

# Chemical Health Risk Assessment of Exposure to Metal Fumes among Employed Workers in a Metal Manufactory with an Electric Arc Furnace

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## Abstract

**Aim:** The aim of this study is a chemical health risk assessment of exposure to metal fumes among employed workers in a metal manufactory with an electric arc furnace based on the United States Environmental Protection Agency (US-EPA) method. **Methods:** This cross-sectional analytical study was conducted in a metal manufactory with an electric arc furnace in 2023. In this study, the method provided by the US-EPA organization was used to assess the health risk. First, workers exposure to Nickel (Ni), Chromium (Cr), Manganese (Mn), and Iron (Fe) metal fumes was measured. Then, the chemical risk assessment of exposure to metal fumes was performed. Finally, data analysis was conducted using the SPSS version 25 software. **Results:** The average concentration of Ni, Cr, Mn, and Fe metal fumes and the total fumes produced in the blast furnace process were evaluated as 0.183, 0.067, 0.308, and 10.55 mg/m<sup>3</sup>, respectively. The results of the chemical risk assessment using the US-EPA method showed that the noncarcinogenic risk was unacceptable for most of the workers who were exposed to metal fumes. The carcinogenic risk level of Ni was acceptable for all workers, but in some workers, the carcinogenic risk level of Cr was unacceptable. **Conclusions:** The employed workers in the metal manufactory with an electric arc furnace are exposed to various heavy metal fumes, so it is necessary to prioritize the intervention programs of technical and engineering controls. Therefore, it is possible to recommend the use of ventilation systems in the workplace and the necessity of performing other control measures.

**Keywords:** Health risk assessment, metal fumes, metal manufactory

## INTRODUCTION

Metal industries, including the steel and casting industry, are the oldest known process to produce desired shapes of metals through melting, pouring the melt into the mold, and cooling and freezing according to the shape of the mold chamber.<sup>[1,2]</sup> In these industries, most acute and chronic lung diseases can be caused by the inhalation of dangerous chemical agents, including metal fumes (such as manganese, cadmium, nickel, copper, chromium, molybdenum, etc.), dust, toxic particles, gases, vapors, and other pollutants in the air.<sup>[3,4]</sup> Lead, magnesium, zinc, copper, aluminum, cadmium, antimony, tin, and beryllium fumes are usually produced in nonferrous castings, and iron oxide is the main fume produced in iron and steel operations.<sup>[5]</sup> “Metal fume fever” may be caused by exposure to these pollutants.<sup>[5,6]</sup> Inhalation and excessive exposure to manganese can cause

neurotoxicity.<sup>[7]</sup> Nickel is a hematotoxic, immunotoxic, neurotoxic, genotoxic, reproductive toxic, pulmonary toxic, nephrotoxic, hepatotoxic, and carcinogenic agent.<sup>[8]</sup> Furthermore, excessive exposure of iron causes gastrointestinal effects in the short term and hypotension, tachycardia, liver necrosis, and sometimes death in the long term.<sup>[9]</sup>

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Risk assessment, which involves describing potential adverse health effects from exposure to environmental hazards, is performed by some agencies and organizations worldwide. Although the exposure and level of detail may be different in organizations or countries, the general framework of these assessments follows the model provided by the National Research Council and divides the risk assessment process into four concepts: (1) risk identification; (2) exposure assessment; (3) dose-response assessment; and (4) risk characteristics investigation.<sup>[10,11]</sup> To protect employees from the adverse effects of chemicals, conducting specific chemical health risk assessments is crucial. Without risk assessment, valuable time and resources may be wasted on less significant risks, while important risks might be neglected.<sup>[12]</sup>

Chemical health risk assessments can be conducted qualitatively, semi-quantitatively, and quantitatively.<sup>[12]</sup> Qualitative assessment involves expressing the severity and probability of consequences with terms such as large, medium, and small. Semi-quantitative methods use statistical scales and mathematical tools for risk estimation, including error states, analysis of their effects, event tree, error tree, and decision tree. In quantitative risk assessment, outcomes are numerically presented and the likelihood is expressed as probabilities or frequencies.<sup>[13]</sup>

The results of Rahimimoghadam *et al.*'s study showed that the average occupational exposure in casting and welding with chromium was less than the recommended level and the risk of carcinogenesis was within an acceptable range, but the risk of noncarcinogenic effects among workers was significant.<sup>[14]</sup> In Mehrifar *et al.*'s study, it was found that gases such as O<sub>3</sub> and NO<sub>2</sub> along with chromium fumes emitted from welding pose a high risk to health.<sup>[15]</sup>

Due to limited research on chemical risks for "furnace operators," this study aimed to evaluate the chemical health risk of metal fume exposure among employed workers in a metal manufactory with an electric arc furnace based on the United States Environmental Protection Agency (US-EPA).

## MATERIALS AND METHODS

### Study design

This cross-sectional analytical study was conducted in the Metal Industry in Isfahan City. In the present study, 10 employed workers in an electric arc furnace manufactory (blast furnace operator) were examined. The high risk of exposure of workers to various metal fumes emitted from the furnace was the reason for choosing these workers to conduct the present study.

### Sample collection and analysis

Different metal fumes, including Chromium (Cr), Nickel (Ni), Manganese (Mn), and Iron (Fe), were measured using the NIOSH 7300 method.<sup>[16]</sup> The sampling equipment included a 30 mm diameter cellulose ester membrane filter with a 0.8 μm pore size, a nylon cyclone, a personal air sampling device with

a 2 L/min flow rate and a digital calibrator. Sampling involved connecting the filter to the worker's collar in the respiratory area using a holder, and metal fumes were collected with a personal sampling pump. The sampling duration ranged from 1 to 4 h to ensure the fume concentration on the filter did not exceed 2 mg. For accuracy, one control sample was collected for every 10 samples. Finally, the samples were analyzed using inductively coupled plasma mass spectrometry.

### Chemical health risk assessment

The risk assessment method used in this study was suggested by the US-EPA.<sup>[17]</sup>

In this method, exposure time (ET) and exposure concentration (EC) values were calculated according to working conditions. The EC was calculated using Equation 1.

$$EC = \frac{CA \times ET \times EF \times ED}{AT} \quad (1)$$

EC: Exposure concentration in air (μg/m<sup>3</sup>), CA: Concentration in ambient air (μg/m<sup>3</sup>), ET: Exposure time (h/day) (assumed 8), EF: Exposure frequency (day/years) (219 assumed), ED: Duration Exposure (years) (assumed 25), AT: The average time that for risk (h) (for noncarcinogenic risk equal to AT = 25 year × 365 day/year × 24 h/day = 219,000 (h), for carcinogenic risk equal to AT = 70 year × 365 day/year × 24 h/day = 631,200).

To calculate the noncarcinogenic risk of the compounds, the hazard ratio (HQ) was calculated for each compound (Equation 2).

$$HQ = \frac{EC}{RfD} \quad (2)$$

EC: Exposure concentration (μg/m<sup>3</sup>). If the HQ value is >1, there is a potential health risk from exposure, and if the HQ is <1, there is probably no acceptable risk of noncarcinogenic effects.<sup>[17]</sup>

Equation 3 is used to calculate the Lifetime Carcinogenic Risk:

$$LCR = IUR \times EC \quad (3)$$

IUR: Inhalation unit risk (μg/m<sup>3</sup>). Based on the proposal of the WHO, the risk range of 10<sup>-5</sup> and less is acceptable and values >10<sup>-5</sup> are considered to be a carcinogenic risk.<sup>[18-20]</sup>

### Data analysis

Data analysis was conducted using the IBM SPSS software version 25 made by SPSS Inc. in USA. Descriptive and analytical statistical tests were used to evaluate quantitative variables, including the mean and standard deviation.

## RESULTS

### Demographic information and particulate matter in the air

The demographic characteristics of the examined samples, including height, weight, age, body mass index, duration, frequency, and time of exposure are indicated in Table 1.

The highest and lowest particulate matters in the air are related to Fe and Cr, respectively. In Table 2, a comparison between the concentration of metal fumes measured in the air and the threshold limit value- time-weighted average (TLV-TWA) recommended by the ACGIH has been showed. According to this table, the average concentration of metal fumes of Mn and Fe as well as the total concentration of metal fumes was higher than their TLV-TWA, but the average concentration of metal fumes of Ni and Cr was lower than their TLV-TWA.

### Chemical health risk assessment of different fumes

Table 3 indicates the reference doses and slope factors values of metals measured for health risk assessment, both carcinogenic and noncarcinogenic. Furthermore, the input parameters of the study for risk assessment are shown in Table 4.

The results of the chemical health risk assessment of workers exposed to different metal fumes are demonstrated in Table 5.

**Table 1: Demographic characteristics and duration, time, and frequency of exposure of the workers**

Parameter	Mean±SD
Weight (kg)	70.73±8.73
Height (cm)	173.31±3
Age (years)	34±3
BMI	23.5±1
Exposure time (h/day)	8
Exposure frequency (days/year)	312
Exposure duration (years)	9.10±2.42

SD: Standard deviation, BMI: Body mass index

**Table 2: Comparison between measured metal fumes concentrations in air (mg/m<sup>3</sup>) and threshold limit value-time-weighted average recommended by the ACGIH**

Type of pollutant	Average concentration (mg/m <sup>3</sup> )	TLV-TWA (mg/m <sup>3</sup> )
Ni	0.183	1.5
Cr	0.067	0.5
Mn	0.308	0.02
Fe	10.55	5
Total	11.108	5

Ni: Nickel, Cr: Chromium, Mn: Manganese, Fe: Iron, TLV-TWA: Threshold limit value-time-weighted average, ACGIH: American conference of governmental industrial hygienists

**Table 3: Reference dose for noncarcinogenic metals and slope factor for carcinogenic metals**

Heavy metals	RFD <sub>inh</sub> (mg/kg.days)	SF <sub>inh</sub> (mg/kg.days)-1	Reference
Cr (VI)	3.00E-05	4.10E+01	[21]
Mn	1.43E-04	-	
Ni	2.06E-02	8.40E-02	
Fe	0.7	-	

Ni: Nickel, Cr: Chromium, Mn: Manganese, Fe: Iron, RFD: Reference dose, SF: Slope factor

According to this Table, the noncarcinogenic risk in most of the workers exposed to the Ni, Cr, Mn, and Fe fumes was unacceptable. However, the carcinogenic risk level of Ni was acceptable for all workers, but in some workers, the carcinogenic risk level of Cr was unacceptable.

## DISCUSSION

In this study, exposure to metal fumes in a group of blast furnace operator workers in the metal manufactory with an electric arc furnace was investigated based on the US-EPA risk assessment method. As shown in Table 2, the average fume concentration of Ni, Cr, Mn, Fe, and the total fume concentration of metal compounds was 0.183, 0.067, 0.308, 10.55, and 11.108 mg/m<sup>3</sup>, respectively. A comparison between the concentration of metal fumes measured in the air and the TLV-TWA recommended by ACGIH showed that the concentration of manganese and iron metals was higher than the TLV-TWA. The results of Table 5 showed that in all operators, the level of carcinogenic risk of Ni was acceptable, but in some operators, the level of carcinogenic risk of Cr was unacceptable. Furthermore, in most of the operators, an unacceptable noncarcinogenic risk was determined when exposed to metal fumes of Ni, Cr, Mn, and Fe.

The study by Singh *et al.* on workers' exposure to respirable suspended particulate matter in small-scale foundry industries showed that a majority of workers in small and medium-sized companies lack appropriate protective equipment due to a combination of insufficient worker knowledge and negligence from both management and workers. Consequently, this results in respiratory symptoms among workers, highlighting the importance of providing training on health and safety practices in the workplace.<sup>[22]</sup> The results of Susihono and Gede Adiatmika study in a foundry industry indicated that workers' respiratory exposure to air pollutants was higher than the permissible limit.<sup>[23]</sup>

A study by Aguilera *et al.* was conducted to assess the risk of exposure to heavy metals produced from street dust using the US-EPA assessment method. In this study, the level of heavy metals in street dust confirms a significant risk to health and requires monitoring and approaches to reduce such toxic levels. Among the measured elements, the average values of risk indicators (noncarcinogenic risk) were the highest for As, Cr, and Pb. Furthermore, the average values of risk indicators (carcinogenic risk) for as were determined to be within the tolerable risk range for children and adults. In the case of lead, the average amount of carcinogenic risk indicators was also within the tolerable range for children.<sup>[24]</sup> Because this study was conducted in an industrial setting, the worker exposure level and worker ET were higher than the above studies, resulting in an increased risk of worker exposure.

In the study of Kalteh *et al.* "Health Risk Assessment of Metal Fume in Iranian Mineral Salt Company" was determined that all concentrations of fumes were below permissible limits.

Nevertheless, carcinogenic and noncarcinogenic risks cannot be ignored.<sup>[25]</sup> The results of this study were consistent with the present study. Therefore, it seems necessary to take control measures to reduce health risks for workers, such as reducing the working hours of operators and using ventilation systems. Mohammadian *et al.*'s study on health risks from exposure to total and manganese fume in the welding process of a metal industry revealed that the average concentrations of total and manganese fumes generated during shielded metal arc welding were approximately 2 and 22 times higher than the ACGIH recommended limits, respectively.<sup>[26]</sup>

### Limitations of the study and suggestions for future research

Workplace variability, including fluctuating production levels and evolving technologies, poses challenges in obtaining consistent and representative data over time, impacting the reliability of risk assessments. In addition, worker cooperation may be lacking in some cases. Future studies could explore specific metal components in metalworking fumes, analyze the influence of work practices on fume generation and exposure, and extend chemical risk assessment to related jobs.

### CONCLUSIONS

According to this study, the exposure level of blast furnace operators, the concentration of Mn and Fe, and the total fumes produced were higher than recommended by ACGIH and TLV-TWA. The results of this study indicated that the risk of noncarcinogenicity in the majority of operators exposed to the evaluated metal fumes (Ni, Cr, Mn, and Fe) was unacceptable. There was a risk of carcinogenicity of Cr among some operators, and the results of their risk assessment were unacceptable. However, for Ni, an acceptable risk of carcinogenesis was observed. Therefore, it is possible to recommend the use of ventilation systems in the workplace and the necessity of performing other control measures. The results of this study can help to perceive the health risks caused by fumes and chemicals in metal industries.

**Table 4: Input parameters of the study**

Operator	Work experience	Weight	Concentration (mg/m <sup>3</sup> )			
			Cr	Mn	Ni	Fe
1	14	72	0.004	0.013	0.30	0.22
2	5	68	0.01	0.0086	0.29	1.31
3	8	74	0.08	0.50	0.013	8
4	9	65	0.03	0.08	0.0028	12
5	10	68	0.10	0.28	0.46	20
6	11	84	0.07	0.12	0.13	16
7	7	71	0.01	0.80	0.17	5
8	8	92	0.07	0.28	0.15	10
9	9	67	0.20	0.40	0.06	15
10	10	66	0.10	0.60	0.26	18

Ni: Nickel, Cr: Chromium, Mn: Manganese, Fe: Iron

**Table 5: Chemical health risk assessment of different metal fumes using the United States environmental protection agency method**

Variables	OP 1	OP 2	OP 3	OP 4	OP 5	OP 6	OP 7	OP 8	OP 9	OP 10
Ni										
Carcinogenicity										
RS	2.45	8.45	6.06	1.47	2.68	8.34	6.94	6.99	3.15	1.52
	E-6	E-7	E-8	E-8	E-6	E-7	E-7	E-7	E-7	E-6
RL	A	A	A	A	A	A	A	A	A	A
Noncarcinogenicity										
RS	1.63	0.56	0.04	0.01	1.79	0.56	0.46	0.47	0.21	1.01
RL	NA	A	A	A	NA	A	A	A	A	NA
Cr										
Carcinogenicity										
RS	1.87	1.67	2.13	8.99	3.33	2.56	2.33	1.87	6.00	3.33
	E-6	E-6	E-5	E-6	E-5	E-5	E-6	E-5	E-5	E-5
RL	A	A	NA	A	NA	NA	A	NA	NA	NA
Noncarcinogenicity										
RS	14.93	13.33	170.67	72.00	266.67	205.33	18.67	149.33	240.00	266.67
RL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fe										
Noncarcinogenicity										
RS	0.04	0.07	0.73	1.23	2.29	2.01	0.4	0.91	1.54	2.06
RL	A	A	A	NA	NA	NA	A	A	NA	NA
Mn										
Noncarcinogenicity										
RS	10.18	2.41	223.78	40.28	156.64	73.85	313.29	125.31	201.40	335.6
RL	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

OP: Operator, RS: Risk score, RL: Risk level, NA: Not available, A: Available, Ni: Nickel, Cr: Chromium, Mn: Manganese, Fe: Iron, US: United States

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## Declaration of interest's statement

The authors declare no competing interests.

## Ethics code

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## Authors' Contributions

Reza Esmaeili: Research Conceptualization, Final Approval; Karim Ebrahimpour: Methodology Design, Critical Revision; Sayed Vahid Esmaeili: Data Analysis, Critical Revision; Azim Karimi: Data Collection, Critical Revision; Mohammad Kamranifar: Research Conceptualization, Critical Revision, Final Approval; Mojtaba Nakhaei Pour: Data Collection, Critical Revision; Hossein Ebrahimi: Data Collection, Final Approval.

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