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Comparative assessment of carcinogenic risk of respiratory exposure to 1,3-Butadiene in a petrochemical industry by the US Environmental Protection Agency (USEPA) and Singapore Health Department methods

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ABSTRACT

Introduction: 1,3-Butadiene is a carcinogenic compound that can be emitted to the atmosphere from several sources like petrochemical industry. One way to determine the level of carcinogenic and health effects of respiratory exposure to pollutants in the workplace is to use risk assessment methods. The aim of this study was to comparative assessment of carcinogenic risk of respiratory exposure to 1,3-Butadiene in a petrochemical industry by the US Environmental Protection Agency and Singapore Health Department methods.

Material and method: This cross-sectional study was carried out in a petrochemical industry that producing copolymer ABS (acrylonitrile, butadiene, styrene) in Iran in 2018. Occupational exposure to 1,3-Butadiene was measured according to the NIOSH 1024 method. Cancer risk assessment was done according to the United States Environmental Protection Agency (USEPA) and Singapore semi-quantitative methods.

Results: The average occupational exposure to 1,3-Butadiene during work shift among all participants was 560.82 ± 811.36 µg.m-3 (0.253 ± 0.367 ppm) and in all cases was below the occupational exposure limit. The average lifetime cancer risk in USEPA method in the present study was 2.71 × 10-3, also in this method 82.2% of all exposed workers were in the definite carcinogenic risk level and 17.8% were in the probable carcinogenic risk level. The results of the Singapore health department method showed that 91.2% of all subjects were in the probable carcinogenic risk level and 8.8% were in the definite risk level.

Conclusion: The findings in present study showed that the results of the Singapore semi quantitative risk assessment method are not in good agreement with the results of the quantitative risk assessment method proposed by the US Environmental Protection Agency. Therefore, given the high accuracy and thoroughness of the US Environmental Protection Agency's risk assessment methodology as a worldwide reference method for assessing the carcinogenic and health risk of exposure to chemicals, it is recommended to use this method instead of the Singapore method in future studies.

Keywords:

1,3-Butadiene, Carcinogenic risk, US Environmental Protection Agency method, Singapore Health Department method.

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1. Introduction

The compounds released from refineries and petrochemicals mainly contain a combination of toxic chemicals such as volatile organic compounds (such as 1,3-butadiene, benzene, etc.), heavy metals, and polycyclic aromatic hydrocarbons [1]. Cohort studies have shown that there is a strong correlation between occupational exposure to 1,3-butadiene and cancer in the blood and lymphatic systems [2]. The present study aimed to comparative assessment of the carcinogenic risk of respiratory exposure to 1,3-Butadiene in a petrochemical industry by the US Environmental Protection Agency and Singapore Health Department methods.

2. Material and Methods

This cross-sectional study was conducted in a petrochemical industry producing acrylonitrile, butadiene, and styrene (ABS) copolymers in Iran in 2018. Occupational exposure to 1,3-butadiene was measured according to the National Institute for Occupational Safety and Health method (NIOSH 1024) [3]. Samples were collected by using activated carbon adsorbent tubes and personal sampling pump with a flow rate of 200 ml/min. Then, by using the optimal NIOSH 1024 method, the extraction of the analyte was carried out by chemical recovery method [3]. Finally, 1µl of the sample was injected into the Gas Chromatography-Flame Ionization Detector (GC-FID) (model CP-3800 gas chromatograph and FID detector, Varian Technologies, Japan).

Cancer risk assessment using the USEPA method: In the present study, to quantitative cancer risk assessment, the USEPA risk assessment methodology and the database of Integrated Risk Information System (IRIS) that provided by USEPA, have been used. In this method, the Lifetime Cancer Risk index (LCR) was used to estimate the carcinogenicity risk of occupational exposure to 1,3-butadiene. LCR is an indicator for determining the likelihood of an increased risk of cancer due to exposure to carcinogenic compounds. The LCR index was calculated using the equation [4]:

$$\mathrm{LCR} = \mathrm{CDI} \times \mathrm{SF}$$

Where CDI is chronic daily intake ($mg.kg^{-1}.day^{-1}$) and SF is the cancer slope factor ($kg.day.mg^{-1}$). The slope factor represents an acceptable range that there is a likelihood of any response for single chemical exposure in a lifetime [5]. In the present study, the amount of SF for 1,3-butadiene was considered as 0.6 kg.day.mg -1 according to IRIS data and previous studies [6]. Chronic daily intake (CDI) indicates exposure to a mass of matter per unit of body weight and time in a relatively long period. CDI was computed using the following equation [6, 7]:

$$\mathrm{CDI} = \frac{C_a \times IR \times ED \times EF \times LE}{BW \times ATL \times NY}$$

Where Ca is the concentration of 1,3-butadiene (mg/m^3) in the sampling area. IR is the mean inhalation rate (m^3/h), ED denotes the exposure time (hours/week), EF is the exposure frequency (week/year), LE indicates exposure duration (years), BW is the body weight (kg) and ATL is the average lifetime (in years) and NY is the exposure duration in one year (day).

Cancer risk assessment using the Singapore Health Department methods: Given that the 1,3-butadiene compound is in group 1 of human carcinogens, the hazard rate of 5 was considered in the present study. Then the exposure rate (ER) was calculated using the actual level of exposure of the workers using the following equation:

$$E = \frac{M \times D \times F}{W}$$

Where E is rate of weekly exposure in milligrams per cubic meter or ppm, F is frequency of exposure per week, M is rate of exposure in milligrams per cubic meter or ppm, D is average duration of each exposure in terms of hours and W is average working hours a week. Finally, the risk rate was calculated using the following equation:

$$\text{Risk Rate} = (HR \times ER)^{0/5}$$

Where HR is hazard rate and ER is exposure rate [8].

3. Results and Discussion

The average occupational exposure to 1,3-Butadiene during work shift among all participants was 560.82 ± 811.36 µg.m-3 and in all cases was below the occupational exposure limit. The results of studies conducted in the petrochemical industry in Finland and Portugal to assess 1,3-butadiene exposure showed that in full-shift breathing zone samples almost 70% of the results were less than 0.2 ppm [9]. In the present study, the concentration of 1,3-butadiene in 65.5% of samples were below 0.2 ppm. The results of the study conducted by Akerstrom et al. in the refinery and petrochemical industry indicated that occupational exposure to 1,3-butadiene is significantly lower than the occupational exposure limit (OEL) [10]. The mean lifetime cancer risk (LCR) index of participants in the present study was $2.71\times10^{-3} \pm 3.77\times10^{-3}$. 82.2% of all exposed workers were in the definite carcinogenic risk level and 17.8% were in the probable carcinogenic risk level. The chronic daily intake (CDI) and lifetime cancer risk (LCR) among all studied workers according to the occupational units are presented in Table 1. The results of carcinogenic risk assessment in different occupational units showed that the highest mean lifetime cancer risk was observed in the safety and fire-fighting station workers with a value of 7.75×10^{-3}, After the mentioned unit, the highest value of calculated LCR were in the laboratory, dryer, compound 2, compound 1, installation and poly-butadiene latex units with the values of 5.38×10^{-3}, 5.17×10^{-3}, 3.47×10^{-3}, 2.62×10^{-3}, 2.60×10^{-3} and 2.56×10^{-3}, respectively. The lowest amount of LCR index in the present study was obtained in the workers of packing and mechanical repair units with the values of 4.56×10^{-5} and 1.26×10^{-4}, respectively. Although the participants' exposure to 1,3-butadiene was below the OEL, most of the carcinogenic risk values were within the definitive risk level range. This can be explained by the high value of 1,3-butadiene hazard rate, which led to has a high slope factor (SF) among volatile hydrocarbons. Since International Agency for Research on Cancer (IARC), have classified this chemical agent as carcinogenic to humans by inhalation and also because of the high slope factor of 1,3-butadiene, exposure at low levels to this compound in occupational and non-occupational environments can affect people's health. [4, 10] . Other reasons for high values of LCR in the present study can be the existence of a high exposure frequency and working hours over 48-hours per week in all of the studied units. The results of the study conducted by Zhang et al. in the refinery and petrochemical industry in China showed that the average LCR from respiratory exposure to 1,3-butadiene in the refinery areas was 1.37×10^{-4} and located in a definite carcinogenic risk level [7]. The results of the Singapore health department method showed that 91.2% of all subjects were in the probable carcinogenic risk level and 8.8% were in the definite risk level. Other results obtained in the Singapore health department method are given in Table 2. The highest carcinogenic risk was related to the safety and fire-fighting department with a risk rating of 3.517. After that, dryer, compound 1, poly butadiene latex, laboratory and installation units, have risk rating values of 3.446, 3.315, 3.108, and 2.868, respectively and have the highest risk rating values among all studied occupational units. The lowest risk rating was determined in two units of packaging and mechanical repairs with a value of 2.236. Also, the values of carcinogenic risk in all studied occupations has been calculated and the results of two methods of quantitative and semi-quantitative carcinogenic risk assessment have been compared among the occupations that have the highest values of carcinogenic risk (Table 3).

It was found that in both risk assessment methods, the highest values of carcinogenic risk were calculated in the safety and fire-fighting department, and the lowest risk values were calculated in the packaging and mechanical repair units (Tables 1 and 2). Given that the highest and lowest mean respiratory exposure to 1,3-butadiene has been observed in these units, the reason for this can be explained. In other cases, the risk levels in the USEPA method were much higher than the results of the Singapore Health Department method, which is consistent with the results of the study of Mohammadian et al. [8]. One of the main reasons for this difference is that the USEPA method also considers important factors such as the exposure duration, body weight, and inhalation rate according to their age. The results showed that in laboratory and compound 2 units, the work experience of individuals is higher than other units, due to the lack of work experience factor in the Singapore health department method the calculated cancer risk values in the mentioned units are much lower compared to results of the USEPA method. Also, in the USEPA method the values of the slope factor are presented exclusively for each compound, while in the Singapore health department method, the values of risk rates of different pollutants are ranked as a category of substances with almost similar toxicity. This issue can reduce the sensitivity and accuracy of the method.

4. Conclusions

The findings of the present study showed that the results of Singapore's semi-quantitative risk assessment method are not consistent with the results of the quantitative method proposed by the US Environmental Protection Agency. Therefore, due to the high accuracy and comprehensiveness of the US Environmental Protection Agency's risk assessment method as a reference method in the world to assess the carcinogenic and hygienic risk of chemicals, it is recommended to use this method instead of Singapore's semi-quantitative risk assessment method in future studies.

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Table 1. Chronic daily intake (CDI) and carcinogenic risk assessment results in different occupational units

Occupational Unit		Chronic Daily Intake (CDI) mg.kg -1.day -1	Mean Lifetime Cancer Risk (LCR) without unit	Carcinogenic Risk Level (Percent)		P*
				Definite	Probable	
Safety and fire-fighting		1.29 ×10-2	7.75 ×10-3	100	0	0.023
Laboratory		8.96 ×10-3	5.38 ×10-3	80	20	
Operation	Compound 1	4.36 ×10-3	2.62 ×10-3	100	0	
	Compound 2	5.79 ×10-3	3.47 ×10-3	100	0	
	polybutadiene latex (PBL)	4.28 ×10-3	2.56 ×10-3	100	0	
	Dryer	8.36 ×10-3	5.17 ×10-3	100	0	
	Power plant	2.27 ×10-3	1.36 ×10-3	100	0	
	Coagulation	4.93 ×10-4	2.96 ×10-4	75	25	
	Packing	7.6 ×10-5	4.56 ×10-5	0	100	
Repair / Technical Inspection / Monitoring / services	Mechanical repairs	2.11 ×10-4	1.26 ×10-4	50	50	
	Electrical repairs	1.03 ×10-3	6.18 ×10-4	50	50	
	Installation	4.30 ×10-3	2.60 ×10-3	100	0	
All Units		4.51 ×10-3	2.71 ×10-3	82.2	17.8	

* Kruskal – Wallis test

Table 2. Average cancer risk among studied workers by Singapore health department method

Occupational Unit		Hazard Rate (HR)	Exposure Rate (ER)	Risk Rate (RR)	Risk Level (Percent)	
					Definite	Probable
Safety and fire-fighting		5	2.5	3.51	20	80
Laboratory		5	1.8	2.86	20	80
Operation	Compound 1	5	2.2	3.31	0	
	Compound 2	5	2	3.10	0	100
	polybutadiene latex (PBL)	5	2.4	3.44	0	100
	Dryer	5	1.5	2.69	0	100
	Power plant	5	1.5	2.69	0	100
	Coagulation	5	1.25	2.47	0	100
	Packing	5	1	2.23	0	100
Repair / Technical Inspection / Monitoring / services	Mechanical repairs	5	1	2.23	0	100
	Electrical repairs	5	1.25	2.46	0	100
	Installation	5	1.8	2.86	0	100
All Units		5	1.64	2.78	8.8	91.2

Table 3. The carcinogenic risk of respiratory exposure to 1,3-butadiene based on type of occupation

Occupation	USEPA Method			Singapore health department method		
	Life Cancer Risk	Risk Level		Risk Rate	Risk Level	
		Definite	Probable		Definite	Probable
Laboratory device analysis expert	1.8×10-2	100	0	4.47	100	0
Head of Safety and Fire-fighting Department	9.3×10-3	100	0	3.66	50	50
Compound Super Mixer Operator	4.2×10-3	100	0	3.20	0	100
Polybutadiene Latex unit services	6.2×10-3	100	0	2.85	0	100
Firefighters	6.85×10-3	100	0	3.44	0	100
Expert in measuring industrial vibrations	6.65×10-3	100	0	3.46	0	100
Senior Mechanical and Mechanical Technician	6.2×10-3	100	0	2.85	0	100
Dryer unit preparation operator	4.00×10-3	100	0	2.61	0	100

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