Risk in the Maritime Sector

— Dealing Skillfully with Risk —

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1. INTRODUCTION

The word “risk” is now used frequently even in everyday life, as seen in terms such as “risk hedge” and “country risk.” However, while “risk” is generally considered to mean “the very picture of danger” in Japan, the understanding is quite different in Europe and the United States, where “risk” is only a “possibility,” that is, “the possibility that an adverse event may occur.”

Although various explanations of the origin of the word “risk” have been proposed, including the Italian *risicare* (to attempt something with courage) or *risico* (disaster) and the Spanish *risco* (a steep, rocky reef), its etymology remains unclear. Nevertheless, it is certain that the development of the concept of “risk” was greatly influenced by the maritime fields of navigation and foreign trade, among others. For example, there is a widely known story that around the end of the 17th century Lloyd’s Coffee House, which was managed by Edward Lloyd in London, England, created a newspaper by gathering information from sailor and merchants, and organized a syndicate to disperse the risk based on it, thus laying the foundation for the marine accident insurance system.

In this paper, the author introduces the concept and practical techniques related to recent risk assessment, particularly to risk assessment in the maritime sector, and would also like to discuss future expansion in the commercial field.

Here, it may be noted that both “risk assessment” and “risk evaluation” are frequently translated as “risk assessment” in Japanese. However, the two terms are slightly different. While “evaluation” simply means the act of evaluating, “assessment” also adds “consideration based on the results of that evaluation” (i.e., the overall process of risk analysis based on risk evaluation), and thus extends to the act of “judging.” Because “judgment” is also included in the meaning in this paper, “risk assessment” will be used here to avoid confusing the two terms.

2. SAFETY

2.1 What Is Safety?

The slogan “Safety First” is often seen in cities and towns. This motto had its origin in 1901, when Elbert Henry Gary, who was the President of US Steel, the world’s leading steel company at the time, was pained by the company’s failure to reduce industrial accidents and revised the general management policy in the industry, “Production First, Quality Second, Safety Third,” to “Safety First, Quality Second, Production Third.” Under this management policy, US Steel not only reduced accidents, but also achieved excellent quality and high productivity in spite of the labor shortage during the wartime, and afterward, the slogan “Safety First” permeated the entire country.

Although realizing “Safety First” is a challenge for humankind, the meaning of “safety” is itself vague and is difficult to define clearly. Conversely, “danger,” which is the opposite concept to “safety,” is clearly visible, for example in diseases and accidents involving injury, and its handling is also practical. This suggests that it is appropriate to define “safety” from the viewpoint of “danger.”

According to ISO/IEC Guide [1)], “safety” is defined as “freedom from risk which is not tolerable. A note states that “For the purposes of this Guide, the terms “acceptable risk” and “tolerable risk” are considered to be synonymous. Similarly, the JIS standard [2)] states to the effect that safety is “a condition in which the danger of harming persons or damage is held to a tolerable level.” In other words, “safety” is defined in terms of “risk” and “danger.” At the same time, even assuming that a condition is “safe,” some degree of risk remains. Therefore, “safety” means a condition in which this element of risk is held to a low level which can be accepted or tolerated. The idea of “absolute safety” (zero risk) is abandoned from the outset, and there is a common recognition of this worldwide.

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2.2 Security and Safety

As can be seen in the slogan "Contributing to the security and safety of the nation's people," "security" and "safety" have frequently been used as a pair in recent years. However, what is the difference between security and safety? While the Japanese word *anzen* (安全) is translated as "safety" in English, the Japanese word for security, *anshin* (安心), is more difficult to translate. If one is forced to choose, "peace of mind" may be possible, but the meaning of this expression is subjective. When the issue of relocating Tokyo's famous fish market to Toyosu became controversial, Tokyo's Governor Koike declared that "Toyosu is safe, but it doesn't inspire peace of mind." This sense of "knowing objectively that a situation is safe, but still feeling uneasy" might be a representative example of the thinking of the Japanese people.

Again, the term *fuuhyou higai* (風評被害), what might be called "reputational damage," is used when unfounded rumors or falsehoods cause some time of adverse effect, particularly economic damage, by affecting the reputation of the person or region concerned. This can also be thought to arise from the same "safe, but not secure" feeling. Why can't a person feel secure, even though they say a situation is safe? Since one cause of this is biased or inadequate knowledge on the user's side, or disregarding knowledge due to indifference, an attitude of self-education is needed. However, this feeling of security is possible only when the user can trust an organization or person that has realized and guarantees safety. Active messaging and mutual communication from such organizations and persons to users are also indispensable for building a feeling of security.

2.3 Safety Targets

Under a condition where absolute safety does not exist, the following problem arises: "How far must risk be reduced before the condition can be called safe?" While the terms "acceptable" and "tolerable" are used in definitions of safety, the ISO/IEC Guide [1)] defines "tolerable risk" as "risk that is accepted in a given context based on the current values of society." This suggests that there are no clearcut criteria for determining how far risk must be reduced in order to be safe, and instead "safety" is decided based on the balance of the magnitude of risk, convenience, costs and other factors. The following are examples of typical judgment criteria [3)].

- Risk-utility criterion

Concept of judging acceptability by comparing the utility, merits and convenience of using a product and the risks associated with using that product.

- Cost-benefit criterion

Concept of judging how far risk should be reduced by comparing the required cost of implementing risk reduction measures against the benefits and utility obtained by implementation.

- Consumer expectation criterion

Criterion based on the safety that ordinary consumers rationally expect; a concept in which the minimum level of risk that must be maintained is set based on common sense.

- Deviation-from-standard criterion

In cases where standards or legal requirements exist, this is the concept that the safety level is acceptable provided those requirements are satisfied.

2.4 ALARP

In many cases, judgments of actual safety targets are made based on the principle called ALARP (As Low as Reasonably Practicable). ALARP is the concept that risk must be reduced as far as is reasonably possible. In this case, risk is reduced as far as possible in accordance with criteria such as the above-mentioned risk-utility or cost-benefit criterion. In actuality, however, risk above a certain level cannot be tolerated ("intolerable"), while risk below a certain level is broadly tolerable ("negligible"), and the ALARP region is the range that is reasonable possible between those two levels. Risk can be limited to this ALARP region only in case it can be shown that the costs required to reduce that risk would be extremely large in comparison with the benefits obtained. Fig. 1 shows a conceptual diagram of the ALARP region, which is called a carrot diagram owing to its carrot-like shape. The handling of the safety targets when using the ALARP principle are quite different depending on the object field, for example, in the nuclear power industry, chemical engineering, transportation (automobiles, aircraft, railways, ships), computers and telecommunications. The applicable safety targets for the various fields are also currently being explored, including in the Science Council of Japan.

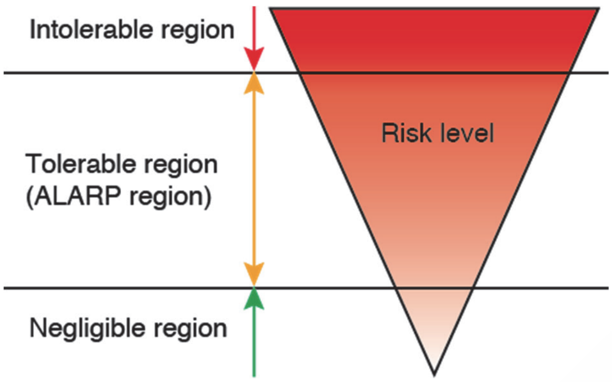

Fig. 1 Concept of ALARP (carrot diagram)

3. RISK

3.1 Various Types of Risk

There are various types of risk. For example, “environmental risk” indicates the possibility that chemical substances, etc. may have adverse impacts on human health or the habitats of living organisms by way of the environment. “Country risk” means the degree of risk of loss of profit when engaged in overseas investment or foreign trade due to changes in the government, economy or social environment of the counterpart country, unrelated to the commercial risk associated with partners in individual projects. The risk caused by the Russian invasion of Ukraine is a typical example of this. Among these various types of risk, the following explains risk in economics and risk in safety engineering, where the concepts are comparatively well-established.

3.2 Risk in Economics

In this field, risk is generally considered to be “uncertainty regarding the variability of certain events.” In other words, risk = uncertainty. Therefore, this type of risk does not include the importance of results.

According to this definition, since the situation that a person is walking along the edge of a sheer precipice is unknown whether he will fall or remain safe, uncertainty, that is, risk is high. However, once the person steps over the edge of the cliff, death is certain, and risk is no longer a question after the person takes that step.

3.3 Risk in Safety Engineering

In safety engineering risk [1] is defined as the degree of uncertainty of an undesirable event for human life or economic activity and the magnitude of the effect of such an event. In other words, risk can be considered as the combination of the frequency of occurrence (frequency) and the seriousness (consequence) of the result. In this case, either the frequency or the consequence of the event must be reduced in order to reduce risk.

For example, considered in the simplest terms, the value obtained by multiplying the consequence of the result and the frequency of its occurrence can be defined as “risk,” as shown in Expression (1), and in fact, this equation is widely used.

$$\text{Risk} = (\text{Consequence}) \times (\text{Frequency}) \qquad (1)$$

However, if this expression is used, the case where the consequence is high but the frequency is low, and the case where the consequence is low but the frequency is high, may result in the same value of risk. As can be understood from airplane accidents and automobile accidents, cases where the frequency is low but the consequence is high attract overwhelmingly high attention. In that sense, there is still much room for consideration in deciding what combination of consequence and frequency should be used to determine the value of risk.

3.4 Terminology Related to Accident Scenarios [4]

In safety engineering, the terminology shown below is used when handling accident scenarios.

“Hazard” is a word that is heard frequently in recent years, for example, in the term “hazard map,” but it expresses a threat to human life, etc. Hazard refers to so-called hazardous situations due to circumstances or conditions that may cause an accident, so-called danger circumstances: A road frozen with snow, a house located near a river and a cup of coffee beside a notebook PC are typical examples. Risk and hazard are also sometimes used interchangeably, but when seen from the viewpoint of risk assessment, they are different terms. That is, “hazard” expresses the dangerous or harmful nature of natural disasters, power outages, deterioration of structures and the like, while “risk” is the degree of possibility (probability) that a hazard may cause adverse effects. In other words, if there is no hazard, risk does not exist.

“Peril” is a direct cause of damage or loss. It indicates all the causes of hazard, and refers to accidents that cause damage or loss, such as fires, explosions, traffic accidents, etc., or the accidents that cause them. Examples include fires, lighting, typhoons, collision, floods, etc.

“Consequence,” as mentioned above, expresses the degree of seriousness of an accident. In many cases, consequence is defined in terms of human death and injury (persons) or the cost of damage (yen or dollars).

In the accident scenario “three persons died when an oil platform was destroyed by a hurricane,” the hazard is the hurricane, the peril is the destruction of the oil platform, and the consequence is the three deaths.

3.5 Image of Occurrence Frequency

Occurrence frequency is a probability and is a nondimensional quantity having a value in the range of [0, 1]. In obtaining the probability of occurrence, first, it is necessary to specify the referenced period, for example, per 1 hour, per 1 year, per 1 voyage, etc. When the object is ships, reference periods such as per ship-year, per working-hour, etc. are used in some cases.

Because frequency of occurrence is a probability, it normally has a small value but is not zero. Accordingly, the discussion will be out of touch with reality if we do not understand the meaning of that value and discuss it using concrete images. An annual probability of 10^{-2} means a probability of occurrence of once in a lifetime, while a probability of 10^{-10} means 1 time since the birth of the universe. For example, there are data showing that the probability of being struck by lighting is about 10^{-6}, but the probability of winning the lottery in Japan is 10^{-7}. While these are not probabilities that should cause concern, they are not probabilities that can be totally ignored.

4. RISK ASSESSMENT

4.1 What Is Risk Assessment?

The ISO standard indicates that risk assessment is a total process which includes risk identification, risk analysis and risk evaluation.

Risk identification (or hazard identification) is the process of discovering, recognizing and describing risk, while risk analysis is the process of understanding the special characteristics of that risk and determining the risk level.

Risk evaluation is the process of comparing the results of the risk analysis with risk criteria in order to determine the acceptability (or tolerability) of the risk (and its magnitude).

Risk assessment is essentially a subprocess within the risk management process. Normally, after a risk assessment, the magnitude of the tolerable risk (tolerable value) is compared with the predicted value of the risk (predicted value), and when the predicted value exceeds the tolerable value, a decision-making action is carried out to decide whether to take risk reduction measures or risk avoidance measures, and a process that realizes a safer condition is implemented.

4.2 Reality of Risk Assessment

4.2.1 Overview of FSA [5)]

Here, FSA (Formal Safety Assessment), which is actually used widely as a risk assessment technique in the maritime field, will be presented as an example. As shown in Fig. 2, the FSA procedure is divided into 5 steps (Step 1 to Step 5). The work in each step will be explained.

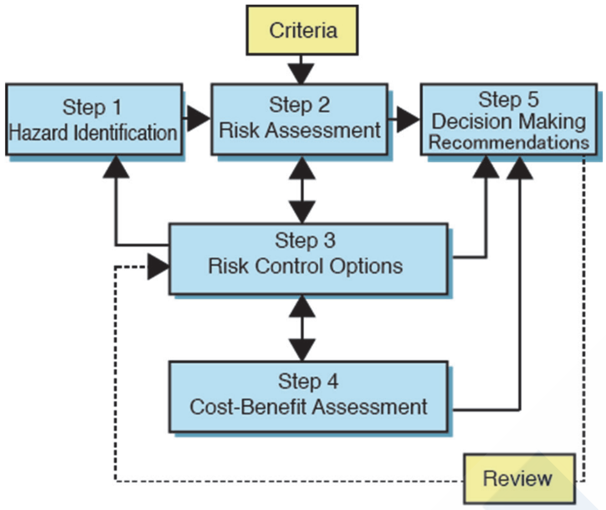

Fig. 2 Procedure of FSA

4.2.2 Step 1: Identification of Hazard

In Step 1, first, the various types of hazards that lead to accidents are identified by utilizing a combination of HAZID meetings and analysis methods.

A HAZID meeting is made up of multiple experts from different fields and held to quantify the consequence and frequency of accidents through meetings in line with a schedule. Analysis methods are used to assign priorities to all accident scenarios by risk level using available data.

In Step 1, it is possible to obtain 3 types of outputs, namely, the hazard list, related scenarios ranked by risk level, and the causes of the accidents and the description of their effects.

4.2.3 Step 2: Risk Analysis

In Step 2, a detailed risk analysis of the scenarios obtained in Step 1 is carried out, and the total risk of the target is obtained as the sum total of the risk of the individual accident scenario based on the accident probability, the probability that the disaster will spread after the accident (secondary disaster), and the seriousness of the accident and secondary disaster.

The risk of this case is an index of safety. Risk is defined as the product of the frequency and consequence of an accident, as shown above in Expression (1), and the assumed types of damage are loss of human life (fatalities), environmental impacts and loss of property. Risk evaluation indexes include individual risk and social risk. As examples, individual risk is an index that shows the frequency of death or injury of an individual while using some means of transportation, and social risk is an index showing the frequency of death or injury of a group using transportation during a target period being considered. The social risk of the group is obtained by multiplying the risk of the individuals who belong to that group by the size of the group. One index of social risk is PLL (Potential Loss of Lives). In the case of ships, PPL is the number of fatalities per 1 ship in 1 year (1 ship-year). Even though the PPL is the same, accidents become increasingly intolerable as the number of fatalities in one accident increases. As an index which reflects this fact, analyses are conducted using an FN (Frequency-Number of fatalities). This is a diagram that graphs the number of fatalities against the frequency of occurrence of accidents that result in a certain number of fatalities or more.

In FSA, the upper and lower limits of the ALARP region are set as risk tolerance criteria. Although the lower limit of the ALARP region for individual risk is 10^{-6}, the upper limit has been set at 10^{-3} for crew members and at 10^{-4} for passengers and the general public, that is, one order of magnitude stricter than for crews. It should be noted that these risk tolerance criteria are provisional values and a review is being studied, as there are also many opposing views.

4.2.4 Step 3: Drafting of Risk Control Options

In Step 3, Risk Control Options (RCO) are examined, and the reduction of risk in case they are introduced is estimated. Here, RCO are defined as safety measures for suppressing the very picture of high-risk hazards in cases where the risk is in the ALARP region, or the occurrence of accident scenarios. In the FSA approach, the individual measures are called RCMs (Risk Control Measures), and the RCMs are collectively called RCO. RCO comprise preventive measures for reducing the frequency of occurrence of accidents and mitigation measures for reducing the seriousness of the result.

4.2.5 Step 4: Risk Evaluation

In Step 4, the cost of achieving the various types of RCO drafted in Step 3 is evaluated, a Cost Benefit Analysis (CBA) is carried out, and the RCO are ranked in order of priority. In the FSA, two indexes are used for this purpose, Gross Cost of Averting a Fatality (GCAF) and Net Cost of Averting a Fatality (NCAF), as shown in Expression (2).

$$GCAF = \Delta C / \Delta R$$
$$NCAF = (\Delta C - \Delta B) / \Delta R \qquad (2)$$

ΔC : Additional cost incurred by introducing RCO (US$)
Includes the cost of RCO, training costs, lost profit, etc.
ΔR : Reduction of risk by introducing RCO
ΔB : Economic benefit of introducing RCO

GCAP means the costs considered necessary to reduce risk by one unit, while NCAF means the net cost in case an economic benefit is obtained by introducing the RCO and includes the monetary value of the damage which is prevented by introduction of the RCO as an economic benefit.

If the value of GCAF or NCAF is smaller than the threshold of the evaluation criterion, the RCO is effective from the viewpoint of costs and benefits (CBA), and introduction of that RCO is carried out. As the threshold of the current Guidelines for Formal Safety Assessment (FSA), US$3 million is used in case of death or disability based on the current condition of GCAF in the OECD countries. However, there are currently moves to review this criterion, as there are many views that this number should be higher.

4.2.6 Step 5: Decision-Making Action

In Step 5, the results of Step 4 are judged, and the RCO which should be introduced is proposed.

5. RISKS IN THE OCEAN DEVELOPMENT FIELD

5.1 Safety Management System for Ocean Development

For ships, there is a unified international safety standard called the SOLAS Convention (Convention for the Safety of Life at Sea). However, the safety management system and regulations for offshore structures used in oil and gas development are established by the producing countries themselves. Well-known safety supervision organizations include the NPD (Norwegian Petroleum Directorate), the HSE (Health and Safety Executive) of the United Kingdom, and the BSEE (Bureau of Safety and Environmental Enforcement) and BOEM (Bureau of Ocean Energy Management) in the United States.

Table 1 History of introduction of risk assessment in the maritime field

Year	Main events of period	Outline
1977	Ekofisk Oil Field blow-out accident in Norwegian sector of North Sea oil field	A blow-out discharged about 150,000 barrels of oil in 1 week. Near-uncontrollable condition, causing a large-scale environmental disaster.
Second half of 1970s	Start of project to apply Quantified Risk Assessment to Offshore Industry.	Research level. Introduction of the approach used in the nuclear power industry.
1980	Alexander L Kielland offshore oil drilling rig accident	Total loss and sinking of an oil rig due to the absence of structural redundancy after fatigue failure of 1 brace.
1981	NPD regulations	Mandatory application of QRA in the conceptual design stage for all newly constructed structures. Verification of Accidental damage Limit State (ALS) or Progressive collapse Limit State (PLS).
1984	NPD regulations	Introduction of quantitative evaluation criteria of ALS.

1988	Explosion and fire accident at Piper Alpha oil rig in UK sector of North Sea oil field	Poor contact at time of shift change. Permission was given for maintenance and other work on a pressure safety valve. Organizational issues of responsibility and authority.
1990	Safety Case of UK Health and Safety Executive (HSE)	Change from prescriptive regulation to goal-setting regulation. Applied to specified facilities and systems.
1997	Guidelines on the Application of Formal Safety Assessment (FSA) to the IMO rule making process	Safety assessment procedure for rule making for ships in the IMO. Applicable to generalized ships.

The history of the introduction of risk assessment in the maritime sector is shown in Table 1. Risk assessment was introduced in the maritime sector from the second half of the 1970s, which as almost the same period as introduction in the nuclear power sector. The FPSO Rule responding to the subsequent Safety Case has already become a *de facto* standard in the United Kingdom, Australia and some other countries. In the ship sector, FSA was adopted in procedures for establishing regulations in the IMO in the second half of the 1990s, and the number of proposals of standards using FSA has continued to increase in recent years.

5.2 Why Is the Concept of Risk Necessary in Offshore Structures?

Why was risk assessment introduced in the field of ocean development from an early date among all industries? The first reason lies in the enormous amount of capital required in ocean development of offshore oil and gas fields. The probability of discovering an oil field by exploratory drilling has increased remarkably from earlier times thanks to technological innovations such as geophysical exploration, but even so, is still less than 20%. Among the offshore oil fields that are discovered, it is said that the number of discoverable fields with a scale of 1 million bbl or more, which is considered to be required for commercial profitability, is about 2 in 100 trials. Therefore, in spite of differences in the cost of developing offshore oil fields differs depending on the location and scale of exploration, a total investment on the order of several tens of millions of US dollars (several billion yen) is necessary at minimum, and a risk assessment is essential in order to attract investors.

The second reason is the fact that rigs are frequently destroyed as a result of the severe natural environment in which they are placed, which includes hurricane attacks, etc. even after reaching the operational condition. Thus, an estimate of the potential loss of life and damage to equipment is also essential for production of oil or natural gas from the sea bottom.

As the third reason, many major accidents attributable to human error have occurred in the past in the development of offshore oil and gas fields, the damage to human life and the environment when an accident occurred was enormous in some cases. For this reason, the importance of rational safety management based on risk assessment was widely recognized, and QRA (Qualified Risk Assessment), which had been researched in the nuclear power sector, was also applied to offshore structures in a project that began from a comparatively early date, in the 1970s. Since the Piper Alpha accident had particularly large influence, the following will briefly introduce the outline of that accident and the subsequent investigation of the cause.

5.3 Piper Alpha Accident

On July 6, 1988, a large gas leak led to a fire, explosion and the collapse of the Piper Alpha, an English fixed-type oil and gas production platform in the North Sea oil field. Of the crew of 229, 167 died, and 2 members of the rescue team also died.

An accident investigation committee chaired by the Hon. Lord William Cullen was organized to investigate the cause of the accident and issued a report on the accident called the Cullen Report [6)] in 1990.

The report consisted of two parts. As the result of the inquiry and elucidation of the root cause of the accident, the first part found that four accidental factors occurred simultaneously in an overlapping manner, leading to a major accident; these were (1) poor operation, (2) unclear authority and responsibility, (3) poor design changes and (4) disregard for training for emergency situations. The second part presented 106 recommendations as countermeasures for the future, which can be summarized in two key points, (1) requirement of a voluntary safety management system by the operator and (2) objective safety assessment.

The Piper Alpha accident showed the world that “proactive investment in safety that is reasonably practicable is the correct management policy,” and the Cullen Report had a decisive influence on the subsequent form and logic of activities of the HSE.

5.4 Swiss Cheese Model

The “Swiss cheese model” is a model of the process by which human error leads to accidents and other troubles which was proposed by the English psychologist James Reason. In this model, a number of “barriers” (elements that prevent error) are provided for events that are assumed to be accidents, and accidents are normally prevented by overlaying many of these barriers.

However, each of the barriers has “holes” in the form of weak parts of individual layer and chain-reaction errors, as illustrated in Fig. 3, and an accident occurs if these holes unfortunately overlap in a straight line so that an error can pass successively through them. Reason’s proposed model likens these holes in an organization’s layers of defense to sliced Swiss cheese. Because four separate failures overlapped at one time in the Piper Alpha accident, this accident is considered to be a typical example of the Swiss cheese model.

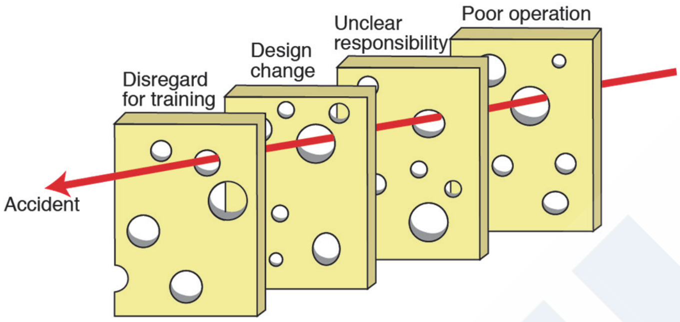

Fig. 3　Concept of the Swiss cheese model

6.　LABOR SAFETY AND RISK

6.1　Labor Safety Law in the UK [7)]

In England, which was the birthplace of the Industrial Revolution, the Factory Act was established in 1802 as the world’s earliest law for worker protection, but with changing times, it became difficult for regulations to keep pace with the progress of industrial technologies. Therefore, a committee chaired by Lord Robens carried out repeated deliberations on safety and health issues (mainly in the administrative aspect) and released the Robens Report [8)] in 1972. Although the Robens Report was an extremely large work consisting of 19 chapters, several of its assertions will be introduced here.

(1) Questions were raised regarding improvement of safety and health by legal and supervisory means. It can be said that there are too many laws for improvement of safety and health, which is counterproductive for achieving the essential goals. New laws must be created successively in line with the progress of society, and laws that have become outdated must be revised.

(2) The subdivision of labor safety and health administration is excessive (at the time, safety and health administration in the UK was divided into 5 related ministries and agencies and 7 supervisory agencies). Responsibility is unclear, and quick measures are not taken.

(3) Based on an awareness of these issues, the Report advocated a shift from a legal and supervisory-centered approach to a voluntary response and unification of administrative authorities.

Based on the Robens Report, in 1974 the UK enacted the new Health and Safety at Work Act (1974 HSW Act) and established the Health and Safety Executive (HSE), which promoted modernization of laws related to labor health and safety over several decades thereafter.

6.2　Basic Concept of the Safety Case Law

In response to the 106 recommendations of the Cullen Report of 1990, the HSE requires operators engaged in the production of oil and gas to prepare and submit a document called a Safety Case. Based on this, the Safety Case Act was enacted, and its practice is linked to HSE (Health, Safety and Environment) activities. Due to the increasing complexity of production technologies, it would be impossible to cover every item which should be done only by laws and ordinances. Therefore, autonomous thinking-type management is required so that each company can discover and solve important problems in the company by itself.

6.3　Safety Case Law

The Safety Case Law refers to Offshore Installations Regulations, which aim to reduce the risk of serious accidents and disasters involving offshore structures operated in British territorial waters and the continental shelf, and requires “objective safety assessment” and an “autonomous safety management system.” Documentary reviews are conducted by the HSE, and certification must be renewed every 3 years.

The Safety Case Law is not a conventional law that requires compliance with regulations, but rather, is a goal-setting type law under which companies are allowed to set their own goals and then demonstrate that they have satisfied them. Its basis is the ALARP concept, that is, reducing risk as low as is reasonably practicable, considering cost-effectiveness.

A "Safety Case" is a document in which each company itself argues the safety of its system, using test results and verification results as evidence, in order to assure or convince those responsible for system certification, users and others of its safety.

The description of an actual Safety Case consists broadly of the following three stages:

(1) FD (Facility Description), meaning a description of the system

(2) FSA (Formal Safety Assessment)

(3) SMS (Safety Management System)

Safety Cases are necessary through the entire Life Cycle of design, operation and disposal, and a Safety Case consisting of the respective stages is required.

6.4 Expanding HSE Activities

The voluntary organization of the oil majors called OCIMF (Oil Companies International Marine Forum) accepted the Safety Case Law fully and cooperatively, and since that time has practiced HSE activities for offshore structures throughout the world and popularized the concept.

Based on the enactment of the Safety Case Law, the E&P Forum (Oil industries Exploration & Production Forum) published Guidelines for the Development and Application of Health, Safety and Environmental Management System (E&P Forum). The main points of these Guidelines are as follows: A PCDA cycle based on risk assessment is followed. All risk reduction measures that are both reasonable and practicable are adopted. Those concerned cooperate in the establishment, practice and dissemination of HSE activities in the offshore field to provide indirect support for the activities of the Health and Safety Executive (HSE).

In addition, the oil majors require practice of HSE activities not only for offshore structures, but also for the navigation and construction of related merchant ships, i.e., LNG carriers and tankers.

Based on this kind of comprehensive backing by the oil majors, the Safety Case Law and HSE activities as its practice have grown remarkably from simply a local system within the UK to activities that are practiced worldwide as a *de facto* standard.

7. RISK IN THE SHIP SECTOR

7.1 FSA (Formal Safety Assessment)

Where ships are concerned, the first version of the unified global standard called the SOLAS Convention (The International Convention for the Safety of Life at Sea) was concluded in response to the sinking of the Titanic in 1912, and since that time, the standard has been revised more than 30 times up to the present. Accordingly, the basic initiatives for safety management of ships that sail on international routes are discussed in the International Maritime Organization (IMO) and reflected in the rules of ship classification societies and various types of standards.

However, since discussions of revisions of rules and regulations in the IMO are frequently carried out in response to a major accident, revisions tend to be unnecessarily excessive due to conditions immediately after the accident. Moreover, because possibly political proposals intended to advantage one's own country were also rampant, FSA (Formal Safety Assessment) based on risk assessment has been introduced as a more rational method for establishing rules.

FSA was proposed by the UK at IMO/MSC62 (62^{nd} meeting of the Maritime Safety Committee) in 1993, and the provisional Guideline was revised and the final FSA Guideline was approved in MSC74 in 2001 based on repeated discussions and test application thereafter. FSA is a comprehensive, rational safety assessment method which is structured and has objectivity and traceability. Its aim is to reduce special proposals and enforcement and drastically limit political discussion so as to create a more rational process for establishing rules in the IMO. While this does not mean that application of FSA to all proposals is mandatory, revision of many standards to apply FSA has been proposed and discussed recently in the IMO. Although FSA has difficulties in the complexity of the procedure and verification, the number of proposals using FSA is increasing year by year.

7.2 GBS (Goal-Based Standards)

The Nakhodka accident in 1997 caused an oil spill of about 6,200 tons of heavy oil in the Japan Sea, resulting in serious damage in coastal areas. This was followed by a series of other major accidents involving aging tankers, including a spill of about 10,000 tons of heavy oil off the coast of France in the Erika accident in 1999 and a spill of about 77,000 tons of cargo oil off the Spanish coast in the Prestige accident of 2002.

These accidents led directly to measures such as the promotion of a phase-out of single hull tankers (by 2010), a ban on the transportation of heavy fuel oil by single hull tankers, and setting of Particularly Sensitive Sea Areas (PSSA). Indirectly, however, they also strengthened the claims of the European Council, that is, the European countries which suffered damage, and shook confidence in the IMO and IACS (International Association of Classification Societies), which had established the rules up to that time. In order to restore the confidence and leadership position of these organizations, the IMO and IACS shifted the focus from responding after an accident to avoiding risk in advance. The IMO introduced GBS (Goal-Based Standards) to clearly specify the purpose, safety levels and functional requirements of rules and regulations, while the IACS introduced CSR (Common Structural Rules) as a unified set of rules for ship construction which is rational and transparent.

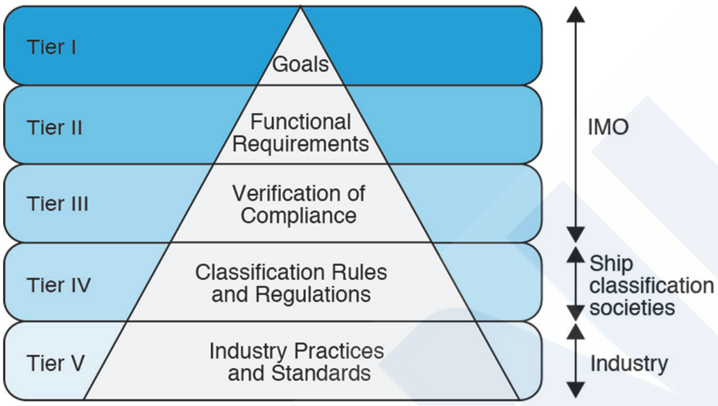

Fig. 4　Composition of GBS

The GBS system is different type of safety assessment from the FSA, in that Tier I to Tier V take the form of a pyramid, as shown in Fig. 4, the tolerable risk levels are set as goals, and rules are established based on the functional requirements for the respective safety levels in order from the top to the bottom of the pyramid.

8.　DEVELOPMENT OF RISK ASSESSMENT IN THE MARITIME SECTOR

8.1　Environmental FSA

In comparison with safety, it has been considered difficult to introduce environmental risk assessment because the parties responsible for damage and the monetary amount of that damage are not as clear. However, based on the safety-related results achieved by FSA, use of the concepts of FSA when introducing new criteria for protection of the marine environment and incorporation of EREC (Environmental Risk Evaluation Criteria) in the FSA Guidelines were studied. The joint research project SAFEDOR (Design, Operation and Regulation for Safety) in the EU introduced an item for oil spills called CATS (Cost of Averting a Tonne of Oil Spilt), that is, “the monetary amount to be contributed as a risk control option (RCO) that is implemented to avoid 1 ton of spilled oil,” and proposed the assessment criterion shown in Expression (3)

$$\Delta C / \Delta R = CATS < CATS_{thr} \qquad (3)$$

ΔC : additional cost of introduction in RCO (US$)
ΔR : oil pollution risk reduction effect of RCO
$CATS_{thr}$: threshold for judging that an arbitrary RCO is cost-effective

Initially, a fixed amount of US$60,000/ton was proposed in SAFEDOR as the threshold $CATS_{thr}$. However, in response to this, Japan and others carried out a regression analysis for the amount of oil pollution (W) and the cost of damage caused by oil pollution (C) based on oil pollution data for the years 1970 to 2005 of the International Oil Pollution Compensation Funds (IOPCF). The results showed that C/W is not a constant value, but rather, is a function of W, and as W increases, C/W becomes smaller. Based on this regression analysis, a functional-type $CATS_{thr}$ was proposed, and this was adopted by the IMO. Although moves to introduce FSA in marine environmental protection are currently limited to oil spills, precisely because the effect will be great, future moves will attract considerable attention.

8.2 RBM (Risk Based Maintenance)

RBM is the concept of evaluating the risks of equipment aging, abnormalities and failures and preparing maintenance and inspection plans based on the evaluation results. It is a method for making rational judgments about maintenance by evaluating risk by calculating from the “magnitude of effect when an equipment failure occurs” and the “ease of occurrence of failure.” In the United States, it has been introduced in infrastructure maintenance and other fields in recent years, as it had become impossible to respond to all maintenance needs due to the increasing number of facilities that require maintenance. The API (American Petroleum Institute) and ASME (American Society of Mechanical Engineers) are promoting wider application of RBM, and use has also begun at petroleum plants affiliated with the oil majors. In Japan as well, the use of this concept in maintenance, etc. of offshore (floating) oil storage bases is considered to be significant, but plans for actual introduction still have not been established.

9. CONCLUSION

This paper has examined risk assessment as a technique for clarifying risk and achieving safety. However, the primary factor which threatens safety is the human factor. Human beings are endowed with characteristics that cause error. Although the concepts of “fool-proof,” “fail-safe,” “advance prevention” and “defense-in-depth” have been researched as methods for preventing accidents caused by the human error, one solution is considered to be cultivating a culture of safety. A “culture of safety” is a condition in which every person in an organization, from top management to each individual at the actual work site, has an awareness that safety is the highest priority and makes efforts to secure safety as an organization, but this is also difficult to quantify. Thus, utilizing risk assessment in prevention of accidents caused by the human factor is an important challenge for the future.

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