International Journal of Reliability, Risk and Safety: Theory and Application

Online ISSN: 2676-3346

OPEN ACCESS

Vol. 7/ Issue 2/ Year 2024/ pp. 101-108
DOI: 10.22034/IJRRS.2024.7.2.9
Received: 14 September 2024, Revised: 14 December 2024, Accepted: 23 December 2024

Available online at: https://www.ijrrs.com

Original Research Article

PHAST Modeling and HAZOP Risk Assessment for NTO Tank in Liquid Propellant Stand

Hamid Isarinia[1*], Shahram Ghanbary Pakdehy[2], Abdulrahman Keshvari[1], Seyyed Reza Karimi[1]

1. Department of Industrial Safety, Safety College, Imam Hossein University, Tehran, Iran

2. Faculty of Chemistry and Chemical Engineering, Malek Ashtar University of Technology, Tehran, Iran

*** heira@chmail.ir**

Abstract

Testing processes of liquid fuels in propulsion engines are complex and associated with high risks. In this research, there are 37 risks identified by the HAZOP method in a static stand of bipropellant N_2O_4/MMH. 48% of these risks have a red and unacceptable high-risk class, and 37% of risks are in the propellant and high-pressure equipment. In this research after the risk assessment with HAZOP method modeling the hazard of MMH and NTO in the test site using PHAST software. One of the most important results of this modeling is that the risk of leakage at the top of the tanks is much higher. In the design of stand tanks, the risk of leakage at the top of the tank can be reduced by increasing the diameter instead of increasing the height, and if tanks with a smaller L/D can be used, we will probably have a smaller radius of pollution. If leakage from the bottom of the tank in normal weather and wind velocity of 5 m/s, the probability of death worker up to 500 meters is 100%. If possible, if tanks with a smaller L/D can be used, we will probably have a smaller radius of pollution.

Keywords: Modeling; PHAST; Risk Assessment; HAZOP; NTO; Tank; Stand; ALOHA.

Nomenclature

I_{SP}	Impulse specific propellant
NTO	Nitrogen tetraoxide
O/F	Oxidizer to fuel mass ratio
P_{cc}	Pressure of combustion chamber
α	Actual fuel-oxide ratio to optimal ratio
$\dot{m}$	mass flow rate
RPA	Rocket propulsion analysis software
PHAST	Process hazard analysis software
TLV	Threshold Limit Value
P&ID	Piping and Instrumentation Diagram
HAZOP	Hazard and operability study
ALOHA	Area Location of Hazardous Atmospheres

1. Introduction

Due to the development of space activities in Iran, the need for propulsion systems is one of the requirements for space development. Based on the document of the comprehensive scientific map of the country approved in 2010, the field of space technology has been prioritized and, in this regard, two important rulings of human access to space and the acquisition of the knowledge of design, construction and launch of geosynchronous satellites have been prioritized and paving the way for the creation and development of design, testing and launch infrastructures has been prioritized [1]. However, the important point of this process is the safety requirements. These systems need to be tested and evaluated before flying and finalizing; perhaps the first document that has addressed the risks is the requirements and issues expressed in the Summary of NASA and USAF hypergolic propellant-related spills and fires [2], in which monomethyl hydrazine (MMH) and nitrogen tetroxide or NTO (N2O4) bipropellant is described as a toxic and high-risk substance. Also, it is mentioned that the N2O4 leak from the Apollo system in 1975 caused damage to the staff [2]. Also, in the AIAA-SP-086-2006 standard [3], while declaring this substance as a space bipropellant, it has declared it to be highly toxic and hypergolic with many substances. Looking at the incidents in the NASA and USAF hypergolic propellant-related document, we

---

How to cite this article:
H. Isarinia,S.Ghanbary Pakdehy, A. Keshvari, S. R. Karimi, "PHAST modeling and HAZOP risk assessment for NTO tank in liquid propellant stand," *International Journal of Reliability, Risk and Safety: Theory and Application*, vol. 7, no. 2, pp. 101-108, 2024, doi: 10.22034/IJRRS.2024.7.2.9.

find that propellant work accidents persist, to the point that the N2O4 leak while charging the roll control system in 2006 resulted in employee injuries, which indicates that propellant work accidents are not limited to a specific time. Also, it has stated that one of the safety tasks of the site is to reduce the risks caused by engine combustion [4]. Therefore, according to the mentioned risks, we will review the documentation and safety standards governing the static stand of liquid fuel based on the above propellant. Therefore, in this article, we have tried to address this issue specifically.

N_2O_4, or nitrogen tetroxide, is one of the most widely used liquid oxidizers in space activities. The specifications of N2O4 are: a molecular weight of 92, yellow to brown color liquid (in the solid state, it turns to colorless), freezing point of -11.79 °C, boiling point of 21.15 °C and density of 1.456 g/cm^3. The lethal doses of this substance through inhalation of vapors at 1 hour and the gases at 4 hours are 220 mg/m3 and 88 ppm, respectively. The threshold limit value (TLV) is 2 ppm, and the Threshold works for 15 minutes is 9.4 ppm. It should be noted that the contact limit is not higher than 20 ppm [5].

Note: can be seen in the diagram, hydrazine-based propellants ignition with N_2O_4 at a temperature of 0 °C and a low concentration (less than 5%) [6].

2. Method

2.1 HAZOP Risk Assessment

HAZOP was initially a developed method for systems involved in the behavior of a fluid environment or the flow of materials in process industries, but its application has been steadily expanded in recent years.

In this method, the unit is first divided into smaller components called nodes. In fact, based on the piping and instrumentation diagrams (P&ID), it is tried to separate the whole unit into smaller and independent pieces. Then, the checks on each part are performed separately. How the maps are separated depends on the available information and the desired results. Unit separation into operational nodes is carried out at the beginning of the study by the team leader.

The seven parameters used in this method are flow, pressure, temperature, surface, phase, composition and operation. The first three parameters are the main and most widely used parameters, and the rest of the parameters are also used in special cases.

Guide words or phrases consisting of several words that are used before parameters are visualized in that node and the possibility of quantitative or qualitative deviations from the design idea or the normal state of operation examined. The seven common guiding words and their meanings are given in Table 1.

Table 1. Common Instruction Words Used in HAZOP

Concept	Keyword
A design or a normal state does not occur at all.	NO
Quantitative increase from the design idea or normal state	MORE
A slight decrease from the design idea or the normal state	LESS
Qualitative increase compared to the design idea or normal state	AS WELL AS
Qualitative reduction in relation to the idea of design or normal state	PART OF
A logical reversal of the design idea or normal state occurs.	REVERSE
Something other than the design idea or the normal state	OTHER THAN

Deviations are made from the combination of keywords and parameters, which, in fact, show possible states away from the idea of design or normal operations. Of course, not all possible combinations of keywords and parameters lead to reasonable deviations. For example, it is not possible to combine the NO guide word with the temperature parameter. Sometimes, the deviation needs further explanation. For example, the combination of "part of flow" means a slight reduction in the composition of the flow.

After revealing the causes of the deviations, it is time to examine the possible consequences of the occurrence of these deviations from the normal state or design ideas. It is very important to identify all possible outcomes because it is possible to judge from them how risky the occurrence of the deviation under study can be, and in fact, from these results, the risks of the system can be qualitatively evaluated.

This method begins by decomposing the unit into small parts, each of which is called a node. A node usually consists of one of the process equipment along with its extensions and connections. Also, it can be considered as a piece of pipe and its extensions. The selection of the node depends on the desired amount of granularity and the available information. After selecting the node, it is tried to consider all the hazards or operational problems related to that area. In order to cover all possible situations, this search is done methodically. In other words, by using a set of keywords and applying them to parameters such as temperature, pressure, and the deviation possibility level from the design objective or the normal state of operation, it is investigated. Suppose such a deviation is possible in a completely creative process. In that case, an attempt is made to reveal all the causes that may lead to this deviation and to determine the possible consequences of this deviation in the process. Then, the available protective factors are investigated to prevent the occurrence of the predicted adverse consequences. Finally, if the guards are insufficient to prevent or deal with that deviation, some suggestions are made. For example, the combination of the keywords NO and the flow parameter shows that the input flow to the studied node has been interrupted. The reasons for the failure of the flow, its consequences, and strategies to ensure the existence of the flow during a creative process are announced by the examining group.

In this research, the ECSS-M-ST-80-C risk management standard was used to weigh the risk indicators and standardize the work method. In this standard, the risk intensity is divided into 5 levels from 1 to 5. Level 5 is the worst and level 1 the lowest, and the probability of risk occurrence is leveled in 5 levels from A to E, where level A is the lowest and level E is the most likely to occur.

Table 2. Risk stratification in accordance with ECSS standard

		severity				
likelihood		1	2	3	4	5
	E	low	medium	high	Very high	Very high
	D	low	low	medium	high	Very high
	C	very low	low	low	medium	high
	B	very low	very low	low	low	medium
	A	very low	very low	very low	very low	low

Also, in the mentioned standard, tables 5 and 6 are stated as the criteria for rejecting or accepting the risk, from which the following table is taken.

Table 3. Risk acceptance criteria according to the ECSS standard

Risk list	Risk size	Action
E4,E5,D5	Very high	unacceptable
E3,D4,C5	high	unacceptable
E2,D3,C4,B5	medium	Unacceptable, management permission
E1,D1,D2,C2,C3,B3,B4,A5	low	Accept
C1, B1, A1,B2,A2,A3,A4	very low	Accept

2.2 PHAST Modeling

The use of computers and performing process calculations with the help of software has expanded day by day, so that their use has many advantages. On the other hand, process engineers are paying more and more attention to process accidents and ways of evaluating their consequences and modeling them in order to predict preventive measures. PHAST software is a product developed by DNV which has been prepared and this software is known as one of the decision-making tools of companies and governments in the matter of industrial hazards and public safety. Forecasting and modeling of process incidents such as fire, release of toxic substances, explosion, etc., can be done with the help of this software. One of the most effective ways to prevent accidents is to study the consequences and model them using the software. Today, there are various models for modeling purposes.

PHAST (process hazard analysis software) and ALOHA (Area Location of Hazardous Atmospheres) are among this software [7].

In qualitative risk assessment methods, it is not possible to carry out comprehensive, quantitative and accurate studies due to reasons such as not identifying all risks, the lack of a risk matrix, not modeling the consequences, etc., with the existing methods when evaluating the continuous effects of multiple factors, are not able to accurately estimate. Reducing safety risks requires understanding the factors that affect the severity of the outcome. Consequence modeling is one of the safety engineering analyses that can predict most accidents and reduce the resulting damages. Modeling and risk assessment for the release of dangerous substances is often done using integrated software packages that are created after modeling the consequences of accidents and releases to flammable and toxic effects on the human population. Confidence in these evaluations requires that calculations be modeled correctly at each stage. Modeling software for the accidental release of flammable and toxic chemicals includes dispersion modeling in the atmosphere to evaluate the effects of ignition and toxicity [8].

In 2015 and 2016, McKenna et al. conducted a series of experiments to test large-scale detection. These experiments were called Jack Bit 2, and sensors were placed up to 11 km from the source of the leak. Also, Whitlux was tested, and the results showed that PHAST is much more accurate than ALOHA software and provides better results [9]. In this research, PHAST version 7 software was applied. The weather conditions based on zero wind and 25 ^{o}C were considered as the reference conditions. Also, the various scenarios were discussed. During the storage or transfer of flammable liquids, if these containers break or leak, a pool of material is formed near these tanks. Since the steam caused by evaporation on the pool forms a gas cloud, if sparks reach, the fire will spread in the direction of the wind of the pool fire [10].

At the same time as the leakage of the outgoing liquid, it is quickly and suddenly released in the air so that the existing liquid is carried as small droplets along with the steam; when flammable gases reach the spark source in an open environment, ignition occurs in a short period, which is called a sudden fire .From a small leak in the pipelines and pressure vessels, the liquid quickly exits from these containers. After exiting and reaching the source of the spark, a continuous beam of fire is formed in the form of a jet [10].

The heat resulting from the ignition is shown as heat waves, and the effect of the amount of heat release and its consequences are given in Table 4.

Table 4. Effects of thermal radiation

Radiation (kW/m^2)	Consequence
4	Pain within 60 seconds
9.5	Second-degree burn after 20 seconds
12.5	Melting of plastic material and energy required for sparking wooden pallets
20	This amount of radiation causes severe damage to humans in such a way that if the team is not rescued, death is certain.
25	Minimum energy for burning wood
27.5	Exposure to radiation levels exceeding this threshold can lead to equipment damage, and if an individual encounters such levels, it may result in immediate fatality.

2.2.1 Calculation of Propellant Mass and Volume

The mission is to design a liquid fuel static stand with a capacity of up to 10,000 kg for MMH-NTO bipropellant and an internal pressure of 15 bar and $\propto$=0.8 for 8 minutes of operation [11].

For the calculation of the bipropellant volume, we used the rocket propulsion software RPA to obtain the temperature, I_{sp} and mass of the propellant.

The first result from the RPA software from this data shows ISP= 226 S and, oxidizer to fuel mass ratio (O/F) = 1.99 and TC= 3211 K. The masses of MMH and NTO are obtained from the RPA software.

a) Calculation of the mass flow rate of the bi-propellant

$$\dot{m} = \frac{F}{I_{sp}} = \frac{10000}{226} = 44.25\frac{kg}{s}$$

$$\dot{m}_{N2O4} = \dot{m}_{MMH} \times \frac{O}{F} = 14.8 \times 1.99 = 29.45\ kg/s$$

The mass flow rates of NTO and MMH will be calculated as 29.45 kg/s and 14.8 kg/s, respectively.

b) Calculation of total mass and volume of the bi-propellant

$$M_{\text{NTO}} = \dot{m}_{\text{NTO}} \times t = 29.45\left(\frac{kg}{s}\right) \times 480(s){:}\ 14136Kg$$

$$V_{\text{NTO}} = \frac{M}{d_4^{20}} = \frac{14136(kg)}{1440(\frac{kg}{m3})} = 9.816m^3 = 9816\ liter$$

3. Results

For risk assessment via the HAZOP method, firstly, there is a need for a diagram with a P&ID map in which the flow paths, pressure paths and structure are clear.

Therefore, 7 nodes, including (the N_2O_4 tank and its charging path, MMH tank and its charging path, N_2O_4 pressurization system, MMH pressurization system, N_2O_4 path to the engine, MMH path to the engine, the engine) were selected, and then the HAZOP worksheet was completed for each node. The results were obtained. It was scored with the indicators of Table 2, and finally, the discovered unacceptable risks were expressed. The worksheet was used for risk.

As stated above, the discovered risks should be divided into three groups: acceptable, needing correction, and unacceptable. The frequency of risks is illustrated in Figure 1.

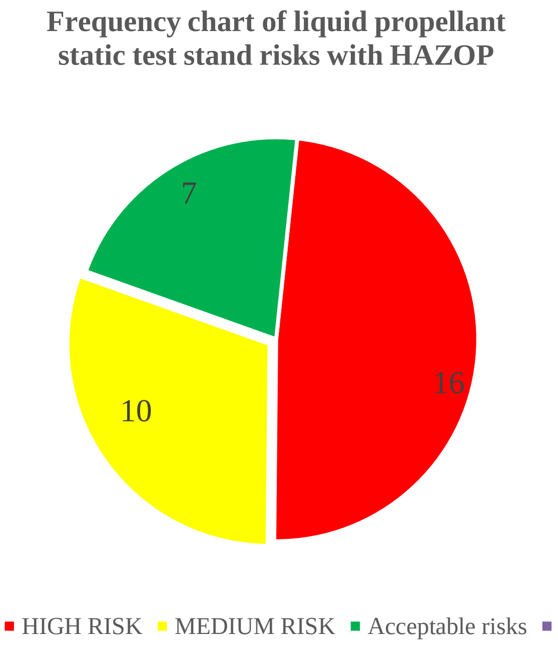

Figure1. Frequency chart of liquid bipropellant static test stand risks

According to the findings of Figure 1, the amount of 48% risk of static test is high risk and risk reduction policies should be applied for them. These risks are expressed in the table 4 and 10 risk is medium, which equals 21%.

Table 5. Unacceptable risks in liquid bipropellant statics stand

Risk	Sheet	Nod
The remained volume of N_2O_4 behind the valve should be greater than zero at the end of work.	7	Engine
The remained volume of MMH behind the valve should be greater than zero at the end of work.	7	Engine
The flow of N_2O_4 at the first moments should be less than the allowed value.	7	Engine
The flow in both engines is less than the nominal value due to the leakage of the valve stem and parts.	7	Engine
The initial flow rate of the fuel is higher than the nominal flow	7	Engine
The flow rate of N_2O_4 is lower than the rate due to the lower voltage	7	Engine
The flow rate of MMH is lower than the rate due to the lower voltage	7	Engine
Overload N_2O_4	1	N_2O_4Tank
Return of MMH vapors to the N_2O_4 tank	1	N_2O_4Tank
Return of N_2O_4 vapors to the MMH tank	1	MMH Tank
Rising pressure of tanks caused by the sun	1,2	MMH/ N_2O_4
The gasket failure	3,4	Valve
Explosion of N_2 pressure tanks due to the end of lifespan and pressure over the working power	6	N_2 Tank
Explosion of pressurized tank and stand due to mistake in supplying N_2 fluid and purchasing incompatible O_2 fluid	6	MMH+N_2O_4 Tank
Increase in tank pressure over the rated pressure due to failure of the valve	2,4	MMH, N_2O_4 Tank
Damage due to non-discharge of static load and lightning	2,4	MMH Tank

Conditional risks in static stand liquid bipropellants are 10 risks shown in Table 5. These risks are accepted by management and usually under control by the safety department.

Table 6. Conditional risks in static stand liquid propellants

risk	Sheet	Nod
Increase in pressure of the N_2O_4 tank due to the failure to open the main tank drain valve	1	N_2O_4 tank
No output flow due to the valve not opening	2	End node of N_2O_4 tank
Flow less than the nominal value caused by valve clogging	2	End node of N_2O_4 tank
Failure to charge MMH into the MMH tank	3	MMH tank
The pressure of the tank is more than the standard pressure due to the heat of solar radiation	3	MMH tank
Failure to charge the liquid into the N_2O_4 tank	1	N2O4Tank

The results of Tables 4 and 5 show that tanks and rocket motors are high-risk places in the static stand test.

9 risks are in the N_2O_4 tank, 9 risks in MMH and finally, 7 risks in the engine. In the case of leakage from the bottom of the tank in normal weather and wind velocity of 5 m/s, the probability of death worker until 500 meters is 100% and until 750 meters probability of death is 50%; finally, until 1200 meters, probability going to 0 %. Figure 2 shows the probability of death in this scenario.

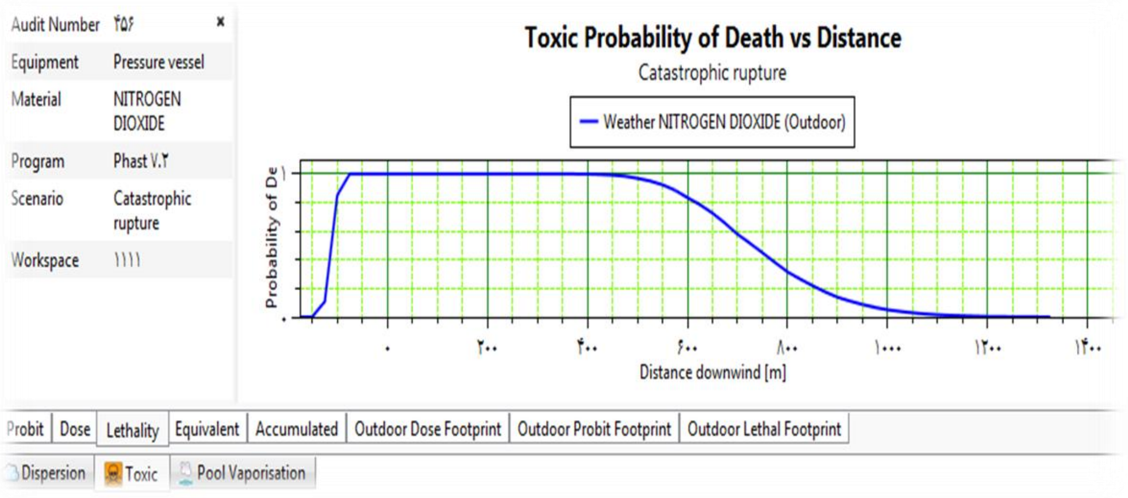
Audit Number ۴۵۶
Equipment Pressure vessel
Material NITROGEN DIOXIDE
Program Phast ۷.۲
Scenario Catastrophic rupture
Workspace ۱۱۱۱

Figure 2. Probability of death from leakage of N2O4 tank in the bottom

According to Figure 2, a worker near the tank may die if the bottom of the tank has an accident and leaks. But the worker opposite the wind, the probability of death is very low. Figure 3 shows the cloud of NTO for this scenario.

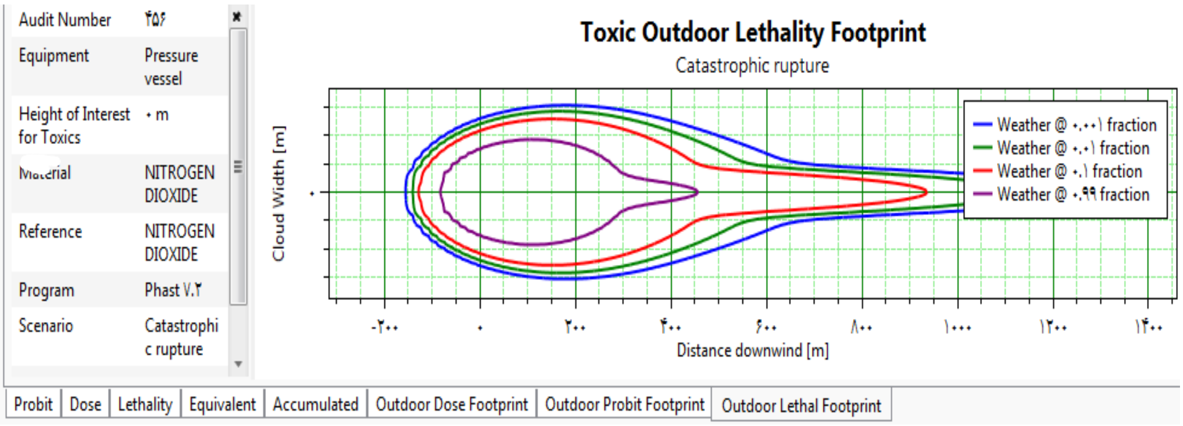
Audit Number ۴۵۶
Equipment Pressure vessel
Height of Interest for Toxics ۰ m
Material NITROGEN DIOXIDE
Reference NITROGEN DIOXIDE
Program Phast ۷.۲
Scenario Catastrophic rupture

Figure 3. Probability of death in percentage of occurrence in the scenario of leakage from the bottom of the tank

This type of leak may be from a safety valve or rupture disk, an accident above the tank or piping and happened. Figure 4 shows this scenario.

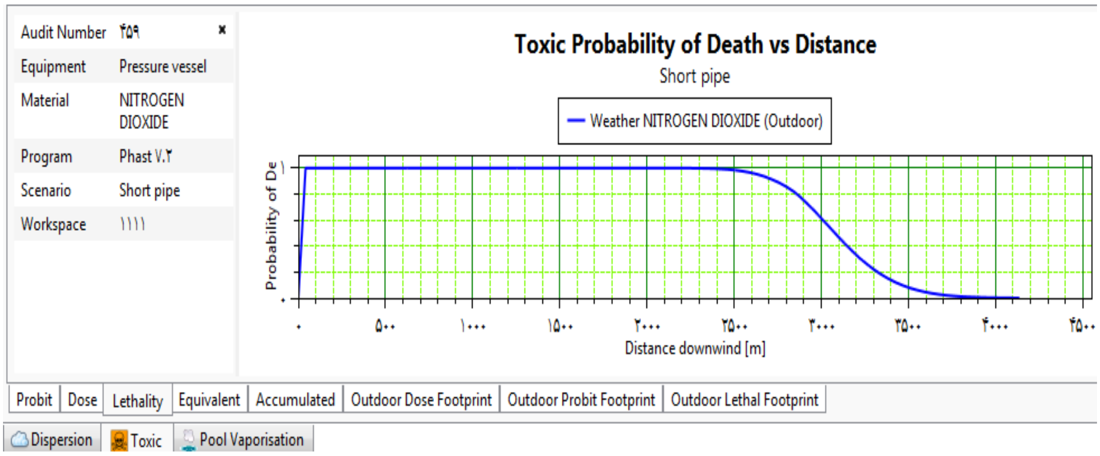
Audit Number ۴۵۹
Equipment Pressure vessel
Material NITROGEN DIOXIDE
Program Phast ۷.۲
Scenario Short pipe
Workspace ۱۱۱۱

Figure 4. Probability of death from leakage of NTO tank in the above

As can be seen from this figure, up to a distance of 2500 meters, there is a high probability of death due to leakage from the head of the tank, and at distances higher than 3500 meters, this probability tends to be zero. Figure 5 shows the cloud of NTO near the tank in this scenario.

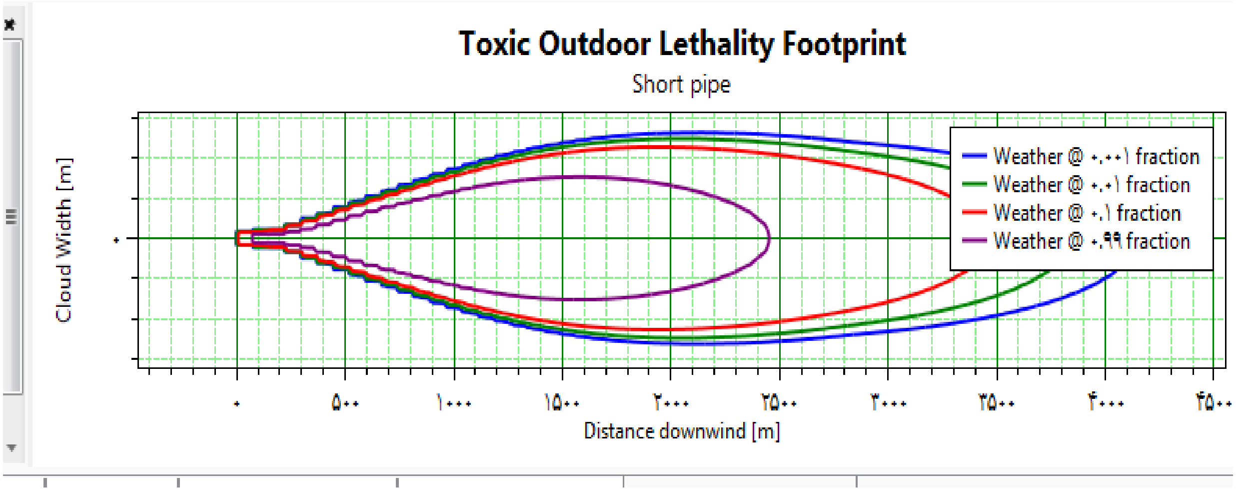

Figure 5. Probability of death in percentage of occurrence in the scenario of leakage from the above tank

Table 7. Comparing and evaluating the level of NTO tank leakage risks in the liquid bipropellant static stand

Place of danger	Risk type	Radius of danger	Severity of	People at risk (without protection)
Leakage from the bottom of the tank	Distribution of hazardous materials	400 meters	The probability of death of people is more than 99%.	Operational staff - supervisors - control engineers
	Distribution of hazardous materials	900 meters	The probability of death of people is more than 10%.	Operational staff - supervisors - control engineers
	Distribution of hazardous materials	1000 meter	The probability of death of people is more than 1%.	Operational staff - supervisors - control engineers
Leakage from tank head	Distribution of hazardous materials	2450meters	The probability of death of people is more than 99%.	Operational staff - supervisors - control engineers
	Distribution of hazardous materials	3700 meters	The probability of death of people is more than 10%.	Operational staff - supervisors - control engineers
	Distribution of hazardous materials	4000 meters	The probability of death of people is more than 1%.	Operational staff - supervisors - control engineers

Table 7 compares two scenarios: leakage from the bottom and leak above. The result of Table 7 shows that leakage in the NTO tank from above of tank is important than the leak bottom.

4. Discussion

Risk management aims to create a systematic and continuous framework for identifying, evaluating, eliminating, or reducing risk. In the risk management process, decisions are made based on comparing the results of risk determination with the risk acceptance criteria [12]. 37 risks were identified in the liquid fuel static stand with N_2O_4/MMH by the HAZOP method. 48% of these risks have a red high-risk class, which indicates the high risk of this place. Out of these 16 risks, 37% of risks are in the propellant and high-pressure equipment, among the unacceptable risks. The first corrective action can be replacing the engine. Some of these risks can be corrected by using extensions and safety items such as one-way valves and separation of pressure paths.

However, 3 risks are the need for a canopy for the tanks, a lightning arrester and a safety valve in the stand. The most important safety risk that is caused by incorrect supply is the risk related to nitrogen supply, which is eliminated if a nitrogen generator is supplied in a stand. Also, NASA's safety requirements emphasize lightning arrester units. In addition, NASA's recommendation for valves is annual replacement, high reliability, and elimination of leaks and blockages in valves.

Suggesting which tanks with a smaller L/D can be used, we will probably have a smaller radius of pollution. And if drawing the wall around the stand can reduce the emission radius.

Risk is determined by conditional probability. If there is any leakage probability from the tank, the risks of death of the employees are higher, and for the high risks of the tank, protective safety guards must be placed. It is also possible to reduce the risk and risks of leaking from the top of the tank by moving the outlets of the safety valve to safe places. Considering double safety valves can also reduce the risk of rupture. Wind direction is very important in positioning. Automation can also help reduce human risk. Process control rooms should be located in such a way that the wind does not drive contaminants into them [13]. A retaining wall should be installed around the stand so that toxic substances are released less. If possible, if tanks with a larger diameter and lower height can be used, we will probably have a smaller radius of pollution. By using water sprinkler and fog sprinkler systems, the volume of leaked vapors in the place will be reduced. The results show that the proposed method can effectively and accurately evaluate the Reliability-Based Multidisciplinary Optimization (RBMDO) of complex systems and can be used for other engineering applications as well [14].

Conflicts of Interest

The authors declare no conflict of interest.

5. References

[1] Statements of the supreme leader in the New Year message of 1400, [Online]. Available: https://www.leader.ir/en/content/24901/The-Leader-s-message-on-the-occasion-of-Nowruz.

[2] SR. Karimi and H. Isarinia: "Reviw of Standard Safety Requirements In The Static Stand Test," *The 11th International engineering Conference on Advancced Reaserch in Scinenc Engirnering And Technology* , Brussels , Belgium, 2023, (in Persian), Art. no. RSETCONF12_040.

[3] "Fire, Explosion, Compatibility, and Safety Hazards of Nitrogen Tetroxide," Rep. AIAA SP-86-2001, American Institute of Aeronautics and Astronautics, 2001.

[4] A. Olivares Rodríguez, "Study and impelemenation of a middle sized-rocket motor bench test system," Master thesis, Aerospace Enineering Universitat Politecnica de Cataluny, 2019.

[5] H.Isarinia, A.keshvary, and R. Karimi, "The safety requirements of the test of the 100 Newton low propellant space liquid thruster with N_2O_4 propellant and 5 minutes operating time," 7th *International Conference on Technology Development in Aerospace Mechanical Engineering*, Tehran, Iran, 2023, (in Persian).

[6] H. E. Perlee, A. C. Imhof, and M. G. Zabetakis, "Flammability characteristics of hydrazine fuels in nitrogen tetroxide atmospheres," *Journal of Chemical and Engineering*, vol. 7, no. 3, pp. 377–379, 1962, doi: https://doi.org/10.1021/je60014a016.

[7] F. Atabi, R. Ghorbani, M. Jabbari:" Assessment of safe distance for five toxic materials commonly in the accidents of chemical road transportation using ALOHA and PHAST software and CEI index (Case Study: Tehran-Qazvin Highway) ", Iranian Journal of Occupational Health, vol. 14, no. 4, 2017, (in Persian)

[8] S,R. Karimi, "Modeling the Consequences of Gasoline Leakage from Refinery Tanks with a Crisis" Management Approach Crisis Management Journal, 2021, (in Persian).

[9] Gh.R. Nabi Javadi Gholamreza Nia, "Evaluation of the Consequences of Chemical Bomb Explosion Using PHAST Software," *7th National Conference on Modern Warfare Defense*, Iran, 2016.

[10] H. Jahed Shahraki, N. Esfandiari," Simulation of the consequences of fire for gas pipelines using PHAST software," *Iranian Chemical Engineering Journal*, Vol. 20, no. 119, 2022.

[11] H. Isarinia, A. Keshvary, and S. R. Karimi,"Safety requirements of space liquid propellant static stand with MMH propulsion," *7th International Conference on Technology Development in Aerospace Mechanical Engineering*, 2023.

[12] M. Nadjafi, H. Naseh, M. Sedigh Koochaki, "FMECA-based risk assessment in monopropellant hydrazine propulsion system," *Journal of Space Science and Technology*, vol. 16, no. Special Issue, pp. 39-50, doi: https://doi.org/10.22034/jsst.2023.1380.

[13] A. Yaseen, "Reducing industrial risk with AI and automation," *International Journal of Intelligent Automation and Computing*, vol. 4, no. 1, pp. 60-80, 2021.

[14] H.R. Alimohammadi, H. Naseh, and F. Ommi, "An integrated methodology applied for reliability based multi-disciplinary design optimization in EPFE with LOX/kerosene," Reliability Engineering and System Safety, vol. 240, 2023, Art. no. 109570, doi: https://doi.org/10.1016/j.ress.2023.109570.