were entirely different (Tables 4-6) due to the stark differences in the parameters involved in determining the severity/hazard group: NanoTool uses information about the properties and toxicity of the parent materials (30%) and nanomaterials (70%) to determine the severity group. In contrast, the Guidance method uses a much simpler method based on only a few properties of nanomaterials for determining the hazard group. In this method, the properties and toxicity of the parent materials are disregarded, and nanomaterials' toxicity has no part in determining the hazard group.

Regarding the determination of the probability/exposure group, the differences between the two methods were less than the determination of the severity/hazard group (Table 4-6). Brouwer [21] states that the basis of NanoTool, Guidance, ANSES, and Precautionary Matrix methods for determining probability/exposure groups relies solely on the release potential; however, methods such as Stoffenmanager Nano and NanoSafer consider the transmission mechanism and modulatory factors in addition to the release potential. However, due to differences in the parameters in determining the probability/exposure group by each method, the results were different.

CONCLUSIONS

If the NanoTool method is selected as a suitable method to assess the risk of activities involving nanomaterials and the Guidance method's acceptance is assessed solely based on a comparison with the NanoTool method, the Guidance method is indeed rendered unfit for assessing the risk of activities involving nanomaterials. However, since the NanoTool method has also been criticized and some researchers have reported serious limitations, disagreeing with the NanoTool results does not mean that the Guidance method is wholly rejected. On the other hand, Guidance is a simple method that can be useful for early evaluations in nanotechnology work & research environments.

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Conflicts of interest

None.

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