1

Current State of Accidents at Universities

1.1 Introduction

While rapid progress is being made in science and technology, many faculty members, researchers, graduate and undergraduate students have been killed in accidents involving chemical experiments in laboratories of universities and academic institutions (hereafter referred to as "universities, etc."). However, the total number of accidents that have occurred in university laboratories worldwide remains unknown, and in many cases, similar accidents have been repeated several years later at other universities. This is because time has passed without a paradigm shift or fundamental change in laboratory safety measures, and universities around the world have not made progress in collaborating to prevent accidents.

According to a questionnaire survey conducted by the author, there are few established accident investigation and analysis methods or uniform rules for accident investigation and analysis in universities, and even when accident investigation and analysis is conducted, the 4Ms (man, machine, media, and method) analysis tool mainly applied in the manufacturing industry is used. In many cases, investigation reports and lessons learned from accidents that occur within universities are never published (Fukuoka 2022a).

In addition, there are no international organizations, such as the International Maritime Organization (IMO) or the International Civil Aviation Organization (ICAO), whose objectives mainly include accident prevention. It is essential for accident investigation and analysis to determine which accident models are applicable to the industry to which it belongs and to conduct the investigation and analysis using the methods associated with those accident models. If an inappropriate accident model is used in an accident investigation, the mechanism leading to the accident will be incorrectly analyzed and the resulting safety recommendations will be misdirected in terms of preventing accident recurrence. However, many chemical accident investigations in university laboratories have not been discussed based on accident models, although case studies have been carried out. Therefore, the lack of uniform methods for accident investigation and analysis raises doubts not only about the accident factors themselves derived as a result of the accident investigation but also about the derived data results, even if the accident factor data are statistically processed (Fukuoka and Furusho 2022).

For many universities to use the lessons learned from accident analyses to reduce accidents, accident investigations must be scientific, investigation and analysis methods must be standardized, and a large amount of accident data must be collected and analyzed. The approach to this is to bring together universities, etc. around the world to formulate investigation and analysis methods and rules, including the preparation of accident investigation reports, to provide education and

Accident Prevention and Investigation: A Systematic Guide for Professionals, Educators, Researchers, and Students,
First Edition. Koji Fukuoka.

training in investigation and analysis methods, and to establish a forum for sharing information to reduce accidents.

This book clarifies the problems that need to be solved to prevent the recurrence and prevention of accidents faced by universities, etc. in comparison with other industries, and describes approaches that can be adapted to universities, etc. First, as a prologue to the content discussed in Chapter 2 and below, issues related to accident prevention in universities, etc. obtained compared with other advanced industries are discussed.

In the subsequent chapters, the term "accident" refers to events involving injuries or fatalities occurring during educational and research activities within universities, etc., while "incident" refers to events threatening the safety of individuals other than accidents during educational and research activities, or events causing damage to facilities or equipment used during activities. Near misses are included within incidents.

1.2 Background

A wide variety of accidents occur in universities around the world, including explosions during chemical experiments in research laboratories. It is not possible to estimate how many accidents occur in university laboratories around the world, as the data itself are not published. The following is an excerpt from a review article by Ménard and Trant (2020) published in *Nature Chemistry*:

Over the past ten years, there have been several high-profile accidents in academic laboratories around the world, resulting in significant injuries and fatalities ... However, the study of academic lab safety is still underdeveloped and necessary data about changes in safety attitudes and behaviours has not been gathered ... More than ten years on from Sangji's death, we can conclude that there is no evidence of sweeping, fundamental changes, nor of major paradigm shifts in how academic lab safety is approached within the discipline.

However, in the field of ship and aircraft accidents, a social transformation, a paradigm shift, took place in the second half of the twentieth century with regard to accident prevention. This involved the following multiple factors (Fukuoka 2023):

- Shift from human error to human factors
- Development of the software, hardware, environment, liveware (SHEL) model
- Development and global adoption of safety management systems (SMSs)
- Development of accident models, such as the Swiss cheese model, which can explain the mechanisms of organizational accidents
- Shift from Criminal Investigation to Safety Investigation

The trigger for these factors was a series of serious accidents in various industries in the 1970s and 1980s that affected society as a whole. In the chemical industry, 28 employees were killed in a chemical plant explosion in Flixborough, United Kingdom, in 1974, and thousands of citizens were killed by acute poisoning in Bhopal, India, in 1984 when a chemical plant released methyl isocyanate, while the exact number of victims was never determined.

In the maritime industry, 193 passengers and crew were killed in the 1987 capsizing of the ro-ro vessel *Herald of Free Enterprise* (HFE), which was traveling to and from the Strait of Dover. In the aviation industry, in 1985, Japan Air Lines (JAL) Flight 123 crashed into Mount Osutaka, killing 520 passengers and crew and leaving only 4 survivors, making it the worst single aircraft accident. In the space industry, in 1986, the US space shuttle Challenger exploded just 73 seconds after lift-off, killing all seven crew members on board.

1.3 Modes and Effects of Human Error

Human error was actively studied by Norman, Rasmussen, Reason, and others in the mid to late twentieth century, and findings were developed and established as follows.

1.3.1 Norman's Theory

Norman (1988) emphasized that people make some errors in error-prone situations that are unrelated to specific personal characteristics. He distinguished between slips and mistakes. In other words, slips are errors of behavior, while mistakes are errors of thought.

1.3.2 Rasmussen's Theory

Rasmussen, Duncan, and Leplat (1987) extended Norman's theory and defined three types of performance and error. They are skill-based, rule-based, and knowledge-based. He states that people display different behavior at these three different levels.

At the skill-based level, it is an automatic method and is used when performing tasks that are routine and highly trained. The rule-based level is used when specific situations are encountered and there are already agreed rules for performing these actions. The knowledge-based level is used when a new situation is encountered that has not been experienced before. This is the highest performance level and involves people working very slowly, using all the resources imprinted in their memory through trial-and-error learning.

Rasmussen emphasizes that the process of people making decisions is not linear and that in real life people often shortcut the process. As a result, he states that the three levels outlined above can coexist at any time.

The three performance aspects of everyday life are explained, covering the process of learning to ride a bicycle. When riding a bicycle for the first time, children learn in detail from their parents and friends how to ride a bicycle, how to balance, when and how to brake, etc. When they actually ride a bicycle, they find it difficult to control it and keep going, so they try to learn to ride a bicycle through a process of repeated trial and error. This process is called knowledge-based performance. After a number of training sessions, the operating skills of riding a bicycle gradually improve and they are able to get out on the road. When they come across a traffic light, they stop, making sure that the rule is that they should not proceed at a red light. They also check that they are traveling on a particular side of the road, as they have learned from their parents. This process is called rule-based performance. They ride their bicycles every day, and after a few months, they become so familiar with it that they no longer need to pull out the bicycle maneuvering and traffic rules from their memory each time and apply them in practice. In particular, they can ride without having to think about how to maneuver it in their minds. When they encounter a red light, they are able to achieve their objectives by skipping rigid procedures experienced in the knowledge-based and rule-based performance, such as stopping reflexively. This process is called skill-based performance.

1.3.3 Reason's Theory

Reason (1990) expanded on Rasmussen's theory. He states that slips and lapses are behavioral errors involving skill-based performance. Mistakes and violations are errors in people's intentions, whereas mistakes occur in either rule-based or knowledge-based performance. He coined the concept of latent conditions, which was previously called latent error, and distinguished between active failure, which was previously called active error, and latent situations. Active failures are committed by operators and manifest themselves quickly, while latent conditions are caused by higher levels, such as designers and managers, and the existence of latent conditions is not exposed in the organization and lies dormant for a long time. He states that active failures are affected by latent conditions and that accidents occur due to rare combinations of these errors. This theory of his was the source for the development of the Swiss cheese model.

1.3.3.1 Slips, Lapses, Mistakes, and Violations

According to Reason (1990), errors are classified into four categories. An unintended act that relates to a person's attention and an error that occurs at the stage of execution is called a slip. Errors that are unintended acts related to memory and occur at the stage of consideration are called lapses. Errors that occur because the action was intended but the plan itself was not fit for purpose due to a design error at the planning stage, and the action was carried out according to the plan, are called mistakes. If a rule exists, the act is a violation. The violation addressed here is a negligent violation without malice. For example, wearing personal protective equipment (PPE) is common knowledge and a safety rule in chemical experiments, but this applies to cases where researchers do not wear the designated PPE because they think it would be safe at their own discretion. Explained from a different perspective, the question is: "Was the action carried out a planned action?" and if the answer is "no," then an unintended action has been executed. The error in this execution is a slip or lapse. A slip is the result of not paying sufficient attention when executing an action. A lapse is a planned action not being executed due to an error in memory. "Was the action carried out a planned action?" If the answer is "yes" to the question, then the intended action was carried out and a mistake was made. The error occurred at the planning stage, which means that there was a problem in the decision-making process. Mistakes may progress more unnoticed by people than slips and lapses, and a longer period of time may pass between the execution of a mistake and its detection.

1.3.3.1.1 Case Study of Slips

- Many readers probably start their day with a cup of coffee every morning. They turn on the coffee machine, pour water, set the capsules in place, place the coffee cup in place, and press the button for their choice of blend or espresso, and their coffee of choice is ready. However, as they become accustomed to this action, doing the same thing over and over every morning, they inadvertently press the espresso button without setting the capsule in place. Only hot water is poured into the coffee cup. You realize for the first time that you did not set the capsule.
- Hotels have bathrooms, some with fixed shower heads (overhead showers) and some with portable shower heads. To use a fixed shower head, turn the left handle, shown in Figure 1.1, backward. To use the portable shower, turn the same handle toward you as for the fixed shower. The handle is marked with a "Caution! Hot Water" sign. The temperature of the hot water is adjusted using the handle on the right. The author was drenched by cold water coming out of the fixed shower head when he accidentally turned the handle because he wanted moderate hot water. Given the warning sign "Caution! Hot Water," one imagines that many people would have been drenched head-first in boiling water against their will.

Shower equipment that does not cause people to make errors would be as follows. The temperature is adjusted with the left handle and the shower head is selected with the right handle, which

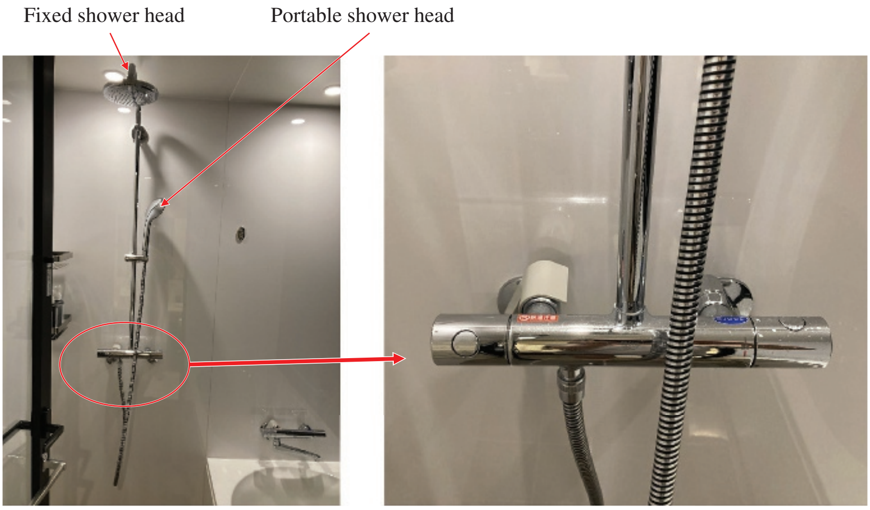

Figure 1.1 Showerheads and their handles as a sample of slips. The left-hand handle is enlarged in the photograph on the right. The handle is marked with a red label with a warning. The large disk-shaped shower head directly above the handle is fixed. To the right of the fixed shower head is the portable shower head. These photographs were taken by the author in the same hotel in December 2022, including Figure 1.2.

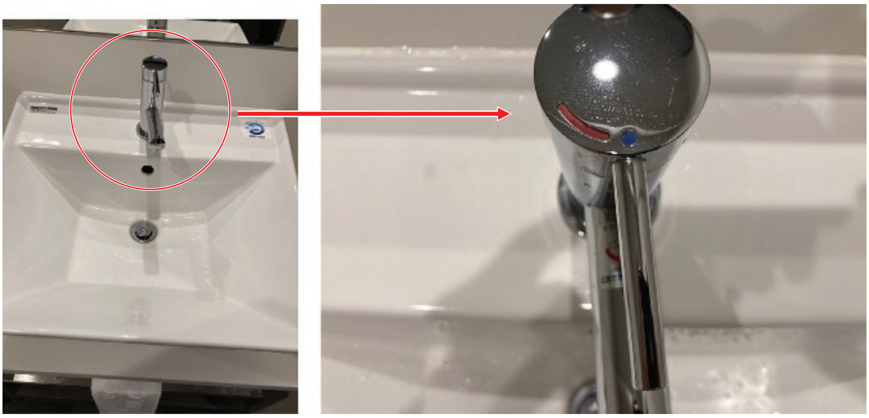

Figure 1.2 A bathroom tap that can prevent slips. The tap in the left photograph is enlarged in the right one. The blue and red markings indicate whether water or hot water is supplied.

has a different shape. There is no room for error. This shows that human error is largely due to external factors as well as human causes.

However, the washroom in the same hotel was designed to prevent slip when using water and hot water. Figure 1.2 shows that on the tap handle, turning the handle in the blue direction provides water and turning the handle in the red direction provides hot water. One can get water or hot water without confusion. It can be seen that by matching a person's intended behavior with their thoughts, by adding shapes, signs, and diagrams to the equipment, it is possible to prevent people from making errors.

1.3.3.1.2 Case Study of a Lapse

- You walk from your room to the kitchen with the intention of taking a teacup from the kitchen cabinet, but you enter the kitchen and stop, unable to remember what you came here to do. You go back to your room again and try to remember what you went to the kitchen to do, only to realize that it was to pick up the teacup.
- You set a single document in the photocopier to make copies and have completed the specified quantity of copies, but forget to remove the document from the photocopier. A colleague informs you that the document is still in the photocopier and you realize that you forgot to take the document out.

1.3.3.1.3 Case Study of a Mistake

- Many people commute to work by train, bus, or other public transport to the university or workplace. When universities are on summer holidays, public transport timetables can change significantly. Without realizing this, they leave home as usual and wait at the bus stop to board their usual bus, but the bus does not come. A notice is posted on the bulletin board at the bus stop, and they learn for the first time that the bus they are using is temporarily out of service due to the university summer holidays. They rush to board another bus but are late for the scheduled work time. They realize that this error was an error in their very plan to use their usual bus to go to the university.

1.3.3.1.4 Relationship Between Errors and External Factors

Grandjean (1969) conducted a scientific experiment on behavioral failure. He measured the frequency of errors when the arrangement of the control panel and the stove was changed. When the arrangement perceived by the person matched the arrangement of the stove and control panel, it was tested 1200 times and not a single error occurred. The three patterns with slightly different arrangements were tested 1200 times and errors occurred in the range of 76–129 times. In other words, it can be demonstrated that individuals are less prone to error when their cognitive processes align with the configuration of the control and display sequences.

The controls in the steering seats of many vehicles, such as cars, trailers, airplanes, and ships, are designed with full consideration of human characteristics, such as a person's physique, range of vision, and thinking patterns, so that errors are unlikely to occur.

1.3.3.2 Impact of Human Error

The examples from everyday life described in Section 1.3.3.1 show that the impact of the error only affects the person who made the error and does not cause significant harm. However, failures of caution, that is slips, have also occurred in university experiments and chemical plant operations and other industries. At a university, a timer and temperature were set on a heating device to heat a sample during an experiment, thinking that the temperature was displayed in Celsius, but the temperature was displayed in Fahrenheit instead of Celsius, causing the temperature to be set much higher than intended, resulting in the sample overheating and smoke coming from the heating device. The alarm in the laboratory was triggered and security guards responded to the incident, which did not lead to a fire.

According to the US Chemical Safety Board (CSB 2021), the accident investigation body, during the silicon emulsion production process in a chemical plant, an employee put calcium hydroxide, a pH-adjusting substance that should not have been mixed in, into a drum in which silicon hydride was stored. This generated hydrogen gas, which mixed with air, and the presence of an ignition source in the plant caused an explosion and fire, killing four employees and wrecking the plant. The drums used to store the three chemicals were of the same color and shape (55-gallon blue plastic drums), identified only by labels, and the incompatible substances were stored in close proximity. The drums were all the same shape and color, so employees could not tell them apart.

The CSB determined that the risk of the chemical combination was not defined in the US Occupational Safety and Health Administration (OSHA) standards, which was also a contributing factor in the accident. The CSB (2021) recommended that the US OSHA, the chemical policing body, review its chemical standards and even influenced legal action.

In a memory failure, lapse, during a leisure dive activity, a diver jumped in without opening the tank valve before entering the water, which made it difficult for him to breathe in the water. In the preparation before the scuba dive started, he inadvertently forgot to open the tank valve.

In an example of a vessel accident, a pilot was maneuvering a cargo ship from one port to another, when he assumed that buoy A, which marked the safe passage boundary, was buoy B, which marked the route exit, and after passing buoy A, he changed the vessel's course to the right and continued sailing, resulting in the ship grounding in shallow water. The pilot stated that he changed course as usual, thinking he had already passed buoy A and reached buoy B, which shows the exit of the passage. The accident affected many stakeholders, including the cargo ship grounded; the crew; the cargo ship's company; the Coast Guard, who maintains the buoys and enforces maritime laws and regulations; the port authority, who manages the safety of passages in the port; and the salvage company that handles the grounding ship and the property insurance company (Japan Transport Safety Board 2010).

1.4 Transition from Human Error to Human Factors

In the second half of the twentieth century, the increasing complexity of socio-technical systems, industrial structures, and accident causal factors made it no longer possible to apply the conventional approach to accident analysis, which is centered on human error. In other words, the idea of preventing accidents by clarifying the systemic problems that induced the error or failed to prevent the accident, rather than focusing attention on the person who caused the human error and attributing the cause of the accident, has spread, particularly in Europe and the United States. In the field of accident model, sequential accident models, such as the domino theory, which are characterized by a mechanism in which the factors of an accident appear sequentially and linearly and then accidents occur, are no longer able to clarify the actual state of accidents and all the factors behind them. The "Tenerife tragedy," an aircraft accident that occurred at a small regional airport in Tenerife Island, located off the western coast of Africa, marked the turning point for this issue and the shift in the focus of accident investigation analysis to human factors. See Chapter 3 for the development of the accident model.

1.4.1 The Tenerife Tragedy

1.4.1.1 Summary of the Accident

In March 1977, two 747 jumbo jets of Dutch Airlines (KLM) and Pan American Airways (Pan Am) collided head-on on the runway at Los Rodeos Airport, Tenerife, Spanish Canary Islands, killing 583 passengers and crew. The accident is still the worst in aviation history. Immediately after the accident, the Air Line Pilots Association (1977), an association of pilots, published an Aircraft

Accident Report, based on interviews with those involved and evidence collected. The details of the accident based on this report are as follows, showing that a number of factors combined to cause the crash.

1.4.1.2 Circumstances and Factors Leading to the Accident

Following a terrorist explosion at the terminal of Las Palmas Airport in the Canary Islands, a well-known resort destination, the airport authority temporarily closed the airport and instructed aircrafts destined to land at Los Rodeos Airport. The airport authority lifted the closure of Las Palmas Airport and resumed landings after the airport was declared safe, but in the meantime, Los Rodeos Airport was crowded with large and small aircrafts that had been instructed to change their landing sites. Los Rodeos Airport is a regional airport with one runway located at 621 m altitude, where stratocumulus and cumulus clouds frequently occur and visibility at the airport can be poor. After the reopening of Las Palmas Airport, passenger aircraft parked at Los Rodeos Airport took off one after another for the airport, but there were aircrafts parked on the taxiway.

The Air Traffic Control (ATC) first instructed KLM aircraft to proceed in the opposite direction on the runway to the takeoff preparation point. The ATC then instructed Pan Am aircraft to proceed in the same reverse direction on the runway and turn left onto the taxiway at C3, which was located near the midpoint of the runway. KLM aircraft reached the designated point at the end of the runway and awaited clearance for takeoff from ATC. Meanwhile, Pan Am aircraft was to proceed to the taxiway at point C3, but crew of Pan Am aircraft either misunderstood the instructions from ATC or overlooked C3 and continued backward down the runway toward the KLM aircraft. The Air Line Pilot Association, which investigated the accident, analyzed in its report that it was physically impossible for Pan Am, a large aircraft, to enter C3, which required a change of course at a sharp angle. It is recorded that the visibility at this time was approximately 100 m. ATC had no radar equipment installed and relied on visual observation with the naked eye to determine the situation at the airport. Both aircraft crew could not see the other, nor could ATC see the situation of the two aircrafts on the runway.

The KLM captain communicated with ATC and attempted to throttle up for takeoff, assuming that the message from ATC telling him how to fly after takeoff was the answer to the takeoff clearance. At this point, the crew's flight engineer informed the captain that he did not have takeoff clearance, but the captain prepared the aircraft for takeoff. The flight engineer did not firmly reiterate to the captain that he did not have clearance for takeoff. KLM aircraft had a team of three: the captain, the copilot, and the flight engineer. The personal relationship was such that there was an authority gradient between the three, as the captain was a person of authority at KLM and also a training instructor. The authority gradient hinders the sharing of useful safety information within the team; the captain may have been in a hurry to takeoff, as KLM aircraft planned to fly back to the Netherlands after arriving at Las Palmas Airport and could have exceeded the working time limit under Dutch working rules if he had not taken off early at Los Rodeos Airport.

Radio communication between the ATC and KLM or Pan Am aircrafts was poor, with interference during conversations, making some conversations inaudible. The ATC is a native Spanish speaker and his English was mixed with Spanish, making some parts difficult to understand. At the time of the accident, the aviation terminology used by air traffic controllers and crews was not standardized worldwide, and misleading and ambiguous terminology was used in communication. As a result, there was a mixture of assumptions.

The KLM aircraft then began its run on runway for takeoff. Shortly before the collision, the Pan Am, which was turning left on the runway toward C4 next to C3, suddenly appeared in the KLM captain's field of vision and he raised the nose of the aircraft in an emergency takeoff attempt. However, the lower fuselage of the KLM aircraft collided with the upper fuselage of the Pan Am

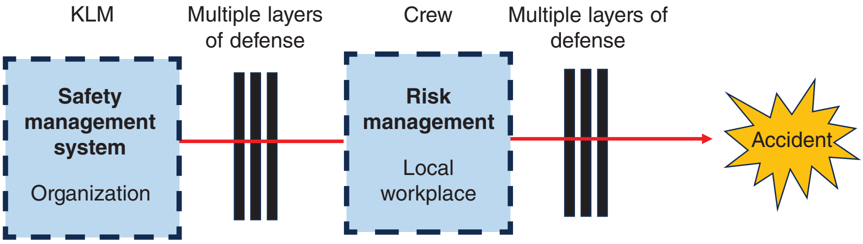

Figure 1.3 The mechanism of the Tenerife tragedy. At the time, KLM's SMS and crew risk management were not functioning and are shown as dashed lines. The accident trajectory is indicated by the red arrow. *Source:* Adapted from Fukuoka (2024).

aircraft, causing the KLM aircraft to crash and burn and most of the Pan Am aircraft to be destroyed and set on fire; only some of the Pan Am passengers and crew survived. The contributing factors that caused the accident are listed in the following:

- Change of destination (S)
- Inconsistent (ambiguous) aviation terminology (S)
- Radio communication status between crew and ATC (H)
- Radar not installed (H)
- Narrow taxiways (H)
- Weather conditions at high-altitude airports and reduced visibility (E)
- Authority gradients, availability of time, assumptions, and low flight time of KLM captain (Lc)
- Communication between crew (Lc)
- Communication between crew and ATC (Lp)
- Language used by crew and ATC (Lp)
- Verbal guidance given to aircrafts by ATC (Lp)

Los Rodeos airport is located at a high altitude, which makes it vulnerable to weather conditions, and at the time of the accident, a new airport was under construction at a lower altitude. The Spanish and Dutch Accident Investigation Authorities have also published accident investigation reports on the accidents that occurred in Tenerife. The details of these reports are not included in this section, as this section discusses the mechanism of the accident, in particular the relationship between human factors and the occurrence of the accident.

The SHEL model indicates that the accident was not the result of a linear sequence of accident factors, as proposed by the domino theory. Rather, it suggests that a number of factors were present prior to the accident. Furthermore, the model indicates that the KLM captain's error, which was a mistake, triggered a number of latent conditions to emerge simultaneously, resulting in the accident. Figure 1.3 is a model of the accident mechanism on the KLM side. At the time of accident, KLM's SMS was not yet in place and crew risk management was not functioning. The accident trajectory shows that the accident occurred after all the multiple layers of defense had been penetrated.

1.5 Development of the SHEL Model

Five years before the Los Rodeos Airport Jumbo Jet accident, in 1972, Professor Edwards developed and published the SHEL model, which included social components related to the accident. SHEL stands for software, hardware, environment, and liveware. Liveware, representing human elements, includes Central liveware (Lc) and Peripheral liveware (Lp). The SHEL model was modified by Hawkins (1987).

The SHEL model has a total of five blocks in the shape of a cushion centered on Lc. The jagged edges of each block do not coincide with their relative edges, indicating that the relationships between the two elements are not well established. The model was originally used as a method for the comprehensive collection of evidence on human factors and others in aircraft accident investigations. The model has since been adopted by the shipping industry and used as a tool to prevent omissions in the collection of evidence during the accident investigation phase. Since the late 1990s, the model, together with the Swiss cheese model, has been adopted by the ICAO and the IMO, two specialized UN agencies, and has been included in manuals for ship and aircraft accident investigation and is still used in accident investigation.

The SHEL model differs from human error in that it focuses on the errors and mishaps of the person who caused the accident (hereafter referred to as the "operator") and includes all factors related to the accident that caused the human error. This includes not only the company to which the operator belongs but also regulatory authorities, inspection bodies, relevant private bodies, international organizations, etc. and all relevant social components involved in the accident can be identified. By viewing the accident as an event that occurred in the context of the interrelationship of all these social components, the clear picture of the underlying factors can be visualized.

1.5.1 Elements of the SHEL Model

The following is a brief description of each element of the SHEL model, adapted to accidents occurring at universities, etc. Details of the SHEL model are given in Chapter 5.

- Software S is employed by faculty, researchers, students, research groups, and fieldwork research teams at the time of an accident at the accident site. It encompasses a range of materials, including procedures, protocols, checklists, experimental plans, dive plans, climbing plans, maps, and instructions on the use of PPE and emergency response plans.
- The letter H refers to the hardware associated with the accident. This encompasses a range of equipment, including laboratory apparatus, gas storage tanks, high-pressure cylinders, ancillary equipment such as piping, laboratory equipment such as centrifuges and beakers, and other types of laboratory apparatus. It also includes diving equipment used for scuba diving and climbing equipment used for mountaineering.
- E represents the environment at the time of the accident. It encompasses specific gas concentrations that have been known to cause explosions and fires, the presence of ignition sources such as electronic devices and equipment power supplies, oxygen concentrations that can lead to oxygen deficiency, gas concentrations of specific substances that can lead to gas poisoning, weather conditions, the speed of tidal and ocean currents, seawater clarity, seabed topography, mountain topography, especially streams in the path of avalanches, marine life, plants, and animals that can harm people.
- Lc represents the condition of the operator at the time of the accident, encompassing a multitude of factors, including physical, physiological, pathological, psychological, workload management, knowledge, skills, education, and training. It encompasses physical limitations, such as instances where the operator's physique is incompatible with the facility or equipment or the underwater mask does not fit the face; sensory limitations, such as an excess of information from the senses, including sight and hearing, that the operator is unable to process; and visual limitations, such as multiple containers of the same color and shape that cannot be distinguished from each other. Other factors that may influence the outcome of the

experiment include physiological factors such as fatigue due to a lack of sleep, psychological factors such as assumptions and stress, knowledge of handling hazardous substances, including chemicals, and risk assessment methods for substances handled in experiments. Attendance at training courses on the handling of specific substances, organized by the organization, may also be a factor. Finally, the experience of such experiments and research may also influence the outcome.

- Lp includes individuals who collaborated with the operator, the organization to which they belonged, and external agencies that were involved in the accident. The presence or absence of safety-related communication with colleagues, the clarity of the research group's responsibilities and authority, the circumstances and actions taken when a near miss occurred, and the operation of the SMS are all factors that must be considered. A more detailed discussion of SMSs can be found in Chapter 4.

1.6 Change in the Social System and the Shift from Criminal to Safety Investigations

Twelve years after the Tenerife tragedy, a major turning point in the maritime industry occurred with the capsizing of the ro-ro vessel HFE, which was traveling between the Strait of Dover. Prior to this accident, the system for investigating marine casualties had been an ad hoc one, with a national authority setting up an accident investigation board, appointing board members, and initiating an accident investigation whenever a marine casualty occurred. The *Titanic* disaster of 1912 also led to the establishment of temporary Accident Investigation Boards in the United Kingdom and the United States, which interviewed passengers and others related to the accident, analyzed the accident, and published recommendations for safety measures before the boards were disbanded.

Following the HFE accident, the Marine Accident Investigation Branch (MAIB) was established in June 1989 as a permanent marine accident investigation body outside the Department of Transport in the United Kingdom. The trend toward the establishment of permanent marine accident investigation bodies has spread throughout the world, with some countries, such as the United Kingdom, now establishing stand-alone marine accident investigation bodies, while others have established transport safety bodies that integrate aircraft accidents with marine and rail accidents. Aircraft, marine, and rail accident investigation reports published by these accident investigation bodies use scientific accident investigation and analysis methods, such as the Swiss cheese model and the SHEL model. Two versions of the report are available: a comprehensive version comprising 20 pages or more, which is typically dependent on the severity of the accident, and a condensed version comprising two to three A4 pages. The reports are accessible to the general public via the website of the accident investigation organization, where they can be viewed and studied. These efforts have reduced the accident rate.

The reason behind this shift was that law enforcement had been focusing on what constitutes a crime and punishing people to improve law-abiding behavior and prevent recidivism, but the number of safety-related accidents had not decreased. The concept of safety investigations was not to punish people, but to establish a system of scientific investigation and analysis to identify all accident factors and issue safety recommendations to those involved to prevent recurrence, thereby reducing the number of accidents and other incidents. Although part of the industry, there is a different way of thinking and operating in the world than the theory of accident prevention through law enforcement.

1.6.1 HFE Capsize Accident

1.6.1.1 Overview of the Accident

The HFE capsize accident is as follows (Department of Transport 1987). In March 1987, HFE left port of Zeebrugge, Belgium, bound for port of Dover, UK, with the bow doors open, and four minutes after passing the outer breakwater in port of Zeebrugge, sea water entered the engine room and other areas of the ship through the bow doors, causing the ship to capsize and kill 193 of the 539 passengers and crew on board.

1.6.1.2 Circumstances and Factors Leading to the Accident

With regard to the roles of the port entry and exit operations, the role of closing the bow door was that of the assistant bosun, the bosun was the team leader who brought all the deckhands together, the first officer was responsible for the port entry and exit operations, and the master being responsible for the safe navigation of the vessel. The bow door is the door through which vehicles enter the ship's car deck when in port, and the bow door is opened to allow vehicles to be loaded on board and the bow door is closed when all vehicles have been loaded.

After all vehicles had been loaded on board at port of Zeebrugge, the first officer assumed that the assistant bosun would close the bow door and proceeded to navigate the vessel on the bridge without checking that it was closed. According to the rules of the HFE management company, the first officer was required to be on the bridge at least 15 minutes before departure to assist the master in navigating the vessel.

The assistant bosun was taking a nap in his bedroom, having finished cleaning the deck after entering port. As the leader of the deck crew, the bosun did not lock up as it was not his duty to do so. There was also no roll call to ensure that all crew members responsible for the work were present at the time of arrival and departure from the port.

Before the accident, the master had asked the company to install indicator lights on the bridge to show the open/closed status of the bow doors, but the request was not accepted by the top management. HFE has a sister ship of the same type operating at the same time, which had five previous incidents of sailing with the bow doors open. Some crew members on the sister ship claimed that the ship did not capsize when sailing with the bow doors open.

At the time, ro-ro vessels did not have watertight bulkheads, and when seawater entered the vessel, the hull structure was prone to capsizing due to the seawater trapped inside.

After leaving the port, the HFE traveled in shallow waters at 19 knots (approximately 33 km h^{-1}), which is a high speed for a vessel, causing squat effect, which leads ship's hull to sink and seawater to easily enter the vessel through the bow door that remained open. After the influx of seawater, the surface effect of the seawater caused the hull to lose its balance and to overturn on the shoal.

The ferry service between Belgium and the United Kingdom was highly competitive and the management put profit before safety and did not accept the master's request to repair the bilge pumps and install indicator lights. In this accident, the assistant bosun's failure to close the bow door was the direct cause of the accident, and it is not believed that he took a nap with the intention of sabotaging the work, which is considered a failure of planning.

The factors involved in this accident are listed as follows:

- Overload of the first officer during departure planning (S)
- Navigation with bow door open (S)
- Bow door closed, indicator light not installed, and bilge pump not repaired (H)
- Underwater bulkheads not fitted (H)
- Hull sinking due to squat effect in shallow water (E)
- Failure to check facts due to assumptions (Lc)

- Breakdown in teamwork and responsibility (Lp)
- Breakdown in communication between crew (Lp)
- Intense competition between companies on the Strait of Dover route (Lp)
- Policy of prioritizing profit over safety (Lp)

1.7 Widespread Use of SMSs

The SMS is based on the quality management system originally created by the manufacturing industry to improve products and services. It has been modified to ensure safety when aircraft and ships are in operation. The concept of a quality management system was originated in the United States, but after the Second World War, the Japanese manufacturing industry recognized the importance of quality management systems and developed its own Total Quality Management (TQM), a method of pursuing quality improvement by considering quality as part of business management. As Japan's manufacturing industry developed, the Japanese version of TQM spread to the United States and the rest of the world, and the ideas and theories of TQM were reflected in the International Organization for Standardization (ISO) quality management system, which became an international standard as ISO 9001 (2008).

The SMS is based on the ISO 9001 concept, which was adopted by the IMO in the late twentieth and early twenty-first century as the International Safety Management Code (ISM Code) and made it mandatory worldwide to establish an SMS in accordance with the Code. The purpose of the ISM Code is to ensure safety and pollution prevention through the implementation of SMS, mainly for ships and ship management companies. This has led to the implementation of SMS on all ocean-going vessels and shipping companies around the world.

ICAO has contributed to the dissemination and development of SMS by establishing Annex 19 Safety Management and the ICAO Safety Management Manual. This trend can also be seen in other industries, and in the chemical industry, an understanding of SMS is essential when reading between the lines of the CSB accident investigation reports.

The specific interaction between the central liveware and the peripheral liveware in the SHEL model shows how organizations far from the accident site are involved in the accident, which is simply represented by the industrial SMSs listed in Figure 1.4. The aviation industry refers to these as Safety Risk Management and Safety Assurance (Stolzer, Halford, and Goglia 2008), and similar systems exist in other industries such as maritime industry.

For universities, etc., SMSs are important from an accident prevention perspective, but it appears that few universities, etc. have implemented the same systems as an organization. The CSB, the US-based accident investigation organization that usually investigates accidents in the chemical industry, but has investigated accidents that have occurred at universities, has closely examined each process of the SMS and analyzed whether there is a discrepancy between the actual accident-contributing factors and the content of the SMS. The SMS is also necessary to understand the mechanism of accidents that occurred at the university and the chemical plant, which are included in this book as real-life examples.

1.7.1 SMSs in the Industry

Figure 1.4 shows a simplified SMS implemented in organizations (e.g. companies) in the transport industry. The left side of the figure shows safety risk management with the risk assessment process as the core. Hazard identification, risk analysis, risk estimation, risk evaluation, and risk treatment are carried out in turn, and if the risk associated with the action is sufficiently low and acceptable

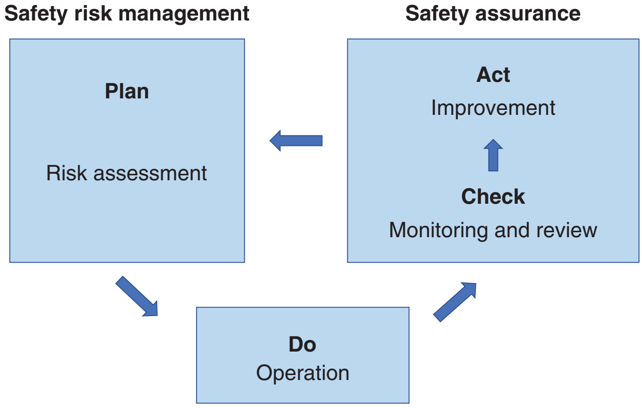

Figure 1.4 Safety management systems.

to the organization, the aircraft, ship, or other means of transport can be operated. If the risk is unacceptable to the organization, the risk must be reduced, and the same process is repeated to reach an acceptable level. The right-hand side is called safety assurance and indicates that the operation is monitored following a risk assessment. If new risks arise due to changes in the environment or other factors, or if the risk control measures taken are no longer effective, the operation is stopped, and the risk assessment on the left-hand side is repeated to minimize the risk and the operation is restarted.

When an accident or incident occurs, the organization conducts an accident investigation. When the investigation and analysis reveal that there is a problem with the system, the defect is rectified. This ensures that the system is optimally designed and operated.

These two processes are combined into a single process known as SMS, which involves conducting risk assessments, continuous monitoring, internal and external audits of the system, investigating accidents and incidents when they occur, and correcting deficiencies identified through monitoring, auditing, and investigations, thereby continuously improving safety regardless of the fluctuating environment. Organizations are required not only to carry out risk assessments as a matter of course but also to investigate and analyze accidents and incidents and ensure that problems are rectified. For further details on risk management and SMS, please refer to Chapter 4.

A similar standard is ISO 14001:2015 (2015) or earlier OHSAS 18001:2007 (2007), which also has a quality management system, or ISO 9001, at its core and is almost the same in concept to Figure 1.4.

1.8 Development of the Swiss Cheese Model

During the 1970s and 1980s, a number of complex and major accidents occurred and the Swiss cheese model was developed to be applied to these accidents. The model was developed to fit the complex and large accidents described in Section 1.4. According to Reason (1997), accidents are generally caused by a combination of latent conditions and active failures, but can also occur without active failures due to hardware problems. Latent conditions are deficiencies in a number of preexisting layers of defenses; active failures are errors or mistakes made by operators in the field; and active failures themselves are also caused by latent conditions and often trigger accidents. Sometimes, as in the case of the Space Shuttle Challenger accident, it is not the operator's error that causes the accident.

A hazard does not immediately lead to an accident, but there are layers of defenses (e.g. SMSs, risk assessment) between the hazard and the accident, and as long as these layers are functioning, accidents do not occur.

Latent conditions are revealed during incidents and accidents through comprehensive and scientific investigation and analysis. These latent conditions exist before the accident, but their existence is not recognized by the operator, team members, or the organization. The time period during which latent conditions are generated can be diverse, such as when the designer of the system installed the system or when factors occur among employees who did not follow procedures when they were using the system before the accident.

In the field of aircraft accident investigation, the use of the SHEL model to collect a comprehensive range of evidence scattered around accident sites, combined with the Swiss cheese model theory that accidents are caused by many latent conditions, has reduced the aircraft accident rate, although this also includes the effect of follow-up actions with the parties involved after the accident investigation report has been published.

1.9 Characteristics of Universities and Other Academic Institutions and SMSs

SMSs are not widely used in universities and other academic institutions. However, it is possible to operate risk management processes and SMSs calibrated from those used in industry and applicable to universities and other academic institutions, details of which are given in Chapter 4. This section describes the characteristics of universities as opposed to industry.

The CSB (2021) describes the organizational structure of the university in its accident investigation report as follows. In universities, the principal investigator (PI) has significant authority over his or her own research. A so-called academic “feudal system” has been formed, whereby departments are divided into smaller units, each of which has a person in charge, i.e. a faculty member. These persons in charge are nominally subordinate to a higher person, but in practice they act almost as they wish, as long as they do not interfere excessively in other feudal domains. Within the organizational structure, the President, Provost, and Vice President of research can exert authority over PIs, while the chair of the department has difficulty influencing all faculty members and PIs in the department, as he or she is also responsible for PI duties.

In industry, however, there is a thorough top-down and line management approach in many companies, with the CEO issuing health and safety commitments, the health and safety department preparing a detailed health and safety plan based on the commitments, which is then rolled out horizontally in each department and communicated to employees at the end of the line, with the plan then being implemented in the local workplace. In this way, compliance with the health and safety rules and guidelines developed by the Health and Safety Department is ensured throughout the organization, and any deficiencies identified during workplace inspections are followed up by the Health and Safety Department until they are rectified in the workplace concerned.

Regarding the use of chemicals, OSHA (2013) in the United States outlines the differences between how chemicals are used in laboratories and in industry in the following. In industry, workers handle chemicals continuously or repeatedly in standardized processes and are exposed to large amounts of hazardous chemicals in the environment. However, researchers in laboratories at universities, etc. use a greater variety of hazardous chemicals than in industrial workplaces, but they use fewer hazardous chemicals at any one time, and their chemical handling procedures may change frequently.

According to the CSB (2010), each PI's work with chemicals can be very different, and as a result, research hazards can vary significantly from laboratory to laboratory. Under one PI, researchers or students in the same laboratory are not working on one project, but on different projects that may pose diverse safety hazards to them. In its conclusion, the CSB states that industry guidelines may not be suitable for direct application to the dynamic environment of university laboratories without modification. Therefore, taking into account the differences in the organizational structure and operation of chemicals in universities, it is necessary to modify the industrial SMS so that it can be used by universities, etc. to establish a SMS to ensure the safety of universities, etc.

1.10 Explosion Accidents in Universities

Accidents at universities are generally not published. If they are published, it is a short report of about one A4 page with a summary of the accident and the main causes of the accident. However, in the United States, the CSB publishes the full version of university accidents, but this is a rare case: the CSB is a federal agency established in 1990 under the Clean Air Act and deals exclusively with chemical accidents that occur in the chemical industry, such as chemical plants, rather than accidents at universities and other academic institutions.

1.10.1 Reanalysis of Explosion Accidents at Universities

The following is a reanalysis of the accident investigation reports published by the CSB using the risk management and quality management process (RMQMP) approach model (Fukuoka 2019), developed by the authors as described in the following (Fukuoka and Furusho 2022).

The accident occurred in January 2010 when a postgraduate student at University A was experimenting with a scale-up of the chemical nickel hydrazine perchlorate (NHP); the recommended use of NHP was 100 mg, but this was exceeded and the powder exploded while the NHP was being stirred with a pestle, injuring the postgraduate student. Measures to prevent the recurrence of this accident are discussed in Chapter 2, the application of the accident model in Chapter 3, the SMS in Chapter 4, and safety recommendations in Chapter 6.

1.10.1.1 Local Workplace Procedures at the Time of the Accident

There were no written procedures, etc., and dates and amounts of reactants were not documented in the experimental records.

1.10.1.1.1 Use of PPE

1. It was an individual's choice whether or not to wear goggles, and the wearing of PPE depended on whether or not the individual perceived the experiment to be dangerous.
2. Several postgraduate students used regular power glasses for eye protection.

1.10.1.1.2 Psychological Factor Due to Familiarity, Complacency, and Assumptions

The postgraduate students had to consult the PI before making a decision to scale up. However, two postgraduate students had found in their pre-accident experience that small amounts of the compound did not ignite or explode on impact when wet with water or hexane and assumed that the hazards would be controlled in a similar way even with large amounts of NHP. Postgraduate students had reduced risk awareness of NHP due to previous experience and familiarity.

1.10.1.1.3 Knowledge, Skills, Education, and Training such as Conducting Risk Assessment, Including Hazard Identification

1. The postgraduate student who synthesized the NHP had only completed a prior literature review to familiarize himself with similar high-energy compounds and had not received any research-specific training.
2. The PI or faculty did not assess the postgraduate student's understanding of the risks prior to starting research on high-energy materials.
3. Most chemistry students, including the injured postgraduate student, had not taken the general laboratory safety training offered by Environmental, Health and Safety (EHS) staff online and in person.

1.10.1.2 Communication

1. Safety restrictions, such as the 100 mg limit on the amount of compounds that could be synthesized, were only communicated verbally to some postgraduate students by the two PIs in the same laboratory and were not shared with everyone.
2. In the laboratory, there were two communication tools for sharing information about daily research activities: group meetings and laboratory notebooks. Before the accident, weekly group meetings were held between the postgraduate students and the PIs, but the focus was mainly on the results of the experiments and not on the actual research activities or work safety.

1.10.1.3 Accidents and Near-miss Response

Prior to the January 2010 explosion, two previous near misses had occurred within the same research group. The near miss occurred during scale-up when a postgraduate student inadvertently got the units of measurement wrong and produced an excess of a known high-energy material. The PI did not investigate the cause of the excessively produced known high-energy material.

1.10.1.4 Development and Operation of General SOPs and Experiment-specific SOPs

Experiment-specific SOPs required for the synthesis of NHP and other high-energy substances had not been developed. The Chemical Hygiene Plan (CHP) developed in 1997 did not address physical hazards, and the CHP was developed in accordance with OSHA's Occupational Exposure to Hazardous Chemicals in Laboratories Standard (29 CFR 1910.1450).

1.10.1.5 Approval of Changes to Experimental Plan

The postgraduate students in the laboratory did not need to obtain permission or seek approval from the PI before changing variables in the research experiment, including increasing the amount of the synthesized substance or changing the temperature.

1.10.1.6 Systematic Training and Education Programs

There was a lack of a systematic education and training program in line with the university's safety management: (1) chemistry postgraduate students were not required to attend general laboratory safety education and training, and there was no record of attendance for this education and training. (2) The safety education and training received by most postgraduate students in the Department of Chemistry consisted of learning from safety video aimed at undergraduate students, which is provided by the American Chemical Society. The video did not explain the need for preexperimental risk assessment.

1.10.1.7 Workplace Inspections, Audits, and Corrective Actions

Both the safety advisor and the EHS safety inspector conducted safety audits and inspections of 118 chemistry laboratories on campus, many of which failed to take corrective action. In academic institutions, PIs may view laboratory inspections by external agencies as a violation of academic freedom.

1.10.1.8 System for Conducting Accident and Near-miss Investigations

Although near misses occurred during scale-up prior to the accident, they were not investigated by the university, and near-miss information was not shared outside the laboratory.

1.10.1.9 Coordination Between EHS and the Laboratory

Safety inspections of laboratories under the responsibility of EHS were carried out in the absence of the PIs and were not coordinated with the laboratories. Safety inspections were not seen as an opportunity to ascertain the reality of how the laboratory is ensuring safety.

1.10.1.10 Organizational Structure to Ensure Safety

(1) EHS was not under the authority of the Vice President for Research and had no authority to close the laboratory based on the results of laboratory safety inspections. (2) There was no person or organization responsible for the safety management of the university, including the development and operation of the CHP.

1.10.1.11 External Organizations Relevant to Accident-Contributing Factors

(1) OSHA's laboratory standards, which University A used as a reference in the development of its CHP, dealt with hazardous chemicals that could cause acute or chronic adverse health effects and did not deal with the physically hazardous chemicals relevant to this incident. (2) The Department of Homeland Security (DHS), the research funding agency, did not have safety regulations specific to the research that was being conducted at University A, missing an opportunity to influence the safety of research at the university. (3) In industry, various methodologies are used to assess hazards with regard to workplace and laboratory safety, and guidelines and examples have been developed and published. However, no guidelines have been published that provide various methodologies for risk management focusing on safety in university laboratories.

1.10.2 Summary of the University's SMS

Judging from the content of the accident-contributing factors identified for the explosion that occurred during an experiment at University A, ranging from "Accidents and near-misses response" to "Organizational structure to ensure safety," it can be seen that the SMS at the university was weak. On the left side of the SMS in Figure 1.4, the risk assessment process is not planned and implemented, and on the right side, the deficiencies identified through monitoring and review process have not been addressed.

1.10.2.1 Safety and Academic Freedom

The challenge is the relationship between academic freedom and safety assurance. Workplace inspections of laboratories by the safety inspector were carried out in the absence of faculty members and PIs, resulting in a lack of coordination between both parties. Furthermore, workplace inspections themselves were a mere formality, indicating that inspections had taken place but not ensuring safety. In addition, due to the organizational structure, EHS, which conducts the workplace inspections, did not have the authority to close the laboratory if the safety inspector determined, based on factual information, that the risk in the laboratory exceeded acceptable level.

1.11 Consequences of Inexhaustive and Nonscientific Accident Investigation

This section discusses the Niseko Annupuri avalanche accident in Hokkaido, Japan, as an example of the importance of systematic and scientific accident investigation and analysis. This real-life example provides us with a lesson as to why people have been caught and victimized by avalanches three times in the same place over a long period of time.

Tourists and others have been killed by surface avalanches at the same location, commonly known as Spring Falls, on three occasions in 1990, 1998, and 2017. The accident in February 1998 in which two snowboarders were killed and injured was the subject of a court case and its details were published (Sapporo District Court 2000). In the 2017 accident, snow and ice research societies conducted survey of accumulated snowfall and measured the amount of new snow near the accident site after the accident occurred, but no systematic accident investigation analysis was conducted in either case.

In the 1998 accident, some contributing factors were identified in the judicial decision, as shown in Table 1.1, but there were insufficient contributing factors on the part of guides. Furthermore, the lack of comprehensive accident investigations involving the organizations managing the Niseko Annupuri ski resort, the company to which the guides belonged, and the local authorities meant that many organizational factors were not identified in the accident.

According to the judicial decision, the guides who led the snowboarders were aware that the Sapporo District Meteorological Office had issued an avalanche warning early that morning; that Spring Falls was designated as an avalanche danger zone; that they did not carry avalanche beacons, zombie poles, or probes as avalanche safety equipment in case of emergency; and that they were unable to take any action after being caught in the avalanche.

The only action taken to prevent the recurrence of avalanche accidents was the distribution of leaflets by the local safety liaison council after the 1990 avalanche accident, indicating that Spring Falls was an avalanche danger zone. Recurrence prevention measures were only taken at one point against a wide range of aspects, and lessons were not drawn from criminal investigations conducted by the police and prosecutors or court rulings. Then, 19 years later, in 2017, two skiers were caught in an avalanche at the same location, and both were killed and injured. The avalanches at this time of year are surface avalanches with high avalanche speeds and are said to be difficult to avoid if a person is in the path of the avalanche.

What this series of tragic events teaches us is that the analysis and conclusions of the inexhaustive accident investigation, and the safety measures taken as a result of those conclusions, were measures taken in the absence of accident factors that should have been present. This reality, and in the light of the theory of the Swiss cheese model, means that many layers of defenses have not been built up and that accidents are likely to recur. It demonstrates that if accident investigation and analysis are not carried out scientifically, covering all accident-contributing factors and targeting safety measures at the components of the social system related to the accident occurrence as a wide range of aspects rather than a point, accidents will recur over the years.

Table 1.1 Analysis of avalanche accidents on Mt. Niseko Annupuri.

SHEL element	Subdivision	Accident-contributing factors
Software	Local workplace procedures at the time of the accident	The originally planned destination was changed due to bad weather. The two tour guides did not explain the specific route of the Spring Falls and the avalanche.
	Practices and regulations used in the field	NA
	Emergency response plans	The tour guide noticed the avalanche and shouted for all four of them to run away, but they were all caught in the avalanche. One guide managed to get out of the snow on his own, while the other three were found and rescued by rescue personnel.
Hardware	Status of facility and equipment relevant to the accident	Avalanche beacon, Zombie pole, or probe not carried with.
Environment	Weather conditions	Snowfall increased by 44 cm between 9 p.m. on 24 May and 9 a.m. on 28 May 1998; Sapporo District Meteorological Observatory issued heavy snow and avalanche warning in the early morning of the accident day.
	Geographical features of the mountains	The rest area is a stream channel with little tree cover and a passing area in the event of an avalanche on the upper part of the stream.
	Features of mountain trails	NA
Central liveware	Physical and sensory limitations	NA
	Physiological factor (accumulation of fatigue)	NA
	Pathological factors (preexisting medical conditions)	NA
	Psychological factors (psychological pressure)	NA
	Psychological factors (familiarity, complacency, assumptions)	One tour guest knew from leaflets and other information that the area around the Spring Falls was an avalanche danger zone but was not worried because they were accompanied by guides.
	Workload management	NA
	Knowledge, skills, education, and training	The two tour guides were aware that there had been heavy snowfall for several days prior to the accident, that a heavy snow and avalanche warning had been issued that morning, and that the snowfall on the day was about 30 cm.
Peripheral liveware	Communication	NA
	Teamwork	NA

SHEL element	Subdivision	Accident-contributing factors
	Accident and near-miss response	An avalanche accident occurred at Spring Falls on 15 January 1990. The Niseko Ski Resort Safety Council produced and distributed leaflets, designating Spring Falls as an avalanche danger zone.
	Establishment of criteria for suspension of tour guides	NA
	Development and operation of SOPs	NA
	Operational arrangements for emergency response plans	NA
	Organizational structure to ensure safety	NA
	External organizations relevant to accident-contributing factors	NA

Note: NA in the table means that the accident-contributing factors based on the SHEL model were not included in the judgment text.

1.12 Challenges in Preventing Accidents in Universities, etc.

What is the current state of accident investigation and prevention in universities, etc? In the case of university accidents, accident investigations are rarely carried out and published for the purpose of a full report, and are usually in the form of a simplified report, in which only a summary of the accident and the main causes of the accident are highlighted. The actual situation at universities, etc. is therefore similar to the accident investigation of avalanche accidents described previously.

Scientific papers do not provide an exhaustive and scientific analysis of accident investigation, but rather case studies (Kemsley 2009), in which partial accident factors are addressed and discussed. These studies are informative with regard to safety measures for the factors addressed, but do not provide measures to prevent recurrence and fall into the category of symptomatic treatment. To use an analogy with a human disease, a person's back hurts, so a poultice is applied to the painful area, which temporarily relieves the pain. However, the pain will recur or persist unless the cause of the pain is thoroughly identified by a thorough examination and the cause is treated. The same applies to accidents: symptomatic treatment will result in the accident recurring.

There are safety standards for chemical experiments, *Guidelines for Chemical Laboratory Safety at Academic Institutions*, published by the American Chemical Society (2016). The guidelines comprise four pillars and explain these in detail: hazard recognition, risk assessment of hazards, minimizing the risk of hazards, and emergency response preparedness for uncontrolled hazards. The guidelines state that accidents and near misses should be reported and shared with people in the laboratory and the department and that accident investigation and accident reporting are important to prevent accident recurrence. However, it does not go into detail on the types of accidents and near misses that should be shared, the methods of accident investigation and analysis, the format of accident investigation reports, and how the information contained in accident investigation reports can be used to prevent accidents.

The reality and background of the accidents that occurred at many universities, as pointed out by Ménard and Trant (2020) in a review article in *Nature Chemistry*, is the same as the reality and background of the avalanche accidents that occurred repeatedly three times over the years at the Spring Falls on Mt Niseko Annupuri. In other words, at the time of the accidents and near misses, no thorough and scientific accident investigation and analysis are carried out, and all accident-contributing factors are not visualized. Therefore, even if safety measures are put in place that do not include factors that should have been present from the outset, similar accidents will still occur at the same university or elsewhere in the world. What universities, etc. need to do to overcome this situation is clear from what has been said so far in this chapter.

The CSB (2010), which published an accident investigation report on the explosion that took place at University A, stated the following:

> "In previous years, other institutions (except for CSB) have attempted to collect data on laboratory incidents, but no nationwide reporting system for tracking near misses and incidents exists; as a result, academia is missing a significant opportunity to communicate, educate, and improve laboratory safety."

Following the identification of issues in comparison with other advanced industries in accident prevention described in this chapter, the first steps to be taken to achieve the goal of preventing the recurrence and proactively prevention of accidents occurring in universities, etc. in the future will include the following items (Fukuoka 2022b).

1. First of all, the accident investigation and analysis methods of universities, etc. need to be standardized. Although there are currently numerous accident models available, it is recommended that an accident investigation analysis methodology based on the scientifically proven Swiss cheese model and the SHEL model be used. Reproducibility is one of the most important elements of a scientific paper. To be reproducible, the methodology must be scientifically proven. In addition, once the data from accident investigation reports have been accumulated, the underlying data must be collected to the same standard when processing the data to predict the circumstances under which an accident might occur on the basis of the data. Unification of accident investigation and analysis methods is therefore necessary for the future development of science and the improvement of safety in education and research at universities, etc. See Chapter 3 for accident models, including the Swiss cheese model, and Chapter 5 for details of the elements of the SHEL model.
2. Next, there is a need to develop common accident investigation and analysis guidelines for use by universities, etc. worldwide. The guidelines should describe the purpose of accident investigation, the methodology of accident investigation analysis, how to write accident investigation reports, how to follow up corrective actions, and how to share lessons learned. The guidelines will specify the content of the accident investigation report, but it is necessary to define the case for preparing a full and exhaustive accident investigation report and the case for preparing a simplified report. Furthermore, a distinction must be made between safety investigations and investigations for punitive purposes. The purpose of a safety investigation is to prevent accidents, not to punish people. This shall be clearly stated in the accident investigation report. The accident investigation personnel shall also explain the above to the persons involved in the accident at the beginning of the accident investigation.

   When writing an accident investigation report, the special features of universities, etc. must be taken into account. Universities and other academic institutions research undisclosed cutting-edge technologies for innovation. Exposure of such technology would cause significant damage and researchers would have a negative view of accident investigations and would not cooperate with accident investigators. Accident investigation reports should focus only on safety-related processes, without exposing such cutting-edge technology. The report should be anonymous, so that personal information, such as the name of the university, research institute, laboratory or individual, is not revealed. See Chapter 6 for further information.

3. Once the above two points have been addressed, the accident investigation personnel at each university, etc. must be educated and trained. This is because the quality of an accident investigation report depends to a large extent on the skills of the person in charge of conducting the accident investigation. Therefore, education and training materials shall be developed, and face-to-face training shall be provided. It is recommended that the content of the training material should include Chapters 2–7.

   This book does not provide a practical exercise for accident investigation personnel. However, this can be achieved through the use of this book. First, divide the trainees into several groups. Using one of the cases in this book, the trainers create a simulated situation of the contributing factors behind the accident, and the trainees interview the trainers and their colleagues to gather factual information. Based on this factual information, an accident analysis is carried out. The causes and contributing factors of the accident are identified and safety measures are recommended to prevent a recurrence. These processes can be practiced by representatives of each group, who make presentations and discuss them.
4. It is then recommended that an international conference of accident investigators be organized on a regular basis. The aim of these meetings is to improve the skills of accident investigation personnel and to exchange information useful for accident investigation and analysis, including the exchange of lessons learned from accident investigation results. The results of international conferences should be published on a website after the conference discussion of what should be made public, in the same way as is done at academic conferences, so that universities, etc. around the world can share information.

It should be noted that accident investigation and analysis and accident prevention measures should be considered and implemented in the context of the SMS referred to in Section 1.7, which is effective in preventing the recurrence of accidents and in proactively preventing accidents from occurring. The introduction and widespread use of SMS will be an important issue for universities, etc. together with other issues such as the introduction of scientific accident investigation methods and the visualization of all accident-contributing factors, taking into account the specificities of the organizational structure of universities, etc.

The benefits to universities, etc. of implementing the four steps mentioned above may include the following (Fukuoka 2022b):

1. First, if universities and other academic institutions around the world participate in this scheme aimed at preventing the recurrence and proactive prevention of accidents, the effect of economies of scale will make visible all accident-contributing factors that have been latent and unexposed up to now. These include, for example, fires, explosions, fatalities, injuries, and serious health hazards resulting from field research activities and chemical experiments, which can be displayed by type of accident. If these accident-contributing factors are present before the start of an experiment at the reader's university or other academic institution, the results of the analysis obtained can be used as lessons learned to prevent accidents from occurring, for example, by taking safety measures before the experiment is carried out.
2. Once a large amount of accident data have been collected, it can be analyzed to derive accident patterns for each type of accident. These patterns could include, for example, fires and explosions involving certain chemicals; explosions involving gas mixtures; marine research diving

accidents; river accidents; and research accidents in mountains, forests, wilderness, etc. New safety education and training programs can be developed and delivered using accident patterns. These need to be more practical and effective than the textbooks of the past.

3. At present, accident data from universities, etc., which is one of the aims of this book, have not been collected, so it is not possible to predict accidents using artificial intelligence based on vast amounts of credible data from the past. Imagine what would happen if we could use data showing the mechanisms of accident occurrence, when vast amounts of reliable and reproducible data have been accumulated. I believe the time will come when AI will be able to predict the occurrence of accidents and tell people what they should do to prevent accidents before the experiment starts. In other words, there will be innovation and a paradigm shift in accident prevention at universities, etc.

1.13 Conclusion

Numerous accidents of various types have occurred in universities, etc., and similar accidents have occurred repeatedly around the world, but the reality of these accidents has not been clarified. Looking at other industries, the second half of the twentieth century saw a paradigm shift in marine and aircraft accidents, with national accident investigation agencies carrying out scientific and thorough accident investigations and analyses, and making the lessons learnt available to the maritime and aviation industries, which were then applied by companies in these industries, contributing to a reduction in the accident rate, particularly in the case of aircraft accidents. By analyzing the situation in other industries that have preceded and succeeded in reducing accidents, the challenges of the safety environment for universities, etc. have been identified.

Accident models represent the mechanisms by which accidents occur. It is important to understand the historical background of the applicable accident models and how the models work before using them for accident prevention. The treatment of back pain has been used as an analogy to illustrate one of the problems associated with accident prevention in universities, etc. Not only explosions in chemical laboratories but also accidents in universities, etc. have a cause-and-effect link, and there are many accident-contributing factors. For these reasons, the epidemiological accident model is applied, as discussed in this chapter. In other words, to prevent accidents, universities, etc. should conduct accident investigations analysis using the concept of the Swiss cheese model, which is classified as an epidemiological accident model, and the accident investigation analysis tool based on the SHEL model, which allows a comprehensive investigation of accident-contributing factors. In addition, when adopting the concept of the Swiss cheese model and the SHEL model, it will be necessary to understand the SMS that was not in operation in many universities, etc. and to implement a modified version of this system well adapted to them.

It takes a long time for an organization to accumulate data on accidents that have occurred in the organization, and for accident prevention measures to be effective, it is essential to analyze accident-contributing factors for each type of accident and clarify accident patterns. However, if a large number of universities, etc. were to come together to formulate rules, including investigation and analysis methods and report writing, to provide education and training in investigation and analysis methods, and to establish a forum for exchanging information to reduce the number of accidents, it would be possible to reduce the number of accidents in a short time through development that takes full advantage of economies of scale.

Once we reach the stage where a large amount of reliable and reproducible data have been accumulated, and where we can use the data to show the mechanism of accident occurrence, AI will be able to inform researchers of the possibility of accident occurrence before they start a particular experiment, and then show them safety measures to prevent the accident, enabling researchers to proactively prevent accidents before they occur. In other words, the time will come when researchers will be able to use AI to prevent accidents, which will lead to innovation and a paradigm shift in accident prevention in universities, etc.

References

Air Line Pilots Association (1977). Aircraft Accident Report, Engineering and Air Safety, Washington, DC. Pan American World Airways Boeing 747, N737PA KLM Royal Dutch Airlines Boeing 747, PH-BUF, Tenerife, Canary Islands, March 27, 1977.

American Chemical Society (2016). *Guidelines for Chemical Laboratory Safety in Academic Institutions*. Washington, DC: American Chemical Society.

Department of Transport, UK (1987). *MV Herald of Free Enterprise Report of Court no.8074 Formal Investigation*. London: H.M.S.O.

Fukuoka, K. (2019). *Safer Seas: Systematic Accident Prevention*. Boca Raton: CRC Press Taylor & Francis Group.

Fukuoka, K. (2022a). New approach to prevent explosion accident. *Kagaku* 77 (9): 31–36. (Japanese).

Fukuoka, K. (2022b). A new approach to preventing accidents occurring at universities. *Presentation Presented at the 9th Asian Conference on Safety and Education in Laboratory (ACSEL) in Singapore*, Singapore (17 November 2022).

Fukuoka, K. (2023). Accident and safety at the universities and chemical industry. *Kinka* 75 (10): 1–6. (Japanese).

Fukuoka, K. (2024). Forward-looking safety with the aim of developing scientific diving. *Lectures Presented at the Symposium to Educate about Scientific Diving in Fukuoka*, Japan (6 June 2024).

Fukuoka, K. and Furusho, M. (2022). A new approach for explosion accident prevention in chemical research laboratories at universities. *Scientific Reports* 12 (1): 3185.

Grandjean, E. (1969). *Fitting the Task to the Man: An Ergonomic Approach*. London: Taylor & Francis.

Hawkins, F.H. (1987). *Human Factors in Flight*. Aldershot: Gower Technical Press.

ISO 9001:2008 (2008). *Quality Management Systems - Requirements*. Geneva: International Organization for Standardization.

ISO 14001:2015 (2015). *Environmental Management Systems – Requirements with Guidance for Use*. Geneva: International Organization for Standardization.

Japan Transport Safety Board (2010). Marine accident investigation report: Bulk carrier *HANJIN BRISBANE* grounding. MA2010-8. (Japanese).

Kemsley, J. N. (2009). Learning from UCLA. *Chemical and Engineering News* 87 (31): 29–34.

Ménard, A.D. and Trant, J.F. (2020). A review and critique of academic lab safety research. *Nature Chemistry* 12 (1): 17–25.

Norman, D.A. (1988). *The Psychology of Everyday Things*. New York: Basic Books.

Occupational Safety and Health Administration, USA (2013). Appendix A to §1910.1450-National Research Council Recommendations Concerning Chemical Hygiene in Laboratories (Non-Mandatory).

OHSAS 18001:2007 (2007). *Occupational Health and Safety Management Systems – Requirements*. OHSAS Project Group.

Rasmussen, J., Duncan, K., and Leplat, J. (1987). *New Technology and Human Error*. New York: John Wiley & Sons Ltd.

Reason, J. (1990). *Human Error*. New York: Cambridge University Press.

Reason, J. (1997). *Managing the Risks of Organizational Accidents*. Surrey: Ashgate Publishing Limited.

Sapporo District Court (2000). Judicial decision of the Sapporo District Court, Otaru Branch: Niseko Annupuri "Haru no Taki" avalanche disaster case. (Japanese).

Stolzer, A.J., Halford, C.D., and Goglia, J.J. (2008). *Safety Management Systems in Aviation*. Aldershot: Ashgate Publishing Limited.

US Chemical Safety Board (2010). Texas Tech University laboratory explosion, No. 2010-05-l-TX. https://www.csb.gov/texas-tech-university-chemistry-lab-explosion/ (accessed 10 May 2023).

US Chemical Safety Board (2021). Chemical reaction, hydrogen release, explosion, and fire at AB specialty silicones. https://www.csb.gov/ab-specialty-silicones-llc/ (accessed 10 May 2023).