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Evacuation Safety Evaluation of High School according to Hydrogen Fluoride Leakage

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Abstract

The purpose is to evaluate evacuation safety by simulating the toxic effects of hydrogen fluoride leaks in areas surrounding national industrial complexes and to suggest alternatives for areas that do not satisfy evacuation safety. For human casualties caused by hydrogen fluoride leakage accidents, Available Safe Egress Time (ASET) is calculated by the toxic effects quantified with the Areal Locations of Hazardous Atmospheres (ALOHA), an off-site consequence assessment program. The Required Safe Egress Time (RSET) is calculated through Pathfinder, an evacuation simulation program. Evacuation safety is assessed by comparing ASET and RSET. The ALOHA program was used to evaluate the time to reach AEGL-2 concentration in 12 scenarios. The Pathfinder program was used to assess the total evacuation time of the high school among specific fire-fighting objects. Of the 12 accident scenarios, ASET was larger than RSET in the worst-case scenarios 1 and 9. For the remaining 10 accident scenarios, the ASET is smaller than the RSET, so we found that evacuation safety is not guaranteed, and countermeasures are required. Since evacuation safety is not satisfactory, we proposed to set up an evacuation area equipped with positive pressure equipment and air respirators inside specific fire-fighting objects such as the high school.

***Key words**: leakage, hydrogen fluoride, evacuation area, ASET, RSET*

1. INTRODUCTION

Hydrogen fluoride is designated as an accident preparation substance. Accident preparedness substances are defined in Article 2 Subparagraph 6 of the 「Chemical Substances Control Act」as"Chemicals that are highly likely to cause chemical accidents due to their strong acute toxicity and explosiveness, or that are likely to cause significant damage in the event of a chemical accident". As a substance, 97 types are designated as chemical substances designated and notified by the Minister of Environment in recognition of

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the need to prepare for chemical accidents [1]. In addition, it is stipulated in the chemical accident prevention management plan to evacuate to the shelter designated by the local government in case of an accident preparation material leak. Of the 234 chemical accidents over the past 3 years, 5 hydrogen fluoride leakage accidents(3 in 2020, 1 in 2021, 1 in 2022) occurs every year [2]. There is a need for discussion to secure evacuation safety in the affected area due to the hydrogen fluoride leak accident(5 deaths, 12 injuries, 7,162 health checkups, 237.9ha of crops damage, 3,209 heads of livestock, etc.) in Gumi City in 2012.

Analyzing previous studies, Yoo Byong-Tae (2016) [3] developed GIS for calculating the level of indoor and outdoor toxic gas contamination to establish an emergency response and dissipation plan in case of toxic gas leakage in order to improve the limitations of the dissipation plan in establishing an emergency response plan for chemical accidents. Based damage impact assessment module and decision-making matrix for selective dissipation were developed. Kim Min-Ju (2018) [4] confirmed the effectiveness of the storage facility separation distance for 15 types of toxic gases and studied an evaluation method for selecting an indoor evacuation area based on the accident point using the ALOHA program. Kim Seo-eun (2019) [5] analyzes the vulnerability of the disaster by probit analysis of the disaster in order to derive a direction for improving the dissipation plan that can support the disaster in the event of a chemical accident, and presents measures to improve indoor and outdoor evacuation did. Kim Bo-min (2019) [6] suggested an appropriate shelter interval according to the calculation of the probability of death by using the Process Hazard Analysis Software Tool (PHAST) program and probit analysis for ammonia, hydrogen chloride, chlorine, and hydrogen sulfide to select a reasonable shelter in the event of a chemical accident. Lee Eun-ji (2020) [7] uses the ALOHA program and probit analysis for hydrogen chloride, hydrogen fluoride, and ammonia with Incheon Metropolitan City as the target area to select a reasonable transition point from indoor evacuation to outdoor dissipation in the event of a chemical accident. Derived. Lee Hak-tae (2020) [8] proposed a methodology that can calculate the relative risk of the elderly by quantifying the exposure analysis to toxic substances using the ALOHA program and the difference in evacuation speed between those in their 20s and 60s when toxic substances leaked. Son Tae-eun (2021) [9] presented a dispersion model at the beginning of the leak using the diffusion equation to predict the range of damage impact for the initial leak into the factory or the leak accident in a narrow space.

Existing preceding studies have been actively conducted on the calculation of the damage impact range for chemical substances, and studies on resident dissipation and human casualties. Unlike previous studies, this study is differentiated in that it evaluates the safety of evacuation in the handling area and surrounding areas by conducting an evacuation simulation within the range of damage caused by hydrogen fluoride leakage using an evacuation simulation. Evacuation time and diffusion concentration of hydrogen fluoride are simulated to verify evacuation safety.

In this study, the safety of evacuation is evaluated by conducting simulations on the toxic effects of hydrogen fluoride leaks in the surrounding areas in national industrial complexes. First, the Acute Exposure Guideline Level (AEGL) concentration of hydrogen fluoride is analyzed using ALOHA, a toxic effect assessment program, and ASET is calculated. Second, RSET is calculated by using Pathfinder, an evacuation assessment program, at high school with many occupants among specific fire-fighting objects in the vicinity of the national industrial complex. Finally, evacuation safety is evaluated by comparing the calculated ASET and RSET. For areas that do not satisfy evacuation safety, we would like to propose appropriate evacuation areas.

2. RESERCH METHODS

2.1. Assessment for evacuation safety

The effects assessment of the area around the chemical plant is evaluated through the off-site effects asses sment of the chemical accident prevention management plan, and safety assurance measures are established. For industrial complexes and surrounding areas, we are going to review evacuation safety around work place s using toxicity assessment and evacuation assessment. ASET is analyzed using toxicity simulation and RSE T is analyzed using evacuation simulation, and evacuation safety is evaluated by comparing the two results. ASET is set to the time it takes for hydrogen fluoride to leak out and reach the concentration of AEGL- 2. R SET is set to the time when occupants complete evacuation to the ground using evacuation simulation. RSET is based on the SFPE Handbook of Fire Protection Engineering as shown in equation (1) below.

RSET = Td + Ta + To + Ti + Te (1)

Here, Td is the time for detecting a hydrogen fluoride leak, Ta is the notification time after leak detection, To is the time for an occupant to recognize a leak, Ti is the time required from recognizing a leak situation to starting evacuation, and Te is the time from occupant to start evacuation to the ground is the time it takes to reach. Since the time from the time the occupant recognizes the hydrogen fluoride leak (Td) to the start of ev acuation (Ti) corresponds to the evacuation delay time, RSET is as follows Equation (2).

RSET = evacuation delay time (Td + Ta + To + Ti) + evacuation time (Te) (2)

According to the notice of the British standard institute, the evacuation delay time by use is as shown in T able 1 [10]. Evacuation safety is secured when RSET is smaller than ASET. If evacuation safety is not secure d, measures to ensure safety are necessary.

Table 1. The evacuation delay time (Pre-movement time)

Occupancy type	W1(min)	W2(min)	W3(min)
Office, commercial and industrial buildings, schools, colleges, universities (Occupants awake and familiar with the building, the alarm system, and evacuation.)	< 1	3	> 4
Shops, museums, leisure-spot centers, and other assembly buildings (Occupants may be asleep but are predominantly familiar with the building, alarm system and evacuation procedure.)	< 2	3	> 6

2.2. Physical and Chemical Properties of Hydrogen Fluoride

As shown Table 2, hydrogen fluoride is a toxic substance that damages the body by penetrating into the sk eleton while hydrogen bonding with the body's moisture. Businesses handling toxic substances such as hydro gen fluoride must establish appropriate emergency response planning in case of leakage or spread hydrogen f luoride because accidents due to negligence during the process or tank transfer, aging of pipes and parts, etc. Hydrogen fluoride is toxic with a high vapor pressure and an AEGL- 2 concentration of 27 ppm.

Table 2. Physicochemical properties of hydrogen fluoride

Chemical	CAS No.	State	Toxicity	Molecular weight	Boiling point	Vapor pressure
Hydrogen fluoride	7664-39-3	Gas and Liquid	AEGL-2 (27 ppm)	20.1g/mol	19.5℃	783mmHg

3. HYDROGEN FLUORIDER LEAK SCENARIO

3.1. Toxicity Simulation Program

ALOHA 5. 4. 7program developed by the United States Environmental Protection Agency (EPA). It is possible to evaluate accident scenarios on land as well as at sea. ALOHA uses the Gaussian Atmospheric Diffusion and Dense Gas Dispersion Model leak models to automatically estimate the extent of impact for each chemical gas. A large amount of Data Base on chemical substances is available separately from outside sources. In addition, the results of the model are compatible with the Google Earth program and can directly express the extent of damage impact on a map. Therefore, ALOHA predicts the scope of impact for each accident scenario (fire, explosion, leakage, etc.) and then displays the extent of damage on a map to be used for establishing emergency response plans. ALOHA considers wind direction, wind speed, atmospheric stability, atmospheric inversion layer, and surface roughness as meteorological conditions, and is greatly affected by wind direction and speed. Leakage is used to evaluate liquid or gas leaked directly from a tank, pipe, pool, or into the atmosphere.

3.2 Accident Scenario

The variables of the hydrogen fluoride leak scenario were selected by reflecting 「Technical Guidelines for Accident Scenario Selection and Risk Analysis of the Chemical Safety Agency Guidelines (No. 2021-3)」. The leakage accident scenario was that the tank storing hydrogen fluoride ruptured and leaked. Hydrogen fluoride leak conditions were selected as 5ton, 10 ton, and 100 ton, and atmospheric stability was selected as A, D, and F as three types. The end point for evaluating the extent of the damage effect is the point at which the AEGL- 2 concentration is reached. The leak hole size was 5cm, the air temperature was 25℃, the humidity was 50%, and the wind speed was selected as 1.5m/s, 3m/s, and 5m/s as 3 types. Scenario 1 is worst case scenario with a wind speed of 1.5 m/s, atmospheric stability F, temperature of 25° C, relative humidity of 25%, and surface resistance of 5 ton leaking in forest or urban conditions. Scenario 2 is a scenario in which 5ton leaks in a forest or city with wind speed of 3m/s, atmospheric stability D, temperature of 25℃, relative humidity of 25%, and surface resistance. Scenario 3 is a scenario in which 5 ton leaked at a wind speed of 3 m/s, atmospheric stability A, temperature of 25° C, relative humidity of 25%, and surface resistance of forest or city. Scenario 4 is a scenario in which 5ton leaks in a forest or city with a wind speed of 5 m/s, atmospheric stability D, temperature of 25° C, relative humidity of 25%, and surface resistance. In the same way scenarios 5, 6, 7, and 8 are cases where 10 tons leaked, and scenarios 9, 10, 11, and 12 are cases where 100 tons leaked. Table 3 summarizes the conditions according to the 12 accident scenarios. concentration of 27 ppm.

Table 3. Evaluation conditions for scenario

End point	Weather Conditions			Leak temperature
Toxic concentration AEGL-2 (27 ppm)	Temperature 25℃	Humidity 50%	Atmospheric stability A, D, F	Operation temperature
Leak size(cm)	Wind speed (m/s)	Leak quantity (ton)	Leak position	Surface curvature
5	1.5 3.0 5.0	5 10 100	bottom	Urban or forest

4. EVACUATION SCENARIO

4.1. Evacuation Simulation Program

The evacuation simulation used the Pathfinder program developed by Thunderhead Engineering, USA. The Pathfinder program is also an evacuation simulation program based on FDS. Currently, various programs such as Building Exodus and Simulex are used in Korea, but the Pathfinder 2022 program, which can convert the topography of CAD drawings in continuous space, was used.

4.2 Scenario

As for the evacuation scenarios, the case of using only the evacuation stairs in the school classroom by oneself (Case 1) and the case of evacuating to the ground using the evacuation stairs and elevator (Case 2) were selected. Personnel allocation for evacuation simulation analysis is based on the number of chairs in the classroom by applying the standard for the number of fixed chairs in the performance hall among the criteria for writing scenarios for fire and evacuation simulations in Annex 1 of the former 「Performance-oriented Design Method」 and was placed to reflect the population in their 20 to 29 years old in Table 4 [11]. A total of 1,090 students were assigned, with 25 students in the general class and 10 students in the special class. All occupants for the evacuation simulation were male, with a height of 1.73m, a moving speed of 1.2m/s, a shoulder width of 45.15cm, and a reduction factor to solve the crowding phenomenon was set at 0.7. Regarding the agent's behavior, it was entered as not taking any sudden action and evacuating on its own

Table 4. Size Korea, 2021

	20 to 29 years old		30 to 39 years old		40 to 49 years old		50 to 59 years old		Over 60	
	M	F	M	F	M	F	M	F	M	F
Height(cm)	173.85	160.95	172.75	160.25	170.2	156.65	168.35	154.35	165.9	152.8
Shoulder width(cm)	40.15	35.7	39.95	35.65	39.65	35.95	38.55	35.75	37.65	35.45
Gait speed(m/s)	1.21	1.1	1.21	1.1	1.21	1.1	1.21	1.1	0.7	0.7

5. EXPERIMENTAL RESULTS

5.1 Effect Range of Hydrogen Fluoride and Time to Reach LOC (Level of Concentration)

Figure 1 shows the toxicity results according to LOC of C high school for scenario 10 with a high probability of occurrence. C high school, which is closest to the hydrogen fluoride leak point, is located at a horizontal distance of 1.03 km.

Figure 1. LOC at high school C according to scenario 10

Table 5 shows the experimental results of the toxic effect range for 12 scenarios of hydrogen fluoride leakage. This is the result of measuring the extent of toxicity for 12 scenarios at the amount of hydrogen fluoride leakage, wind speed, atmospheric stability, atmospheric humidity of 50%, and atmospheric temperature of 25℃. It shows the result of measuring the toxic effect range for each concentration of AEGL-1, 2, and 3 with respect to the LOC of interest according to the horizontal distance from the leak point

Table 5. Distance output to Simulation

Scenario	Leakage (ton)	Wind speed (m/s)	Stability	AEGL-3 (km)	AEGL-2 (km)	AEGL-1 (km)
1	5	1.5	F	3.0	3.9	10
2	5	3	D	3.2	4.2	10
3	5	3	A	1.2	2.6	10
4	5	5	D	3.0	4.0	10
5	10	1.5	F	5.2	6.9	10
6	10	3	D	3.8	5.2	10
7	10	3	A	2.1	2.8	10
8	10	5	D	3.1	4.4	10
9	100	1.5	F	6.9	9.3	10
10	100	3	D	4.7	6.7	10
11	100	3	A	2.6	3.5	10
12	100	5	D	4	5.4	10

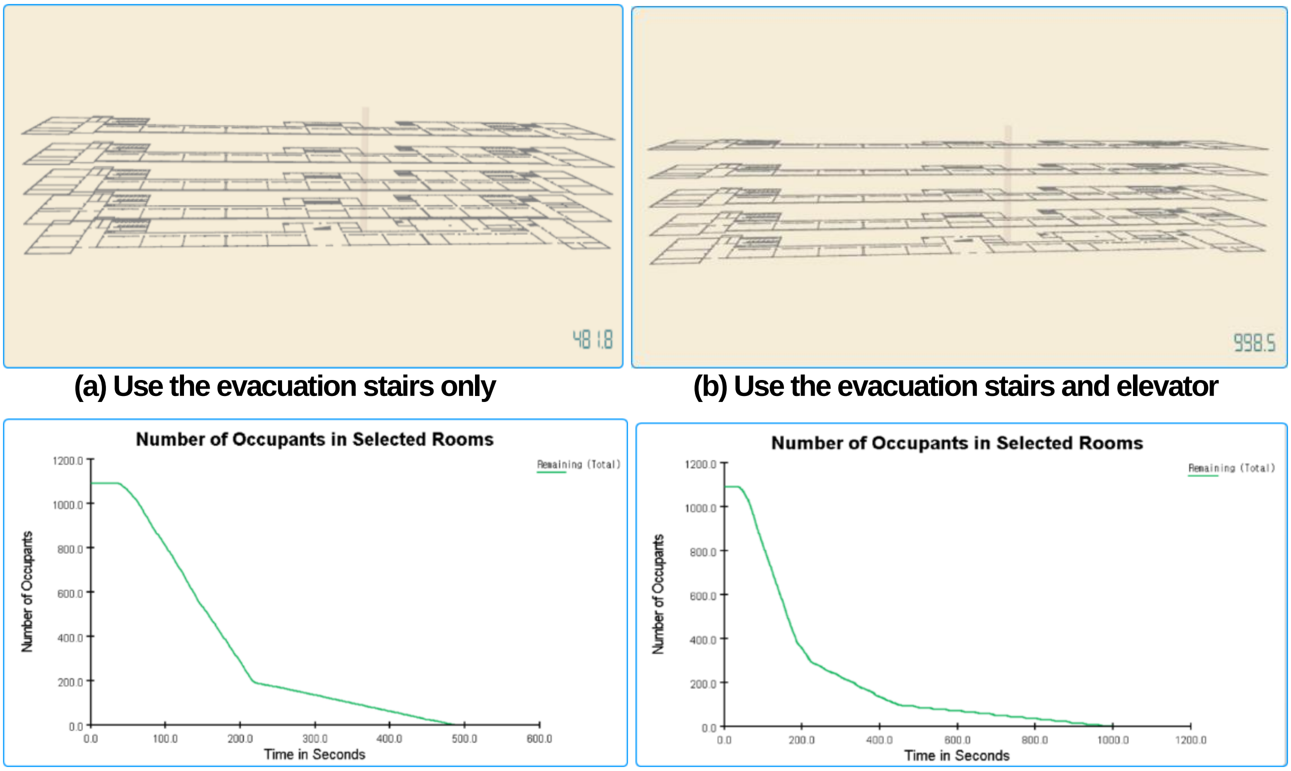
Table 6. Time output to Simulation

Scenario	Leakage (ton)	Time (min)								
		1km			3km			5km		
		AEGL-1	AEGL-2	AEGL-3	AEGL-1	AEGL-2	AEGL-3	AEGL-1	AEGL-2	AEGL-3
1	5	21.0	23.6	24.2	60	60	60	60	-	-
2	5	6.0	7.5	8.0	15.2	19.0	20.8	24.2	-	-
3	5	5.8	7.0	7.5	15.0	-	-	24.0	-	-
4	5	3.0	3.6	4.0	7.5	10.0	12.5	13.0	-	-
5	10	9.8	10.0	10.1	22.5	26.2	28.0	35.0	44.0	49.2
6	10	7.0	7.5	7.7	15.0	19.2	21.0	25.0	33.0	-
7	10	6.2	7.3	7.5	14.2	-	-	24.0	-	-
8	10	3.0	3.1	3.2	7.5	10.0	11.0	12.5	-	-
9	100	21.0	22.5	23.0	60	60	60	60	60	60
10	100	7.0	8.0	8.1	16.5	20.1	21.0	26.0	33.0	-
11	100	5.0	7.0	7.5	15.1	19.0	-	24.0	-	-
12	100	3.3	3.1	3.1	7.5	9.2	11.0	11.2	17.5	-

Table 6 shows the experimental results of the time to reach the LOC of toxic effects for 12 scenarios of hydrogen fluoride leakage. Time to reach the concentration of AEGL- 1, 2, 3 at three points (1km, 3km, 5km) for 12 scenarios of hydrogen fluoride leakage is measured according to wind speed, atmospheric stability, atmospheric humidity of 50% and air temperature of 25℃. In National Industrial Complex B located in City A, Jeollabuk-do, high school C at 1.03 km horizontal distance, University D at 3 km horizontally, and downtown A within 5 km horizontal distance, so the time of LOC to reach was measured.

5.2 Total evacuation time (RSET)

For the evacuation delay time, 4 minutes of evacuation delay time (W3) in the case of an emergency alarm using the fire alarm signal in Table 1 and untrained staff assisting is applied. The evacuation time (Te) to the ground using only the evacuation stairs in the school classroom was measured as 481.8 seconds (8.03 minutes), and the evacuation time (Te) to the ground using the evacuation stairs and the elevator at the same time was measured as 998.5 seconds (16.64 minutes). The experimental results of evacuation time (Te) are shown in Figure 2.



(a) Use the evacuation stairs only (b) Use the evacuation stairs and elevator

(c) Use the evacuation stairs only (d) Use the evacuation stairs and elevator

Figure 2. Time of evacuation (Te)

RSET = evacuation delay time (W3) + evacuation time (Te). Therefore, the total evacuation time (RSET) was 12.03 minutes in the case of using only the evacuation stairs (Case 1) and 20.64 minutes in the case of using the elevator and the evacuation stairs at the same time (Case 2). Table 7 summarizes RSET.

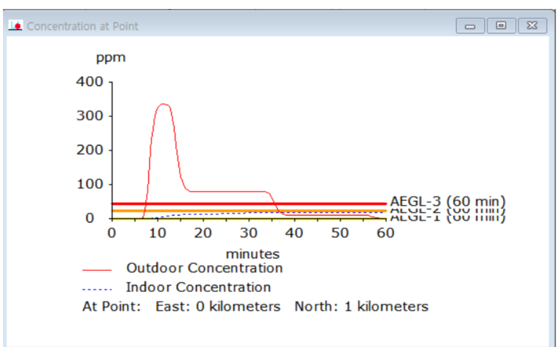
Table 7. RSET

Case	RSET (min)	Note
Usage of the evacuation stairs only	12.03	RSET = W3 + Te W3 = 4 min Te = 8.03, 16.64 min
Usage of the evacuation stairs and elevator	20.64	

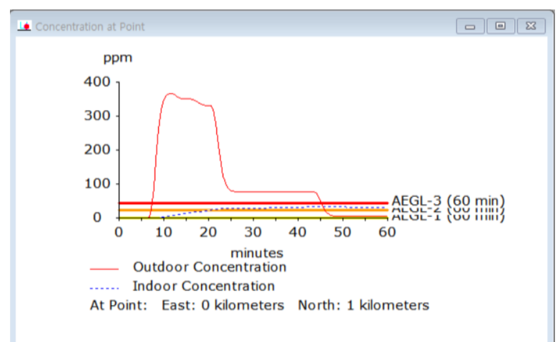
6. DISCUSSION

6.1 Time to LOC (ASET)

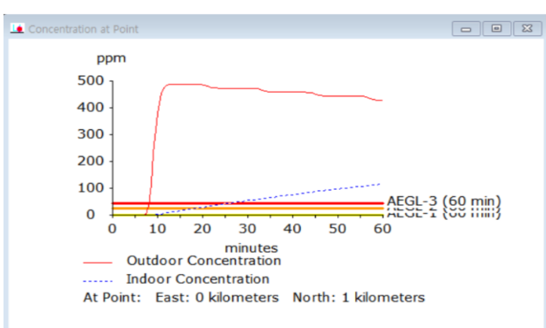
From national industrial complex B located in A city, Jeollabuk-do, C high school is located at a horizontal distance of 1.03 km, D university at a horizontal distance of 3 km, and A city is located at a horizontal distance of 5 km. Since the nearest C school is located at a horizontal distance of 1.03 km from the leak point, We intends to analyze LOC at a horizontal distance of 1 km from the leak point in the Table 6. Looking at the time to reach the concentration of AEGL- 2 or higher, which is the endpoint, the worst case scenarios 1, 5, and 9 ranged from 10 minutes to 23.6 minutes, scenarios 2, 6, and 10 with high probability of occurrence ranged from 7.5 to 8.0 minutes, and scenarios 4, 8, and 12 was analyzed to range from 3.1 to 3.6 minutes. Habitability time refers to the time required for hydrogen fluoride to leak and reach the endpoint concentration. Therefore, ASET, the habitable time of C school with a horizontal distance of 1 km according to 12 scenarios, was evaluated from 3.1 minutes to 23.6 minutes. In addition, it was analyzed that the habitable time (ASET) was inversely proportional to the amount of hydrogen fluoride leakage, wind speed, and atmospheric stability. The habitable time (ASET) at a horizontal distance of 3 km was analyzed from 9.2 minutes to 60 minutes. In addition, the habitable time (ASET) at a horizontal distance of 5 km was analyzed from 17.5 minutes to 60 minutes. In Table 5, the range of damage impact where the end point reached the concentration of AEGL-2 or higher was analyzed to be 2.6km or more and 9.3km or less. The extent of the damage effect was also analyzed to be inversely proportional to the amount of hydrogen fluoride, wind speed, and atmospheric stability. Figure 4 shows the time curves from the horizontal distance of 1 km from the leak point to the AEGL-2 concentration for accident scenarios 2, 6, and 10 with high probability of occurrence.



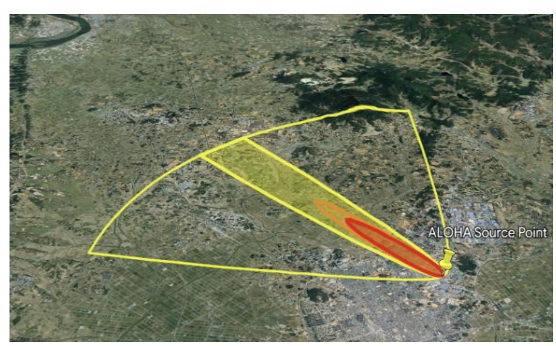
(a) Time at 1km in scenario 2



(b) Time at 1km in scenario 6



(c) Time at 1km in scenario 10



(d) Toxic distance in scenario 10

Figure 3. Time at 1km according to scenario 2, 6, 10

Figure 3 (a) shows the time curve from the toxicity to the concentration of AEGL- 1, 2, and 3 at 1 km for Scenario 2 with a leakage of 5 ton, wind speed of 3 m/s, atmospheric stability D, atmospheric humidity of 50%, and atmospheric temperature of 25°C. Figure 3 (b) shows the time taken to reach the concentration of AEGL- 1, 2, and 3 at 1 km for the toxicity of Scenario 6 with a leak amount of 10 tons, wind speed of 3 m/s, atmospheric stability D, atmospheric humidity of 50%, and atmospheric temperature of 25°C. Figure 3 (c) shows the time taken to reach the concentration of AEGL-1, 2, and 3 at 1 km for the toxicity of scenario 10 with a leak amount of 100 tons, wind speed of 3 m/s, atmospheric stability D, atmospheric humidity of 50%, and atmospheric temperature of 25°C. Figure 3 (d) shows the range of influence by concentration of AEGL-1, 2, and 3 in scenario 10 under the same conditions on the map.

6.2 Total Evacuation Time (RSET)

In RSET = evacuation delay time (Td + Ta + To + Ti) + evacuation time (Te), the evacuation delay time in Table 1 was applied to the school evacuation delay time (W3) of 4 minutes. This is because there is no proper warning means in the event of a leak of an accident preparation material such as hydrogen fluoride, so additional time is required before evacuation begins. In addition, the time Td for detecting the leak of hydrogen fluoride is longer than the time for detecting fire occurrence by the detector. This is because it takes time for the company to notify the local government after detecting a leak at the chemical plant, and the time for the local government to notify the school. In fact, department A took 5 minutes to send an emergency text message after issuing an alert, and local government B took 10 minutes to send an emergency text message after issuing an alert.. The total evacuation using only the evacuation stairs (Case 1) resulted in a shorter evacuation time than the case of using the elevator and evacuation stairs (Case 2), resulting in a smaller RSET. Therefore, schools need to guide occupants to evacuate using the evacuation stairs.

6.3 Evaluation of Evacuation Safety

Evacuation safety evaluation compares RSET and ASET and evaluates that evacuation safety is secured when RSET is smaller than ASET. In school C at 1km away from hydrogen fluoride leakage, ASET was greater than RSET only in worst case scenarios 1 and 9 out of 12 accident scenarios. For the remaining 10 accident scenarios, ASET is smaller than RSET, so countermeasures are needed because evacuation safety is not secured. Table 8 summarizes the evacuation safety evaluation results for 12 accident scenarios.

Table 8. Assessment of evacuation safety

ASET (min)		RSET (min)		Evacuation safety
Scenario	Time (min)	Case1 (min)	Case2 (min)	
1	23.6	12.03	20.64	Safety
2	7.5	12.03	20.64	Unsafety
3	7.0	12.03	20.64	Unsafety
4	3.6	12.03	20.64	Unsafety
5	10.0	12.03	20.64	Unsafety
6	7.5	12.03	20.64	Unsafety
7	7.3	12.03	20.64	Unsafety
8	3.1	12.03	20.64	Unsafety

9	22.5	12.03	20.64	Safety
10	8.0	12.03	20.64	Unsafety
11	7.0	12.03	20.64	Unsafety
12	3.1	12.03	20.64	Unsafety

6.4 Improvement according to Evaluation of Evacuation Safety

As a result of comparing and analyzing simulations of the toxic effects of high schools located at 1 km horizontally due to hydrogen fluoride leakage, the improvement plans are as follows.

First, since the ASET is smaller than the RSET at a horizontal distance of 1 km from the leakage point outside the national industrial complex, evacuation safety is not secured, so we propose to establish an emergency response plan at C high school. In addition, we propose to prepare an emergency response plan that reflects matters such as cooperation with the local community, evacuation and accident information transmission system, and prompt evacuation plan, just like the chemical accident prevention management plan for specific fire-fighting object.

Second, since there is no evacuation time to evacuate to the designated shelter, we propose to install an evacuation safety area inside the school that can accommodate occupants. In addition, a positive pressure facility of 100Pa or more must be installed to ensure safety of occupants so that outside air with the concentration of AEGL- 2 or higher cannot enter the evacuation safety area of specific fire-fighting object.

Lastly, we propose to equip evacuation safety area or classrooms with respirators of 10% or more of the number of occupants, goggles, and protective clothing of LEVEL D or higher. This is because emergency evacuation of occupants through areas exceeding ASET and response personnel conducting response activities in areas with AEGL- 2 concentration or higher may occur.

7. CONCLUSION

This study conducted an evacuation safety evaluation on the toxicity of the area around the national industrial complex due to the leakage of hazardous chemicals manufactured, stored, and handled in the national industrial complex. For the toxic effects of the accident preparation material, hydrogen fluoride leakage accident, ASET was analyzed using ALOHA, an off-site consequence assessment program, and RSET was analyzed using Pathfinder, an evacuation simulation program. The ALOHA program was used to evaluate the time to reach AEGL-2 concentration in 12 scenarios. The Pathfinder program was used to assess the total evacuation time of the high school among specific fire-fighting objects. Of the 12 accident scenarios, ASET was larger than RSET in the worst-case scenarios 1 and 9. For the remaining 10 accident scenarios, the ASET is smaller than the RSET, so we know evacuation safety is not guaranteed, and countermeasures are required. Since evacuation safety is not satisfactory, we propose to set up an evacuation area equipped with positive pressure equipment and air respirators inside specific fire-fighting objects such as the high school. In this study, when calculating the RSET, the time to detect the leak of hydrogen fluoride (Td) was applied as the fire detection time by the detector. In reality, after detecting a leak in a chemical plant, it takes more time to notify local governments from inside the company and from local governments to schools, which takes longer than fire detection time (Td), so additional research is needed on this.

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