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Improvement Plan for Prevention Regulations to Improve Hazardous Material Safety Management

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Abstract

The purpose of this study is to suggest improvement plans for prevention regulations by reflecting the toxicity, fire and explosion effects of hazardous materials factories and surrounding areas using an off-site consequence assessment program. Regarding the effects of the hydrogen cyanide leak accident, which is the 1st petroleum of the 4th class flammable liquid, Areal Locations of Hazardous Atmospheres (ALOHA) program was used to compare and analyze the extent of damage effects for toxicity, overpressure, and radiation. As a result, the toxicity was analyzed to exceed 5km in the area with Acute exposure guideline level (AEGL)-2 concentration or higher, the overpressure was 103m in the range of 1 psi or more, and the radiant heat was analyzed to be 724m in the range of 2 kw/㎡ or more. Toxicity and radiation affected the area outside the hazardous material storage area, but the overpressure was limited to the inside of the hazardous material storage area. Therefore, we propose to improve the safety management of hazardous materials by conducting a risk assessment for hazardous materials and reflecting the results in internal and external emergency response plans to prepare prevention regulations.

Keywords: *Toxicity, Overpressure, Radiation, Hazardous materials factories., Prevention regulations*

1. Introduction

Prevention regulations refer to safety regulations established in the「Hazardous material Safety Management Act」for fire prevention at hazardous material factories and emergency measures in the case of disasters such as fires [1]. The submission of prevention regulations is 12,891(manufacturing site 1,705, general handling site 2,426, transfer handling site 338, outdoor storage 444, indoor storage 815, outdoor tank storage 7,134, rock tank storage 29) [2]. In the last 5 years, 335 hazardous material accidents occurred (272 at manufacturing plants, 59 less than designated quantities, and 4 others) [3]. In order to prevent large-scale incidents such as the Goyang storage fire, the implementation of prevention regulations has been discussed, and as of January 3, 2023, the implementation evaluation system for prevention regulations was stipulated in the「Hazardous material Safety Management Act」. The current prevention regulations consist of contents to prevent and

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respond to fires. Therefore, since accidents at facilities that store and handle hazardous material have a great impact on the surroundings, it is necessary to discuss prevention regulations to secure the safety of hazardous material factories and surrounding areas from fire as well as explosion and toxicity.

Analyzing previous studies, it was provided safety management education centered on field work through the maintenance of laws and regulations related to hazardous material. It was suggested that the hazardous material safety manager, which is not applied to storages with 25 or less than 20 times of the designated quantity [4]. It was necessary that supplements seismic design, improves regular inspection system, introduces a hazardous material design and supervision system, and strengthens practical training for hazardous material safety managers. It was proposed to expand technical manpower, expand investment in facilities, and improve the personnel [5]. It was suggested a plan to improve the operation of a hazardous material safety manager and the maintenance of hazardous material facilities as the way to improve the safety of small and medium-sized outdoor tank storages [6]. It was suggested practical training and regular inspection items to improve the safety management of facilities, fire-fighting facility inspection, formation of a dedicated organization, and expansion of technical manpower [7]. It was necessary to analyze the impact of the training and inspection ability of safety managers at hazardous material facilities on accident response, and derive the actual conditions of hazardous material safety managers and the problems of training to real fire-fighting and inspection capabilities of self-fire brigade [8].

Existing precedent studies have actively conducted research on the independence of hazardous material safety manager duties, placement of fire-fighting qualified personnel, real fire training for safety managers, development of regular inspection checklists, strengthening of practical training, and hazardous material inspection for hazardous materials safety management. These studies are not of practical help in the event of an accident. Unlike previous studies, this study is differentiated in that it uses an off-site consequence assessment program to evaluate the internal and external effects of hazardous material handled in factories, and reflects the results in the prevention regulations.

In this study, in order to identify the matters to be reflected in the prevention regulations, we are going to experiment on hydrogen cyanide, which is the 1st petroleum of the 4th class flammable liquid, at a hazardous material manufacturing factory. We will experiment using ALOHA, an off-site consequence assessment program, identify the effects of fire, explosion, and toxicity, which are an off-site consequence factor, and propose items to be included in prevention regulations.

2. Research Method

2.1 Fire, Explosion, Toxicity Simulation Program

The ALOHA program developed by the United States Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) was used. ALOHA uses the Gaussian Atmospheric Diffusion and Dense Gas Dispersion Model (DEGADIS) leak models to automatically estimate the extent of effects for each chemical, both in the general case and applied to heavier-than-air or cryogenic gases. Therefore, ALOHA predicts the scope of effects for each accident scenario (fire, explosion, leakage of toxic substances), 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 reversal layer, and surface roughness as meteorological conditions, and is applied to liquid or high-pressure gas leaks from tanks, pipes, and pools. As shown in Table 1 AEGL-2 of hydrogen cyanide is toxic at 7.1 ppm, and if inhaled, it can cause irreversible cardiovascular and nervous system diseases. Hydrogen cyanide is fire hazard, explosive hazard and toxic.

Table 1. Physicochemical properties of hydrogen cyanide

Chemical	CAS No.	State	Toxicity	Molecular weight	Vapor pressure
Hydrogen cyanide	74-90-8	Gas and Liquid	AEGL-2 (7.1 ppm)	27.03g/mol	750 mmHg
Specific gravity	**LEL**	**UEL**	**Vaper density**	**Flash point**	**Boiling point**
0.7	5600ppm	40000ppm	0.94	-18℃	25.5℃

2.2 Leak Accident Scenario

The variables of the hydrogen cyanide leakage accident scenario were selected by reflecting the 「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 stored hydrogen cyanide was ruptured and leaked. Hydrogen cyanide leakage conditions were selected as 2 ton for manufacturing factory and general handling facilities, 20 ton for outdoor storage, and 50 ton for outdoor tank storage at atmospheric stability of A, D and F. The end point for evaluating the damage effect range is the point at which the AEGL-2 concentration is reached, the leak hole diameter is 5cm, the air temperature is 25℃, the relative humidity is 50%, and the wind speed is 1.5m/s, 3m/s, and 5m/s respectively. The accident scenario is summarized in Figure 1.

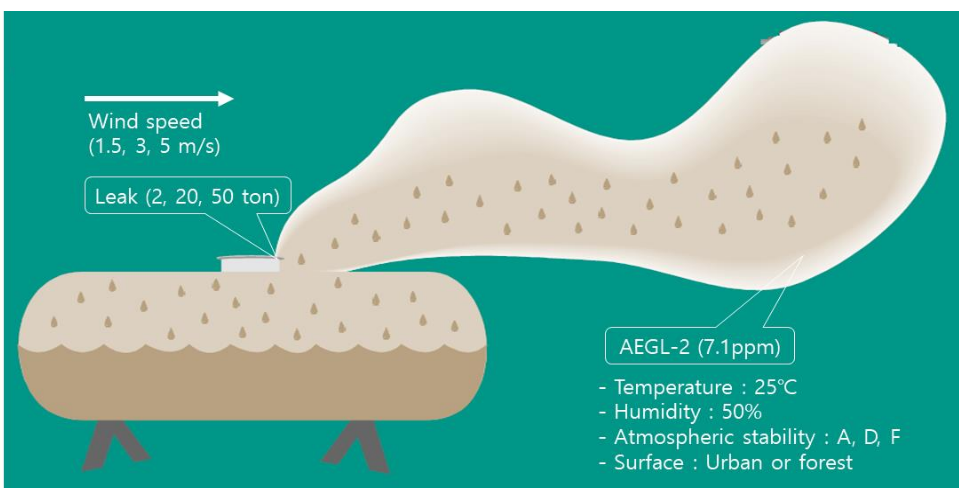


Figure 1. Evaluation of scenario

Scenario 1 is the worst scenario in which 2 tons leak at a wind speed of 1.5m/s, atmospheric stability F, temperature of 25°C, relative humidity of 50%, and surface resistance of forest or city. Scenario 2 is a case in which 2 tons leaked at a wind speed of 3m/s, atmospheric stability D, temperature of 25°C, relative humidity of 50%, and surface resistance of forest or city. Scenario 3 is a case in which 2 tons leaked at a wind speed of 3m/s, atmospheric stability A, temperature of 25°C, relative humidity of 50%, and ground resistance in a forest or city state. Scenario 4 is a case in which 2ton leaks at wind speed of 5m/s, atmospheric stability D, temperature of 25°C, relative humidity of 50%, and surface resistance is forest or city. In the same way, scenarios 5, 6, 7, and 8 leaked 20 tons, and scenarios 9, 10, 11, and 12 leaked 50 tons. Table 2 is summarized the conditions according to the 12 accident scenarios.

Table 2. Conditions for scenario

Endpoint	Weather Conditions			Leak temperature
Toxic concentration AEGL-2 (7.1 ppm)	Temperature 25℃	Humidity 50%	Atmospheric stability A, D, F	Operation temperature
Leak duration	**Leak size**	**Leak quantity**	**Wind speed**	**Surface curvature**
10 ~ 60min	5cm	2ton 20ton 50ton	1.5, 3, 5 m/s	Urban or forest

2.3 Input Variables and Input Values

Three types of hydrogen cyanide leakage, 2ton, 20ton, and 50ton, and three types of A, D, and F for atmospheric stability are entered. Also, enter the diameter of the leak hole at 5cm, the air temperature at 25℃, the humidity at 50%, and the wind speed at 1.5m/s, 3m/s, and 5m/s, respectively. The end point is entered automatically.

2.4 Evaluation Standard

Toxicity evaluation uses the AEGL-2 concentration, which is a guideline for exposure of the general public due to chemical leakage or disasters set by the EPA. AEGL-1 is the highest concentration that does not cause discomfort or irritation, and is the concentration that is reversibly restored when exposure is discontinued. AEGL-2 is the concentration at which irreversible, lasting adverse health effects or impairment of the ability to evacuate may be experienced. AEGL-3 is the concentration at which life-threatening or fatal experiences can be experienced. For radiant heat evaluation, 2kw/㎡ is used according to 「KOSHA GUIDE P-102–2021」 Attached Table 1. When exposed for 60 seconds, 2kw/㎡ causes pain, 5kw/㎡ causes second-degree burns, and radiant heat intensity that can cause death is 10kw/㎡. For overpressure evaluation, 1 psi (6.9 kPa) is applied according to 「KOSHA GUIDE P - 102 – 2021」 Attached Table 2. 1 psi (6.9 kPa) is the strength of partial destruction of houses that cannot be repaired, 3.5 psi (24.2 kPa) is the strength of unsupported steel structures or oil storage tanks, and 8 psi (55.2 kPa) is the collapse of brick walls with a thickness of 20-30 cm.

3. Experimental Results

Table 3 to Table 6 show the experimental results of toxicity, overpressure, and radiant heat effect range for 12 accident scenarios of hydrogen cyanide, the 1st petroleum of the 4th class flammable liquid. Table 3 shows the results of measuring the effect range of each concentration of AEGL-1, 2, 3 on the toxicity of 12 scenarios at hydrogen cyanide leak, wind speed, atmospheric stability, atmospheric humidity of 50%, and atmospheric temperature of 25℃.

Table 3. Toxic Output to Simulation

Scenario	Leakage (ton)	Wind speed (m/s)	Stability	AEGL-3 (km)	AEGL-2 (km)	AEGL-1 (km)
1	2	1.5	F	4.3	6.3	10.0
2	2	3	D	1.2	1.8	3.7
3	2	3	A	0.45	0.63	1.1
4	2	5	D	1.0	1.5	3.1
5	20	1.5	F	6.1	8.6	10.0
6	20	3	D	5.0	7.2	10.0
7	20	3	A	2.7	3.9	7.0
8	20	5	D	4.3	6.3	10.0
9	50	1.5	F	7.7	10.0	10.0
10	50	3	D	6.4	9.3	10.0
11	50	3	A	3.4	4.9	9.0
12	50	5	D	5.2	7.8	10.0

Table 4 shows the overpressure of 8psi(55.2kPa), 3.5psi(24.2kPa), and 1psi(6.9kPa) for 12 scenarios under hydrogen cyanide leakage, wind speed, atmospheric stability, atmospheric humidity of 50%, and atmospheric temperature of 25℃. This is the result of measuring the range of influence for each.

Table 4. Over-Pressure Output to Simulation

Scenario	Leakage (ton)	Wind speed (m/s)	Stability	8psi(55.2kPa) (m)	3.5psi(24.2kPa) (m)	1psi(6.9kPa) (m)
1	2	1.5	F	32.0	45.0	91.0
2	2	3	D	0	0	0
3	2	3	A	0	0	0
4	2	5	D	0	0	0
5	20	1.5	F	35.0	48.0	99.0
6	20	3	D	0	0	0
7	20	3	A	0	0	0
8	20	5	D	0	0	0
9	50	1.5	F	36.0	50.0	103.0
10	50	3	D	0	0	0
11	50	3	A	0	0	0
12	50	5	D	0	0	0

Table 5 shows the effect of radiant heat on 12 scenarios at hydrogen cyanide leakage, wind speed, atmospheric stability, air humidity of 50% and air temperature of 25℃ in case of pool fire. This is the result of measuring the influence range according to the radiant heat of 10kw/㎡, 5kw/㎡, and 2kw/㎡ for the effect of radiant heat.

Table 5. Radiation (Pool fire) Output to Simulation

Scenario	Leakage (ton)	Wind speed (m/s)	Stability	10kw/㎡(m)	5kw/㎡(m)	2kw/㎡(m)
1	2	1.5	F	13.0	18.0	29.0
2	2	3	D	13.0	18.0	29.0
3	2	3	A	14.0	20.0	30.0
4	2	5	D	17.0	22.0	31.0
5	20	1.5	F	17.0	24.0	37.0
6	20	3	D	17.0	24.0	37.0
7	20	3	A	17.0	24.0	37.0
8	20	5	D	22.0	28.0	39.0
9	50	1.5	F	18.0	26.0	40.0
10	50	3	D	18.0	26.0	40.0
11	50	3	A	18.0	26.0	40.0
12	50	5	D	24.0	31.0	43.0

Table 6 shows the effect of radiant heat on 12 scenarios at 25℃, air velocity, atmospheric stability, atmospheric humidity of 50%, and leakage of hydrogen cyanide in the case of a boiling liquid vapor explosion. This is the result of measuring the influence range according to the radiant heat of 10kw/㎡, 5kw/㎡, and 2kw/㎡ for the effect of radiant heat.

Table 6. Radiation (Boiling Liquid Vaper Explosion) output to Simulation

Scenario	Leakage (ton)	Wind speed (m/s)	Stability	10kw/㎡(m)	5kw/㎡(m)	2kw/㎡(m)
1	2	1.5	F	115.0	165.0	260.0
2	2	3	D	115.0	165.0	260.0
3	2	3	A	115.0	165.0	260.0
4	2	5	D	115.0	165.0	260.0
5	20	1.5	F	239.0	344.0	542.0
6	20	3	D	239.0	344.0	542.0
7	20	3	A	239.0	344.0	542.0
8	20	5	D	239.0	344.0	542.0
9	50	1.5	F	320.0	460.0	724.0
10	50	3	D	320.0	460.0	724.0

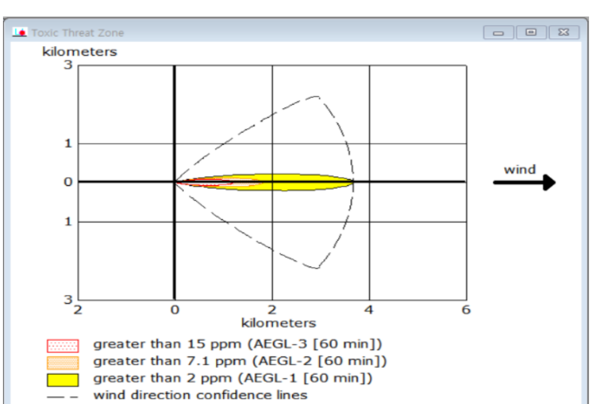
11	50	3	A	320.0	460.0	724.0
12	50	5	D	320.0	460.0	724.0

Table 6 shows the effect of radiant heat on 12 scenarios at 25℃, air velocity, atmospheric stability, atmospheric humidity of 50%, and leakage of hydrogen cyanide in the case of a boiling liquid vapor explosion (BLEVE). This is the result of measuring the influence range according to the radiant heat of 10kw/㎡, 5kw/㎡, and 2kw/㎡ for the effect of radiant heat.

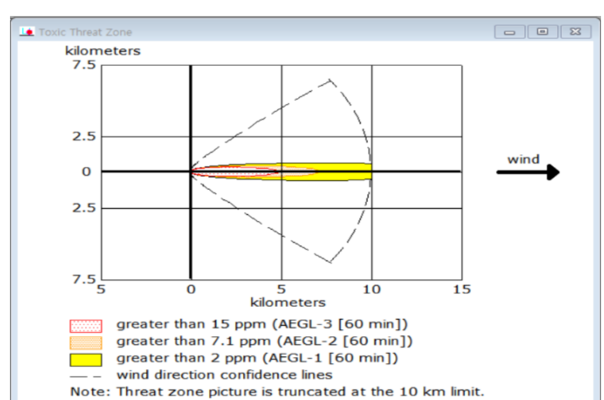
4. Discussion

4.1 toxicity Analysis

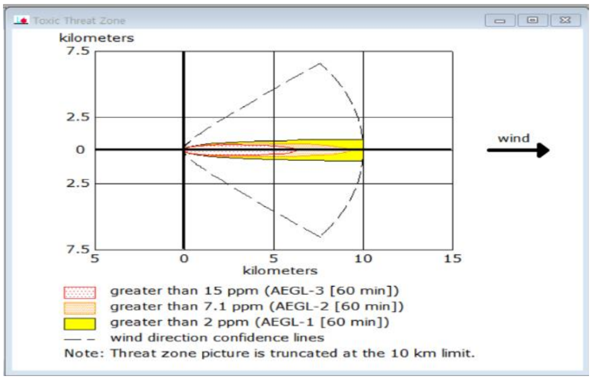
A university, sales facility, apartment complex, general hospital, etc. are located at a horizontal distance of 5km from storage A, and the nearest apartment complex is located at a horizontal distance of 0.82km from the leak point. The nearest apartment complex is analyzed as an area where all 12 accident scenarios correspond to AEGL-3 concentrations or higher and can cause death. Seven accident scenarios correspond to the case where the end point of the area exceeding 5km horizontally from the leak point has an AEGL-2 concentration or higher. Due to the leakage of hazardous materials, the area with AEGL-2 concentration or higher expanded not only to the inside of the hazardous materials storage, but also to the surrounding area. Therefore, we confirm that it was necessary to establish an emergency response plan inside and outside the hazardous materials storage based on the risk assessment. Figure 2 shows the range of toxicity effects according to the most likely scenarios 2, 6, and 10. Figure 2 (a) shows the effect range of each concentration of AEGL-1, 2, 3 on the toxicity for Scenario 2 with a leak amount of 2 ton, wind speed of 3m/s, atmospheric stability D, atmospheric humidity of 50%, and atmospheric temperature of 25°C. Figure 2 (b) shows the effect range of each concentration of AEGL-1, 2, 3 on the toxicity for Scenario 6 with leak amount of 20 ton, wind speed of 3m/s, atmospheric stability D, atmospheric humidity of 50% and atmospheric temperature of 25℃. Figure 2 (c) shows the effect range of each concentration of AEGL-1, 2, 3 on the toxicity for Scenario 10 with a leak volume of 50 ton, wind speed of 3 m/s, atmospheric stability D, atmospheric humidity of 50% and atmospheric temperature of 25℃. Figure 2 (d) shows the effect range of each concentration of AEGL-1, 2, 3 in scenario 10 under the same conditions on the map.



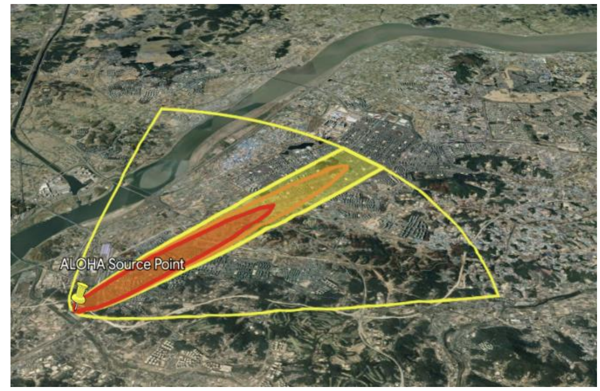
(a) Toxic distance in scenario 2



(b) Toxic distance in scenario 6



(c) Toxic distance in scenario 10

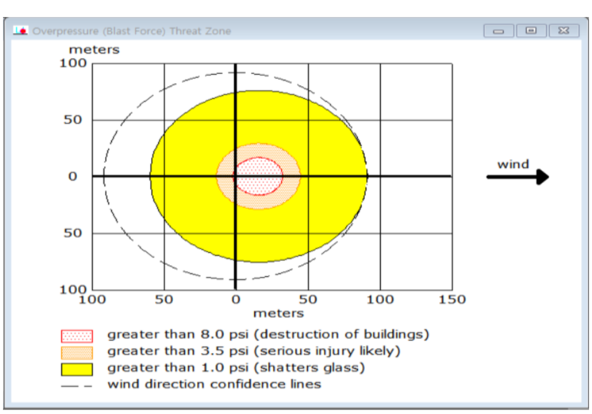


(d) Toxic distance in scenario 10

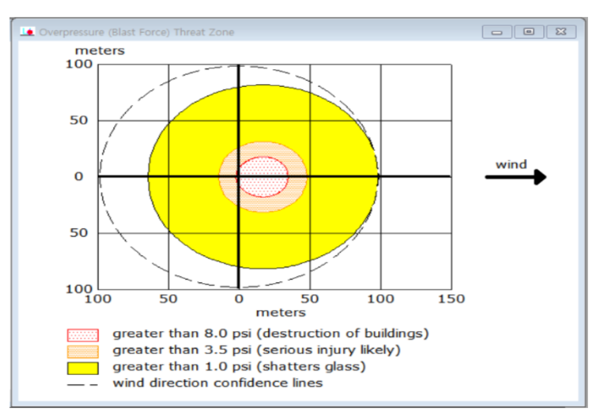
Figure 2. Toxic output according to scenario 2, 6, 10

4.2 Overpressure Analysis

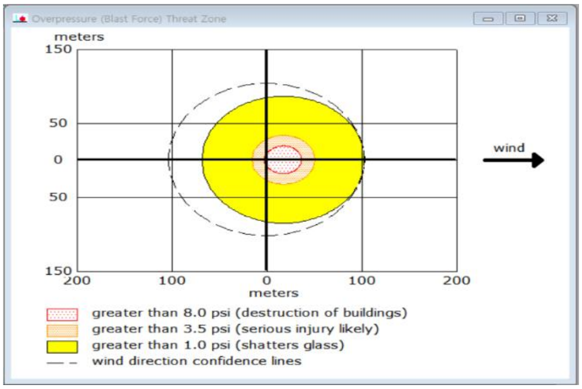
In the case of the overpressure test in Table 4, the effect range was limited to the inside of the hazardous materials storage with a horizontal distance of 32m or more and 103m or less in the case of the worst scenario. Overpressure was analyzed to be proportional to the amount of stored hazardous materials and the stability of the atmosphere. It was evaluated as 1 psi range for partial damage of houses that cannot be repaired is 45~103m, 3.5 psi range for damage to unsupported steel structures or oil storage tanks is 45~50m, 8 psi range for collapse of 20~30cm thick brick walls is 32-36 m. Figure 3 shows the overpressure influence range according to the most likely scenarios 2, 6, and 10. Figure 3 (a) shows the overpressure influence range of 8 psi (55.2kPa), 3.5 psi (24.2kPa), 1 psi (6.9kPa) for Scenario 2 with a leak of 2 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 overpressure influence range of 8 psi (55.2kPa), 3.5 psi (24.2kPa), 1 psi (6.9kPa) for scenario 6 with a leak of 20 ton, wind speed of 3 m/s, atmospheric stability D, atmospheric humidity of 50%, and atmospheric temperature of 25°C. Figure 3 (c) shows the overpressure influence range of 8 psi (55.2kPa), 3.5 psi (24.2kPa), 1 psi (6.9kPa) for scenario 10 with a leak of 50 ton, wind speed of 3 m/s, atmospheric stability D, atmospheric humidity of 50%, and atmospheric temperature of 25°C. Figure 3 (d) shows the overpressure range of scenario 10 on the map under the same conditions.



(a) Over-pressure distance in scenario2



(b) Over-pressure distance in scenario6



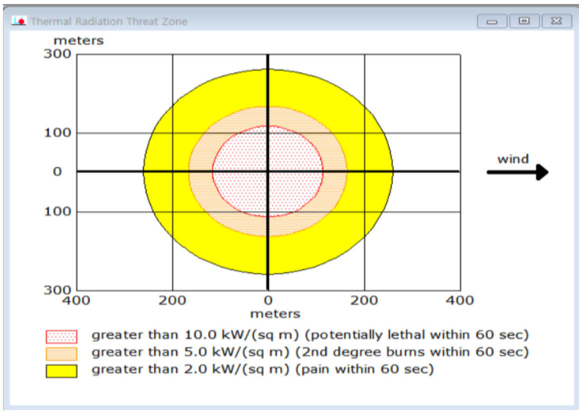
(c) Over-pressure distance in scenario10

(d) Over-pressure distance in scenario10

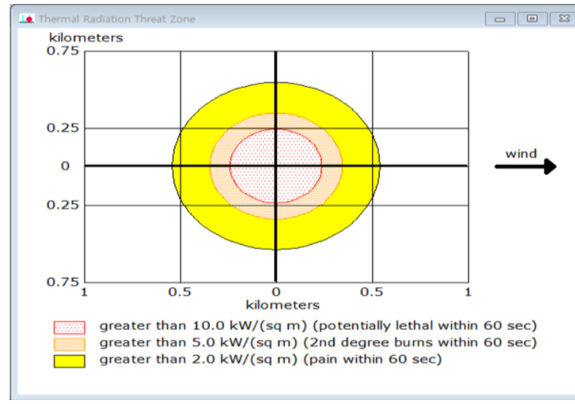
Figure 3. Over-pressure output according to scenario 1, 5, 9

4.3 Radiant Heat Analysis

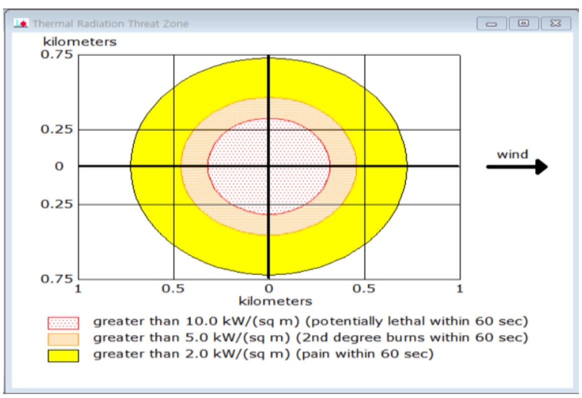
The range of influence of radiant heat was 13m or more and 43m or less in the horizontal distance from the leak point for pool fire, and 115m or more and 724m or less for BLEVE as the horizontal distance from the leak point. It was confirmed that the scope of influence of the pool fire was limited to the inside of the hazardous materials storage, but the boiling liquid vapor explosion also had the effect of radiant heat outside the hazardous materials storage. It is analyzed that pool fire is proportional to the quantity of dangerous substances handled in the hazardous materials storage and wind speed, and BLEVE is proportional to only the quantity of dangerous substances handled. It was evaluated that the range of 2kw/㎡ that causes pain is 724m or less, the range of 5kw/㎡ that causes second-degree burns is 460m or less, and the range of 10kw/㎡ that can cause death is 320m or less. In addition, since radiant heat also affects the outside of the storage, it is required to establish an emergency response plan based on risk assessment inside and outside the storage for hazardous materials. Figure 4 shows the radiant heat impact range according to scenarios 2, 6, and 10 with high probability of occurrence. It shows the range of influence that Figure 4 (a) shows the radiant heat effect of 10 kw/㎡, 5 kw/㎡, and 2 kw/㎡ for Scenario 2 with a leak of 2 ton, wind speed of 3m/s, atmospheric stability D, atmospheric humidity of 50%, and atmospheric temperature of 25°C. at 10 kw/㎡, 5 kw/㎡, and 2 kw/㎡. It shows the range of influence that Figure 4 (b) shows the radiant heat effect of 10 kw/㎡, 5 kw/㎡, and 2 kw/㎡ for Scenario 6 with a leak of 20 ton, wind speed of 3m/s, atmospheric stability D, atmospheric humidity of 50%, and atmospheric temperature of 25°C. at 10 kw/㎡, 5 kw/㎡, and 2 kw/㎡. It shows the range of influence that Figure 4 (c) shows the radiant heat effect of 10kw/㎡, 5 kw/㎡, and 2 kw/㎡ for Scenario 2 with a leak of 50 ton, wind speed of 3m/s, atmospheric stability D, atmospheric humidity of 50%, and atmospheric temperature of 25°C. at 10 kw/㎡, 5 kw/㎡, and 2 kw/㎡ and Figure 4 (d) shows the range of radiant heat in scenario 10 under the same conditions on the map.



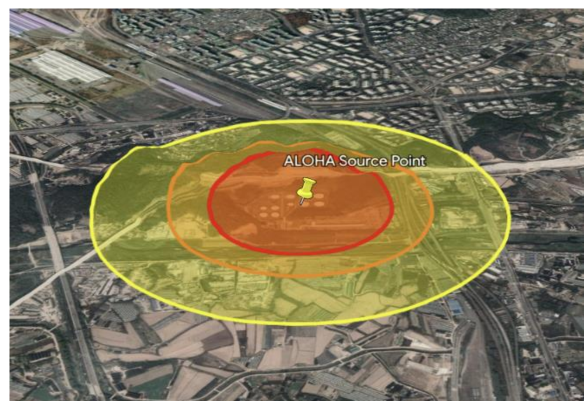
(a) Radiation distance in scenario 2



(b) Radiation distance in scenario 6



(c) Radiation distance in scenario 10



(d) Radiation distance in scenario 10

Figure 4. Radiation (BLEVE) output according to scenario 2, 6, 10

4.4 Improvement Plans based on Analysis of Experiment

As a result of analyzing simulations of toxicity, overpressure, and radiant heat in hazardous material storage, the improvement plans are as follows.

1) The end point of the area exceeding 5km from the leak point beyond the inside of the hazardous material storage area is identified as an area with an area of AEGL-2 concentration or higher and 724m of a range of 2kw/㎡. Emergency Response Plan based on risk assessment needs to be established. Currently, the prevention provisions of Article 17 of the 「Hazardous material Safety Management Act」 do not stipulate risk assessment. The process safety management under Article 49-2 of 「Industrial Safety and Health Act」, the chemical accident prevention management plan under Article 23 of the 「Chemicals Control Act」, and the safety management system under Article 11 of the 「High Pressure Gas Safety Control Act」 stipulate risk assessment. Fire risk assessment is also regulated in the performance based design of 「Fire Protection Installation and Management Act」 Article 3. Therefore, we propose to improve the safety management of hazardous material by conducting risk assessments on toxicity, overpressure and radiant heat, and reflecting the results in prevention regulations.

2) We propose emergency response (ERP) plan because it is confirmed that toxicity and radiant heat are affecting the surrounding area outside the hazardous material storage. As with the chemical accident prevention

plan, matters such as cooperation with the local community, evacuation information and information delivery system, resident protection and evacuation plan need to be reflected in the prevention regulations. Due to the limited sensing range of individual unmanned vehicles, it was insisted that needed to cooperate to achieve an effective sensing coverage and move to a more polluted region in ERP [9]. Confined Plasma Source (CPS) is proposed to save environment and improve ERP by replacing harmful gases which are innocuous gases or incineration with plasma [10].

3) It was analyzed that the influence range of toxicity, overpressure and radiant heat is proportional in a quantity. So, we insist to increase the number of storage tanks for hazardous material, reduce the amount of storage per tank, or to implement preventive regulations that reflect devices that can urgently transport hazardous material in the event of an accident.

5. Conclusion

This study is an experiment on toxicity, overpressure, and radiant heat of hazardous materials factories and surrounding areas due to leakage of hazardous material in order to prepare prevention regulations reflecting the physical and chemical characteristics of hazardous material manufactured, stored, and handled in hazardous material factories. Regarding the impact of hydrogen cyanide leakage accident, the results of toxicity, fire, and explosion were analyzed using ALOHA, an off-site consequence assessment program. As a result, the toxicity was analyzed to exceed 5km in the area with AEGL-2 concentration or higher, the overpressure was 103m in the range of 1 psi or more, and the radiant heat was analyzed to be 724m in the range of 2 kw/㎡ or more. Toxicity and radiation affected the area outside the hazardous material storage area, but the overpressure was limited to the inside of the hazardous material storage area. Therefore, we insist to improve the safety management of hazardous materials by conducting a risk assessment for hazardous materials and reflecting the results in internal and external ERP plans to prepare prevention regulations. In this study, it was found that toxicity, overpressure, and radiant heat affected the surrounding area at the hazardous material manufacturing plant, so additional research is needed on the overlapping areas and the adjustment of competent departments with the chemical accident prevention management plan, process safety management, and safety management system.

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