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A Simple Hazard Scenario Identification Method for Risk Assessment on Chemical Hazards to Prevent Fire and Explosion for Open Space Work

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When performing risk assessment on chemical hazards, such as fire and explosion, it is necessary to comprehensively identify the hazards and the scenarios leading to the occurrence of fire and explosion in order to consider specific risk reduction measures. It is required to utilize specialized knowledge about the characteristics of chemical substances related to the reaction process, ignition phenomena, and associated functions. Especially in medium-sized enterprises (SMEs), it is difficult to perform risk assessments for hazardous chemicals. This paper proposes a simple hazard scenario identification method focusing on the three elements of combustion (fire triangle), that is fuels, ignition source, and oxygen. Hazard scenarios of causing a fire or explosion when combustible chemicals are handled in an open area can be classified into four patterns. Based on the confirmed pattern for hazard scenarios, the triggering event could be comprehensively identified, and the hazard scenario leading to the occurrence of fire and explosion could be easily identified. Furthermore, by considering workplace condition, etc., the occurrence of industrial accidents and the spread of damage to the surrounding area could be included in the hazard scenario.

1. Introduction

To perform risk assessments for hazardous chemicals and to devise specific risk reduction measures, it is necessary to comprehensively identify the hazards and the hazard scenarios of how they cause a fire or explosion. It is required to utilize specialized knowledge about the characteristics of chemical substances related to the reaction process, ignition phenomena, etc. This paper proposes a simple hazard scenario identification method focusing on the three elements of combustion (fire triangle), that is fuels, ignition source, and oxygen.

2. Patterns of Causing Fire/Explosion (How Three Elements of Combustion Coexist)

The basis for identifying the hazard scenarios of causing a fire or explosion is to find the conditions under which the three elements of combustion coexist. This means that a fire or explosion occurs when combustible or inflammable chemicals come into contact and mix with oxygen (air), which form an explosive atmosphere as an unsafe condition, and at the same time an ignition source occurs. When targeting open space work, oxygen (air) is always present, and it is enough to focus on the two points of the formation of an explosive atmosphere and the occurrence of ignition sources. Based on whether risk reduction measures are taken against these two points, hazard scenarios of the causation of fire or explosion, when combustible chemicals are handled in an open area, can be classified into four patterns based on the coexistence of the three elements of combustion, as shown in Table 1.

Pattern (a): No measures are taken to prevent the formation of an explosive atmosphere and to prevent the occurrence of ignition sources.
Pattern (b): Measures are taken only to prevent the occurrence of ignition sources.
Pattern (c): Measures are taken only to prevent the formation of an explosive atmosphere.
Pattern (d): Measures are taken to prevent both the formation of an explosive atmosphere and the occurrence of ignition sources.

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This paper proposes the simple hazard scenario identification method by checking in advance in which pattern the work subject to risk assessment is performed. Various hazard scenarios leading to the occurrence of fire and explosion are identified by preparing three types of sheets in order:

i) Working Condition Check Sheet: Check in which pattern in Table 1 the work subject to risk assessment is performed (and if it is already in an unsafe condition) by checking the characteristics of the handled chemical substances, workplace conditions, measures already taken, and others.
ii) Trigger Event Check Sheet: Comprehensively identify trigger events that can cause an unsafe condition.
iii) Hazard Scenario Identification Sheet: Identify the hazard scenario of causing a fire, explosion, or effects on others (including industrial accidents).

The proposed method is explained in view of selected work examples (MHLW).

Table 1 Identification Patterns for Hazard Scenarios of Causing Fire/Explosion during Work in an Open Area

I. Use of combustible chemicals		II. Formation of explosive atmosphere	
		(1) Measures are NOT taken to prevent formation of explosive atmosphere	(2) Measures are taken to prevent formation of explosive atmosphere
III. Occurrence of ignition source	(3) Measures are NOT taken to prevent occurrence of ignition sources	Pattern (a) Three elements of combustion may be coexisting Explosive atmosphere Ignition source There is always a high risk of fire and explosion, so prompt measures are required.	Pattern (c) Three elements of combustion can coexist Explosive atmosphere Ignition source An explosive atmosphere can be formed by a failure such as forgetting to close the container lid (trigger event B).
	(4) Measures are taken to prevent occurrence of ignition sources	Pattern (b) Three elements of combustion can coexist Explosive atmosphere Ignition source Ignition sources can occur due to a failure such as poor ground connection caused by deterioration (trigger event A).	Pattern (d) Three elements of combustion can coexist Explosive atmosphere Ignition source An explosive atmosphere can be formed and ignition sources can occur due to the simultaneous occurrence of trigger events A and B.

3. Checking Characteristics of Handled Chemical Substances, Working Conditions, Current Measures, etc.

Prepare a “Working Condition Check Sheet” (Table 2) to check which identification pattern for hazard scenario of causing a fire or explosion in Table 1 is applicable to each work subject to risk assessment.

[Column A]: Enter work procedures and details referring to the latest version of the work procedure manual that reflects the details and methods of the work actually performed at the work site. At this time, clarifying the purpose (intent) of the work will enable more detailed analysis.

[Column B]: 1) Enter the name of the chemical substances to be handled. 2) Obtain information on hazards and applicable laws and regulations by checking GHS labels, SDSs, and the like. Enter the points that require special attention, such as physical property data (e.g., flash point and possibility of dust explosion of powdered material), if any. 3) Enter the conditions of use (temperature, humidity, amount handled, storage conditions, etc.) of the handled chemical substances, and how to dispose them. 4) List the facilities, equipment, and tools used in the work, and enter their names. Also check their purposes of use and appropriate use.

[Column C]: Enter the answers to Check I through III below in their corresponding columns, and check which of the identification patterns of hazard scenarios of causing a fire or explosion in Table 1 applies.

I. Check if the handled chemical substances are combustible.

Fires and explosions occur when combustible chemicals are handled. Check if the handled chemical substances are combustible by referring to the GHS labels or SDSs. If combustible chemicals are handled, enter the product name and chemicals name, and then go to next steps II and III.

II.Check whether measures are taken to prevent the formation of an explosive atmosphere.

In open work sites, oxygen is always present, and an explosive atmosphere is formed (the condition becomes unsafe) when combustible or inflammable chemicals come into contact or mix with oxygen. (1) If measures are

NOT taken to prevent the formation of an explosive atmosphere, enter “No measures taken.” An explosive atmosphere can always be present and the reason(s) why it has not been considered necessary to take measures, if any. (2) If measures are taken to prevent the formation of an explosive atmosphere, enter the measures taken to prevent the formation of an explosive atmosphere, and also check their purposes.
III. Check whether measures are taken to prevent the occurrence of ignition sources.
(3) If measures are NOT taken to prevent the occurrence of ignition sources, enter “No measures taken.” Ignition sources can occur at any time and the reason(s) why it has not been considered necessary to take measures, if any. (4) If measures are taken to prevent the occurrence of ignition sources, enter the measures taken to prevent the occurrence of ignition sources, and also check their purposes.
IV.Check the identification pattern of the hazard scenario that the three elements of combustion coexist, causing a fire or explosion.
Based on the answers to I through III, check which of the identification patterns (a through d) of hazard scenarios of causing a fire or explosion in Table 1 applies. The following apply depending on the pattern.
Pattern (a): Fire or explosion could occur at any time. It is necessary to take some risk reduction measures before performing risk assessment.
Patterns (b) to (d): A trigger event can cause a fire or explosion. Some risk reduction measures have already been taken, and provided these measures work, the three elements of combustion will not coexist, but the occurrence of a trigger event, such as an equipment failure and work error, can invalidate them, as a result of which the three elements of combustion coexist, causing a fire or explosion.

Table 2 Working Condition Check Sheet (Form and an example)

[A] Work procedure /details	[B] Handled chemical substances and facilities, equipment, and others used for work				[C] Confirmation of pattern of the three elements of combustion that can cause fire or explosion			
	Substances handled	Information on hazards of chemical substances concerned	Handling conditions (temperature, humidity, amount handled, storage conditions, etc.)	Facilities, equipment, and tools used for work	I. Are the chemical substances handled combustible?	II. Are measures taken to prevent the formation of an explosive atmosphere?	III. Are measures taken to prevent the occurrence of ignition sources?	Pattern (a) - (d)
2 Dispose of the used waste cloth in a trash can.	Lacquer thinner (toluene, ethyl acetate, butyl acetate, etc.)	Flammable liquids, Category 2 (water-insoluble)	Room temperature, 500 mL Pour lacquer thinner into a plastic container, moisten a waste cloth with lacquer thinner from the container, and then use the cloth. Dispose of the waste cloth in a trash can.	- Plastic container - Waste cloth (cotton) - Trash can	Yes (Lacquer thinner)	No measures taken	- Use explosion-protected equipment - Prohibit bringing-in non-explosion-protected equipment (e.g., smartphones) - Use a conductive flooring - Ground metal products - Wear antistatic work clothes and antistatic shoes - Control the use and bringing-in of fire	(b)

The purposes of preparing a “Working Condition Check Sheet” are as follows: 1) to confirm that the contents of the work procedure manual match the work actually being performed, 2) to check the characteristics of the handled chemical substances, handling conditions, equipment used, etc., and 3) to check how risk reduction measures are currently taken, and classify them into patterns to ascertain if an unsafe condition has arisen.

4. Identification of Trigger Events of Fire/Explosion

When performing risk assessment on chemical hazards, it is important to analyze all potential hazards in the work and equipment used to handled chemical substances. The JNIOSH method (JNIOSH, 2016, Shimada et al., 2019) comprehensively identifies the events that can actualize potential hazards (trigger events) for each work described in the work procedure manual. Trigger events are broadly classified into (i) facility, equipment, and tool failures and (ii) inappropriate work/operations (human errors) as shown in Table 3. The proposed method checks if the formation of an explosive atmosphere or the occurrence of ignition sources is triggered by these events. In order to identify various hazard scenarios that are hard to imagine (or recognize) only by checking work sites at normal times, prepare a “Trigger Event Check Sheet” (Table 4) to comprehensively identify (i) facility, equipment, and tool failures and (ii) inappropriate work/operations.
[Column D]: Check the purposes of use of facilities, equipment, and tools. Based on the idea that “machines can break (can fail to operate as expected),” identify facility, equipment, and tool failures as trigger events.
[Column E]: Check the purpose and method of work or operation. Based on the idea that “people can make errors,” identify failures in work or operation as trigger events, classifying them into the seven types of human errors shown in Table 5 (Swain and Guttmann, 1983).

Table 3 Classification of Trigger Events

Classification	Description and examples of how to identify the hazard scenario
(i) Facility, equipment, and tool failures	- Machines can break. E.g. What happens if the local exhaust system does not work? What happens if the container lid is damaged?
(ii) Inappropriate work/operation	- People (workers) can make errors. E.g. What happens if you forget to turn on the local exhaust system? What happens if you press the wrong switch?

Table 4 Trigger Event Check Sheet (Form and an example)

[A] Work procedure /details	[B]	[C]	[D] Trigger events related to facilities, equipment, and tools	[E] Trigger events related to work/operation (human errors)						
			Facility, equipment, and tool failures (Failure mode)	Omission errors	Commission errors					
					Selection errors	Sequential errors	Time errors	Qualitative errors	Quantitative errors	Other errors
2 Dispose of the used waste cloth in a trash can.	Same with column [B] in Table 2	Same with column [C] in Table 2	- Damage to plastic container - Damage to trash can - Explosion-protected lighting failure - Deterioration of antistatic work clothes - Dirty soles of antistatic work shoes - Deterioration of ground wire of conductive flooring - Deterioration of ground wires of metal products	- Leave the used waste cloth as it is	- Dispose of the plastic container in a container at hand other than a trash can	-	- Dispose of the plastic container in a container at hand other than a trash can	-	-	- Spill lacquer thinner - Bring in non-explosion-protected lighting - Lay a stain-proof vinyl sheet on the flooring - Wear non-antistatic work clothes or work shoes

Table 5 Classification of Human Errors

Classification	Description
(1) Omission errors	Fail to carry out the required work.
Commission errors	Carry out the wrong work.
(2) Selection errors	Select the wrong tool. Work on the wrong part. Issue the wrong instruction or information (setting error).
(3) Sequential errors	Work in the wrong order.
(4) Time errors	Work at the wrong time (too early or too late).
(5) Qualitative errors	Non-standard work intensity (quality).
(6) Quantitative errors	Non-standard amount of work (filling rate, duration time, etc.).
(7) Other errors	Errors other than the above.

The purposes of preparing a “Trigger Event Check Sheet” are as follows: 1) to understand the work details (procedure), characteristics (risks) of the handled chemical substances, and how they are handled, and to check the purposes of the facilities, equipment, and tools and how they are used, 2) to check in advance whether measures are taken to prevent the formation of an explosive atmosphere and the occurrence of ignition sources, to clarify the purposes of such measures, and also to be aware that such measures can be invalidated, 3) to comprehensively identify facility, equipment, and tool failures and inappropriate work/operations as events that can actualize the potential hazards of the handled chemical substances, 4) to detect inappropriate alteration of the work procedure manual (e.g. shortcuts and unfounded changes) and unsafe behavior that deviates from the rules, and 5) to identify more specific hazard scenarios of causing a fire or explosion by examining the cases where an identified trigger event occurs.

5. Identifying Hazard Scenarios of Causing Fire/Explosion

Figure 1 shows the flow of events from a trigger event to fire or explosion and the resulting industrial accident and the spread of damage to the surrounding area. There are cases where the condition is already unsafe due

to insufficient measures (1) and (3) and cases where the condition becomes unsafe if a trigger event occurs (2) and (4). In either case, if both the formation of an explosive atmosphere and the occurrence of ignition sources occur, it could cause a fire or explosion. Furthermore, a fire or explosion can cause industrial accidents (5) and damage to the area around the factory (e.g., spread of fire to neighboring houses) (6). Such a series of events that can lead to disasters should be identified as a hazard scenario.

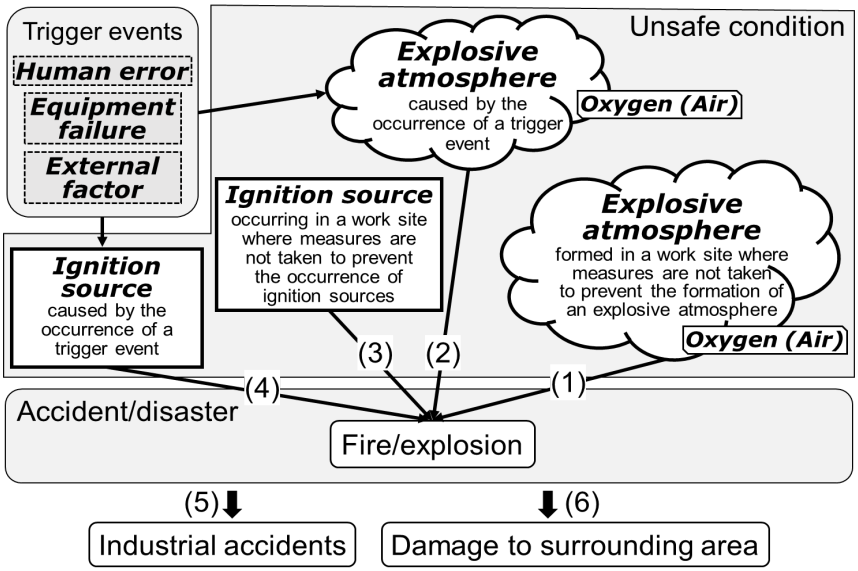

Figure 1 Flow of Events from Fire/Explosion to Industrial Accidents and Spread of Damage to Surrounding Area

In order to identify the hazard scenario of causing a fire or explosion, prepare a “Hazard Scenario Identification Sheet” (Table 6)

[Column F]: Select one from the trigger events listed in [Column D] or [Column E] of the “Trigger Event Check Sheet” and confirm whether an explosive atmosphere can be formed and whether ignition sources can occur (possible unsafe conditions) based on the identification patterns (b) to (d).

If pattern (b): Check whether the occurrence of ignition sources can be caused by any of the identified trigger event A under the unsafe condition that an explosive atmosphere can always be present.

If pattern (c): Check whether the formation of an explosive atmosphere can be caused by any of the identified trigger event B under the unsafe condition that ignition sources can occur at any time.

If pattern (d): Measures have been taken to prevent the formation of an explosive atmosphere and the occurrence of ignition sources, and the three elements of combustion cannot coexist and no fire or explosion will occur provided these measures work, but if trigger events occur, invalidating these measures, it could cause a fire or explosion. The following two types of processes should be examined:

- Check whether the occurrence of ignition sources can be caused by any of the identified trigger event A under the condition that the formation of an explosive atmosphere has been caused by one of the identified trigger event B.
- Check whether the formation of an explosive atmosphere can be caused by any of the identified trigger event B under the condition that the occurrence of an ignition source has been caused by one of the identified trigger event A.

[Column G]: Check the following based on whether an explosive atmosphere can be formed and whether ignition sources can occur that are described in [Column F].

- If an explosive atmosphere is formed and ignition sources occur (the three elements of combustion coexist), there is a risk of fire or explosion. Describe that process in as much detail as possible. Further, considering the number and placement of workers and workplace condition (e.g., implementation status of 5S activities, equipment layout, evacuation routes, factory location), examine other effects (e.g., industrial accidents and damage to the surrounding area).
- If no explosive atmospheres are formed or no ignition sources occur (the three elements of combustion do not coexist), fires and explosions cannot occur.

The purposes of preparing a “Hazard Scenario Identification Sheet” are as follows: 1) to comprehensively identify the hazard scenarios of causing a fire or explosion triggered by the occurrence of a trigger event, 2) to

clarify the purposes of devising and implementing risk reduction measures, such as preventing the occurrence of ignition sources and the formation of an explosive atmosphere, and 3) to help perform the risk analysis of the identified hazard scenario and devise and implement additional risk reduction measures by describing the hazard scenario in the “Risk Assessment Sheet”, which is used for the JNIOSH method.

Table 6 Hazard Scenario Identification Sheet (Form and an example)

[A] Work procedure /details	[C]	[D] [E] Trigger events	[F] Unsafe conditions		[G] Accidents and disasters	
			Formation of explosive atmosphere	Occurrence of ignition source	Fire / explosion	Other effects
2 Dispose of the used waste cloth in a trash can.	Same with column [C] in Table 2	- Explosion-protected lighting failure	Working in an open area can cause an explosive atmosphere to be formed around thinner.	Poor lighting insulation can cause electric sparks.	Fire caused by ignition of vapor around thinner	Burns caused by fire, spread of fire to surrounding combustibles, spread of fire to work clothes, etc.
		- Lay a stain-proof vinyl sheet on the flooring	Working in an open area can cause an explosive atmosphere to be formed around thinner.	Workers can become charged, causing electrostatic sparks.	Fire caused by ignition of vapor around thinner	Fire caused by ignition of vapor around thinner

6. Example of Identification of Hazard Scenarios of Causing Fire/Explosion

The following is an example that applies the proposed method to the metal coating work (MHLW). The part of results for Step 2 “Dispose of the used waste cloth in a trash can” are shown in Tables 2, 4, and 6.
This work is carried out in an open area where oxygen (air) is present. (I) All the handled chemical substances are combustible. (II) Measures taken to prevent the formation of an explosive atmosphere are shown in [Column C] in the Table 2. (III) Measures taken to prevent the occurrence of ignition sources are shown in [Column C] in the Table 2. (IV) From the above, this work is confirmed as pattern (b). Although measures are taken to prevent the occurrence of ignition sources, an explosive atmosphere can always be present.
The facility, equipment, and tool failures and inappropriate work/operations (seven types of human errors) in the Table 4 are identified as trigger events. In addition to the facility, equipment, and tool failures in [Column B], errors (failures) in the measures to prevent the formation of an explosive atmosphere and those to prevent the occurrence of ignition sources confirmed in [Column C] are identified.
For the trigger events described in [Column D] or [Column E], hazard scenarios of causing fire or explosion and subsequent effects on others are identified on the basis of the information on the work details/conditions, chemical substances to be handled, and others as shown in Table 6.

7. Conclusions

This paper proposes a simple hazard scenario identification method focusing on the three elements of combustion. This useful method is the first initiative for SMEs to implement effective risk reduction measures in precise and accurate ways as part of the implementation of risk assessment practices. It is expected that the proposed method will have widespread implementations. Occupational safety consultants have evaluated this method and concluded that it is simple and easy-to-introduce method. The proposed method demonstrates that minimum points to be checked to identify the hazard scenario of causing a fire or explosion easily when performing risk assessment and developing risk reduction measures of hazardous chemicals. It is noted that this method does not necessarily cover all risks (all fire and explosion hazard scenarios), which require further studies.

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