Quantitative risk assessment of respiratory exposure to acrylonitrile vapor in petrochemical industry by U. S. Environmental Protection Agency method: a cross-sectional study

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Abstract

Acrylonitrile is a potential carcinogen for humans, and exposure to this substance can cause adverse effects for workers. This study aimed to carcinogenic and health risk assessment of acrylonitrile vapor exposure in exposed personnel of a petrochemical complex. This cross-sectional study was performed in 2019 in a petrochemical complex. In this study, to sample and determine acrylonitrile's respiratory exposure, the method provided by the National Institute of Occupational Safety and Health (NIOSH 1601) was used, and a total of 45 inhaled air samples were sampled from men workers, aged 39.43 ± 9.37 years. All subjects' mean exposure to acrylonitrile vapors was 71.1 ± 122.8 μg/m^3. Also, the mean exposure index among all subjects was 0.02 ± 0.034. The non-carcinogenic risk assessment results showed that the mean Hazard quotient index was 4.04 ± 6.93. The mean lifetime cancer risk index was also $2.1 \times 10^{-3} \pm 3.5 \times 10^{-3}$ and was in the definite risk range. Considering that both carcinogenicity and health indicators of exposure to acrylonitrile in the studied petrochemical complex are more than the recommended limits, the necessary engineering and management measures to control and manage the risk to an acceptable level are essential to improving the worker's health.

Key words: acrylonitrile; EPA method; Hazard Quotient; health risk assessment; integrated risk information system; lifetime cancer risk; occupational exposure; petrochemical

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INTRODUCTION

Countless chemicals are introduced to global markets every year, adding to the thousands of chemicals now available worldwide. Therefore, in many workplaces, exposure to chemicals and their hazards has been increased.[1] According to the World Health Organization statistics, approximately four million people worldwide engage in the chemical industry and similar activities annually. One million people have died or become disabled due to hazardous exposure to chemicals.[2]

The petrochemical industry has a high environmental risk among the existing chemical industries because it uses many toxic, hazardous, flammable, and explosive substances in the manufacturing and operation stages.[3] Among these substances, volatile organic compounds are one of the leading air pollution causes. Due to the high evaporation rate and rapid diffusion in the environment, many people are exposed. Consequently, there are irreversible effects on their health in various jobs. Acrylonitrile is also one of the compounds used in the petrochemical industry. Acrylonitrile is a clear, colorless, flammable liquid with an unpleasant and irritating odor.[4] This material, consisting of a vinyl group and a nitrile, produces acrylic fibers, resins, and synthetic rubber products.[5] Poly-acrylonitrile fibers have been widely used in the last two decades to create high-performance composites, including in technologies such as automobiles and aerospace.[6] Acrylonitrile poisoning in humans causes eye and nose irritation, weakness, difficulty breathing, dizziness, impaired decision making, cyanosis, nausea, and seizures. Chronic exposure to this compound has also been shown to damage normal liver and kidney function.[7]

Preliminary epidemiological studies have shown a potential association between occupational exposure to acrylonitrile and respiratory cancer.[8] Subsequently, four extensive cohort studies were performed, but no evidence was presented to prove a cause-and-effect relationship between occupational exposure and cancer, particularly respiratory cancer.[5,9-11] However, epidemiological data indicate that this relationship cannot be completely ruled out.[12]

In 1978, fears that acrylonitrile might be a carcinogen in humans led to limiting occupational exposure in the United States to be more than 2 ppm in the air as the mean hourly weight (TLV-TWA), with a 15-minute limit of 10 ppm

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(TLV-C).[13] In 1979, the International Agency for Research on Cancer classified acrylonitrile as a potential human cancer (Category 2A) based on sufficient evidence of carcinogenicity in laboratory animals and limited evidence in humans.[14] In 1999, citing epidemiological studies, the International Agency for Research on Cancer reduced its classification to human carcinogenicity (Group 2B).[15] Acrylonitrile is also thought to be reasonably a carcinogen.[16]

Risk assessment, which includes the description of potential health side effects due to environmental hazards, is performed by several agencies and organizations worldwide. Although the exposure and level of detail may vary by organization or country, the overall framework of these assessments follows the model presented by the National Research Council, dividing the risk assessment process into four components: 1) risk identification, 2) dose-response assessment, 3) exposure assessment and 4) risk characterization.[17]

The Integrated Hazard Information System is a U. S. Environmental Protection Agency (USEPA) database containing the USEPA's scientific position on the adverse effects on human health resulting from chronic (lifetime) exposure to food or inhalation of chemicals in the environment under certain conditions.[18] It is also a scientific human health assessment program that assesses quantitative and qualitative risk information on the effects that may be caused by exposure to environmental pollutants.[19]

Due to growing concerns about the possibility of their health being affected by occupational and environmental exposures, risk assessment, especially human health risk assessment, has been the focus of attention. Therefore, considering the destructive effects of acrylonitrile on the health of the workforce in high-risk environments, such as the petrochemical industry, and considering that no comprehensive studies have been conducted in the country to assess the health risk and carcinogenicity of acrylonitrile in these industries, as well as the critical role of these industries in the economic dynamism of the country, the present study was conducted to evaluate the carcinogenic risk of occupational exposure to acrylonitrile vapors in a petrochemical company in 2019.

Participants and Methods

Sampling method

This retrospective and cross-sectional study was performed in 2019 in a petrochemical industry producing ABS copolymer (acrylonitrile, butadiene, and styrene). This study was sponsored by Tehran University of Medical Sciences with ethics code of IR.TUMS.SPH.REC.1398.036 in June 2018. The occupations assessed in this study included technicians and technical workers.

The model proposed by the National Institute of Occupational Safety and Health (NIOSH) called Similar Exposure Groups was used to determine the sample size. Forty-five inhaled air samples (3 samples per person) were sampled. The inclusion criteria were at least 12 months of work experience, having respiratory exposure to acrylonitrile vapors according to the preliminary survey results, non-smoking, and enough consent to participate in the study.

NIOSH 1604 method was used for sampling. According to the mentioned method, for the sampling of inhaled air, absorbent tubes containing activated charcoal of SKC Company (Chino Hills, CA, USA) with a ratio of 50/100 and a sampling pump made by the same company and calibrated with a soap bubble tube were used. Sampling flow was calculated according to the method to prevent the phenomenon of pollutant cracking of 150 mL/min. According to NIOSH Strategy 6, sampling was performed in three 90-minute periods. Also, to cover the maximum exposure hours of individuals, environmental samples were collected in different parts of the industry. After collecting the samples, the adsorbent tubes were transferred to the laboratory for analysis and quantification.

Sample preparation and analysis

Samples were prepared according to NIOSH 1604 method. The activated carbon content in the front and back of the sampling tube was transferred to separate vials with a volume of 2 mL. The samples were extracted by chemical recycling using 1 mL of benzene (99.5%) made by the MERCK Company (Kenilworth, NJ, USA). It took at least 30 minutes to completely remove acrylonitrile from activated carbon.

After extraction, the samples were analyzed by gas chromatography device VARIAN CP-3800 made in Tokyo, Japan, equipped with an ion flame detector with a capillary column with a minimum length of 25 meters and an inner diameter of 0.25 mm. For this purpose, based on the 1604 NIOSH method and using the standard mother solution (from this solution, concentrations of 1, 5, 10, 50, 100, and 200 ppm were prepared and injected into the gas chromatography device), the machine was adjusted and calibrated (R2: 0.9976). The initial column temperature was 50°C, which increased by 10°C/min to 100°C, and the final analysis time of each sample was 5.1 minutes. The injection site temperature and the detector were adjusted to 200 and 220°C, respectively. Helium gas with a flow rate of 2 mL was also used as a carrier gas. The injection volume was 1 μL with a split ratio of 3, injected into the device with a 10 μL Hamilton syringe.

Occupational exposure assessment

The permissible occupational exposure to acrylonitrile vapors was 2 ppm (4.34 mg/m^3) based on the American Society of Industrial Health Professionals. Also, the occupational exposure index (E_i) was calculated, and the level of exposure of individuals was evaluated based on it[20]:

$$E_i = \left(\frac{C_i}{TLV_{TWA_i}}\right)$$

C_i is the amount of acrylonitrile vapor concentration measured from individuals' respiratory area during work shifts in terms of mg/m^3 and TLV_{TWAi} the amount of occupational exposure acrylonitrile vapors in terms of mg/m^3.

Given that the amount of TLV-TWA provided is assumed to be 8 hours of work per day or 40 hours per week, in cases where the working hours are longer than this, the amount of TLV-TWA is modified using the Scala brief model. In this model, the amount of TWA decreases with an increasing exposure period. To apply this model in unusual encounters, the daily or weekly decrease in the amount of TLV-TWA used is multiplied by the following equation[21]:

$$TLV_{TWA_c} = TLV_{TWA_i} \times (\frac{40}{hr} \times \frac{168 - hr}{128})$$

TLV_{TWAc} is the allowable amount of corrected occupational exposure in terms of mg/m^3 and hour, working hours per week. Thirteen environmental samples were collected to determine the amount of exposure of individuals during rest, traffic, and lunch.

After calculating the concentration of samples, the risk of carcinogenicity and non-carcinogenicity of acrylonitrile was evaluated using the USEPA. However, this method's most important limitation is that it cannot consider the synergistic effects of hybrid solutions.[22]

Carcinogenic risk assessment

Given that acrylonitrile is classified as Category 2B (possibly carcinogenic to humans) by the International Agency for Research on Cancer, the following formula has been used to assess the risk of cancer (lifetime cancer risk, LCR) for acrylonitrile[23]:

LCR = CDI × CSF

Where CSF is slope factor and CDI is chronic daily absorption and calculates from the following equation[24]:

CDI = (C × IR × ED × EF) / (AT × BW)

According to previous studies and the standard of the World Health Organization, the LCR value is more than 1×10^{-4} as a definite risk, the LCR value is between 1×10^{-4} to 1×10^{-5}, the possible risk, The LCR value is divided between 1×10^{-5} to 1×10^{-6}, the possible risk and the LCR value less than 1×10^{-6}, as the minimum risk.[25]

Non-carcinogenic risk assessment

For this purpose, the risk index (HQ) method was used to calculate the non-carcinogenic risk of acrylonitrile, which is calculated from the following equation[24]:

HQ = EC/RFC

Where EC is the exposure concentration and is calculated from the following equation[26]:

EC = (C × ET × ED × EF) / AT

According to the World Health Organization and previous study,[23] if the HQ value is less than 1, there is no significant risk in terms of adverse health effects, and if this value is more than 1, there is a possibility of such effects.

The other parameters are summarized in **Table 1**.

Results

Mean exposure

The mean exposure of employees by job unit is presented in **Table 2** among the occupational units, there is the highest exposure in the safety and firefighting unit employees with a mean of 244.3 ± 228.5 µg/m^3; also, the highest mean exposure index is related to the personnel of the same unit with the value of 0.064 ± 0.059. After safety and firefighting units, the highest concentration of acrylonitrile vapors is present in styrene acrylonitrile (SAN) units, electrical and instrumentation, installations, and mechanics with 155, 140, 69, and 41 µg/m^3, respectively. Exposure index values in SAN, electrical, and instrumentation units, facilities, and mechanics are 0.05, 0.038, 0.019, and 0.012, respectively, after safety, and firefighting units. Maximum and minimum pollutant densities were recorded in safety, firefighting, and acrylonitrile, butadiene, styrene (PBL) units with values of 433.8 and 3.5 µg/m^3, respectively. Also, the lowest mean exposure index is related to PBL unit personnel with a value of 0.0008 ± 0.0001. The results of the collected environmental samples, which

Table 1: Parameters used in the risk assessment model

Parameter	Definition	Unit	Value	Source
C	Concentration	mg/m^3	–	Individual on-site sampling
IR	Respiration rate	m^3/d	6.64 ± 1.66	Reference[27]
ED	Exposure duration	Year	30	Demographic questionnaire
EF	Exposure frequency	Day in a year	300 ± 10	Demographic questionnaire
ET	Exposure time	Hours a day	8 ± 2	Demographic questionnaire
BW	Body mass	kg	75 ± 15	Demographic questionnaire
AT	Average lifetime	For EC: hours	657450	
		For CDI: day	27393	Reference[28]
CSF	Cancer slope factor	$(\frac{mg}{kg-day})^{-1}$	1	Reference[29]
RFC	Reference concentration	mg/m^3	0.002	Reference[30]
CDI	Chronic daily absorption	$(\frac{mg}{kg-day})$	Accounting	–
EC	Exposure concentration	mg/m^3	Accounting	–
LCR	Lifetime cancer risk	–	Accounting	–
HQ	Hazard quotient	–	Accounting	–

Table 2: Exposure of employees to acrylonitrile vapors in different occupational units

Occupational unit	*N*	Minimum concentration*	Maximum concentration*	Mean concentration*	Occupational exposure index
Safety and firefighting	5	7.1 (0.0033)	433.8 (0.2)	244.3 (0.112)	0.064
Laboratory	9	3.1 (0.0014)	62.2 (0.028)	18.2 (0.0083)	0.005
Styrene acrylonitrile	4	7.5 (0.0034)	375.1 (0.172)	155.2 (0.071)	0.05
Coagulation	2	4.1 (0.0018)	64.3 (0.029)	34.1 (0.016)	0.0095
Compound 1	3	4.7 (0.0022)	52.1 (0.024)	27.2 (0.012)	0.007
Compound 2	3	3.5 (0.0016)	28.1 (0.013)	18.2 (0.0082)	0.005
Supervision	3	7.3 (0.0034)	30.2 (0.014)	15.1 (0.0069)	0.0042
Packing	2	3.6 (0.0016)	5.1 (0.0023)	4.3 (0.002)	0.0014
Acrylonitrile, butadiene, styrene	2	3.3 (0.0015)	3.5 (0.0016)	3.4 (0.0015)	0.0008
Dryer	2	3.4 (0.0015)	4.2 (0.002)	3.8 (0.0016)	0.001
Power and instrumentation	4	10.1 (0.0046)	350.8 (0.16)	140.1 (0.064)	0.038
Facilities	4	3.4 (0.0016)	233.1 (0.102)	69.1 (0.0031)	0.019
Mechanics	2	35.1 (0.0016)	46.1 (0.021)	41.1 (0.0019)	0.012

Note: *The unit of data is μg/m^3 (ppm).

are shown in **Table 3**, showed that the highest densities of acrylonitrile vapors were recorded in the lounge of the SAN unit and the control room of the compound unit 1 with values of 4.9 and 3.5 μg/m^3, respectively. In the lounges of PBL and dryer units, the concentration of environmental samples was less than the detection limit.

Table 3: Acrylonitrile vapor concentration values collected in environmental samples

Sampling location	Concentration*
Restaurant	1.2 (0.0006)
Unit 610	3.3 (0.0015)
Compound Control Room 1 (Unit 300)	3.5 (0.0016)
Compound Control Room 2 (Unit 310)	2.5 (0.0012)
Safety and firefighting unit	2.8 (0.0013)
Acrylonitrile, butadiene, styrene unit lounge	ND
Street between packing unit and compound 1	2.4 (0.0012)
Dryer unit lounge	ND
Chemistry laboratory	2.8 (0.0013)
Physical laboratory	2.2 (0.001)
Office Street	1.4 (0.0007)
Styrene acrylonitrile unit lounge	4.9 (0.0022)
Packing unit lounge	2.9 (0.0013)

Note: *The unit of date is μg/m^3 (ppm). ND: Not detected.

Table 4: Mean values of risk ratio in terms of different occupational units studied

Occupational unit	Mean HQ (mean±SD)	Non-carcinogenic risk level (%)	
		Above the limit (HQ > 1)	Below the limit (HQ < 1)
Safety and firefighting	13.05±12.10	60	40
Laboratory	1.05±1.13	44.4	55.6
Styrene acrylonitrile	10.13±10.95	100	0
Coagulation	1.96±2.41	50	50
Compound 1	1.43±1.15	66.6	33.3
Compound 2	1.03±0.74	66.6	33.3
Supervision	0.871±0.721	33.3	66.7
Packing	0.28±0.11	0	100
Acrylonitrile, butadiene, styrene	0.168±0.027	0	100
Dryer	0.217±0.036	0	100
Power and instrumentation	7.68±7.39	75	25
Facilities	3.9.±6.25	50	50
Mechanics	2.45±0.27	100	0

Note: HQ: Hazard quotient, which is a risk index.

Carcinogenicity and non-carcinogenicity risk assessment

The results of non-carcinogenic risk using the HQ method showed that 46.7% of the subjects in the range of permissible non-carcinogenicity (HQ < 1) and 53.3% of the subjects in the range above the allowable limit (HQ > 1) are located. The mean values of risk ratio in terms of different occupational units studied are given in **Table 4**.

The results of carcinogenic risk assessment for the lifetime of exposure to acrylonitrile vapors using USEPA method showed that 80% of the subjects were in the definite risk range and 20% were in the potential risk range. The results obtained from the LCR in terms of occupational units studied are presented in **Table 5**.

Discussion

The study results showed that the mean concentration of acrylonitrile in the studied petrochemical is much lower than the recommended occupational exposure limit (4.34 mg/m^3 or 2 ppm).

A study by Marsh and Zimmerman[16] in 2015 showed that the mean exposure of people working in a chemical plant between 2000 and 2011 was 0.24 ppm. Another study conducted by Thepanondh et al.31 to investigate volatile organic compounds and their health effects in areas adjacent to the petrochemical industry determined the exposure rate in the range of 0.008 to 1.2 μg/m^3. The Bricarello's study[32] obtained the mean value of 0.0052 μg/m^3 for exposure to acrylonitrile vapors, which is

Table 5: Mean values of carcinogenic risk by different occupational units studied

Occupational unit	LCR Index (mean±SD)	Carcinogenic risk level (%)	
		Definite (LCR > 10^{-4})	Possible (10^{-5} < LCR < 10^{-4})
Safety and firefighting	$6.6\times10^{-3}\pm6.0\times10^{-3}$	100	0
Laboratory	$5.9\times10^{-4}\pm6.2\times10^{-4}$	66.6	33.3
Styrene acrylonitrile	$5.2\times10^{-3}\pm5.3\times10^{-3}$	100	0
Coagulation	$1.0\times10^{-3}\pm1.2\times10^{-3}$	100	0
Compound 1	$7.0\times10^{-4}\pm5.6\times10^{-4}$	100	0
Compound 2	$5.9\times10^{-4}\pm4.2\times10^{-4}$	66.6	33.3
Supervision	$4.4\times10^{-4}\pm3.4\times10^{-4}$	100	0
Packing	$1.5\times10^{-4}\pm7.4\times10^{-5}$	50	50
Acrylonitrile, butadiene, styrene	$8.1\times10^{-5}\pm2.9\times10^{-6}$	0	100
Dryer	$1.1\times10^{-4}\pm2.1\times10^{-5}$	50	50
Power and instrumentation	$3.8\times10^{-3}\pm3.6\times10^{-3}$	100	0
Facilities	$2.1\times10^{-3}\pm3.4\times10^{-3}$	75	25
Mechanics	$1.3\times10^{-3}\pm8.4\times10^{-5}$	100	0

Note: LCR: Lifetime cancer risk.

much less than the permissible limits studied and is consistent with the results of the present study.

The highest mean concentration of acrylonitrile is in the respiratory air of people working in safety and firefighting with a mean of 244.3 ± 228.5 μg/m^3 (0.112 ppm); also, the highest mean exposure index is related to people working in the same unit with the exposure index value is 0.064. One of the reasons for this is the constant presence of firefighters in various halls to continuously monitor the industry's safety situation, which intensifies firefighters' exposure to acrylonitrile vapors. Also, firefighters' constant presence during the discharge of pure acrylonitrile into storage tanks exposes them to significant amounts of acrylonitrile vapors. After safety and firefighting units, the highest concentration of acrylonitrile compound is present in SAN units, electrical and instrumentation, installations, and mechanics with 155, 140, 69, and 41 μg/m^3, respectively.

Exposure index values in SAN, electrical and instrumentation units, facilities, and mechanics are 0.05, 0.038, 0.019, and 0.012. In SAN, due to the high temperature during the processing of pure acrylonitrile and the lack of proper ventilation system in this area, exposure to acrylonitrile vapors increases. The electrical and instrumentation unit personnel responsible for troubleshooting the industry's equipment in question have had more respiratory exposure to acrylonitrile vapors (140 μg/m^3) than other units due to visiting various halls. In Compound 1, one of the most important reasons for increasing working peopl's exposure is the existence of four extruder lines and vapors from ABS copolymer production operations at high temperatures in this section.

Each extruder line in this hall has two local ventilation systems, and based on the tests performed, all the hoods are in poor condition. Unit 2 is similar to Unit 1, except that it produces polymeric materials with black pigments. The amount of daily production volume and, consequently, the number of extruder lines in this hall is minor than Compound Hall 1, and also the more area and ease of air entry and exit create a large number of windows in the upper part of the hall walls. So the exposure of employees in this unit is less than workers in the Compound 1 unit.

The HQ method's non-carcinogenic risk assessment results also showed that the mean HQ among all subjects was higher than the allowable limit. 46.7% of the subjects were in the range of permissible non-carcinogenicity (HQ < 1), and 53.3% of the subjects were in the range above the allowable limit (HQ > 1). To date, no study has reported on the extent to which calculated HQ values above baseline one can cause occupational injury.

Chan et al.[33] assessed the exposure and health risks of exposure to toxic pollutants in China's petrochemical complexes. They showed that HQ values were higher than the set standard value (HQ = 1) in five companies due to the pollutants such as benzene, toluene, ethylbenzene, methyl ethyl ketone, Keller forum, and isopropanol. The highest calculated health risk was related to acrylonitrile, the HQ of which was calculated in the range of 43.5–47.8. The final evaluation showed that acrylonitrile is the most observable health risk for employees, consistent with the present study results.[33] The study of Thepanondh et al.[31] that investigated volatile organic compounds and their health effects in the vicinity of petrochemical complexes showed that the concentration of pollutants is a function of proximity to the petrochemical industry. The calculated values of risk indicators for each of the studied areas were less than 1, which indicates that the non-carcinogenic (health) risk due to exposure to volatile organic compounds is lower in the study area.[31] Also, during their study on the risk assessment of consumer goods containing acrylonitrile in the United States, they concluded that in the presence of a concentration of 1 ppt (0.0021 μg/m^3), the non-carcinogenic index was calculated to be 0.053 – 0.238.[34]

Among the reasons for the increase in the mean health index in the present study compared to other studies, we can mention the increase in exposure to acrylonitrile vapors during work shifts, work experience, frequency of exposure, and working hours per day. Given the relationship presented to calculate the non-carcinogenic HQ, it is clear that the increase in these cases leads to an increase in the HQ.

The results of carcinogenic risk assessment for acrylonitrile vapors using the method provided by USEPA and information in the Comprehensive Risk System Database also showed that the overall assessment of the carcinogenicity of longevity index among all subjects is in the definite risk range. (80% of all subjects in the range of definite carcinogenic risk (LCR more than 1×10^{-4}) and 20% in the range of potential risk (LCR between 1×10^{-4} to 1×10^{-5} are located).

It is important to note that despite exposure to concentrations well below the permissible limits, most carcinogenic risk values obtained are in the definite risk range. The high risk of acrylonitrile compound leads to a higher carcinogenicity factor (slope factor). The slope factor or resonance factor is an acceptable range in which there is a possibility of a response per unit of chemical consumption over a lifetime.[35] Because the compound is classified as a Group 2B carcinogen by the International Agency for Research on Cancer. Because of its high slope factor, low levels of exposure to the compound's vapors in both occupational and non-occupational environments can severely affect individuals' health.

This is why this compound's permissible occupational exposure limits are also very low at 2 ppm.[13] Other reasons for the high values of the Longevity Carcinogenic HQ are the work experience in the majority of subjects, high frequency of exposure and also working hours over 48 hours per week in all studied units influencing the rate of chronic daily respiratory absorption (CDI) and consequently the Longevity Carcinogenic HQ.

The results of a study by He et al.[20] in plastic waste recycling plants in China showed that the mean LCR was 1.8×10^{-3} due to respiratory exposure to ABS copolymer vapors in ABS recycling plant areas, which is a definite risk range. This is consistent with the results of the present study. A study by Strother et al.[36] entitled acrylonitrile as a carcinogen, which aimed to review previous studies and research on the carcinogenicity of acrylonitrile, reported that the carcinogenicity rate among the studied mice was in the 95% confidence range of 2.5×10^{-3} and is in the definite risk range. The USEPA conducted a study in 2011 to review the toxicity of acrylonitrile during respiratory exposure, with a concentration of 1 μg/m^3, estimated the overall risk of exposure 3.3×10^{-5} and in the range potential risk.[37] Also, a study conducted by Chen et al.[38] in 2016 to assess the risk of cancer in the lifespan of volatile organic matter emitted from a petrochemical industrial complex in adjacent residential areas showed that the risk of cancer in four selected locations cumulative residential areas around petrochemicals ranged from 9.3×10^{-5} to 1.7×10^{-4}. Also, the LCR for acrylonitrile was calculated between 2.8×10^{-5} to 4.3×10^{-5}, which is in the range of potential risk.[38] A study conducted by Bricarello in collaboration with the California State Resource Organization (ARB) on the measurement of acrylonitrile in ambient air using solid absorber tubes and heat recovery method in 2010 showed that in the presence of inhalation at a concentration of 0.65 μg/m^3, the possible carcinogenic rate of 65 cancers per million was reported, or in other words, the carcinogenicity index was estimated to be 6.5×10^{-5} and stated that the difference in the results showed that the final concentration of the samples depended on the condition of the sample. Further studies showed that the time between measurement and analysis of samples and possibly the room temperature at the sampling time play a significant role in the results.[32]

Among the limitations of the present study are the lack of consideration of the effect of different seasons and air temperature on the dispersion of acrylonitrile vapors, non-consideration of the use or non-use of personal protective equipment, especially respirators, and non-consideration of metabolites in acrylonitrile exposure. The body pointed to the time constraint and the framework defined in the plan because these factors can play an essential role in the rate of respiratory exposure and the level of carcinogenic risk in people exposed to acrylonitrile vapors. Among the strengths of the present study can be the evaluation of respiratory exposure to acrylonitrile vapors and also the evaluation of quantitative carcinogenic and health risk due to exposure to vapors in one of the country's petrochemical industries as industries with a high risk of exposure to acrylonitrile vapors and for It was mentioned for the first time in Iran. The results of this study can lead to a new perspective in the field of carcinogenic and non-carcinogenic risk assessment due to exposure to fumes of hazardous organic compounds such as acrylonitrile in industries with a high risk of exposure to the compound as refineries and petrochemicals as parent industries in the country.

The present study results revealed that the respiratory exposure of acrylonitrile vapors in the studied subjects is lower than the permissible limits in all studied cases. The calculation of carcinogenic and non-carcinogenic HQ due to exposure to acrylonitrile vapors showed that despite the concentrations far below the allowable limits used, most carcinogenic risk values obtained are definite risk range. This is due to the high risk of acrylonitrile compound, leading to a higher carcinogenicity factor than other volatile hydrocarbons. The subjects' high work experience, the frequency of exposure, and the working hours per week increase the value of the carcinogenic HQ in the present study. It was also found that the health HQ's value is in the unauthorized range in more than half of the subjects. Therefore, the results of the present study, the need to use control systems, planning and implementation of management measures to reduce exposure to acrylonitrile vapors, as well as continuous monitoring of the concentration of the compound in the respiratory air through annual measurements and once every six months and monitoring the metabolite. To face it in biological body fluids, to evaluate the effectiveness of control measures taken in the petrochemical industry reveals one of the essential industries in society's dynamics.

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Author contributions
AAS, MSY and VAM collected the data. AK, AGK and FG performed sample analysis. AAS and VAM analyzed the data. All authors contributed equally to draft the manuscript, revise the manuscript and approve the final version.

Conflicts of interest
All the authors have no conflict of interest to declare.

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