

Analysis of Construction Safety Risk in House Power of a Power Plant Based on Bow-Tie Technique

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ABSTRACT

Large construction projects are always at high risk, so the safety of these projects would be of utmost importance. Analysis of risk resources and safety risk is one of the important activities to prioritize the existing risks as well as managing them in the process of building a power plant as one of the most at-risk industries in terms of safety issues. The purpose of this study was to analyze the safety risks existing in the construction phase of a power plant based on the Bow-tie technique. This cross-sectional analytical study was carried out in 2017 at the house power of a combined cycle power plant. Safety analysis of the risks was performed based on the Bow-tie technique using the Bow Tie ProTM software. For the more effectiveness of this study, two phases, including system descriptions and identification of the risk sources were designed and implemented before the risk analysis steps, and prior to identifying the path of each branch of the Bow-tie chart (from consequence to event occurrence). The results showed that the highest level of threats is related to “pressure cylinders”, “welding”, and “cutting” (including 8 threats of mechanical damage, heat, transportation, unsafe connections, cylinders storage, oil and grease, leakage, and flame retardation). In addition, the most significant consequences were related to heavy loading (including 3 consequences of human injury, damage to cranes, and damage to facilities and equipment), pressure cylinders, welding, and cutting (including 3 consequences of human injury, fire and explosion, and damage to facilities and equipment). The findings indicated that Bow Tie ProTM software would be a suitable tool in analyzing the safety risks of large projects, such as the construction of power plants that involves considering preventive and limiting safety measures for prevention or mitigation of threats as well as controlling the safety implications of the construction activities.

KEYWORDS: Safety, Risk analysis, Bow-tie technique, Power plant

INTRODUCTION

Large and complex industrial projects are always exposed to different risks and their success will not be possible unless such risks are appropriately managed. In fact, identification, analysis, and evaluation of risks, resulting in the

success of project activities, are important parts of risk management [1]. In other words, in order to prevent or decrease harmful events and accidents,

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risk sources need to be identified and analyzed carefully [2]. Bow-tie, as is one of the effective risk analysis techniques, provides a more realistic understanding of the relationship between the factors activating hazards, consequences, and any barriers preventing accidents [3].

In comparison with other techniques, Bow-tie provides answers to the questions in relation to the consequences of risk source, the control of consequences, and the path between a threat and a consequence. The use of this technique offers some practical suggestions for the removal or control of risks, provides a better understanding of risk prevention, and determines the necessary protection measures for a safe operation [4, 5]. The results of some studies have shown that Bow-tie is the ideal technique for analyzing risks; it demonstrates the relationship between controlling techniques and the organization of a management system. It also can be used to suggest some techniques for controlling risk sources and the reduction of accidents [3, 6-8].

As a result of advances in technological advances, power plants—the most fundamental part of the economy of every country—are exposed to many risks and accidents; therefore, if the power plants face any sort of technical difficulty, there will be occurred serious consequences [9]. Accordingly, offering an approach to identify, analyze, and evaluate risks will be effective in reducing occupational accidents. Some studies into occupational accident analysis of power plant industries have shown that the root causes contributing to the accidents were the result of individual ignorance of safety cautions, the lack of safety training program, age, and family situation [10-12].

Moreover, activities involved in the construction of a house power in power plants would be at high levels of risk. Diggings, installation of armatures, concreting, loading, installing metal structures and equipment, scaffolding and working at height, working with electricity, welding, cutting, grinding, working in enclosed places, radiography, sandblasting, and painting are examples of such activities. It should be noted that following safety rules in the construction of a house power in power plants is of great importance because if something goes wrong in the process of construction, the electricity generation will face difficulty [13].

The present study was carried out aiming at analyzing the safety risks involved in the construction of a house power unit in a power plant. The study also suggested some risk management approaches based on the Bow-tie technique to prevent accidents.

MATERIALS AND METHODS

This is a cross-sectional analytical study conducted in 2017 in the house power of a combined cycle power plant in order to identify safety risk sources and analyze the risks involved in the construction of the unit. The data were analyzed by the use of Bow Tie Pro™ software.

Bow tie technique

Bow tie technique is one of the useful and effective ways for risk management. The underlying idea behind this technique was introduced in 1979 by Queensland University, Australia [3, 14]. Bow tie technique is effective in risk analysis where qualitative approaches are impossible to implement. This technique is represented in a diagram consists of three parts: fault tree, event tree, and danger. The fault tree (a set of causes) is on the left side of the diagram, while the event tree (the consequences) is on the right side, and danger is placed in the middle of these two trees [4]. In order to draw such a diagram, some information is needed about the event, the threats causing the event, the consequences of the events, preventive actions (controls), and the reduction of consequences.

Bow Tie Pro™ software is a scientific tool used for the implementation of risk analysis based on the Bow-tie technique. Influential Bow-tie diagrams of the risk analysis process are produced by the use of this tool. In order to analyze the consequences, the Bow Tie Pro™ software uses the risk analysis matrix and it also is able to store valuable management information about the controlling approaches toward the risks. The next part of this technique is related to the analysis and evaluation of risks and making decisions about controlling actions. Bow-tie diagram allows for all the individuals taking part in a process to be aware of their responsibility in relation to a specific danger, the occurrence of the event, the consequences, and the manner of safely implementing required actions such as maintenance [4, 15]. The bow-tie diagram, a practical tool for the identification and qualitative analysis of risks, not only demonstrates probable risk paths, but also explicitly distinguishes between preventive actions and reduction actions (restricting safety layers). Helping to prioritize safety actions, which are so important for supporting the decision making process, is another feature of this technique. Moreover, using this technique helps illustrate all the causes and consequences of an event and presenting the influence of all safety systems and barriers involved in the accident scenario; bow tie could also evaluate the operations of safety barriers, such as reactions and safety levels [4, 5, 7].

Study Procedure

At the first step, the system and all the operating activities were defined. Then, the activities were categorized based on the features of the construction process of a house power in a power plant. After that, each occupational activity was carefully studied. In the next step, by using the bow-tie technique, risk sources, threatening factors, all the events, and their probable consequences were identified and safety risk analysis and evaluation were done. The risk analysis matrix, which was consisted of 6 probability items and 6 severity items, was developed in the Bow Tie Pro™ software to analyze the risks. Moreover, some preventive actions were prioritized for each branch in the diagram (from threat to accident) and controlling actions were determined to reduce the severity and the effect of the consequences.

RESULTS

According to the obtained results, the threatening risk sources of the construction of the house power were (1) cranes and heavy loading; (2)

working at height with the basket; (3) scaffolds and working on them; (4) working with electricity and electricity box; (5) high-pressure cylinders, welding, and cutting with gas; (6) electric welding; and (7) grinding. Based on the results of risk identification by Bow Tie Pro™ software, heavy loading operation included six threats (an unsafe or a deficient crane, sling, loading equipment, insecure loading, unsafe workplace, lack of proficient crane operators, and inappropriate lifting plan) and three consequences of “casualties” (human injuries), “damage to the crane and loads”, and “damage to the installation and equipment”. Tables 1, 2, and 3 and Figures 1 and 2 explicitly show the results of the study.

DISCUSSION

The results of the graphic risk analysis represent a comprehensible view on the process of converting potential factors into accidents and final consequences. The analysis also provides a more complete understanding of the relationship between the causes of accidents, their consequences, and the barriers at each step of the process.

Table 1. Threats due to working with high-pressure cylinders, and cutting and welding with gas

| Risk source risk event threat | Cylinder/Capsule Welding and cutting Gas leak and release of energy | Control actions |
|--|--|-----------------|
| Mechanical defects | Avoid throwing cylinders or rolling them Use safety guards when they are not in use Avoid forcing too much energy while opening or closing the valve of the cylinders (hammering) Use an appropriate wrench when opening the cylinders | |
| Heat | Install safety signs such as non-smoking sign Natural or artificial ventilation system in the store place Failure to test the cylinder’s leakage by flame Avoid leaving cylinders when the job is finished No heating the cylinders with the flame | |
| Transfer | Transport the cylinders vertically Fix the cylinders with chains Use appropriate crats for transporting cylinders (avoiding rolling the cylinders) Transport cylinders with a removable steel cap, a safety fuse plug, and a regulator Transport the restrained cylinders using trucks | |
| Unsafe and deficient installations | Control the regulator valve, pressure, pipes, and installations before the operation Avoid using cylinders without a regulator valve Use a standard and calibrated pressure gauge and monometer | |
| Maintaining and keeping cylinders | Monitor the store place of cylinders periodically Keep cylinders in a suitable place Stand cylinders vertically in the pre-determined place Use chains and metal belts to keep cylinders together Keep full and empty cylinders separately | |
| Oil and grease | Avoid using greasy gloves or dirty cloths Avoid keeping cylinders in oily or greasy places Clean cylinders by a dry and clean cloth | |
| Leakage | Use appropriate connectors specific for each cylinder Make sure to close the valve of cylinders when opening or closing the regulator valve Protect cylinders from the mechanical damage | |
| Flashback | Regulate the speed of mixing the oxygen with fuel Use flashback arrestor Use check valves | |

Table 2. Consequences related to the in working with high-pressure cylinders, and cutting and welding with gas

| Consequences | Controls |
|---|---|
| Human casualties (death) or severe injuries | Availability of necessary transportation of cylinders |
| | Separately keeping flammable and toxic gases |
| | Evacuate sites and offices in the case of fire in the store place |
| | Present safety instructions and guidance for staffs in the case of fire in the store place |
| | Safety training related to cylinders to the staffs and personnel |
| | Fireproof wall in the store place of cylinders |
| | Keep a safe distance between the store place and office buildings |
| Fire and explosion | Avoid the use of copper in the body of cylinders containing acetylene |
| | Keep cylinders in an open space |
| | Avoid keeping cylinders in a closed area |
| | Keep cylinders away from flammable substances |
| | Keep acetylene and oxygen cylinders, separately |
| | Fireproof the building where the cylinders are stored |
| Damages to equipment and tools in the site | Keep firefighting safety equipment needed for each kind of cylinders |
| | Avoid using oxygen instead of compressed air for cleaning dust from clothes and machines |
| | Avoid the proximity of cylinders with sensitive equipment in the site |
| | Fireproof walls and buildings to prevent severe damages from explosion or fire |
| | Observe the safe distance between the store place of cylinders and the site according to the standard |

Table 3. Secondary threats related to the working with high-pressure cylinders, and cutting and welding with gas

| Threat/Consequence | Control | Threat/Control (secondary threats) | Secondary Control |
|--------------------------------|---|--|---|
| Heat | Failure to test the leakage of cylinders and their accessories by flame | Leakage test for cylinders and their accessories | Using soap bubbles or another substitution for leakage test |
| Heat | Avoid leaving the cylinders on the site after the operation | Presence of out-of-service cylinders on the site | 1. Regular and periodic monitoring 2. Giving safety instructions and holding training sessions |
| Heat | Avoid heating cylinders with flame | Frozen valve or cylinder | Heating cylinders using steam or warm water |
| Keeping and store of cylinders | Keep empty and full cylinders, separately | undetermined full and empty cylinders from each other | 1. Labeling full and empty cylinders 2. Putting someone in charge of the storekeeper for controlling the transportation of cylinders |
| Human casualties | Evacuate offices in case of fire in the store | lack of unity between the personnel of different offices and sites | Holding related maneuvers and emergency response plans |

Bow-tie technique also makes it easy to understand the dangers and the consequence management, and to determine different kinds of controls, which in this case are in two layers; the control layers of the primary consequences and the restrictive/protective layers of the secondary consequences [5-7]. Safety and safety risks are valuable subjects in terms of technical, management, human resource, and economics. The identification of all risk sources and risk analysis are necessary for the construction of a powerhouse [10, 11, 16]. Mohammadfam et al. (2017) claimed that safety risks and their related criteria are of

paramount importance and effective factors in the construction industry (e.g., powerhouse). The results of the studies on the identification and categorization of threatening risks in the construction of a powerhouse indicated that because of the nature of such projects, they are always at a high level of risks and their success depends on effective risk management. Therefore, the entire risk management process will be ineffective unless all risks are identified [11, 12, 16]. The risk analysis of the present study by the use of Bow Tie Pro™ revealed that although there were some overlaps in some parts, each of

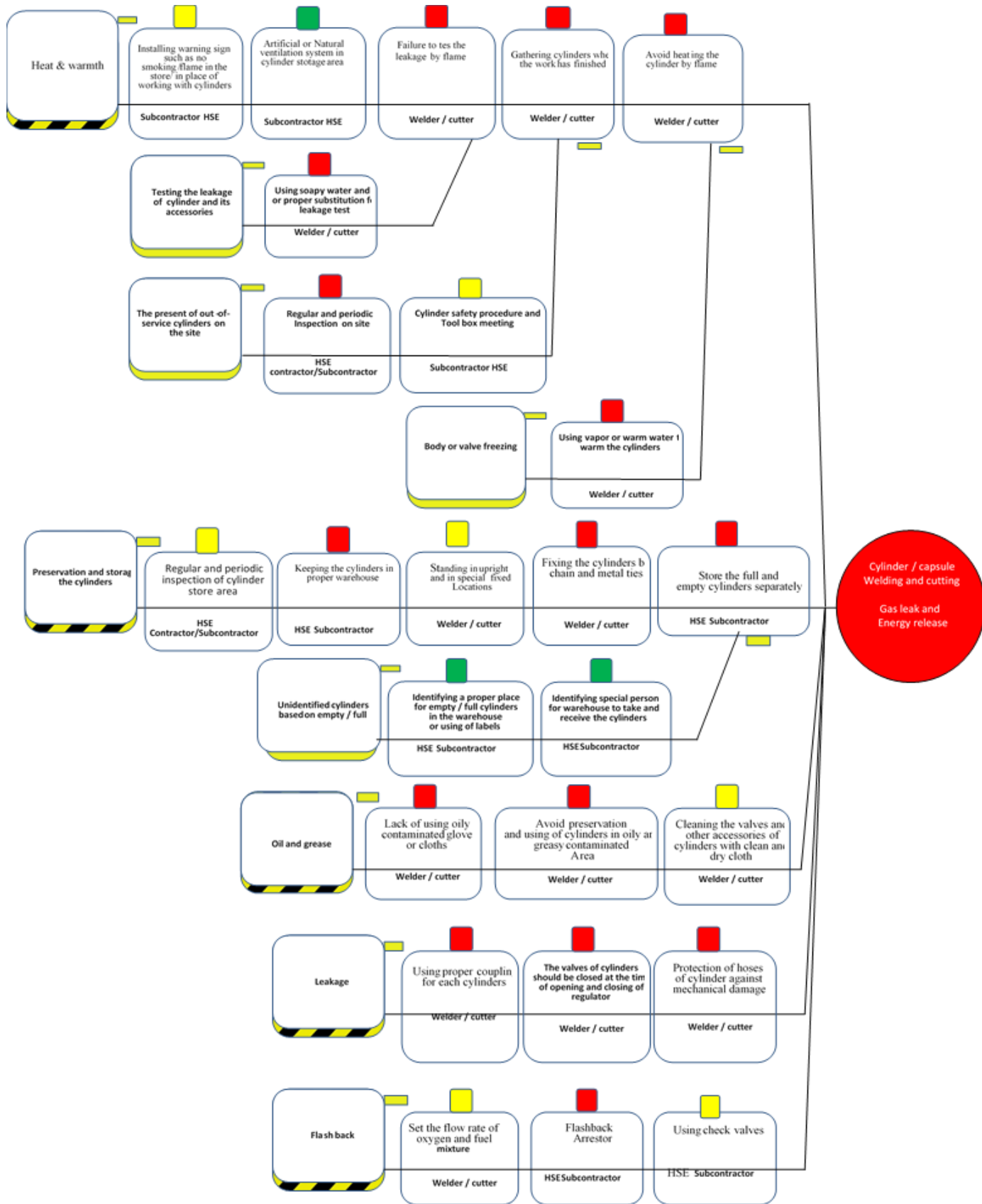


Figure 1. Bow-tie diagram for working with high-pressure cylinders, and cutting and welding with gas (threats)

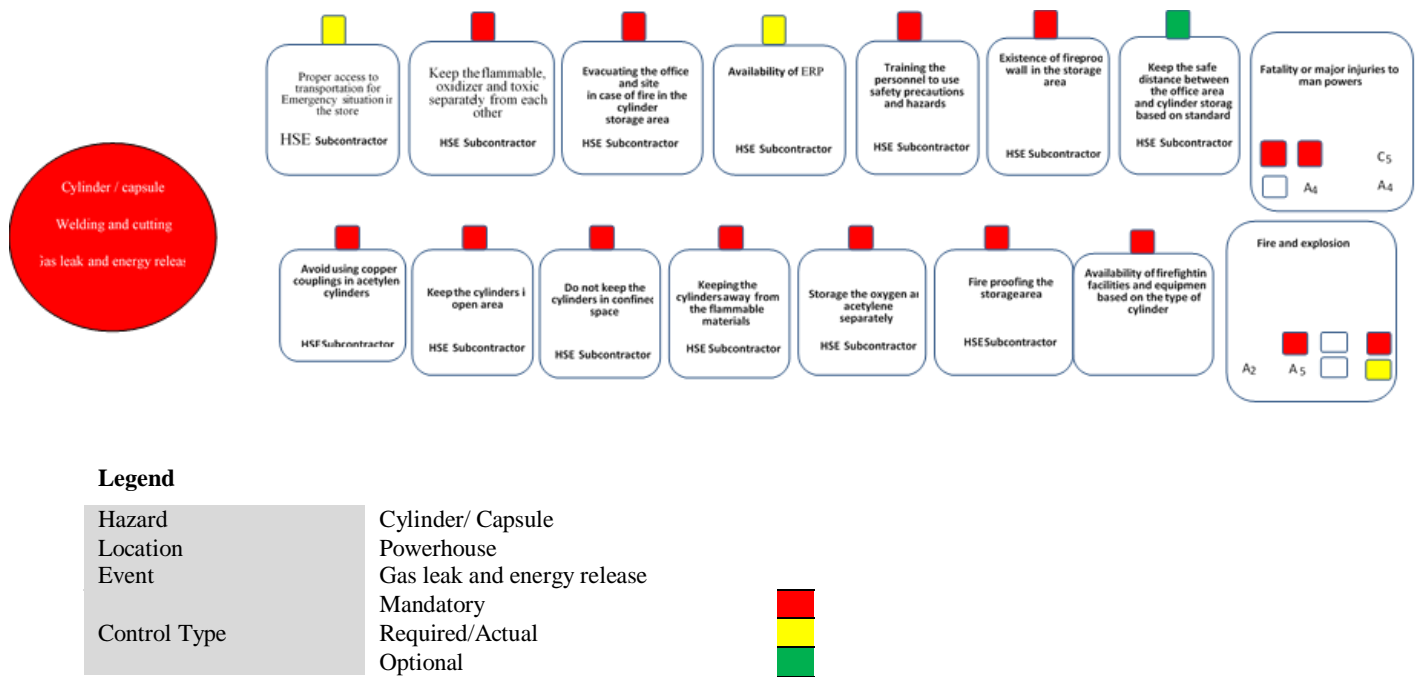


Figure 2. Bow-tie diagram for working with high-pressure cylinders, cutting and welding with gas (consequences)

the seven identified risk sources included different threats and consequences. The relationship between the components of this chain, based on the process of converting a danger into an accident, reveals the importance of risk analysis by the Bow tie technique.

Some studies have indicated that most of the basic events have no determined consequences or there is no enough data for the estimation of them. As a result, using the fault tree or event tree would be ineffective in terms of accuracy or reliability. Bow-tie technique, however, can overcome such problems [6, 17, 18].

The findings of the present study showed that Bow-tie technique was very helpful in the analysis, evaluation, and prioritization of risk sources for the purpose of management controlling activities such as prevention, reduction, and restriction of risk sources. The risk analysis showed that activities related to the high-pressure cylinders, welding, and cutting, including eight threats and three consequences, are ranked the highest in terms of threats, damages, and consequences, so they are put on top of the list of risk management and risk control activities in the construction of a powerhouse. Mulcahy et al., (2017) concluded that Bow tie technique can provide a structural approach for the identification of risks and safety barriers, and more effective control and monitoring of strong

points so as to promote risk management and prevent the occurrence of risks and accidents [7]. Generally, the findings confirm that risk sources and safety risks in the construction of a powerhouse need a structural and causal analysis based on the threat-consequence relationship, which can be done by the Bow-tie technique.

Although a small domain was chosen in this study for safety risk analysis, the identification of seven risk sources as well as the illustration of Bow-tie diagram for the analysis of each source call for in-depth attention to risk sources, threats, consequences, and safety preventive actions.

CONCLUSION

According to the results of the present study, Bow-tie technique and Bow Tie Pro™ software are appropriate ways to analyze risks, suggest preventive actions, reduce the threats, and control the consequences of risk sources involved in the construction of a power plant or any other industrial projects. This technique illustrates all the causes and consequences of an accident. Accordingly, individuals, being aware of their responsibilities and all of the possible dangers, would be able to control the threats and consequences. This technique can also prioritize safety actions in order to prevent accidents.

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