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GUIDELINES FOR DESIGN AND INSTALLATION OF GAS FUEL ENGINE SYSTEMS OF LIQUEFIED GAS CARRIERS

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Contents

Preface

The International Maritime Organization introduces alternative design and arrangements in several convention regulations, e.g.: SOLAS regulation II-1/55, SOLAS regulation II-2/17, SOLAS regulation III/38 and SOLAS regulation XIV/I-B/4. With the development of shipbuilding technology and the innovation of design concepts, alternative design and arrangements have been widely used in ship design of various passenger ships, nuclear power generation platforms and offshore engineering support ships.

Alternative design and arrangements is a goal-based approach to ship design. Through risk analysis, the designer can propose a novel design that complies with the goal and functional requirements and can effectively control the risk, so as to obtain the optimal design plan and the most reasonable (cost-benefit ratio) safety protection under the safety level equivalent to that required by prescriptive requirements.

For the purpose of facilitating the implementation of alternative design and arrangements, CCS has developed the Guidelines for Application of Alternative Design and Arrangements of Ships on the basis of IMO Guidelines on alternative design and arrangements for fire safety (MSC/Circ.1002), Guidelines on alternative design and arrangements for SOLAS chapters II-1 and III (MSC.1/Circ.1212) and Guidelines for the approval of alternatives and equivalents as provided for in various IMO instruments (MSC.1/Circ.1455) and in connection with engineering analysis methods related to safety design and arrangements, which serves as reference for technical personnel of ship/system design, manufacture, use and survey unit.

Chapter 1 General

1.1 General provisions

1.1.1 The Guidelines for Application of Alternative Design and Arrangements of Ships (hereinafter referred to as "the Guidelines") are developed to effectively implement requirements for alternative design and arrangements (hereinafter referred to as "alternative design") of IMO conventions, regulations of the Administrations and CCS rules, in order to ensure that the alternative design has a safety level equivalent to that required by prescriptive requirements.

1.1.2 Alternative design means measures which deviate from the prescriptive requirement(s) of international conventions, regulations and rules, but are suitable to satisfy the intent (goal and functional requirements) of relevant prescriptive requirement(s) by means of alternative methods. The term includes a wide range of measures, including novel or unique designs, as well as traditional shipboard structures and systems that are installed in alternative arrangements or configurations.

1.1.3 In case of a new-build ship, the application for alternative design is to be submitted to CCS at an early stage of ship design (generally at the concept design stage). The alternative design documents and analysis reports are to be submitted as a part of drawings to CCS for review.

1.1.4 In view of the uniqueness of the alternative design, one application can only be submitted for one ship in principle. For a subsequent ship, the alternative design of an approved first ship may be used, provided that the following principles are met:

(1) the subsequent ship has the same design and construction;

(2) the subsequent ship is built in the same shipyard as entrusted by the same shipowner in accordance with the same construction contract;

(3) the subsequent ship flies the same flag and is classed with the same classification society;

(4) the interval between the date of commencement of the construction of the first ship (keel laying) and the delivery date of the subsequent ship is not to exceed a certain period of time unless the design team can prove that:

① there is not any design modification that invalidates the original alternative design;

② the original alternative design is not affected by applicable revisions of prescriptive requirements in force during the period;

③ there is not any feedback of incident/casualty related to design conditions, analysis and decision-making that affects the original alternative design during the period.

1.1.5 The implementation of alternative design is also to comply with relevant provisions of the Administration.

1.2 Application

1.2.1 The Guidelines outline the general design process and engineering analysis methodology for the alternative design, apply to safe engineering design to provide technical justification and guidance for alternative design deviating from prescriptive requirements.

1.2.2 The application of alternative design is generally limited within the scope of regulations of international conventions, regulations and rules where the use of alternative design is explicitly allowed.

1.2.3 The Guidelines are not intended to be applied to the type approval of individual materials, components or portable equipment.

1.3 Terms and definitions

For the purposes of the Guidelines, the following terms and definitions apply:

1.3.1 Design casualty means an engineering description of the development and severity of a casualty for use in a design scenario.

1.3.2 Design casualty scenario means a set of conditions that defines the development and severity of a casualty within and through ship space(s) or systems and describes specific factors relevant to a casualty of concern.

1.3.3 Design fire means an engineering description of the development and spread of fire for use in a design fire scenario. Design fire curves may be described in terms of heat release rate versus time.

1.3.4 Design fire scenario means a set of conditions that defines the fire development and the spread of fire within and through ship space(s) and describes factors such as ventilation conditions, ignition sources, arrangement and quantity of combustible materials and fire load accounting for the effects of fire detection, fire protection, fire control and suppression and fire mitigation measures.

1.3.5 Submitter means an interested party submitting the alternative design to CCS for review or approval, which may be the shipowner, designer or shipyard.

1.3.6 Administration means the Government of the State whose flag the ship is entitled to fly.

1.3.7 Prescriptive requirements mean detailed technical requirements given in international conventions, regulations and rules.

1.3.8 Goal means ships are to be designed and constructed for a specified design life to be safe and environmentally friendly, when properly operated and maintained under the specified operating and environmental conditions, in intact and specified damage conditions, throughout their life.

1.3.9 Functional requirements explain, in general terms, what function the ship or system is to provide to meet the objectives of international conventions, regulations and rules.

1.3.10 Risk evaluation criteria are formally recognized objective criteria defining the acceptable risk.

1.3.11 Performance criteria are measurable quantities to be used to evaluate the adequacy of trial designs.

1.3.12 Regulation-based design is a design where safety measures are designed to satisfy the prescriptive requirements of international conventions, regulations and rules.

1.3.13 Risk-based design is a design where the design process has been supported by a risk assessment or the design basis has resulted from a risk assessment. That is, it is a structured and systematic methodology aimed at ensuring safety performance and cost-effectiveness by using risk analysis and cost-benefit assessment.

1.3.14 Preliminary design is a design developed for the design preview and the first analysis phase. The preliminary design is a high-level design taking into account the general arrangement, major systems, components, etc.

1.3.15 Final design. Elaboration of the preliminary design. The final design complies with the results of the preliminary analysis, e.g. with respect to risk control options already identified, and the requirements of the Administration.

1.3.16 Risk control measure is a means of controlling a single element or risk; typically, risk control is achieved by reducing either the consequences or the frequencies; sometimes it could be a combination of the two.

1.3.17 Risk control option (RCO) is a combination of risk control measures.

1.3.18 Safety margin means adjustments made to compensate for uncertainties in the methods and assumptions used to evaluate the alternative design.

Chapter 2 Alternative Design Process

2.1 Basic process of alternative design

2.1.1 The alternative design process generally consists of the following stages, see Figure 2.1:

(1) preparation for alternative design (concept design stage);

(2) qualitative preliminary analysis (preliminary design stage);

(3) quantitative analysis (final design stage);

(4) testing and engineering analysis.

2.2 Preparation for alternative design

2.2.1 At the early stage of ship design, due to the ship's specific functional and operational needs, or the introduction of novel technologies or designs, the submitter proposes alternative design requirements and then carries out alternative design preparations, including:

(1) determination of the analysis scope of alternative design;

(2) analysis of the relationship between alternative design and prescriptive requirements;

(3) analysis of the degree of novelty of alternative design;

(4) applicable assessment criteria (if any);

(5) plan of establishing an alternative design team;

(6) alternative design working plan, including risk assessment plan.

2.2.2 Upon completion of the preliminary preparation, the submitter is to submit an alternative design application (see Annex 1) to CCS, accompanied by relevant technical description materials.

2.2.3 CCS reviews the necessity and feasibility of the alternative design application, as well as the completeness of the application materials, and holds a review meeting. Review experts are generally composed of technical experts from maritime management, ship management, ship design, shipbuilding, and other relevant disciplines.

2.2.4 The submitter is to improve the corresponding technical documents according to the opinions of the review meeting and submit them to CCS.

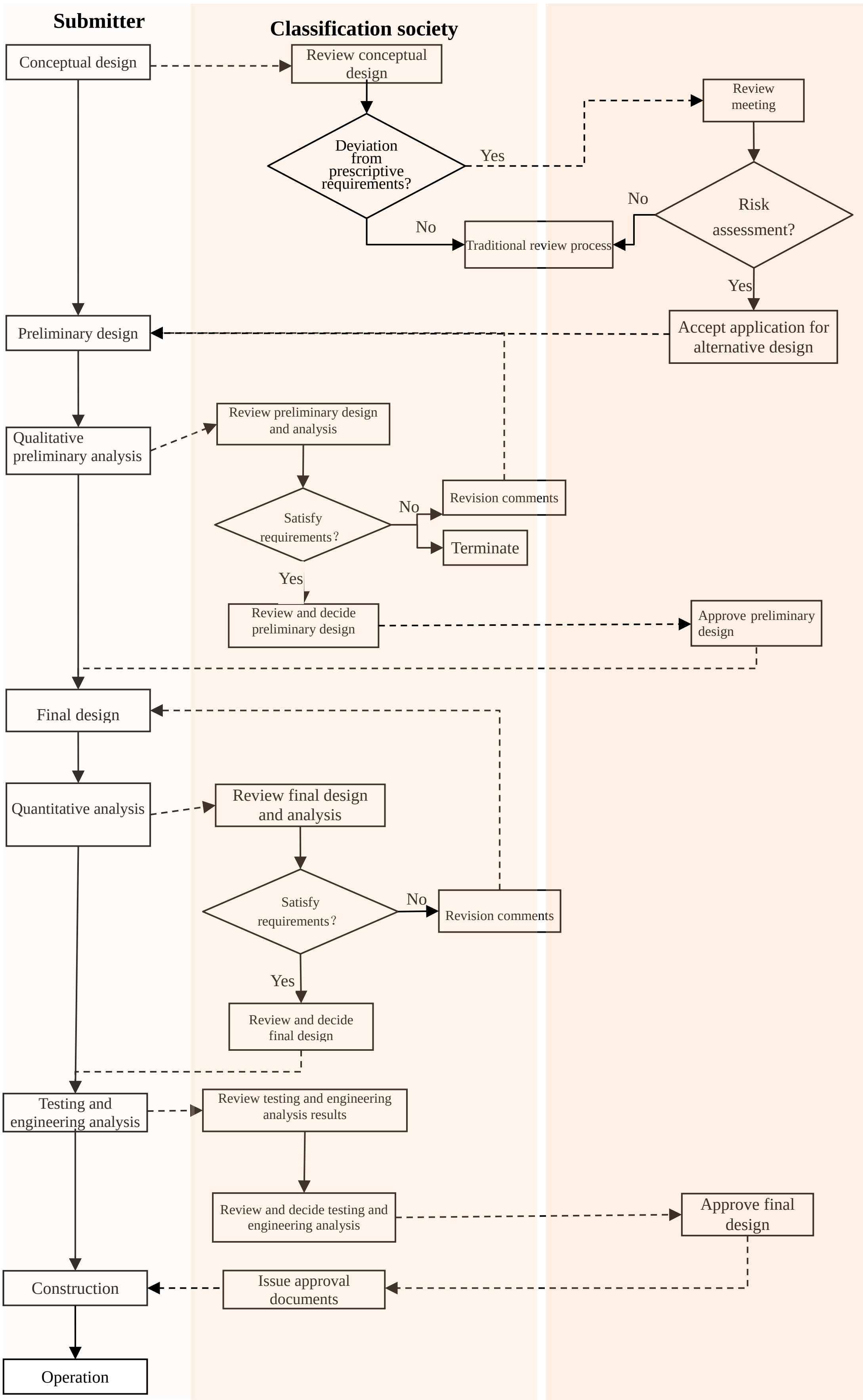

Figure 2.1 Alternative Design Process

2.3 Qualitative preliminary analysis

2.3.1 After the alternative design application is accepted, the submitter can organize subsequent alternative design work, including preliminary design, final design, and testing and engineering analysis. In this process, the submitter is to cooperate closely with CCS according to the risk assessment plan of the alternative design in order to carry out the development and analysis of alternative design.

2.3.2 In a qualitative preliminary analysis, the design team needs to further analyze the relevant arrangements and systems that are affected by the alternative design, as well as the main operational scenarios. Based on this, hazard identification is carried out, which identifies various hazards and their casualty scenarios, and ranks them according to their risk level relative to the problem under consideration, in order to carry out more detailed quantitative analysis of the main hazard and casualty scenarios. For casualty scenarios with high risk levels, corresponding risk control measures can be proposed and one or more alternative design plans can be developed accordingly.

2.3.3 The design team is to report to CCS before organizing hazard identification. CCS witnesses the hazard identification process as necessary and maintains independence from the design team.

2.3.4 Upon completion of the qualitative preliminary analysis, the submitter is to submit the preliminary design and analysis results to CCS, including:

(1) general arrangement;
(2) drawings of relevant systems;
(3) hazard identification report, which may include risk control measures proposed initially;
(4) design casualty scenario;
(5) risk model and assessment method;
(6) evaluation criteria used;
(7) testing and engineering analysis plan;
(8) identification of issues requiring special attention with regard to operation and survey.

2.3.5 During the review of the preliminary design, CCS is to review:

(1) feasibility of the preliminary design plan;
(2) completeness of hazard identification related to design;
(3) development of preliminary risk control measures;
(4) adequacy of design casualty scenario;
(5) adequacy of evaluation criteria.

If it is found that there is a major problem with the preliminary design and the evaluation criteria for the alternative design cannot be met, the approval process may be terminated or the design may be revised and resubmitted.

2.4 Quantitative analysis

2.4.1 After the preliminary design is approved, the design team needs to update and deepen the alternative design and focus on quantitative analysis.

2.4.2 Detailed investigations of identified casualty scenarios are conducted and factors affecting the risk level are identified. Quantification of the casualties is to be carried out for each of the incidents. Quantification will require specification of all factors that may affect the type and extent of the hazard

2.4.3 Performance criteria are developed to evaluate the alternative design plan. Performance criteria are quantitative expressions of the intent of the prescriptive requirements. The developed performance criteria are to be approved by CCS.

2.4.4 Quantitative analysis is carried out to the alternative design plan. Design upgrades are carried out through pre-planned risk control measures for non-compliance with performance criteria. Quantitative analysis is carried out to the updated design until the requirements of performance criteria are met, i.e. the measures or activities relevant to the risk are controlled within acceptable risk limits.

2.4.5 Based on quantitative analysis, the design team completes the final design and analysis and submits to CCS for review, including:

(1) identified hazards associated with the alternative design (update of preliminary design analysis);

(2) identified potential safeguards already considered in the design;

(3) identification of frequencies and consequences associated with the hazards, and the resulting risks;

(4) establishment of a risk analysis model;

(5) description of data references, assumptions, uncertainties and sensitivities;

(6) comparison of risk levels with evaluation criteria;

(7) development of risk control measures;

(8) cost-benefit assessments (if any);

(9) identification of issues that may require further engineering analyses and testing;

(10) identification of issues requiring special attention with regard to operation and survey.

2.4.6 When reviewing the quantitative analysis results, CCS is to confirm:

(1) the conformity of the submitted documents, which are clear, complete and sufficient;

(2) recognized risk assessment methods are used by the hazard identification method.

(3) main risk factors affecting the risk level;

(4) consistency of expert opinions when using expert judgement;

(5) whether assumptions, exclusions and limitations are justified;

(6) whether the applied risk control options are considered effective and viable;

(7) whether historical/statistical data is as recent as possible and is relevant for the application;

(8) whether the numerical tools used are fit and validated for purpose;

(9) whether the results of the risk assessment can be reproduced;

(10) whether evidence prevails that intended or planned further tests and analyses will have an acceptable outcome.

2.5 Testing and engineering analysis

2.5.1 When CCS reviews the final design, detailed requirements will be defined for the alternative design by CCS and the Submitter jointly on the basis of the results of the quantitative risk analyses, e.g. testing and engineering analysis, manufacturing and operation.

2.5.2 The design team conducts the work according to the requirements of the test and engineering analysis, and submits the test and analysis results to CCS for review. CCS will review the test and analysis methods and results and develop requirements related to survey in service, testing, monitoring and testing.

2.5.3 After completing the review of the test and analysis results, CCS is to submit the final design and analysis report and test report to the Administration for final approval.

2.5.4 Upon approval by the Administration, CCS issues a Document of Approval of Alternative Design and attaches it to the ship certificate. The approval document may include approval conditions that require the ship to implement appropriate measures before starting operations.

2.6 Construction and operation

2.6.1 At the stage of shipbuilding and system/equipment installation, the design requirements and risk control measures proposed by the alternative design analysis are to be implemented. CCS will conduct newbuilding survey and keep abreast of the progress of the project.

2.6.2 During operation of the ship, the ship management company and shipboard personnel are to monitor and confirm that operational requirements and conditions proposed by the alternative design are effectively implemented, including ship operation and loading limits, as well as additional safety procedures or measures, in order to ensure that the alternative design maintains the safety level determined at approval.

2.6.3 For ships adopting alternative design[1], the following documents are to be maintained onboard the ship for check:

(1) Document of Approval of Alternative Design and relevant certificates

(2) Information on alternative design, including:

① scope of the analysis or design, including the critical design assumptions and critical design features;

② description of the alternative design and arrangements, including drawings and specifications;

③ listing of affected convention regulations;

④ summary of the results of the engineering analysis and basis for approval, including performance criteria and design casualty scenario;

⑤ test, inspection and maintenance requirements.

2.6.4 In addition to checking certificate and the onboard documentation, CCS is to check in accordance with the approved alternative design documents maintained on board and confirm that the conditions specified in the alternative design documents are maintained and that the ship is in good condition. If the design conditions made during the design approval are changed during the survey, indicating that the ship is in an unseaworthy state, the ship certificate will be invalid, and the ship operator is to carry out analysis according to the new operating conditions subject to review and approval by CCS.

2.7 Other requirements

2.7.1 In case of change of flag, CCS is to review the alternative design documents approved by the original Administration. After confirmation by onboard survey, the Document of Approval of Alternative Design is issued subject to the approval by the new Administration.

2.7.2 In case of change of ship company, the new company is to incorporate the relevant requirements of approved alternative design documents into the safety management system of the company, and carry out training of crew as necessary.

2.7.3 In case of ship repair or modification, the modification plan is to be reviewed by CCS, in order to confirm whether the approval condition of the original alternative design is affected, or whether there will be a new alternative design. In such cases, alternative design is to be carried out

[1] For bulk carriers and oil tankers complying with GBS requirements, the alternative design documents are also to satisfy relevant requirements for SCF in IACS UR Z23.

again.

Chapter 3 Design Team

3.1 Composition of the team

3.1.1 At the beginning of the application for alternative design, the shipowner, designer and shipyard are to designate competent personnel to establish a design team. Other members are to include marine surveyors, ship operators, safety engineers, equipment manufacturers, human factors experts, naval architects and marine engineers or other technical experts in the field of similar operations as necessary for the alternative design and risk assessment at hand.

3.1.2 The level of expertise that individuals are to have to participate in the team may vary depending on the complexity of the alternative design for which approval is sought. Since the evaluation, regardless of complexity, will have some effect on a particular field of safety, at least one expert with senior professional title who has knowledge and experience in that appropriate safety field and who has been engaged in the industry for more than 5 years is to be included as a member of the team.

3.1.3 The design team is to appoint a coordinator serving as the primary contact in order to carry out the alternative design orderly and effectively.

3.1.4 The list of design team members and the areas, organizations, laboratories or companies they represent, as well as technical background information and certifications, are to be submitted to the CCS for review along with the alternative design application.

3.2 Responsibility of the team

3.2.1 Main responsibilities of members of the design team are as follow:

(1) the shipowner provides information on vessel function, operation and operation needs;

(2) the designer is responsible for implementation of the alternative design in ship design;

(3) the shipyard/subcontractor provides information that may affect equipment procurement, production planning, etc.;

(4) the technical expert assists the design team in hazard identification and provide professional technical support in risk assessment

3.2.2 Throughout the entire process of alternative design, the design team is to:

3.2.2.1 communicate with the Administration and CCS for advice on the acceptability of the engineering analysis of the alternative design;

3.2.2.2 develop the conceptual design at the design preparation stage. This includes a clear definition of the scope of the alternative design and prescriptive requirements which affect the design; a clear understanding of safety objective and functional requirements of prescriptive requirements;

3.2.2.3 determine the safety margin at the outset of the design process and review and adjust it as necessary during the analysis;

3.2.2.4 conduct a preliminary analysis to develop appropriate casualty scenarios, if necessary, and trial alternative designs. This portion of the process is documented in the form of a report that is reviewed and agreed by all interested parties and submitted to CCS before the quantitative portion of the analysis is started;

3.2.2.5 conduct a quantitative analysis to evaluate possible trial alternative designs. This consists of the specification of design thresholds, development of performance criteria and evaluation of the trial alternative designs against the agreed performance criteria. From this step the final alternative design is selected and the entire quantitative analysis is documented in a report;

3.2.2.6 prepare documentation, specifications and a life-cycle maintenance programme. An operations and maintenance manual is to be developed for this purpose. The manual is to include an outline of the design conditions that is to be maintained over the life of the ship to ensure compliance with the approved design;

3.2.2.7 develop requirements for crew training in accordance with operational limits and requirements for alternative design.

Chapter 4 Preparation for Alternative Design

4.1 Scope of analysis

4.1.1 The ship, ship system(s), component(s), space(s) and/or equipment subject to the analysis are to be thoroughly defined. This includes the ship or system(s) representing both the alternative design and the regulatory prescribed design.

4.1.2 On this basis, a general description of the alternative design is to be developed, including various environmental conditions, design objectives and operational plans (including operational constraints), and interfaces with other systems/operations; functional descriptions of alternative designs, including design principles, design functions, design scope, operating modes, maintenance and operational requirements, etc.

4.1.3 The relationship between the alternative design to be developed and the prescriptive requirements and the intent is to be clearly described.

4.2 Analysis of novelty of the alternative design

4.2.1 It is to decide whether the alternative design challenges any prescriptive requirements of international conventions, regulations and rules to such an extent that a risk analysis is required.

4.2.2 The novelty of the alternative design may be determined by applying Table 4.1 to decide if a risk analysis is required. In this table, the new technology classification is determined by a comprehensive evaluation of the technology status and its application areas. The application areas are divided into known fields and new fields. The corresponding scores are 0 and 1, respectively. The technology status is divided into three types: proven, limited field history, new or unproven, and the corresponding scores are 1, 2 and 3. Through the combined analysis of the application area and technology status, the comprehensive score of the new technology is obtained. Technology in category 1 is proven technology where proven methods for classification, tests, calculations and analyses may be used. Technology in categories 2-4 is defined as new technology and may follow the procedure described in the Guidelines.

Categorization of new technology **Table 4.1**

			Technology status		
			Proven	**Limited field history**	**New or unproven**
			1	**2**	**3**
Application Area	Known	0	1	2	3
	New	1	2	3	4

4.2.3 The objective of using the categorization is to establish whether or not the alternative design qualifies as a novel design and to gain a general understanding of the variation from proven designs. The categorization will also assist in defining the level of detail of the different analyses that will be required in the following phase.

4.3 Development of evaluation criteria

4.3.1 The expected safety performance of the alternative design is to be quantitatively specified in the form of the evaluation criteria. The design team is to first develop safety objectives of the alternative design and transfer them to evaluation criteria. Once the safety objectives and evaluation criteria are developed, they become the focus of the design and the benchmark for evaluating the alternative design.

4.3.2 The submitter and CCS are to jointly study and develop the evaluation criteria according to the goal and functional requirements of the prescriptive requirements in light of the actual conditions of the project, and approve them when the alternative design application is approved.

4.3.3 The basic principle for the evaluation criterion is to be "safety equivalence". This means that the alternative design will be designed so that it will perform its intended safety related function(s) in a manner that is equivalent to or better than the prescriptive requirement it is deviating from.

4.3.4 The development of alternative design safety objectives requires an analysis of the implied intent of the prescriptive requirement it is deviating from, either in qualitative or quantitative terms.

4.3.5 Depending on the area to which the approval of the alternative design is being sought, the evaluation criteria could fall into one or more of the following categories:

(1) life safety criteria – These criteria address the survivability of passengers and crew and may represent the effects or flooding, fire, etc.;

(2) damage to ship structure and related systems – These criteria address the impact that a casualty might have on a ship structure, mechanical systems, electrical systems, fire protection systems, etc.;

(3) damage to the environment – These criteria address the impact of an accident on the atmosphere and the marine environment.

4.3.6 The evaluation criterion can be also specified by means of performance criteria. In that case the performance criterion should be developed, taking into consideration the intent of the prescriptive requirements and related mandatory instruments.

4.3.7 For alternative design falling into areas where no appropriate prescriptive requirements or other relevant industry standard exist the evaluation criteria may be specified by means of risk acceptance and agreed with Administration.

4.3.8 The Revised Guidelines for Formal Safety Assessment (FSA) for use in the IMO rule-making process of IMO includes the contents of risk evaluation criteria, of which the risk matrix method, F-N method, etc., as appropriate may be used as the evaluation criteria of alternative design.

Chapter 5 Qualitative Preliminary Analysis

5.1 Casualty scenario development

5.1.1 Casualty or operational scenarios are to provide the basis for analysis and trial alternative design evaluation and, therefore, are the backbone of the alternative design process. Proper casualty or operational scenario is to be developed depending on the extent of deviation from the prescribed design.

5.1.2 During casualty scenario development, the reason for selecting the casualty scenarios is to be outlined. For life-saving arrangements, this may focus on casualty scenarios where an alternative design will provide an equivalent (or greater) level of safety. Mechanical or electrical arrangements may focus on an operational scenario that will provide an equivalent level of safety, but may increase efficiencies or reduce cost to the operator.

5.1.3 When developing casualty scenarios, all systems and arrangements affected by the alternative design are to be considered. For example, the provision of large lifeboats may affect the launching appliance, evacuation and embarkation of personnel. As such, devices that are often used for training may be subject to wear and tear, affecting their availability in an emergency.

5.1.4 Casualty scenario development can be broken down into three areas.

5.1.4.1 Identification of hazards

Hazards may be identified using historical and statistical data, expert opinion and experience and hazard evaluation procedures. For hazard identification techniques, refer to CCS Guidelines for Application of Formal Safety Assessment to Ships. As a minimum, the following conditions and characteristics should be identified and considered:

(1) pre-casualty situation: ship, platform, compartment, available potential and kinetic energy, environmental conditions;

(2) potential initiating events, causes;

(3) detailed technical information and properties of potential hazards;

(4) secondary hazards that might be subject to effects of initial hazard;

(5) extension potential: beyond compartment, structure, area (if in open);

(6) target locations: note target items or areas associated with the performance parameters;

(7) critical factors relevant to the hazard: ventilation, environment, operational, time of day, etc.;

(8) relevant statistical data: past casualty history, probability of failure, frequency and severity rates, etc.

5.1.4.2 Selection of hazards

All of the hazards identified above are to be grouped into one of three incident classes: localized, major or catastrophic. A localized incident consists of a casualty with a localized effect zone, limited to a specific area. A major incident consists of a casualty with a medium effect zone, limited to the boundaries of the ship. A catastrophic incident consists of a casualty with a large affect zone, beyond the ship and affecting surrounding ships or communities. For cruise ships, only localized and/or major incidents need to be considered. Examples where the catastrophic incident class may be considered would include transport and/or offshore production of petroleum products or other hazardous materials where the incident effect zone is very likely to be beyond the ship vicinity.

All identified hazards are to be reviewed and tabulated. The number and type of hazards that are to be selected for the quantitative analysis is dependent on the complexity of the trial alternative design. In determining the selection, frequency of occurrence does not need to be fully quantified. The selection process is to identify a range of incidents which cover the largest and most probable range of enumerated hazards (which may be ranked in accordance with Frequency Index and Severity Index, see CCS Guidelines for Application of Formal Safety Assessment to Ships). The selection of highly unlikely or inconsequential hazards is to be avoided.

5.1.4.3 Specification of design casualty scenarios

Based on the hazards selected, the casualty scenarios to be used in the quantitative analysis are to be clearly documented. The specification is to include a qualitative description of the design casualty (e.g., initiating and subsequent chain of events, location, etc.), description of the vessel, compartment or system of origin, safeguard systems installed, number of occupants, physical and mental status of occupants and available means of escape. The casualty scenarios are to consider possible future changes to the hazards (increased or decreased) in the affected areas.

5.2 Development of trial alternative designs

5.2.1 At this point in the analysis, one or more trial alternative designs are to be developed so that they can be compared against the developed performance criteria. The trial alternative design is also to take into consideration the importance of human factors, operations and management. It is to be recognized that well defined operations and management procedures may play a big part in increasing the overall level of safety.

5.2.2 Generally, the trial alternative design is proposed by the design team at the conceptual design stage, so that the subsequent alternative design process can be carried out more effectively and rapidly.

5.2.3 For development of trial alternative designs, due consideration is also to be given to risk control measures which may be introduced by each design, which helps to reduce the probability of hazard occurrence or better control the consequence.

Chapter 6 Quantitative Analysis

6.1 General requirements

6.1.1 According to the requirements of engineering technology, the alternative design is to carry out necessary quantitative analysis to assess the safety level of the alternative design. Unlike qualitative preliminary analysis, quantitative analysis usually requires more detailed input data, e.g. failure rate of components and systems, probability of casualty occurrence, probability calculation of structural strength, fire heat and smoke distribution, and personnel evacuation. The source of these input data, as well as other data items used in the analysis, are to be recorded in the analysis report.

6.1.2 The quantitative analysis consists of quantifying the design casualty scenarios, developing the performance criteria, and evaluating the performance of trial alternative designs.

6.2 Quantification of design casualty scenarios

6.2.1 Quantification of the selected casualty scenarios is to be carried out, which will require specification of all factors that may affect the type and extent of the hazard. The casualty scenarios are to consider possible future changes to the affected systems and areas. This may include calculation of specific casualty parameters, ship damage, passenger exposure to harm, time-lines, etc. It is to be noted that the limitations and assumptions of the models used are to be well understood and documented. This becomes very important when deciding on and applying safety margins. Documentation of the alternative design is to explicitly identify the models used in the analysis and their applicability.

6.2.2 For each of the identified hazards, a range of casualty scenarios are to be developed. In many cases, it may only be necessary to analyse one or two scenarios if this provides enough information to evaluate the level of safety of the alternative design.

6.2.3 A timeline or casualty parameter change is to be developed for each of the casualty scenarios This timeline may include personnel response, activation of safety systems or measures, untenable conditions, etc. The casualty scenario is determined by using the various correlations, models and data from the literature or actual tests.

6.2.4 Consequences of various casualty scenarios are to be quantified in relevant engineering terms. This can be accomplished by using existing correlations and calculation procedures for determining the characteristics of a casualty. In certain cases, full scale testing and experimentation may be necessary to properly predict the casualty characteristics. Regardless of the calculation procedures utilized, a sensitivity analysis is to be conducted to determine the effects of the uncertainties and limitations of the input parameters.

6.3 Development of performance criteria

6.3.1 Performance criteria are quantitative expressions of the relevant prescriptive requirements. The required performance of the trial alternative designs is specified numerically in the form of performance criteria. Performance criteria may include tenability limits or other criteria necessary to ensure successful alternative design.

6.3.2 If the performance criteria for the alternative design cannot be determined directly from the prescriptive requirements because of novel or unique features, they may be developed from an evaluation of the intended performance of a commonly used acceptable prescriptive design, provided that an equivalent level of safety is maintained.

6.3.3 Before evaluating the trial alternative design, the design team is to agree on what specific performance criteria and safety margins is to be established. Depending on the prescriptive requirements to which the approval of alternative design is sought, these performance criteria could fall within one or more of the following areas: life safety criteria, criteria for damage to ship structure and related systems and criteria for damage to the environment.

6.3.4 The design team is to consider the impact that one particular performance criterion might have on other areas that might not be specifically part of the alternative design. For example, the failure of a particular safeguard may not only affect the life safety of passengers and crew in the adjacent space, but it may result in the failure of some system affecting the overall safety of the ship.

6.3.5 Once all of the performance criteria have been established, the design team can then proceed with the evaluation of the trial alternative designs.

6.4 Evaluation of trial alternative designs

6.4.1 All of the data and information generated during the preliminary analysis and specification of design casualty is to serve as input to the evaluation process.

6.4.2 Each selected trial alternative design is to be analysed against the selected design casualty scenarios to demonstrate that it meets the performance criteria with the agreed safety margin.

6.4.3 The level of engineering rigor required in any particular analysis will depend on the level of analysis required to demonstrate equivalency of the proposed alternative design to the prescriptive requirements. Obviously, the more components, systems, operations and parts of the ship that are affected by a particular alternative design, the larger the scope of the analysis.

6.4.4 The final alternative design is to be selected from the trial alternative designs that meet the selected performance criteria and safety margins.

6.4.5 Where several trial alternative designs satisfy the requirements of 6.4.4, analysis and comparison may be carried out by means of cost-benefit assessment (see CCS Guidelines for Application of Formal Safety Assessment to Ships), in order to choose the best one as the final alternative design.

Chapter 7 Preparation of Documents/Reports

7.1 General requirements

7.1.1 The development and review of alternative design are to be clear and transparent, recorded completely and in detail, and the results are correct and repeatable and are accessible to the third party.

7.1.2 When a design plan is selected, the report or document describing the design is to be officially prepared. The document is to contain clear records of the analysis process, including assumptions, tools and methods used, results and various essential elements which may be necessary to get the design finally approved.

7.1.3 The document is to be started from the unanimous opinions of the design team on the objective. The form of final report and document will be changed with the nature and scope of the project. Normally the following aspects are included:

(1) analysis and design participants

To list the participants of the process and brief their roles.

(2) reasons for analysis or design

Possible reasons may be: newbuildings, repair of ships, change of the purpose of ship, new working procedures, assessment of the existing capability, etc.

(3) explanation of design method

To describe the method adopted and the reason for the usage of this method, assumptions made and the used engineering tool.

(4) background information

Functional limitation of facilities, hazard analysis and description of structure, technique, special hazard or risk, structural material and its purpose, ship arrangement, existing safety system, personnel characteristics etc.

(5) purpose of submitter and explanation of objectives

To obtain unanimous safety objective and loss objective through alternative design or analysis.

(6) performance criteria

To develop engineering design objective and performance criteria clearly, including each safety margin applied or reliability of considered means and provide the source of data or information on the criteria.

(7) casualty scenario

To describe the method used for identification of casualty scenario, select basic information which may reflect casualty scenario and all assumptions and limitation are to be included.

(8) design casualty

To describe the design casualty of representational loss scenario, select and reflect the major part of the design casualty, including assumptions and limitation.

(9) adopted engineering tool and method

The engineering tool and method adopted in analysis or design, including appropriate reference (author, publisher, date, software version etc.), assumptions, limitation, engineering judgment of input data, and verification model of data or step or sensibility analysis of empirical correlation, scope of application, assumptions and limitation of tool and method are also to be explained.

(10) alternative design plan

To describe the selected alternative design plan, to select their basis, including assumptions and limitation and requirements for test and maintenance.

(11) The output results of computer model are to be provided to CCS for examination by verifiable means. If necessary, relevant equipment and their installation specifications are also to be prepared.

(12) Other information

Software documents, results of sensibility research, source of data of model and test results etc.

7.2 Conceptual design documents

7.2.1 Generally, the conceptual design documents are to include:

(1) list of prescriptive requirements involved and specification;

(2) general description of alternative design, including various environmental conditions, design objectives and operational plan (including operational limits) and interfaces of other system/operation;

(3) descriptions of the functions of alternative design, including design principles, design functions, scope of design, operational modes, requirements for maintenance;

(4) interface between alternative design and other system/operation;

(5) general arrangement;

(6) relevant system drawings (if any);

(7) evaluation criteria intended to be adopted (if any);

(8) work plan for alternative design, including risk assessment plan;

(9) plan of alternative design team intended to be established.

7.3 Initial design and analysis report

7.3.1 Generally, the analysis report of initial design is to include:

(1) general arrangement;

(2) relevant system drawings;

(3) hazard identification report: including the assessment of the status quo of ship space, identification and selection of source of hazard, frequency and consequence in relation to hazard and its resulting risks;

(4) specification of casualty scenario;

(5) adopted evaluation criteria;

(6) items for which further tests and engineering analysis may be required;

(7) risk model and assessment method, including details of seminar;

(8) data reference, expert judgment, assumption, uncertainty and sensitivity;

(9) measures taken to reduce risks;

(10) cost-benefit assessment (if any);

(11) plans for test and engineering analysis;

(12) identification of issues to which special attention is paid in respect of operation and surveys.

7.4 Final design and analysis report

7.4.1 In addition to documents approved by initial design, the quantitative analysis documents of final design are to include:

(1) casualty scenario, including key assumption, initial conditions, engineering judgment, calculation procedures, test data, sensitivity analysis etc.;

(2) performance criteria;
(3) assessment of alternative design plan;
(4) description of final design plan;
(5) requirements for testing and maintenance;
(6) other relevant documents required to be submitted by CCS based on actual needs.

7.5 Other documents

7.5.1 Test and engineering analysis report contains:
(1) relevant regulations and standards applied and deviations in application;
(2) the selection of assessment criteria for design assessment;
(3) design calculation;
(4) analysis report, including purposes, scope, assumptions, results, conclusions and suggestion;
(5) test report, including the descriptions of the established models and tests and test purposes, scope, results, analyses, conclusions and suggestion;
(6) more detailed design drawings generated with the detailing of design.
7.5.2 Items to be specially noted in operation and maintenance are to be proposed in the preparation of alternative design, including:
(1) construction or installation manual, maintenance procedures and operational plan etc.;
(2) product specifications, including limitation, disclaimer and tolerance (where applicable);
(3) material data and/or production certificate (where applicable) and necessary design specification (including basic analysis, test and calculation defining basic design principles) and documents and plans (including final general arrangement and detailed plans of related systems).
7.5.3 The purchase and installation of equipment are to be described in detail in the specifications, so as to ensure the safety objectives are met. If special equipment, installation material or methods are required, special explanations are to be given. Tests and performance testing of equipment, material or systems are also to be clarified.
7.5.4 Needs of surveys, maintenance and periodical tests are to be proposed in the form of user guidelines and the trainings for personnel involved in the above items and other special personnel are also to be determined.

Appendix 1
Alternative Design for Fire Safety

1.1 Evaluation criteria

1.1.1 According to the provisions of SOLAS Reg.II-2/17, fire safety design and arrangements may deviate from the prescriptive requirements set out in parts B, C, D, E or G, provided that relevant alternative design meets the fire safety objectives and the functional requirements.

1.1.2 In the alternative design for fire safety, evaluation criteria are usually developed in the manner of performance criteria. In this case, the intention of prescriptive requirements and relevant mandatory requirements are to be considered, i.e. the fire safety objectives and the functional requirements for fire safety in Chapter II-2 of SOLAS Convention.

1.1.3 According to the prescriptive requirements involved in the alternative design for fire safety, the performance criteria may involve one or more of the following aspects: life safety criteria (e.g. toxicity effect, smoke effect and heat effect, etc.), structural failure criteria or environmental damage criteria. In general, performance criteria applicable to alternative design for fire safety are as follows.

1.1.4 Performance criteria for life safety

1.1.4.1 If the fire safety objective of alternative design is to reduce the risk to life caused by fire, the design objective is to maintain appropriate state of means of escape and ensure that all personnel can have sufficient time to evacuate to a safe area so that they will not be threatened by instantaneous or cumulative danger, including effects of heat, smoke, toxicity and reduced visibility.

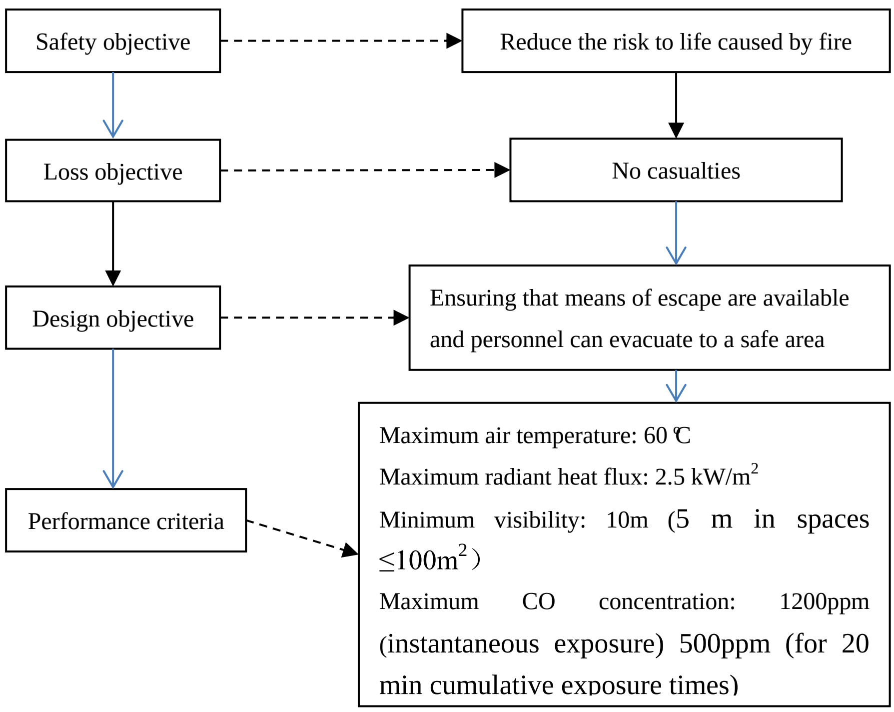

Figure 1.1 Example of performance criteria for life safety

1.1.4.2 In general, required safety egress time (RSET) and available safety egress time (ASET) are used to analyze and evaluate safe escape of all personnel or determine amount of affected personnel within the space. For details, see Figure 1.2.

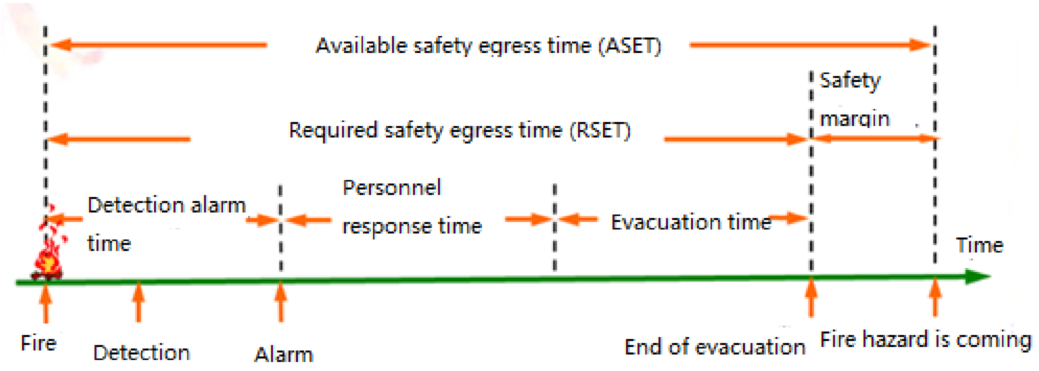

Figure 1.2 Schematic diagram of personnel evacuation safety judgement

1.1.4.3 If the ASET in all design fire scenarios exceeds RSET, it shows that personnel evacuation is safe and no further analysis is needed. Relevant risk control measures such as smoke management systems and equipment may be provided to aid in the achievement of this result, subject to the satisfaction of the Administration.

1.1.4.4 If any of the values in paragraph 1.1.4.8 of this Appendix are exceeded during the evacuation (ASET < RSET), then at a minimum, a fractional effective dose calculation is to be performed in accordance with standard ISO 13571:2012 to demonstrate that a maximum threshold criterion of 0.3 will not be exceeded prior to the RSET being reached.

1.1.4.5 Determination of RSET: RSET means the required time to egress safely the space/spaces affected by the fire or smoke. It is to use the method in the Revised guidelines on evacuation analysis for new and existing passenger ships (MSC.1/Circ.1533) to determine the maximum RSET to completely evacuate the space, using either the day or night case response time distributions, as applicable to the affected space(s), assuming occupancy in accordance with chapter 13 of the FSS Code. If advanced evacuation analysis is adopted, the safety factor of 1.25 given in MSC.1/Circ.1533 is to be applied.

1.1.4.6 Determination of ASET: ASET means the available time to egress safely the space/spaces affected by the fire or smoke, i.e. the time required to maintain tenability between the ignition of a fire and the performance criteria thresholds (specified in paragraph 1.1.4.8 of this Appendix).

(1) In public spaces, it means the range of zero to two meters (0-2 m) above the deck;

(2) In all other areas, it means the range of zero to one point eight meters (0-1.8 m) above the deck;

(3) In multiple open deck spaces (e.g. atrium), each deck normally accessible to persons on board is to be considered simultaneously.

When determining ASET of persons affected by fire in design fire scenarios, accepted proper fire simulation software is to be applied.

1.1.4.7 Hazard due to fire combustion mainly includes toxic gas, smoke and large amount of heat. Therefore, life safety criteria involved in ASET calculation include tolerance limits of toxic gas, shading level of hot smoke and high temperature, heat radiation intensity acceptable to personnel, etc. Alternative design usually adopts a certain parameter value to determine ASET, i.e. for the parameter which reaches the hazardous state in a fire first, the time of that parameter to reach performance criteria value is adopted as ASET, i.e.

$$ASET = \min (t_{air\ temperature}, t_{radiation}, t_{visibility}, t_{CO})$$

where:

$t_{air\ temperature}$ means the time of rising to the performance criteria value with regard to ambient temperature, in s;

$t_{radiation}$ means the time rising to the performance criteria value with regard to heat radiation intensity received by people in a fire scenario, in s;

$t_{visibility}$ means the time declining to the performance criteria value with regard to visibility in a fire scenario, in s;

t_{CO} means the time rising to the performance criteria value with regard to CO concentration in a fire scenario, in s.

1.1.4.8 When evaluating and determining ASET, life safety performance criteria to be adopted include:

Maximum air temperature	$60^{o}C$;
Maximum radiant heat flux	2.5 kW/m^2;
Minimum visibility	10 m;
	5 m in spaces ≤ 100 m^2;
Maximum CO concentration	1200 ppm (instantaneous exposure);
	500 ppm (for 20 min cumulative exposure times).

1.1.5 Structural failure criteria

1.1.5.1 If the alternative design involves alternative and equivalence of compartment division structure, the design team need to develop performance criteria preventing fire penetrating the fire-resistant structure. Therefore, criteria can be developed as follows:

(1) SOLAS Reg.II-2/2 contains the fire safety objective "to contain, control and suppress fire and explosion in the compartment of origin ";

(2) The functional requirements in which this objective is embodied are “division of the ship into main vertical and horizontal zones by thermal and structural boundaries” and “separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries”;

(3) Prescriptive requirements for compartment division structure are developed according to SOLAS Reg.II-2/9. Different division requirements are judged according to following performance criteria:

① A class division: the average temperature of the unexposed side will not rise more than 140℃ above the original temperature, nor will the temperature, at any one point, rise more than 180℃ above the original temperature, within the time listed below:

Class A-60	60 min
Class A-30	30 min
Class A-15	15 min
Class A-0	0 min

② B class division: the average temperature of the unexposed side will not rise more than 140℃ above the original temperature, nor will the temperature, at any one point, rise more than 225℃ above the original temperature, within the time listed below:

Class B-15	15 min

Class B-0 0 min

1.1.6 Restriction of environmental damage

1.1.6.1 Environmental performance criteria are to restrict sewage discharge during the fire-fighting process as well as combustion and release of fire-fighting medium so as to further protect the ship and surrounding environment.

1.2 Design of fire scenario

1.2.1 Design of fire scenario includes identification of design fire scenario and design fire. Evaluating whether selected fire prevention, fire detection and fire-extinguishing systems meet set performance criteria is carried out by detailed analysis of design fire scenario. Therefore, design of fire scenario is critical for the ship to achieve fire safety objective.

1.2.2 In an actual ship environment, the fire, ship and persons form a very complicated system which may cause numerous fire scenarios. It is impossible and unnecessary for the alternative design to evaluate all fire scenarios. Therefore, representative fire scenarios with larger fire risk are selected by identification of design fire scenario. The selected fire scenarios are to at least include following information: fire type, ignition source location and performance of various fire-fighting facilities.

1.2.3 Identification of design fire scenario is to be according to the most unfavorable principle, considering all reasonable, serious and frequent potential hazards as well as fire with high frequency and low risk, fire with low frequency and high risk and fire in special circumstances.

1.2.4 For hazard ranking of fire scenario, refer to Appendix 1 of CCS Guidelines for Application of Formal Safety Assessment to Ships.

1.2.5 When a design fire scenario is screened out from possible fire scenarios, design fire is also needed, i.e. quantitative description of fire characteristics in a fire scenario, including variation of fire parameters over time, e.g. heat release rate, fire temperature and production of toxic components, and other important model input data, e.g. fire load density, etc.

1.2.6 Design of fire scenario is to:

1.2.6.1 Evaluate general situation: understanding the basic condition of object being assessed, e.g. function of ship space, fuel type and distribution as well as existing fire protection measures, etc.

(1) pre-fire situation: ship, platform, compartment, fuel load, environmental conditions;

(2) ignition sources: temperature, energy, time and area of contact with potential fuels;

(3) initial fuels: state (solid, liquid, gas, vapor, spray), surface area to mass ratio, rate of heat release;

(4) secondary fuels: proximity to initial fuels, amount, distribution;

(5) extension potential: beyond compartment, structure, area (if in open);

(6) target locations: note target items or areas associated with the performance parameters;

(7) critical factors: ventilation, environment, operation, time of day, etc. ; and

(8) relevant statistical data: past fire history, probability of failure, frequency and severity rates, etc.

1.2.6.2 Analyze fire safety objectives: determining fire hazard to be considered by analyzing fire safety objectives of the alternative design. Common fire safety objectives include ensuring life safety, property protection and ensuring continuous operation of equipment. Relevant fire hazards to be considered include fire threat to life safety as well as property loss and equipment damage due to fire. Therefore, special consideration needs to be given to such scenarios as fire in a crowded area, fire blocking evacuation exits, fire which may lead to structural failure, fire liable to cause combustion of hazardous substance and quick-developing fire.

1.2.6.3 Determine the initial event of fire scenario event tree: including determination of fire type and ignition source location. Different fire types have different fire processes and consequences. Determining fire type can guide construction of fire scenario event tree and fire hazard assessment, and is also necessary for subsequent quantitative analysis.

1.2.6.4 Determine the path factor of fire scenario event tree: path factor is the event after initial event, representing condition status and aging effects. For ships, status of various fire safety systems is usually selected as path factor of fire scenario event tree, as shown in Table 1.1

1.2.6.5 Construct the fire scenario event tree: the fire scenario event tree can be constructed according to the response event sequence of fire safety system after determining the initial fire event and path factor. Figure 1.3 is an example of fire scenario event tree, in which FPS1 to FPS4 represent path factor, e.g. FPS1 to FPS4 can represent whether detection alarm system is successful, whether smoke extraction system is in normal condition, whether automatic sprinkling fire-extinguishing system can extinguish fire successfully and whether automatic sprinkling fire-extinguishing system can control fire size respectively.

Path factor of fire scenario event tree Table 1.1

Fire-fighting system	Status
Fire detection system	Normal condition, abnormal condition
Fire alarm system	Normal condition, abnormal condition
Smoke extraction system	Normal condition, abnormal condition
Automatic fire-extinguishing system	Success or failure of fire extinguishment
	Success or failure of fire size control
Fire division	Whether design division effects have been achieved

1.2.6.6 Probability of occurrence of a fire scenario is obtained by multiplying the probability of occurrence of an initial event by the conditional probability of a branch event. Taking the fire scenario event tree in Figure 1.3 as an example, the probability of occurrence of fire scenarios S1 to S9 is shown in Table 1.2.

Probability of occurrence of fire scenarios S1 to S9 Table 1.2

Fire scenario No.	Probability of occurrence of fire scenario
S1	$P_{S1}=P_1P_{11}P_{111}P_{1111}$
S2	$P_{S2}=P_1P_{11}P_{111}P_{1112}P_{11121}$
S3	$P_{S3}=P_1P_{11}P_{111}P_{1112}P_{11122}$
S4	$P_{S4}=P_1P_{11}P_{112}P_{1121}$
S5	$P_{S5}=P_1P_{11}P_{112}P_{1122}P_{11221}$
S6	$P_{S6}=P_1P_{11}P_{112}P_{1122}P_{11222}$
S7	$P_{S7}=P_1P_{12}P_{122}P_{1221}$
S8	$P_{S8}=P_1P_{12}P_{122}P_{1222}P_{12221}$
S9	$P_{S9}=P_1P_{12}P_{122}P_{1222}P_{12222}$

1.2.6.7 Conditional probability of a branch event (success probability of a fire-fighting system) is the basis for quantifying the probability of occurrence of a fire scenario. There are two methods to obtain the success probability of a fire-fighting system, i.e. event tree analysis method and historical statistical data.

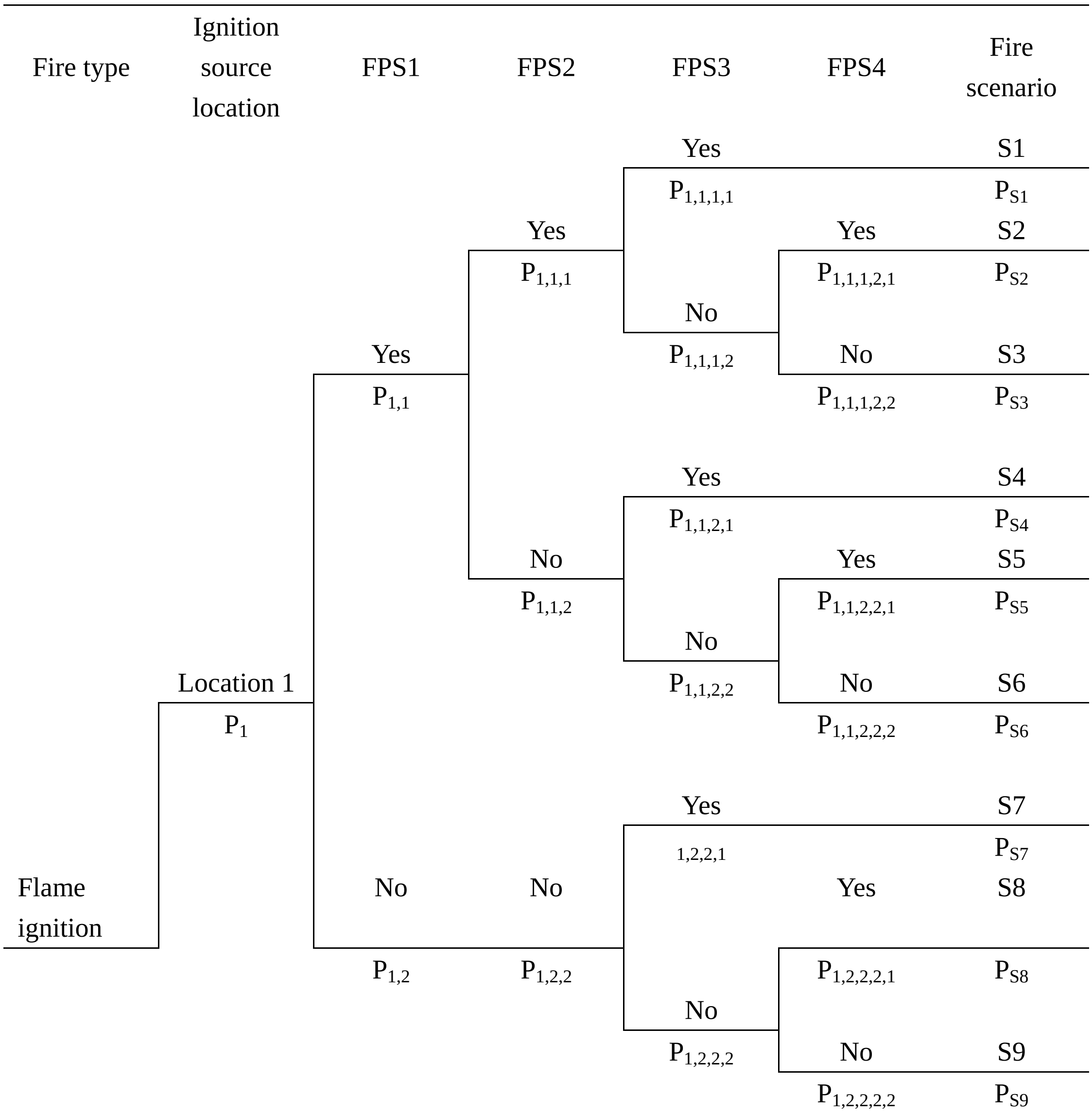

Figure 1.3 Example of fire scenario event tree

1.2.6.8 Consequence analysis of a fire scenario

(1) Quick and simple estimation of the risk level related to a fire scenario can be carried out by analyzing the fire hazard source and other risk parameters, granting appropriate value according to certain principle and synthesizing by mathematical method to get values describing the consequence of a fire scenario. This process is semi-quantitative analysis of the consequence of a fire scenario. The concept of fire affected area is introduced to represent the possible scope of fire hazard under a particular fire scenario. Fire affected area generally has three levels:

① Scope of fire consequence is restricted to a certain local area;

② Fire spreads to the whole compartment and space;

③ Fire spreads beyond the fire-resistant division of hull structure to other areas.

(2) According to fire safety design objectives, fire consequence in fire affected area (*C*) generally includes injury to life of persons caused by fire (C_p) and property loss caused by fire (C_w). The Guidelines introduce fire influence (*I*) and hazard (*H*) coefficients to carry out semi-quantitative analysis of fire consequence. For fire scenario with m affected area, the fire consequence can be obtained from following formula:

$$\begin{cases} C_p = \sum_{i=1}^{m} I_{p_i} \times H_{p_i} \\ C_w = \sum_{i=1}^{m} I_{w_i} \times H_{w_i} \end{cases}$$

Where: I_{pi} means the total number of persons in No.i affected area;

H_{pi} means the extent of hazard to persons in No.i affected area;

I_{wi} means the total value of property in No.i affected area;

H_{wi} means the extent of hazard to property in No.i affected area.

(3) Fire influence means the total number of persons or total value of property in the fire affected area. Total number of persons in No.i fire affected area I_{pi} can be determined by person density and area of affected area:

$$I_{p_i} = D_{p_i} \times S_i$$

Where: D_{pi} means person density of No.i affected area, in person/m^2;

S_i means area of affected area, in m^2.

Total value of property in No.i fire affected area I_{wi} can be determined by property value density and area of affected area:

$$I_{w_i} = D_{W_i} \times S_i$$

Where: D_{wi} means property value density of No.i affected area, in yuan/m^2, different types of compartment generally have different value density;

S_i means area of affected area, in m^2.

(4) Hazard coefficient *H* means the extent of fire damage or threat to person and property in the affected area, which is mainly determined by characteristics of fire hazard source, fire protection measures against fire hazard and vulnerability of fire safety objectives, and the value range is [0,1].

1.2.6.9 Collecting reliable data is an important step of fire scenario design, and data necessary for fire scenario design may include:

(1) fire statistics: fire statistics include statistics of potential combustion area and potential area to which the fire will spread, past fire history and fire frequency, etc.;

(2) Ship data: continuous fire combustion and potential consequence are determined by many factors, such as:

① fire load;

② structural strength;

③ number of passengers and environment;

④ system reliability data. Sometimes fire-fighting system may fail due to lack of maintenance, mechanical failure and abnormal large fire. The manufacture is to provide such data as frequency of mechanical or power failure of system and fire intensity sustained by the system. The manufacturer is also to clearly indicate frequency of fire environment and human error in fire event. For example, an automatic fire detection and control system is to provide following reliable data:

(i) corresponding data of detection system;

(ii) operational data of smoke control system;

(iii) data of fire-extinguishing system;

(iv) data that break isolation condition.

1.2.6.10 If there is no reliable data support, assumption may be made through expert judgement for further analysis.

1.3 Design fire

1.3.1 Design fire is a quantitative description of characteristics of fire in design fire scenario, mainly including variation of fire parameter over time and other important model input data, of which the most important is developing ignition source power which is the most basic input parameter for fire simulation. Calculation of fire development and smoke flow can only be carried out until ignition source power is developed.

1.3.2 Development of fire load density. Fire load density means heat released by complete combustion of a unit area of combustible material. Fire load within a compartment or an enclosed space may affect fire duration and fire heat release rate. Therefore, fire load density is an important parameter in design fire. Fire load generally includes following three categories:

1.3.2.1 Fixed fire load Q_1 means combustible materials for compartment interior decoration with basically unchanged location (e.g. wallpaper, suspended ceiling, soft package of wall, closet, wall, etc.) and part of combustible materials used on bulkhead structure (e.g. wooden doors and windows).

1.3.2.2 Movable fire load Q_2 means rearranged combustible materials for normal use of compartment with greater variability of location and amount, usually means a variety of objects and fuel, etc.

1.3.2.3 Temporary fire load Q_3 means temporary combustible material with short stay. Such fire load has uncertainty and may not be taken into account in normal calculation.

1.3.3 Setting of fire heat release rate curve. In principle, heat release rate of combustion of combustible materials in fire can be obtained according to mass combustion rate:

$$\dot{Q} = \phi \times \dot{m} \times \Delta H$$

Where: $\dot{m}$ is mass combustion rate of combustible material;

ΔH is heat value of combustible material;

ϕ is combustion efficiency factor, reflecting the extent of incomplete combustion.

In practical engineering application, each item in right side of above formula is difficult for reasonable determination. In general, fire combustion characteristics of typical objects can be determined by test, and heat release rate of specific object is evaluated accordingly. Heat release rate of combustible materials can be measured by cone heatmeter (ISO 5660) and furniture heatmeter (ISO9705).

Fire heat release rate curve is usually set by following methods:

(1) Setting constant ignition source, i.e. setting ignition source power as a constant which does not change with time. For example, main combustion stage of fire of combustible gas ejected at

certain rate or fire of oil pool with constant container area can be deemed to have constant ignition source power. For the stable combustion stage of fire of some combustible solids, the combustion rate can also be deemed as basically constant. Setting constant ignition source is an idealized assumption which can greatly simplify the calculation process. For calculation of fire safety design, design parameters are determined according to fire with maximum ignition source power which may occur in the space (constant). This method is conservative and complies with the requirements for fire hazard analysis;

(2) Time square fire: the ignition source power of actual fire is time-varying. Fire development generally has three basic stages: continuous growth, stable combustion and gradual weakening, as shown in Figure 1.4. For design fire, the main concern is fire growth and stable combustion stages. The discussion of setting fire heat release rate curve is divided into two parts.

① Fire growth stage. A lot of experiments have shown that the heat release rate of many objects generally grows according to the time index law from the ignition to stable combustion stage, i.e. fire growth is described by t^2:

$$\dot{Q} = \alpha \cdot t^2$$

Where: fire growth factor *α* indicates how fast a fire spreads, in kw/s^2, which is divided into four types according to NFPA standards, i.e. very fast, fast, medium and slow, as shown in Table 1.3.

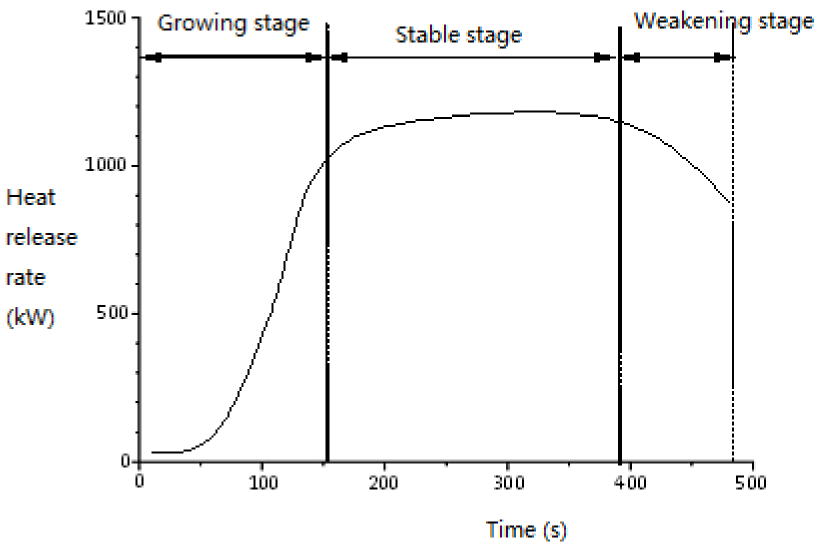

Figure 1.4 Fire development curve diagram

Fire growth factor parameter value **Table 1.3**

Combustible materials	Fire growth classification	$a/kW/s^2$
Without indication	Slow	0.0029
Without cotton product Polyester mattress	Medium	0.0117
Plastic foam Stacked plank	Fast	0.0469
Fasting burning cushion seat	Very fast	0.1876

② Fully developed stable combustion stage. Heat release rate of stable combustion stage is mainly calculated according to empirical formula. For liquid combustible materials such as fuel oil, the heat release rate of stable combustion can be estimated with reference to previous research:

$$\dot{Q} = \dot{m}'' \times A_p \times \Delta H_c$$

Where: $\dot{Q}$ is heat release rate, in MW;

$\dot{m}''$ is mass loss rate of per unit area of combustible materials, in kg/sm^2;

A_p is effective exposure surface area of combustible materials, in m^2;

ΔH_c is combustion heat value, in MJ/kg.

The duration of fire can be calculated according to following formula:

$$t_f = \frac{\text{Total fire load}}{60Q_f}$$

For cellulose combustible materials such as wood:

$$Q = \begin{cases} [2.5 \cdot \chi \cdot \exp(-11\chi) + 0.048]A_{fuel} & (\chi > 0.1) \\ 0.13A_{fuel} & (0.081 < \chi \le 0.1) \\ 1.6 \cdot \chi \cdot A_{fuel} & (\chi \le 0.081) \end{cases}$$

Where: x is index of combustion type:

$$\chi = \frac{\sum A_{op}\sqrt{H_{op}}}{A_{fuel}}$$

$$A_{fuel} = 0.26 \times q^{\frac{1}{3}} \times A_r + \sum \varphi \times A_f$$

Where: A_{op} —area of each opening, in m^2;

H_{op} —vertical distance from top end to bottom end of opening, in m;

A_{fuel} —surface area of combustible materials, in m^2;

A_r —area of room floor, in m^2;

q —fire load density, in MJ/m^2;

$\sum \varphi \times A_f$ —effective exposure area of combustible decoration materials of wall and ceiling, in m^2.

(3) Self-setting ignition source. Self-setting ignition source is developing ignition source power according to combustion change of specific objects within ship space. Fire is usually a process that an object catches fire first, then other surrounding objects are ignited and thus it grows. The collocation form of objects in the space is complicated, and the heat release rate of object under combined condition can be estimated according to relevant data. For example, if the heat release rate of an object in the space and the ignition source and ignition time of other objects are known, total heat release rate can be obtained by overlaying heat release rate curve according to ignition

time, as shown in Figure 1.5.

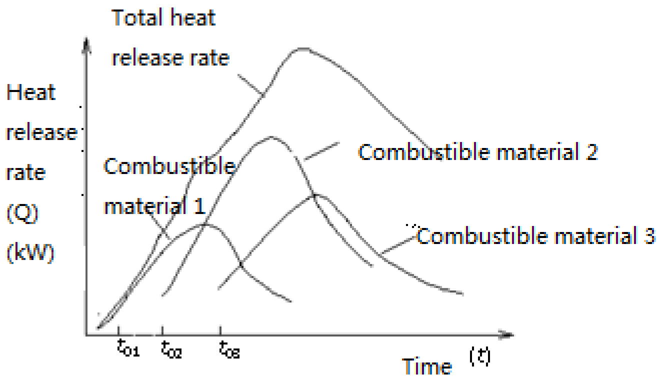

Figure 1.5 Setting total heat release rate of ignition of combustible materials

1.4 Fire computer simulation

1.4.1 Fire developing and spreading process need to be simulated by computer on the basis of design fire scenario to analyze safety performance of alternative design for fire safety.

1.4.2 For alternative design aiming at life safety, fire hazard such as heat and smoke is analyzed by fire computer simulation to finally get ASET value.

1.4.3 There are a lot of models or software for fire computer simulation, and at present, the most common two types are zone model and field model. The applicability of two models is shown in Table 1.4.

Applicability of calculation models Table 1.4

Model	**Advantage**	**Disadvantage**
Zone model	Fast calculation speed, no strict requirements for computer; Good indication of fire trend.	Some details of flow field cannot be obtained, and at the same time, special fire phenomena such as gas entrainment and smoke backflow are difficult to simulate precisely.
Field model	Slow calculation speed, with strict requirements for computer; Change of fire parameters at different position with time can be obtained.	For field simulation, due to complexity of algorithm and restriction of computer capacity, some large-scale fire simulation computation takes a long time.

1.4.4 Most fire models do not simulate the actual combustion process of combustible materials, fire combustion condition is very complicated and the choice is based on satisfying engineering needs. Correctness of simulating computation results is strongly dependent on rationality of input data. Therefore, for fire computer simulation, basic parameters determined during design fire scenario need to be treated as input parameter and boundary condition, including fire heat release rate, opening and ventilation condition, etc. These set conditions are to be described in detail in analysis report for review by CCS.

1.5 Personnel evacuation analysis simulation

1.5.1 In the alternative design for fire safety, personnel evacuation analysis simulation is carried out not only on the basis of personnel evacuation scenario required by MSC.1/Circ.1533 but also in combination with design fire scenario to analyze personnel evacuation condition, and additional personnel evacuation analysis scenario is set on the basis of the least favorable principle, e.g. the access or door is not accessible due to fire block, or some vertical zones are not available as a whole due to fire, or effects of hot smoke and radiation caused by fire on safe passage of personnel in evacuation access are considered.

1.5.2 Main steps of personnel evacuation analysis are as follows, with detailed flow being shown in Figure 1.6.

(1) Software verification;

(2) Modeling;

(3) Scenario setting;

(4) Calculation of moving time;

(5) Analysis;

(6) Report preparation.

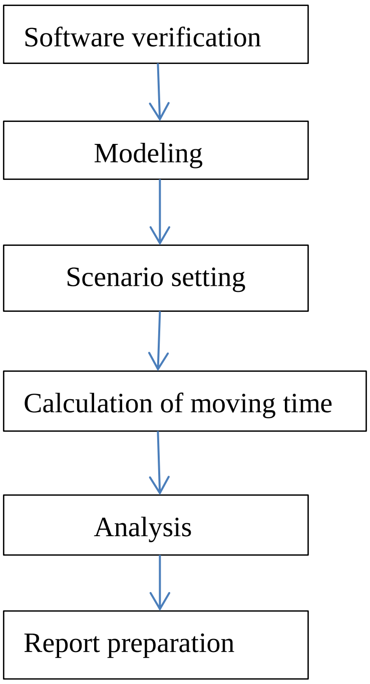

Figure 1.6 Personnel evacuation analysis flow

1.5.3 Software for personnel evacuation analysis are to be subject to module verification, functional verification and qualitative analysis verification. The flow is shown in Figure 1.7, and the verification requirements and methods are detailed in Appendix 2, Annex 3 of MSC.1/Circ.1533.

1.5.4 Personnel evacuation analysis modeling is determination of such parameters as geometric modeling, personnel composition, response time, movement speed (platform and stairway) and exit flow rate with the help of advanced evacuation analysis software and by means of numerical simulation.

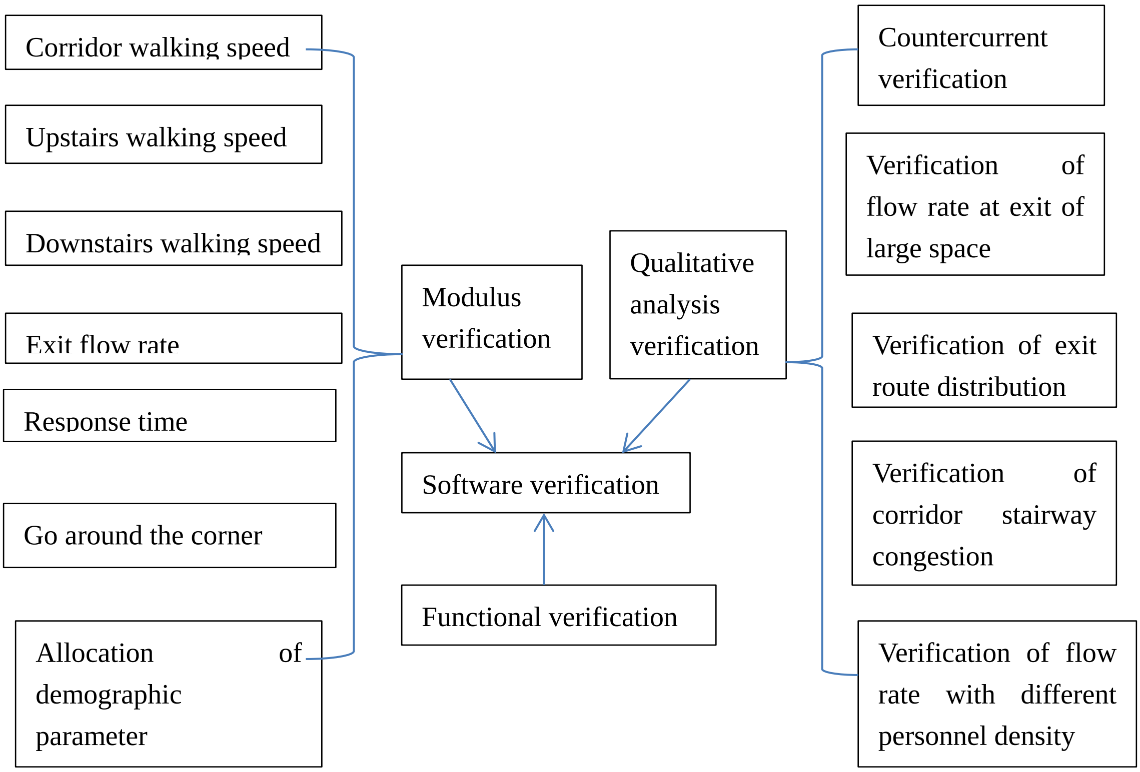

Figure 1.7　Verification flow of personnel evacuation analysis software

1.5.5　Report on personnel evacuation analysis is at least to include:

(1) basic condition of target passenger ship for advanced evacuation analysis, including basic layout, personnel distribution and provisions for personnel evacuation route;

(2) the variables used in the model to describe the dynamics, e.g. walking speed and direction of personnel on board ship;

(3) the functional relation between the parameters and the variables;

(4) the type of updating instantaneous calculation results, e.g. the order in which the persons move during the simulation (parallel, random sequential, ordered sequential or other);

(5) the representation of stairs, doors, assembly stations, embarkation stations, and other special geometrical elements and their influence on the variables during the simulation (if there is any) and the respective parameters quantifying this influence; and

(6) a detailed user guide/manual specifying the nature of the model and its assumptions and guidelines for the correct use of the model and interpretations of results are to be readily available.

1.6　Application example

1.6.1　General condition

A certain type of luxury cruise ship is arranged with a large banquet hall crossing two layers of deck, and at the same time, the expanding area of single deck is large (with a length of 60 m, for plane layout and design parameters, see Figure 1.8 and Table 1.5), and the dining hall is crowded at the same dining time (with about 1700 person).According to the definition of main vertical zone in Chapter II-2 of SOLAS Convention, the mean length and width of main vertical zone on any deck does not in general exceed 40 m. According to the provisions of SOLAS Reg.II-2/9.2.2.1.2, the length and width of main vertical zone may be extended to a maximum of 48 m provided that the total area of the main vertical zone is not greater than 1600 m^2. It is obvious that the length 60 m of the large banquet hall has gone beyond the provisions of SOLAS Convention for the maximum length of 48 m of main vertical zone.

According to SOLAS Reg.II-2/17, design deviating from existing mandatory fire safety provisions is allowed, provided such design has a safety level equivalent to the design based on IMO prescriptive requirements. This provides possibility and technical route for luxury cruise ship to break through the fire safety restriction.

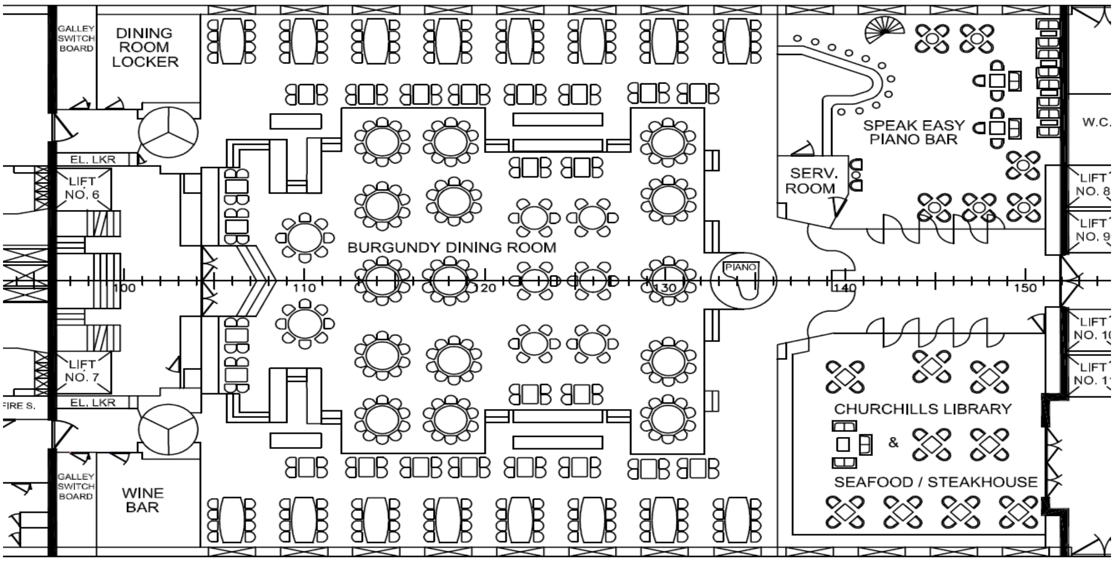

Figure 1.8 Plane layout of banquet hall

Design parameters of banquet hall **Table 1.5**

Design of banquet hall		Trial alternative design
Length/m		60
Total number of person	Upper deck	700
	Lower deck	980
All exit width/m	Upper deck	11
	Lower deck	11.5
Ground area/m^2	Upper deck	1800
	Lower deck	1890

1.6.2 Project design objective

With regard to fire safety problems existing in the large banquet hall of cruise ship and according to fire safety objectives specified in SOLAS Convention, main safety objective of this project is to guarantee personnel safety, i.e. to ensure that all personnel can evacuate safely when the design fire occurs; secondly, to secure property safety and reduce direct and indirect loss due to fire. The key standard for life safety is that ASET is to be more than RSET. ASET is the interval of time between outbreak of a fire and the time when the situation is out of control so that personnel cannot complete effective evacuation by themselves, i.e. time to reach fire hazard condition.

Fire hazard considered in this project means direct hazard to personnel (e.g. smoke hazard). The objective of securing property safety can be achieved by early fire detection and effective fire suppression. Focusing on above design objective, the alternative project carries out following evaluation:

(1) Design of fire scenario, i.e. analyzing characteristics of fire hazard source and potential fire scenario;

(2) Analysis of fire hazard, i.e. analyzing fire smoke and its development characteristics, and evaluating possibility of fire reaching hazardous state and corresponding ASET;

(3) Analysis of safe evacuation of personnel, i.e. analyzing personnel characteristics, obtaining RSET in combination with set fire detection time and personnel preparation time, and evaluating whether personnel can evacuate safely in comparison with RSET;

(4) Evaluation of fire detection and fire-extinguishing systems, i.e. evaluating effectiveness of designed fire detection alarm and fire-extinguishing systems and effects on shortening RSET and reducing fire loss.

1.6.3 Alternative design and arrangement process

1.6.3.1 Design of fire scenario

According to distribution of fire load in banquet hall of cruise ship and in combination with structural characteristics of space, functional design and installation of automatic sprinkler system, fire scenario is set reasonably. In particular, whether fire scenario can prove that the design can satisfy detailed fire safety objective is to be fully considered. Main safety objective of the evaluation is to guarantee personnel safety. Selection of fire scenario is mainly carried out from the angle of personnel evacuation.

Banquet hall is a crowded space, with large amount of combustible material such as tables and chairs and tablecloth, and the wine for banquet can also be the fuel for fire. There is a service room inside the banquet hall to provide food heating service, which leads to certain potential of electrical fire hazard. In addition, the service room is located near an evacuation exit which will be unavailable due to fire effects in case of fire and pose the maximum threat to safe evacuation of personnel. Therefore, fire scenario in which the banquet hall reaches hazardous condition fastest is shown as follows:

Fire scenario parameters **Table 1.6**

Scenario No.	Location of ignition source	Design fire	
		Growth speed	Fire size/MW
1	Service room	Fast	2.5
2	……		

1.6.3.2 Quantitative analysis

To quantify risk, the occurrence rate and consequence of design scenario need to be evaluated. But taking special condition of alternative design into account, only consequence is used to quantify risk. SMART Fire is used to calculate fire developing and spreading process, and consequence is quantified based on it. Marinetime EXODUS is used to carry out advanced evacuation analysis, and the amount of injury/death is obtained in combination with output result of fire simulation by computer. The amount of death depends on evacuation time from each space and time of smoke hazard reaching hazardous condition in the space. According to set design objective, all personnel need to complete evacuation before reaching hazardous state. If the risk level of the scenario being evaluated is unacceptable, potential risk control plan is to be evaluated.

In the design scenario, smoke caused by fire spreads to upper deck in about 240 s, and at the same time, the fire blocks an evacuation exit at right side of dining hall, thus passengers nearby have to use other off-courses, which increases congestion and extends total evacuation time. The results of quantitative calculation are as follows:

Analysis of alternative design results Table 1.7

Space	Evacuation time/s	Time of danger/s	Number of passengers affected
Upper deck	480	360	30
Lower deck	540	360	55

In the scenario being considered, fire in the service room on lower deck is shown in Figure 1.9, and smoke diffuses upwards through the opening between lower deck and upper deck.

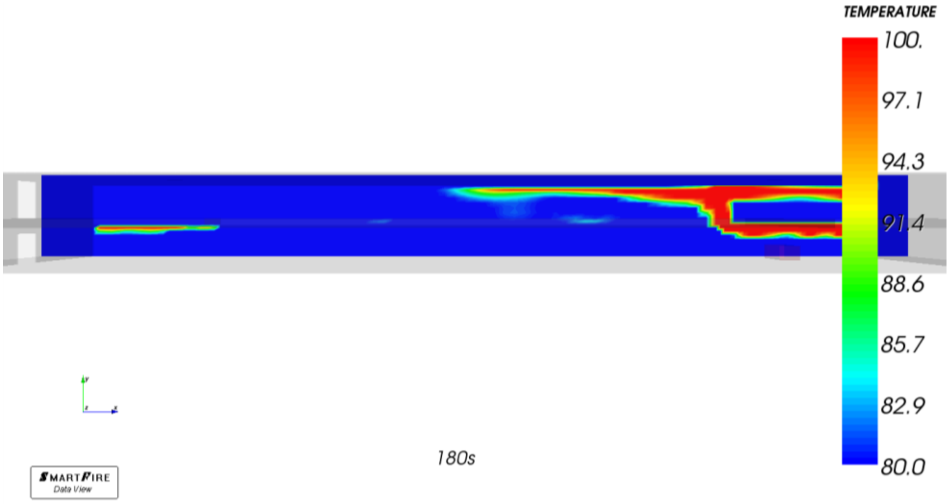

Figure 1.9 Schematic diagram of fire passing through lower deck and upper deck of banquet hall

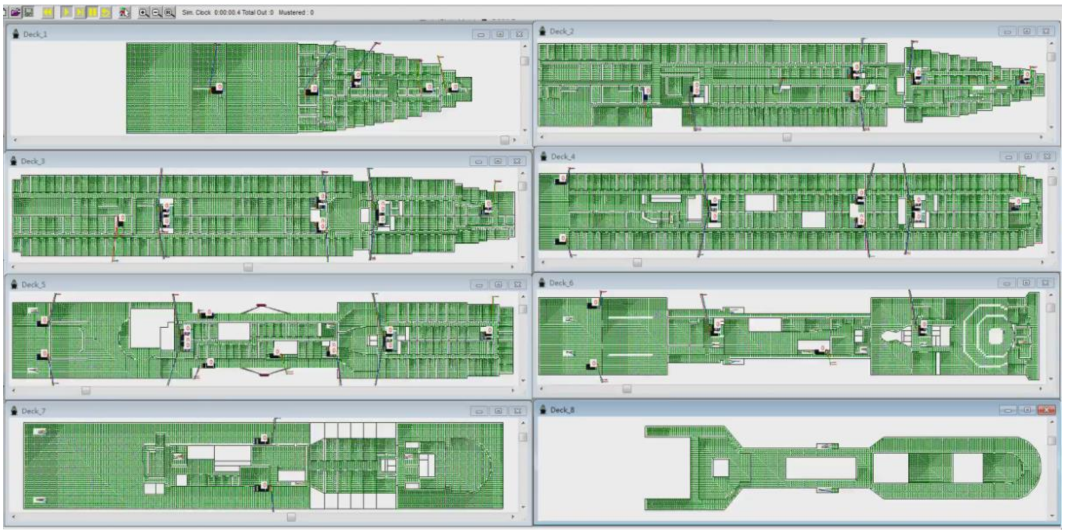

Figure 1.10 Personnel two-dimensional modeling result

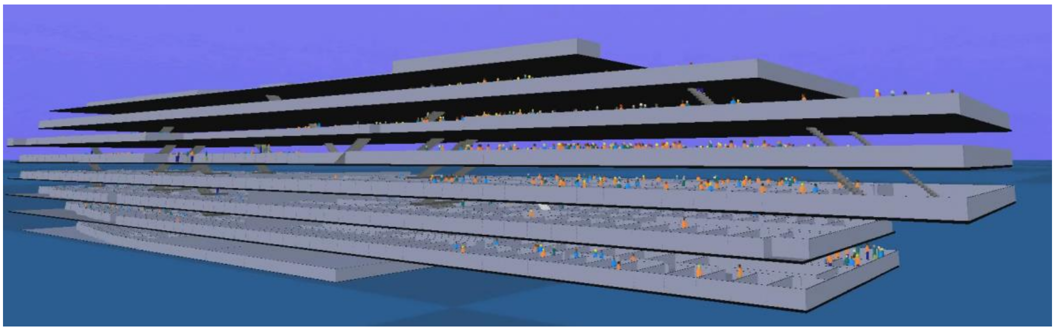

Figure 1.11　Personnel three-dimensional modeling result

Quantitative calculation results in above Table shows that this trial alternative design cannot guarantee safe evacuation of all personnel, which is an unacceptable result. Therefore, consideration is needed to take appropriate risk control measures to improve evacuation possibility of personnel in banquet hall, among which the most reasonable and effective measures include:

(1) increasing the amount of upper smoke outlet from 2 to 4;

(2) increasing the amount of air-supplement openings from 2 to 4;

(3) increasing the width of evacuation exit.

The fire risk of the banquet hall has become acceptable after applying above risk control measures, as shown in Table 1.8

Result analysis of alternative design after improvement　　　　Table 1.8

Space	Evacuation time/s	Time of danger/s	Number of passengers affected
Upper deck	400	520	0
Lower deck	430	520	0

1.6.4　Document preparation

(blank)

Appendix 2 Alternative Design for Life-saving Appliances

2.1 Evaluation criteria

2.1.1 According to SOLAS regulation III/38, life-saving appliances and arrangements are allowed to deviate from the provisions of part B of SOLAS Chapter III, however relevant alternative design is to meet the objectives to provide safe evacuation and maintaining the life in emergency for persons onboard the ship and is to provide the safety level equivalent to that required by SOLAS chapter III and the International Life-Saving Appliance Code (hereinafter referred to as LSA Code).

2.1.2 According to the above safety objective, evaluation criteria in relation to alternative design for life-saving appliances may include:

(1) to minimize the injury of personnel and prevent the loss of human life during the abandon of ship;

(2) to limit and eliminate the effect of failure of appliances and to ensure sufficient safety protection and prevention measures;

(3) to prevent delay in the evacuation, muster and embarkation of personnel and ensure safe and timely evacuation of personnel;

(4) lifeboats and survival crafts are to ensure the survival of personnel at sea.

2.2 Analysis scope

2.2.1 The analysis object of the alternative design for life-saving appliances is the whole life-saving system. Information on composition, arrangement and operation of life-saving system is to be considered in determining the analysis scope of alternative design, mainly including:

(1) type, number, arrangement and performance of life-saving appliances;

(2) performance of launching arrangements and related accessories;

(3) arrangement of escape routes, assembly stations and embarkation stations;

(4) service characteristics and operational conditions of ship;

(5) procedures for operation and maintenance of life-saving appliances in the case of drills and casualty;

(6) personnel assigned for operation of life-saving appliances and evacuation procedures.

2.2.2 Procedures for evacuation and abandon of ship, including evacuation, embarkation, abandon of ship (mother ship) and survival at sea, are to be clarified.

2.2.3 Furthermore, characteristics of evacuation personnel onboard the ship is to be considered, including physical ability and age distribution of personnel and special attention is to be paid to the aged or physically inconvenient.

2.3 Casualty scenarios

2.3.1 The design team is to determine the major hazard and corresponding casualty scenarios required to be considered for assessment.

2.3.2 Hazard identification

Potential hazards which may affect the normal operation of life-saving system are to be determined by analyzing possible failure of components of life-saving system (hydraulic system failure, boat hook failure, etc.,) and the reaction of personnel in dangerous situations, including strike, low temperature and seasickness, etc. During this process, hazards are to be identified for lifeboat and its launching arrangement by means of hazard identification method such as FMEA and it is to be ensured that the risk ranks of all identified hazards are within low risk range after the risk control measures are taken (see CCS Guidelines for Application of Failure Mode and Effects Analysis).

2.3.3 After all potential hazards are identified, they are to be analyzed and ranked from the perspective of probability and consequence so as to define the hazard and casualty scenarios for which quantitative analyses are required.

Examples of Hazards **Table 2.1**

Stage	Hazards
Preparation	Failure, lifeboat is locked
	Availability/operation under severe weather conditions (related to service area)
	Availability/operation of the ship under severe conditions (trim, heel, rolling)
	Hydraulic system failure and fail to start
Embarkation	Mobility difficulties of personnel
	The number of assembly station is too little and the area is not sufficient
Launching	Released too early
	Not able to release
	Insufficient carrying capacity of davit device
	Collision with the hull of the parent ship
	Center of gravity of the boat is raised and the launching is uneven when the boat is hanged at both ends
Releasing	Not able to release
	Damage/slamming
Unlocking	Operation failure
At sea	Severe living conditions in the boat
	Seasickness
	Propulsion is not sufficient to withstand large size of boat and great numbers of persons
	Capsize

2.3.4 The following ship and environmental conditions are to be considered when the casualty scenario is designed, including:

(1) evacuation route;

(2) sea conditions;

(3) survival period at sea;

(4) sea/air temperature;

(5) heading angle of parent ship in the waves (including dead ship condition);

(6) heel and trim of parent ship (to reflect the condition of the damaged ship);

2.3.5 A certain number of assessment scenarios is designed through hazard identification and analysis of scenario conditions, as shown in the table below:

Examples of Scenarios Table 2.2

No.	Hazard	Descriptions of scenario
Scene 1	Embarkation station area is not sufficient	Congestion and counter impact in the process of evacuation
Scene 2	Failure of hydraulic system and fail to start	Some lifeboat is not available
…		

2.4 Quantitative analysis

2.4.1 Whether personnel may be evacuated and abandon the ship safely and timely in the alternative design of life-saving appliance is determined through analysis of personnel evacuation so as to verify the safety of life-saving system and its arrangement.

2.4.2 Quantification of performance criteria. According to the safety objective and evaluation criteria established by 2.1 of this Appendix, in addition to meeting the requirements of SOLAS and LSA Code, the performance criteria involved in the alternative design of life-saving appliances of passenger ships are to be considered as follows, if applicable:

(1) The ship and the life-saving system are to comply with the following requirements at the same time:

Calculated total evacuation time: $1.25 (R + T) + 2/3 (E + L) \leq n$

Embarkation and launching time: $E + L \leq 30$ min

where:

R—response duration (min) is the duration it takes for people to react to the situation. This duration begins upon initial notification (e.g. alarm) of an emergency and ends when the passenger has accepted the situation and begins to move towards an assembly station.

T—total travel duration (T) is the duration it takes for all persons on board to move from where they are upon notification to the assembly stations.

E+L— embarkation and launching duration (E+L) is the duration required to provide for abandonment by the total number of persons on board, starting from the time the abandon ship signal is given after all persons have been assembled, with lifejackets donned until lifeboat/survival craft is loaded with its full complement of persons and equipment and reaches the water.

n—maximum permissible total evacuation duration (min); for ro-ro passenger ships, n=60; for other passenger ships, n=60 if the number of main vertical zones of the ship does not exceed 3; n=80 if the number of main vertical zones exceeds 3.

The analyses and calculation of R and T above may be carried out according to relevant requirements of MSC.1/Circ.1533. E+L is to be calculated separately based on real ship test or results of simulated embarkation analysis or data provided by the manufacturer. If the data provided by the manufacturer is used, documented evidence is to be provided for relevant calculation method.

(2) The arrangement of lifeboat is to meet the following requirements:

$E \leq 10$ min

where:

E—embarkation duration (min) is the duration it takes for all persons on board to complete embarkation starting from the time the embarkation order is given.

E is to be calculated based on the actual embarkation test or results of simulated embarkation analysis or data provided by the manufacturer. If the data provided by the manufacturer is used, documented evidence is to be provided for relevant calculation method.

(3) If a large lifeboat (capacity of more than 150 persons) is used, the lifeboat and launching arrangements are also to meet the following requirements:

① After the lifeboat and its launching arrangement are analyzed by means of FMEA, the risk level is to be within the low risk range after the risk control measures are taken for the identified hazards.

② The lifeboat is to have sufficient strength and the following items are to be checked:

i) the structural strength of the hull of lifeboat, CCS Rules for Construction of Coastal Boats and other recognized standards may be taken for reference;

ii) the structural strength of the hull of lifeboat under overload lifting condition is to be calculated according to 4.4.1.6 of Chapter IV of LSA Code.

③ the intact stability and damage stability calculation of lifeboats are to be provided, relevant requirements of Technical Regulations for Surveys of Coastal Boats and other recognized standards may be taken for reference.

④ suitable living conditions in the boat is to be provided, such that the long-term CO_2 concentration in the boat is not to be higher than 5000 ppm within 24 hours. The transformation relation between the long-term CO_2 concentration and ventilation volume within the boat may be calculated by means of establishing analysis model so as to determine the type of ventilation equipment and arrangement within the boat.

⑤ Strength criteria of launching and release devices

Strength of launching and release devices (including the connection and supporting structures of the hull of boat) is to be calculated according to relevant requirements of 4.4 of Chapter IV and 6.1 of Chapter VI of LSA Code.

2.4.3 Assessment of alternative design plan

Corresponding to the above performance criteria, alternative design plan of life-saving appliances is to be assessed, including the assessment of the safety of arrangement of life-saving appliances through personnel evacuation analysis and the safety of lifeboat and launching arrangements are determined through relevant calculation, test and engineering analyses.

2.5 Tests and engineering analyses

2.5.1 Tests and engineering analyses involved in the alternative design of life-saving appliances are mainly to inspect whether the novel lifeboat, launching arrangements and embarkation appliances comply with the requirements of Code of Practice for the Evaluation, Testing and Acceptance of Prototype Novel Life-saving Appliances and Arrangements (IMO A.520(13)), LSA Code and the Revised Recommendation on Testing of Life-Saving Appliances (MSC.81(70)) and its amendments.

2.5.2 In addition to the basic requirements of 2.5.1 of this Appendix, the lifeboat and launching arrangements are to be surveyed in accordance with the performance criteria specified in 2.4.2(2) and (3) of this Appendix.

2.6 Cases of application

2.6.1 Provision and arrangement of life-saving appliances

A passenger ship engaged on international voyage: carrying 1290 crew members, 5010 passengers, rated passenger capacity of 6300 persons. Ten lifeboats are arranged in starboard and port sides of the ship respectively and there are 20 totally enclosed lifeboats in total. The rated passenger capacity of each lifeboat is 315 persons. The embarkation deck of the lifeboat is G deck or H deck and each layer of deck is arranged with 3 assembly stations in starboard, port and mid-ship, the areas of assembly stations meet the requirements of the Convention.

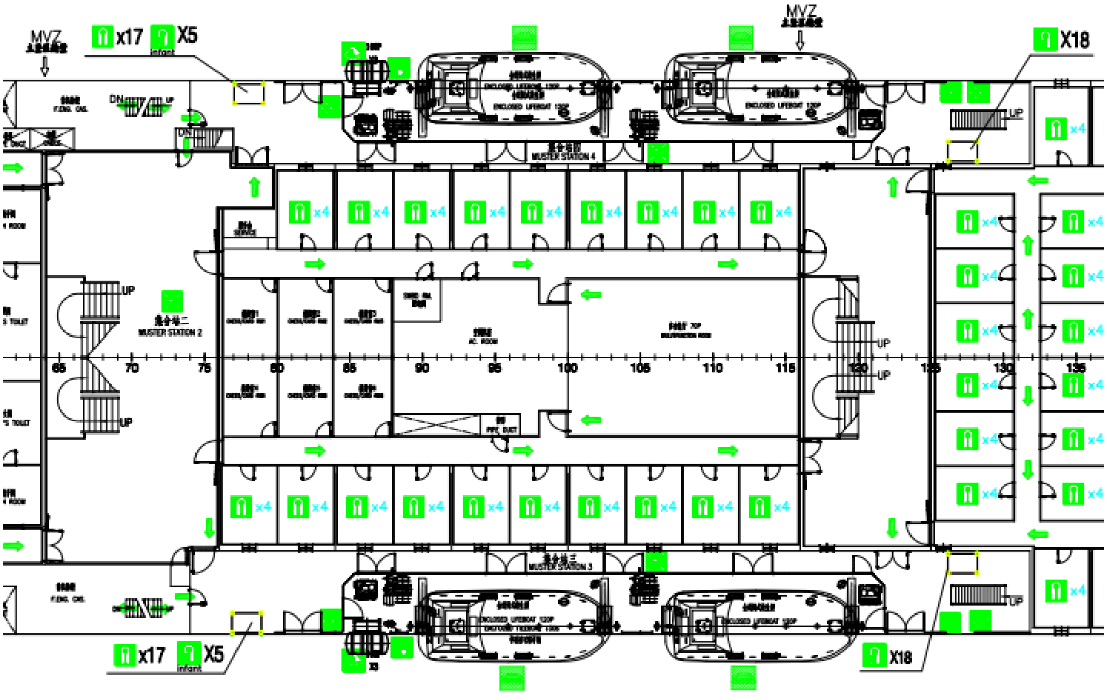

Figure 2.1 Part of the Arrangement of lifeboats of a Passenger Ship

2.6.2 Provisions of convention which requires alternative design

The maximum number of persons onboard the lifeboat is over 150 persons, which exceeds the provision in 4.4.2.1 of Chapter IV of LSA Code that “No lifeboat shall be approved to accommodate more than 150 persons”; therefore, assessment is required by means of alternative design of life-saving appliances.

2.6.3 Initial analysis

First, FMEA analysis is to be carried out for lifeboat and its launching arrangements respectively so as to identify the risks due to the fact that the capacity of lifeboat exceeds the limit of LSA Code. For detailed analysis, see Tables 2.3 and 2.4, the analysis results show that:

For lifeboat: no unacceptable risk, 7 risk items are within ALARP area (yellow), among which 40 items are within acceptable area (green);

For launching arrangement: no unacceptable risk, 8 risk items are within ALARP area (yellow), among which 52 items are within acceptable area (green);

For the above 15 risk items in ALARP area (7 for lifeboat, 8 for launching arrangement), among which 5 items may be addressed through personnel training and operational level. Separate quantitative analysis is required for another 10 items.

FMEA Analysis Sheet of Lifeboat System **Table 2.3**

No.	Equipment	Component	Function	Failure mode	Failure cause	Failure effect		Failure hazards			Risk control measures	Actions recommended
						Local	System	Severity	Probability	Risk		
1.1	Main hull	Bottom shell	To provide buoyancy for lifeboat and a certain degree of stability is guaranteed	Damage	Material/design/ operation		√	4	1	5	…	…
1.2			Frames or longitudinals are normally fixed on the bottom shell, and sometimes the bottom shell will be strengthened by means of transverse bulkheads so as to increase the sustainability	Damage	Material/design/ operation	√		2	1	3	…	…
1.3			The bottom shell is normally made with fire-resistant reinforced fiber plastic product and is with a certain fire resistant capability	Damage	Material		√	2	1	3	…	…
1.4		Seat	Seats are made with reinforced fiber plastic product and the bottom shell is taken as a supporting point to sustain a certain weight	Failure	Material/design/ operation	√		2	1	3	…	…
1.5			Seat structure connecting with the bottom shell may be taken as a strength structure to sustain a certain loads	Failure	Material/design/ operation	√		2	1	3	…	…
1.6		Cover	Cover is a seal structure connected with the bottom shell, which may provide shelter for personnel and equipment in the boat	Damage	Material/design/ operation		√	4	1	5	…	…
1.7			The cover is inter-connected with the bottom shell so as to sustain a certain loads of the boat body	Damage	Material/design/ operation		√	4	1	5	…	…
1.8			The cover is normally made with fire-resistant reinforced fiber plastic product and is with a certain fire resistant capability	Damage	Material		√	2	1	3	…	…

1.9			The cover is similar to the bottom shell that it has wide and large molded line and a certain buoyancy and stability may be provided when the boat is overturned	Damage	Design/operation		√	3	1	4	…	…
2.1	Hatch cover	Fore hatch cover	The external openings of lifeboat are used for entry and evacuation of personnel	Damage	Design/operation	√		…	…	…	…	…
2.2			Natural ventilation opening is provided by opening the hatch cover. Other hatch covers are provided with sandwich structure which may be taken as ventilating ducts	Damage	Design/operation	√		…	…	…	…	…
2.3			The boat hook is positioned near the fore and aft hatch covers. The operation personnel is to operate at the hatch cover to confirm that the boat hook is restored completely when the boat is recovered.	Damage	Design/operation	√		…	…	…	…	…
2.4		Top hatch cover	The external openings of lifeboat are used for entry and evacuation of personnel	Damage	Design/operation	√		…	…	…	…	…
2.5			Natural ventilation opening is provided by opening the hatch cover.	Damage	Design/operation	√		…	…		…	…
2.6			The boat hook is positioned near the fore and aft hatch covers. The operation personnel is to operate at the hatch cover to confirm that the boat hook is restored completely when the boat is recovered.	Damage	Design/operation	√		…	…		…	…
2.7		Aft hatch cover	The external openings of lifeboat are used for entry and evacuation of personnel	…	…	√		…	…		…	…
2.8			Natural ventilation opening is provided by opening the hatch cover. Other hatch covers are provided with sandwich structure which may be taken as	…	…	√		…	…		…	…

			ventilating ducts									
2.9			The boat hook is positioned near the fore and aft hatch covers. The operation personnel is to operate at the hatch cover to confirm that the boat hook is restored completely when the boat is recovered.	…	…	√		…	…		…	…
…	**…**		…	…	…	…		…	…	…	…	…

FMEA Analysis Sheet of Launching Arrangements **Table 2.4**

No.	**Equipment**	**Component**	**Function**	**Failure mode**	**Failure cause**	**Failure effect**		**Failure hazards**			**Risk control measures**	**Actions recommended**
						Local	**System**	**Severity**	**Probability**	**Risk**		
1.1	Base	Eye plate	To provide interface for the base and gib arm and connect with deck to transmit the force on the base to the stiffening structures below the deck	Damage	Material/design/ operation		√	4	1	5	…	…
1.2		Supporting structure	To transmit the force and force moment of gib arm to the deck supporting structure	Damage	Material/design/ operation		√	4	1	5	…	…
1.3		Continuous bolt	Connect base and gib arm	Damage	Material/design/ operation		√	3	1	4	…	…
2	Gib arm	Gib arm structure	Main supporting structure of lifeboat davit, which is used to control the rope throwing position for the recovery and release of steel wire rope	Damage	Material/design/ operation		√	4	1	5	…	…
3	Cylinder supporting arm	Supporting structure	Main structure of supporting gib arm, used together with hydraulic cylinder, which is capable of controlling the recovery and flare of gib arm	Damage	Material/design/ operation		√	4	1	5	…	…
4.1	Lifting hook assembly	Sheave	To transmit the loads of lifeboat to the connection assembly of steel wire rope to reduce the force on single rope and sheave is normally provided; Fixed pulley is fixed on the gib arm to change the force direction of steel wire rope	Damage	Material/design/ operation	√		2	1	3	…	…

4.2		Eye plate	Connect steel wire rope and gib arm	Failure	Material/design/ operation	√		2	1	3	…	…
4.3		Link	Connect the steel wire rope and other lifting hook assembly	Failure	Material/design/ operation	√		2	1	3	…	…
4.4		Fixed pulley	To change the direction of steel wire rope	Failure	Material/design/ operation	√		2	1	3	…	…
4.5		Fall	To transmit the loads of lifeboat to gib arm	Failure	Material/design/ operation	√		3	1	4	…	…
…	…		…	…	…	…	…	…	…	…	…	…

2.6.4 Determination of evaluation criteria

2.6.4.1 According to the results of above FMEA analysis, related criteria are to be established for the risks below and further quantitative analysis is to be carried out:

(1) Changes of evacuation route, location of assembly station, areas, lifeboat embarkation speed are to be considered due to the increase in the number of passengers on lifeboat. According to the existing SOLAS convention, the personnel evacuation performance criteria are as follows:

1）$E \leq 10$ min.；

2）$E + L \leq 30$ min.；

3）$1.25\,(R + T) + 2/3\,(E + L) \leq n$。

where: E is embarkation duration, L is launching duration, R is response duration, T is the total travel duration.

(2) The effect on the comfort inside the boat due to the increase in the number of passengers is to be considered and the long-term CO_2 concentration inside the lifeboat is at least to be controlled below 5000 ppm within 24 hours.

(3) The effect on the structural strength resulting from the increase in the size of lifeboat due to the increase in the number of passengers is to be considered. In addition to relevant criteria in 4.4 of Chapter IV of the existing LSA Code, the structural strength is to meet relevant criteria in CCS Rules for Construction of Coastal Boats.

(4) The effect on the stability of boat resulting from the increase in the size of lifeboat due to the increase in the number of passengers is to be considered. The intact stability, damage stability, passengers crowding to one side and reserve buoyancy are to be checked according to relevant criteria of 4.4 of Chapter IV of LSA Code. For ships flying the flag of China, relevant criteria in China MSA Technical Regulations for Surveys of Coastal Boats are to be met.

(5) The effect on the strength of launching arrangements and release mechanism together with the supporting structures due to increase in the weight of lifeboat is to be considered. Strength is to be checked according to relevant criteria in 6.1 of Chapter VI of LSA Code.

2.6.5 Quantitative analysis

2.6.5.1 Effect on personnel safety of lifeboat and arrangement of life-saving appliances is to be assessed through personnel evacuation analysis.

Examples for personnel evacuation scenarios **Table 2.5**

No.	Scenario illustration	Result
1	Analysis of personnel evacuation under normal condition	
2	A lifeboat is not available under severe condition and evacuation system is used	
3	…	

2.6.5.2 Quantitative analysis of performance criteria for lifeboat and its davit

(1) Criteria for the environmental fitness within lifeboat

Performance criteria: the long-term CO_2 concentration within the boat is not to exceed 5000 ppm within 24 hours.

…

According to the model calculation results, ventilation volume of [x]m^3/h is to be provided by the ventilation arrangements of lifeboat, mechanical ventilation is actually provided in lifeboat and the ventilation volume is qualified.

(2) Criteria for structural strength of body of lifeboat

Calculation of the strength under overload lifting condition

…

Structural rules calculation

…

(3) Stability criteria of lifeboat

Intact stability calculation

…

Damage stability calculation

…

Calculation of passengers crowding to one side

…

Reserve buoyancy calculation

…

(4) Criteria of strength of launching arrangements and release mechanism

Strength calculation of launching arrangements

…

Calculation of release mechanism and its base and supporting structure inside the boat

…

2.6.6 Conclusions

After assessment, the safety of the alternative design plan for lifeboat was proved to meet various performance criteria and indexes and the safety level was guaranteed not to be lower than that specified in prescriptive requirements of SOLAS and LSA Code.

Annex 1 Application for Alternative Design and Arrangements

Particulars of ship	Name of ship Main dimensions Structure Major equipment Service area
Background and necessities	
Scope of application	
Applicable prescriptive requirement	
Attachments	

Note: additional pages may be attached if the space is not enough.

Submitted by_______________(Signature/stamp)

DD____MM____YYYY_______