U.S. Department
of Transportation

**United States
Coast Guard**

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NAVIGATION AND VESSEL INSPECTION CIRCULAR NO. 3 01

Subj: GUIDE TO ESTABLISH EQUIVALENCY TO FIRE SAFETY REGULATIONS FOR SMALL PASSENGER VESSELS (46 CFR SUBCHAPTER K)

1. PURPOSE.

a. This Circular explains the Coast Guard accepted equivalency process for evaluation of small passenger vessel designs under Subchapter K, Title 46, Code of Federal Regulations (46 CFR) 114.540 and 116.340. These guidelines are intended for application of fire safety engineering design as a means to provide technical justification for alternative design and arrangement equivalencies to Subchapter K without compromising the minimum level of safety. The guidelines serve to outline a methodology for the engineering analysis and thereby establish a consistent process for submitting and evaluating proposed equivalencies.

b. This approach provides designers and regulators with a formal method for incorporating novel designs which provide a level of safety that is equivalent to 46 CFR Subchapter K. This approach shall not be used to justify the use of material or equipment, where material or equipment Coast Guard type approvals exist, from a manufacturer that has not undergone the type approval process. As an example, this process should not be used to demonstrate the equivalence of a specific manufacturer's non-type approved structural fire protection insulation, as there are already a number of sources of type approved structural fire protection insulation.

c. This approach shall not be used to justify reduced fire protection requirements based solely on short evacuation times and/or operational restrictions. It should be recognized that due to the number of passengers, a vessel is it's own best rescue platform.

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2. ACTION. Officers in Charge, Marine Inspection and Commanding Officer Marine Safety Center are encouraged to bring this NVIC to the attention of marine interest within their areas of responsibility. It is available on the World Wide Web at **http://www.uscg.mil/hq/g-m/nvic/index.htm**.

3. DIRECTIVES AFFECTED. None.

4. BACKGROUND. Existing regulations have established a level of safety for small passenger vessels that carry more than 150 passengers based on several prescriptive fire safety requirements, including the use of steel or equivalent non-combustible construction. Subchapter K allows for equivalencies and alternative design considerations that provide the same minimum level of safety. However, Subchapter K did not define the procedures or steps necessary to achieve and demonstrate this equivalence. In a joint effort between the Passenger Vessel Association (PVA) and United States Coast Guard, a natural working group (NWG) was therefore chartered to research the feasibility of establishing guidelines for design equivalence with the specified fire safety provisions of Subchapter K and to conduct a trial application to explore the viability of the developed equivalency guidelines. The results of the trial application indicated that the use of standard equivalency guidelines offers an achievable path to demonstrate equivalency through fire safety engineering. The NWG used "*The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings, Society of Fire Protection Engineers and National Fire Protection Association, 2000,*" which deals with similar efforts in design and assessment of building fire safety.

5. DISCUSSION. For the application of these guidelines to be successful, it is essential that all interested parties, including the Officer in Charge, Marine Inspection (OCMI), Marine Safety Center, vessel owners, operators, and designers, be in continuous communication from the onset of a specific proposal to utilize these guidelines. This approach may require significantly more time in calculation and documentation than a typical regulatory design review because of increased engineering analysis.

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Acting Assistant Commandant
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Encl: (1) GUIDE TO ESTABLISH EQUIVALENCY TO FIRE SAFETY REGULATIONS FOR SMALL PASSENGER VESSELS (46 CFR SUBCHAPTER K)

GUIDE TO ESTABLISH EQUIVALENCY TO FIRE SAFETY REGULATIONS FOR SMALL PASSENGER VESSELS (46 CFR SUBCHAPTER K)

Appendices

The following documents are incorporated by reference:

(1) The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings, Society of Fire Protection Engineers and National Fire Protection Association, 2000.

(2) ISO/TR 13387-1 through 13387-8, "Fire safety engineering", International Standards Organization, 1999.

GUIDE TO ESTABLISH EQUIVALENCY TO FIRE SAFETY REGULATIONS FOR SMALL PASSENGER VESSELS (46 CFR SUBCHAPTER K)

1 Application

These guidelines document the required approach for using a fire safety engineering evaluation in order to demonstrate equivalence in accordance with 46 CFR §114.540. While the general framework for this approach is not specific to Subchapter K, the underlying analysis of the existing regulations and safety goals was developed specifically for Subchapter K. In order to adapt this approach to other classes of vessels, a regulatory analysis and agreement as to the goals would have to be agreed upon and documented prior to employing the remainder of the engineering approach.

The fire safety engineering equivalencies developed using this approach will be vessel and application specific. As discussed in section 4 and 5 of this guide, the equivalency analysis must provide detailed documentation of the vessel design and application. As a result, each proposed operating or outfitting change over the course of the vessel's lifetime will need to be evaluated per the original design constraints of the equivalency determination.

This approach provides designers and regulators with a formal method for incorporating novel designs which provide a level of safety that is equivalent to 46 CFR Subchapter K. This approach shall not be used to justify the use of material or equipment, where material or equipment USCG type approvals exist, from a manufacturer that has not undergone the type approval process. As an example, this process should not be used to demonstrate the equivalence of a specific manufacturer's non type approved structural fire protection insulation, as there are already a number of sources of type approved structural fire protection insulation.

For the application of these guidelines to be successful, it is essential that all interested parties, including the Officer in Charge, Marine Inspection (OCMI), Marine Safety Center, vessel owners, operators, and designers, be in continuous communication from the onset of a specific proposal to utilize these guidelines. This approach usually requires significantly more time in calculation and documentation than a typical regulatory prescribed design because of increased engineering rigor. The potential benefits include more options, cost effective designs for unique applications, and an improved knowledge of loss potential.

2 Definitions

For the purposes of these guidelines, the following definitions apply:

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 vs. time.

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.

Fire Safety Concepts Tree (FSCT) - Fault Tree Analysis approach that uses a fault tree diagram to describe the relationships of events that can lead to a system failure.

Fire Safety Goals - In this document the term "goals" refers to the overall intent or purpose of the fire safety regulations.

Fire Safety Objectives - In this document the term "objectives" is used to provide an additional detailed description of the fire safety goals.

Functional Requirements explain, in general terms, what function the ship must provide to meet the fire safety objectives.

Performance Criteria are measurable quantities stated in engineering terms to be used to judge the adequacy of proposed designs.

Prescriptive based design or prescriptive design means a design that complies with the prescriptive regulatory requirement(s) set out in of Subchapter K.

Proposed Design and Arrangements means a design that deviates from and is alternative to the prescriptive regulatory requirement(s) of Subchapter K.

Safety Margin means adjustments made to compensate for uncertainties in the methods and assumptions used to evaluate the proposed design, e.g. in the determination of performance criteria or in the engineering models used to assess the consequences of fire.

Sensitivity Analysis means an analysis to determine the effect of changes in individual input parameters on the results of a given model or calculation method.

Subchapter K means the small passenger vessel regulations contained in 46 CFR §114 through §122.

3 Equivalency Process

The process used to show that the proposed design provides an equivalent level of safety to the Subchapter K regulations should follow an established engineering framework for fire safety design. This approach should be supported by sound fire science and engineering practice incorporating widely accepted methods, empirical data, calculations, correlations, and computer models. Two examples of established approaches to fire safety engineering are listed here.

- The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings, Society of Fire Protection Engineers and National Fire Protection Association, 2000.

- ISO/TR 13387-1 through 13387-8, "Fire safety engineering", International Standards Organization, 1999.

As described in the above referenced documents, the equivalency process consists of two phases: preliminary analysis and quantitative analysis. This process is shown graphically in Figure 1 on the following page. The objective of the preliminary analysis is to review and agree upon the scope of the design proposal, identify potential fire hazards, define performance criteria, and specify representative fire scenarios which are suitable for detailed analysis and quantification. The objective of the quantitative analysis is to demonstrate, using standard tools and methodologies, that the vessel design meets the performance criteria agreed to in the preliminary analysis. The quantitative analysis should be based on both probabilistic and deterministic methods, including engineering calculations, computer modeling, Failure Modes and Effects Analysis, event trees, and scientific fire tests. The following sections provide more detail regarding completion of the equivalency process and the level of documentation that is expected for equivalency determinations.

4 Preliminary Analysis

4.1 The preliminary analysis may begin with a concept review meeting between the USCG Marine Safety Center and the design team. Depending upon the scope and the level of innovation of the equivalency, such meetings may need to be undertaken at a very early stage to agree on the project's scope. Items to be agreed upon may include a definition of the project scope, composition of the team; level of analysis necessary for this project, and fire safety goals and objectives that the proposed design should meet. Early communication between the designers, Marine Safety Center and Officer in Charge, Marine Inspection is critical for ensuring later success of the proposal.

Although much of the information required for the preliminary analysis as described in section 4.9 may not be known, the design team should be prepared to present a proposed text for such a report at this concept review meeting. The purpose of such a meeting is to achieve agreement on the scope of the proposed equivalency and not for the designer to seek out the Coast Guard's opinion of what they need to do.

4.2 Define project scope

The purpose of this stage is to thoroughly define the boundaries of the problem for the proposed design. The vessel, vessel system(s), component(s), and/or equipment subject to the analysis must be thoroughly specified. This includes the vessel or system(s) representing both the proposed design and a regulatory prescribed design. Depending on the extent of the equivalency, some of the information that may be required includes: detailed vessel plans, drawings, or photographs, equipment information and drawings, fire test data and analysis results, vessel operating characteristics and conditions of operation, operating and maintenance procedures, material properties, etc. Accordingly, the project scope definition must, at a minimum, contain all of the relevant information required by Chapter 4 of the SFPE Guide.

This stage of the process should be started during the earliest stages of the design conception, i.e. at the first point at which the owner or naval architect acknowledges that an equivalency will be necessary. This stage should also be the indication for the naval architect or owner to arrange the concept review meeting to discuss the scope of the equivalency with the USCG Marine Safety Center. If a basic evaluation is required then it is likely that all of the project definition can occur during the initial meeting.

USCG Fire Safety Equivalency Process

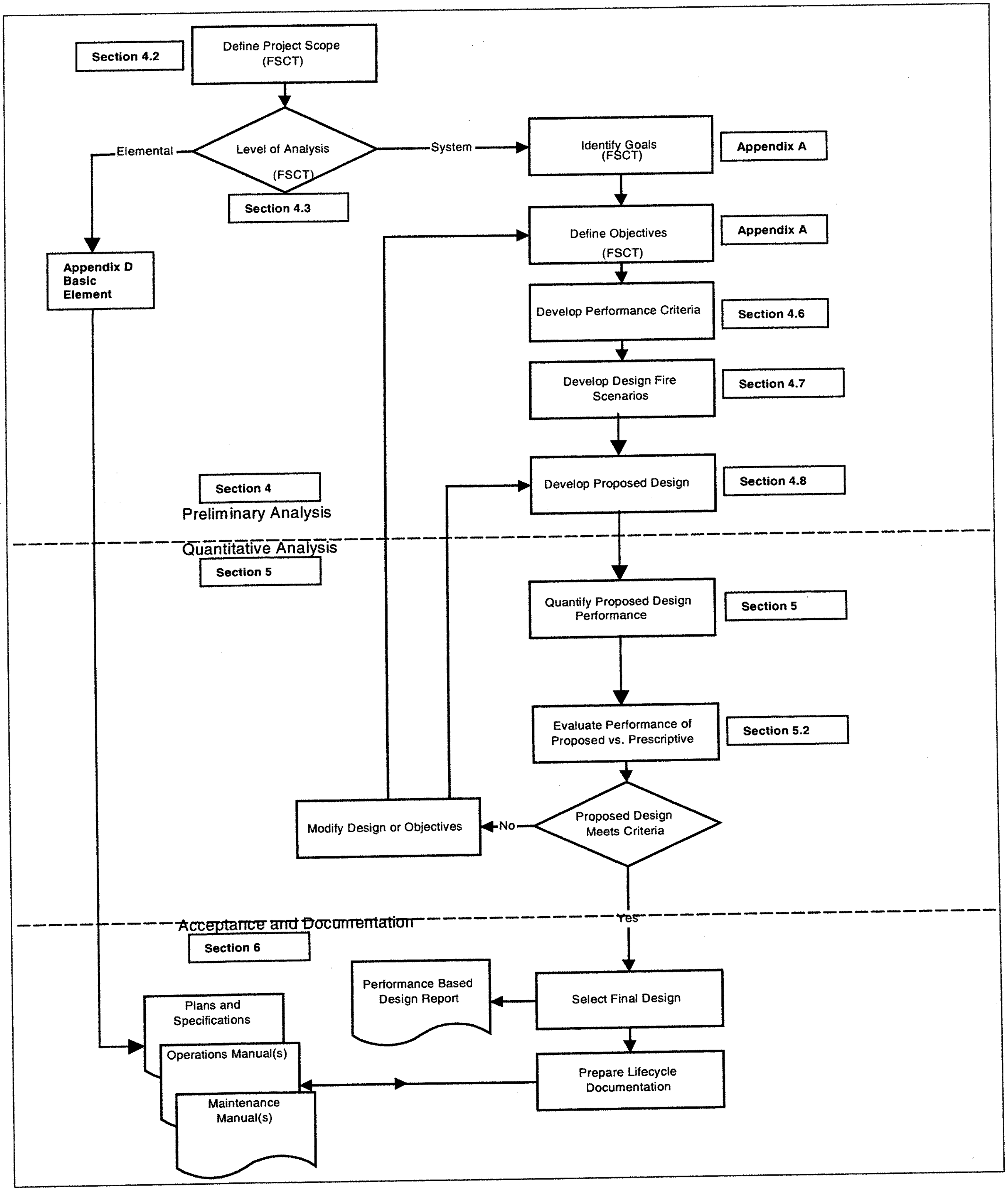


Figure 1

4.3 Level of analysis

In order to select the level of analysis that will be necessary, it is important to gain a specific understanding of how the deviation will affect the fire safety system. To assist with this decision, the Subchapter K regulations have been mapped to their corresponding fire safety concepts, as shown in Appendix A. Thus, when agreeing upon the level of analysis, it is recommended that the design team consult Appendix A to determine whether the proposed equivalency constitutes a basic element or system wide equivalency. In general, a basic element equivalency is an equivalency that affects a regulation at only the lowest level in the FSCT. Basic equivalencies require much less documentation and rigor for the preliminary analysis. As such, it is recommended that the simplified analysis discussed in Appendix D be used for a basic element analysis. A system analysis is appropriate when the equivalency will affect multiple nodes on the same branch or multiple branches of the FSCT. As such, a system analysis should follow the procedures and requirements outlined in the following sections.

4.4 Design team

A design team should be established by the owner, builder or designer and may include, as the proposed design or arrangement demands, a representative of the owner, and builder or designer. Other members may include marine surveyors, fire protection engineers, vessel operators, safety engineers, equipment manufacturers, human factor experts, naval architects and marine engineers. The design team should communicate with the Coast Guard for advice on the acceptability of the engineering analysis of the proposed design and arrangement throughout the entire process. The level of expertise that individuals should have to participate on the team will vary depending on the complexity of the proposed design or arrangement for which approval is sought. Since the evaluation, regardless of complexity, will have some effect on fire safety, at least one expert with knowledge and experience in fire safety should be included as a member of the team.

4.5 Goals and objectives

Once the project scope has been defined and agreed upon, the design team should identify and agree on the fire safety goals and objectives. Although some of the regulations now include a statement of goals and objectives the Subchapter K regulations do not. Thus the goals and objectives of Subchapter K had to be interpolated from the existing regulations. Appendix A provides a list of the goals and objectives (and the method used to determine them) for the Subchapter K regulations. It is recommended that these goals and objectives be the foundation for developing the performance criteria that are specific to the equivalency proposal.

4.6 Develop performance criteria

Performance criteria are quantitative expressions of the fire safety objectives and functional requirements of the regulations. The required performance of the proposed design is specified numerically in the form of performance criteria. Performance criteria may include tenability limits such as smoke obscuration, temperature, height of the smoke and hot gas layer in a compartment, evacuation time, or other criteria necessary to ensure a successful fire safety design and arrangements. Depending on the prescriptive requirements to which the approval of the proposed design or arrangement is sought, these performance criteria could fall within one or more of the following areas:

- Life safety criteria – These address the survivability of passengers and crew and may represent the effects of heat, smoke, toxicity, reduced visibility, and evacuation time.

- Criteria for damage to ship structure and related systems – These address the impact that fire and its effluents might have on the ship structure, mechanical systems, electrical systems, fire protection systems, evacuation systems, propulsion and maneuverability, etc. These criteria may represent thermal effects, fire spread, smoke damage, fire barrier damage, degradation of structural integrity, damage to environment, etc.

- Criteria for damage to the environment - These address the impact of heat, smoke and released pollutants on the atmosphere and marine environment.

The design team should consider the impact that one particular performance criterion might have on other areas that might not be specifically part of the proposed design. For example, the failure of a fire barrier may not only affect the life safety of passengers and crew in the adjacent space, but it may result in structural collapse, exposure of essential equipment to heat and smoke, and the involvement of additional fuel in the fire.

For the purposes of this document, the performance criteria should be developed from one of the following sources: (1.) Direct interpretation of the current prescriptive regulations (See section 3.3.2 of the SFPE Guide); (2.) Quantitative analysis of a "similar" vessel that is built in accordance with the regulatory requirements.

4.6.1 Direct Interpretation

In some cases, performance criteria may be determined by a direct interpretation of the regulations, taking into consideration the fire safety objectives and the functional requirements. The following example is an illustration of this:

<u>Example of deterministic Performance Criteria drawn directly from the regulations</u>:

Assume that a design team is developing performance criteria for preventing fire spread through a bulkhead separating a galley from an accommodation space. They are seeking a numerical form for the performance criteria.

e.1 46 CFR §116.415 requires an A-60 boundary between areas of high fire risk (like a machinery space or galley) and accommodation spaces.

e.2 46 CFR §116.415 contains the definition of an A-class division, which includes the maximum temperature rise criteria of 181 °C at any one point, during the 60-minute fire exposure required by the regulations.

e.3 Therefore, one possible performance criterion for this analysis is that "no point on the other side of the bulkhead shall rise more than 180 °C above ambient temperature during the 60-minute fire exposure required by the regulations."

4.6.2 Quantitative evaluation of a comparable regulatory design

If the performance criteria for the proposed design and arrangements cannot be determined directly from the prescriptive regulations because of novel or unique features, they may be developed from a quantitative evaluation of the intended performance of a similar vessel built to Subchapter K regulations. This is a useful method for developing performance criteria where it is difficult to quantify the desired performance in terms of absolute values. By stating the performance criteria in terms of the performance of a regulatory design, it can be inherently assumed that the features incorporated in the regulatory design provide an overall acceptable level of safety.

Comparative performance criteria should be specified in terms of a comparison to a similar prescriptive design. Further, since the proposed design will invariably have some differences from the regulatory design, the criteria should also address cases when the regulatory design does not provide a sufficient level of performance. As an example: "*The proposed design shall provide the lesser of: the evacuation time for a vessel built to the requirements of 46 CFR 116.500; or the minimum evacuation time required by the assumed design fires for the proposed design.*" When the performance criteria are determined through comparative analysis it will be necessary for the design team to quantify the performance of both the proposed design and the regulatory prescribed design during the quantitative analysis.

Once all of the performance criteria have been established, the design team can then proceed with the evaluation of the proposed design(s).

4.7 Develop fire scenarios.

Fire scenarios will provide the basis for analysis and proposed design evaluation and therefore are the backbone of the proposed design process. Proper fire scenario development is essential and depending on the extent of deviation from the prescribed design, may require a significant amount of time and resources. For each of the identified fire hazards, a range of fire scenarios should be developed. The use of event trees is recommended to systematically determine all of the possible fire scenarios resulting from a specific hazard. Because the proposed design approach is based on a comparison against the regulatory prescribed design, the quantification can often be simplified. In many cases, it may only be necessary to analyze one or two scenarios if this will provide enough information to evaluate the level of safety of the proposed design and arrangements against the agreed performance design. Appendix B provides a minimum design fire scenario that should be considered. This process can be broken down into the identification of fire hazards, enumeration of fire hazards, selection of fire hazards, and specification of design fire scenarios.

4.7.1 Identification of fire hazards

This step is crucial in the fire scenario development process as well as in the entire alternative design methodology. If a fire hazard or incident is omitted, then it will not be considered in the analysis and the resulting final design may be inadequate. Fire hazards may be identified using historical and statistical data, expert opinion and experience, and hazard evaluation procedures. There are many hazard evaluation procedures available to help identify the fire hazards such as failure modes and effect analysis and What-if, analysis. As a minimum, the following conditions and characteristics should be identified and considered:

.1 Pre-fire situation: vessel, 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, and 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, operational, time of day, etc.

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

4.7.2 Selection of fire hazards

The number and type of fire hazards that should be selected for the quantitative analysis is dependent on the complexity of the proposed design and arrangements. All of the fire hazards identified should be reviewed for selection of a range of incidents. In determining the selection, frequency of occurrence does not need to be fully quantified, but it can be utilized in a qualitative sense. The selection process should identify a range of incidents that will cover the largest and most probable range of enumerated fire hazards. Because the engineering evaluation relies on a comparison of the proposed design and arrangements with prescriptive designs, demonstration of equivalent performance during the major incidents will adequately demonstrate the design's equivalence for all lesser incidents and provide the commensurate level of safety. In selecting the fire hazards it is possible to lose perspective and to begin selecting highly unlikely or inconsequential hazards. Care should be taken to select the most appropriate incidents for inclusion in the selected range of incidents.

4.7.3 Specification of design fire scenarios.

The fire scenarios to be used in the quantitative analysis should be developed based upon the fire hazards selected and clearly documented. The specification should include a qualitative description of the design fire (ignition source, fuel first ignited, location, etc.), description of the vessel, compartment of origin, fire protection systems installed, number of occupants, physical and mental status of occupants, and available means of escape. The fire scenarios should consider possible future changes to the fire load and ventilation system in the affected areas.

4.8 Develop proposed designs

At this point in the analysis one or more proposed designs should be developed that will be compared against the developed performance criteria. The proposed design should also take into consideration the importance of human factors, operations, and management. It should be recognised that well defined operations and management procedures may play a big part in increasing the overall level of safety

4.9 Preliminary analysis report

A report of the preliminary analysis should include clear documentation of all steps taken to this point, including identification of the design team, their qualifications, the scope of the alternative design analysis, the functional requirements to be met, the description of the fire scenarios, and proposed designs selected for the quantitative analysis.

The preliminary analysis report should be submitted to the Marine Safety Center for formal review and agreement prior to beginning the quantitative analysis. The report may also be submitted to the local Officers in Charge, Marine Inspection for informational purposes, if the intended construction and/or calling ports are known during the design stage. Chapter 11 of the SFPE Guide contains the minimum requirements for the information that must be contained in the preliminary analysis report in addition to the following key results:

- definition of the project scope;
- agreement on the level of analysis necessary for this project;
- agreement on the fire safety goals and objectives;
- agreement on the performance criteria;
- specified design fire scenario(s) acceptable to all parties; and
- proposed design(s) to be evaluated.

5 Quantitative Analysis

From a fire safety-engineering standpoint the quantitative analysis is the most labor intensive. It consists of quantifying the design fire scenarios and evaluating the performance of proposed designs against the agreed prescriptive performance criteria.

The quantification of the design fire scenarios may include calculating the effects of fire detection, alarm and suppression methods; and estimating consequences in terms of fire growth rate, heat fluxes, heat release rates, flame heights, smoke and toxic gas generation, etc. This information will then be utilized to evaluate the proposed design(s) selected during the preliminary analysis.

Risk assessment may play an important role in this process. It should be recognised that risk cannot ever be completely eliminated. Throughout the entire performance based design process, this fact should be kept in mind. The purpose of performance design is not to build the fail safe design, but to specify a design with reasonable confidence that it will perform its intended function(s) when necessary and in a manner equivalent to or better than the prescriptive fire safety requirements of Subchapter K.

5.1 Quantify the proposed designs

Quantification of the fires should be accomplished for each of the incidents identified in the preliminary analysis. Quantification will require specification of all factors that will affect the type and extent of the fire hazard. This may include calculation of heat release rate curves, flame height, length, and tilt, heat fluxes, smoke production rate, pool fire size, duration, etc. A number of correlations and models are contained within the references listed in Appendix C. It should be noted that when using any of these tools or others, the limitations and assumptions of these models should be well understood and documented. This becomes very important when deciding on and applying safety margins. Documentation of the proposed design should explicitly identify the fire models used in the analysis and their applicability. Reference to the literature alone will not be considered as adequate documentation.

Time lines should be developed for each of the fire scenarios beginning with fire initiation. These time lines should include one or more of the following: ignition, established burning, fire detection, fire alarm, fire suppression/control system activation, personnel response, fire control, escape times (to muster station, evacuation stations, and lifeboats as necessary), manual fire response, untenable conditions, etc. The time line will include fire size throughout the scenario, as determined using the various correlations, models, and fire data from the literature or actual fire tests.

In certain cases, live fire testing and experimentation may be necessary to properly predict the fire characteristics. Regardless of the calculation procedures utilized, the persons conducting such analyses should fully understand the uncertainties and limitations involved and where necessary, a sensitivity analysis should be conducted.

5.2 Evaluate the proposed designs

All of the data and information generated during the preliminary analysis and specification of design fires will serve as input to the evaluation process. The level of engineering rigor required in any particular analysis will depend on the level of analysis required to demonstrate equivalency of the proposed design and arrangements to the prescriptive requirements. Obviously, the more components, systems, operations, and parts of the ship that are affected by a particular proposed design, the larger the scope of the analysis.

Each selected proposed design should be analyzed against the selected design fire scenarios to demonstrate that it meets the performance criteria with any agreed safety margin, which in turn demonstrates equivalence to the prescriptive design. This represents a decision point in the quantitative analysis: if the quantitative analysis demonstrates an equivalent level of safety, then the process is done; otherwise, additional alternatives or new design constraints need to be sought out. Once the design team determines that the performance criteria have been satisfied, the quantitative analysis should be submitted to the Marine Safety Center for approval. In reviewing the quantitative analysis, the Marine Safety Center will ask the following questions:

- Have all the performance criteria been demonstrated?
- Has an industry accepted engineering approach been used to quantify the analysis?
- Have safety factors that are appropriate to the method of analysis been applied?

The final proposed design and arrangements should be selected from the proposed designs that meet the selected performance criteria and safety margins.

6 Documentation

Because the alternative design process may involve substantial deviation from the regulatory prescribed requirements, the process should be thoroughly documented. This provides a record that will be necessary if future design changes to the vessel are proposed, as well as providing much detail and information that may be adapted for use in future designs. The following information should be provided for approval of the proposed design and arrangements:

1. Scope of the analysis or design;

2. Description of the proposed design(s) and arrangements(s), including drawings and specifications;

3. Results of the Preliminary Analysis:

   .1 members of the design team (including qualifications);

   .2 description of each proposed design(s) and arrangement(s) being evaluated;

   .3 discussion of affected 46 CFR Regulations, and their functional requirements;

   .4 fire hazard identification;

   .5 enumeration of fire hazards;

   .6 selection of fire hazards; and

   .7 description of design fire scenarios;

4. Results of Quantitative Analysis:

   .1 design fire scenarios:

   - critical assumptions
   - amount and composition of fire load
   - engineering judgements
   - calculation procedures
   - test data
   - sensitivity analysis
   - time lines

   .2 performance criteria;

.3 evaluation of proposed designs against performance criteria;

.4 description of final design;

5. Test, inspection, and maintenance requirements; and

6. References

The following items should be maintained onboard the ship or at another location acceptable to the local OCMI:

1. Scope of the analysis or design, including the critical design assumptions and critical design features.

2. Description of the proposed design(s) or arrangement(s), including drawings and specifications.

3. Listing of affected 46 CFR Regulations.

4. Summary of the results of the Preliminary and Quantitative Analysis and basis for approval.

5. Documentation of approval by the Coast Guard.

6. Test, Inspection, and Maintenance Requirements.

APPENDIX A: Application of the Fire Safety Concepts Tree (FSCT) to Subchapter K

Existing regulations have established a level of safety for small passenger vessels carrying more than 150 passengers based on several passive fire safety requirements, including the use of steel or equivalent non-combustible construction. There are provisions for equivalency in the regulations for Subchapter K passenger vessels in 46 CFR 114.540 and 116.340 which allow deviation from specific fire safety provisions of the regulations provided an equivalent level of safety is demonstrated. This appendix provides a method to identify the fire safety concepts inherent in the Subchapter K regulations.

1 Fire Safety Goals and Objectives of 46 CFR Subchapter K

Goals and objectives identified for preventing fire and managing fire impact must be used in the comparative analysis. The goals state what is expected in terms of the overall fire safety design. The objectives explain, in general terms, what function the vessel or vessel system must provide to meet the goals. The performance criteria developed during the preliminary analysis serve as detailed requirements necessary to achieve the objectives and specifically address the deviations from the prescriptive regulations.

1.1 Main Fire Safety Goal

.1 To ensure the life safety of passengers and crew.

1.2 Prevent Fire/Ignition Goals

.1 To prevent ignition to combustible materials and flammable liquids.
.2 To prevent ignition/explosion of flammable vapors.

1.2.1 Prevent Fire/Ignition Objectives

.1 Flammable liquid storage, processing and pumping systems and components shall be installed in a manner that reduces the potential of leaks and accumulation and concentration of flammable vapors.
.2 Fuel burning machinery, appliances, and services shall be installed in a manner that reduces their potential as a source of fire ignition to flammable liquids or combustible materials.
.3 Electrical equipment, appliances, and services shall be installed in a manner that reduces their potential as a source of fire ignition to flammable liquids or combustible materials.

1.3 Manage Fire Impact Goals

.1 To protect passengers and crew from injury or illness when evacuating from a vessel or vessel area during a fire.
.2 To limit the spread of fire and smoke within, on or through the interior and exterior of the vessel.
.3 To provide protection to crew response personnel during rescue and firefighting operations.

1.3.1 Manage Fire Impact Objectives

.1 Vessels shall be provided with safeguards against fire spread so that occupants have time to escape to an area of safe refuge without being overcome by the effects of fire and crew firefighters may undertake rescue and firefighting operations.

.2 Vessels shall be constructed to maintain structural integrity for an adequate time to allow passengers and crew to evacuate safely to an area of safe refuge and to allow crew firefighters to undertake rescue and firefighting operations.

2 Fire Safety Analysis of 46 CFR Subchapter K

The method for performing an actual fire safety analysis of Subchapter K was exemplified over a six-month period from June 1998 to January 1999 by a diverse group of personnel from the passenger vessel industry. The group selected National Fire Protection Association (NFPA) 550, *Guide to the Fire Safety Concepts Tree*, 1995 Edition, as the methodology for documenting the concepts embodied in the existing regulations. Expert opinion was used to map the Subchapter K regulations to fire safety concepts presented in the tree. The analysis revealed that the regulations provide a balanced approach to fire safety, relying on both fire prevention and fire management. The following sections provide a brief discussion of the methodology, analysis, and results.

2.1 Methodology: The Fire Safety Concepts Tree

The FSCT provides a system-based approach for describing and documenting fire safety concepts. Similar to the fault tree methodologies, developed as a part of the U.S. space program, the FSCT was first employed in the early 1970s to identify and define adequate fire safety measures for high-rise structures. In 1980, the FSCT was updated and formally adopted as a recommended practice by the NFPA. Since becoming an NFPA Code, the FSCT has been used for all aspects of fire protection analysis including building design, building management, code equivalency, and fire science research. Additionally, the FSCT has been used, or proposed for use, as a guide for code organization, standards organization, information retrieval, curriculum development, marketing, indexing, and fire investigation. It has been successfully employed in both the private and government industries: a major U.S. Corporation adapted the FSCT as a table to their "Fire Safety Practices" and the U.S. Department of State used the FSCT to evaluate their foreign property. The FSCT's widespread use and easy-to-understand framework made it an ideal tool for documenting the fire safety concepts in Subchapter K. The following paragraphs provide a basic introduction to the FSCT. For more detailed information, the reader is referred to the full text of NFPA 550.

The FSCT starts with a set of objectives, and then offers options as to how to accomplish those objectives by expanding upon two basic approaches to fire safety: fire prevention and fire management. Figure A1 on the following page, shows that theoretically, fire safety objectives can be accomplished by either preventing the fire or by managing the fire impact. The OR gates used in the FSCT are inclusive. Inclusive OR's allow contributions from all of the lower elements, but recognize that only one of the elements is required to satisfy the objectives. As shown in Figure 1, the tree branches out as each concept is further simplified into basic elements. As Figure 1 shows, fire prevention can be accomplished by either controlling the heat, fuel, or heat-fuel interactions. Fire management consists of either managing the fire, or managing the exposed resources. Figure A1 shows that theoretically meeting the main fire safety goal is a function of either preventing a fire from starting or by managing the impact of the fire. It should be noted that in actuality, as can be seen in Figures A2 and A3 on pages A-5 and A-6 respectively, the specific fire safety regulations address both preventing a fire and managing the impact to achieve the fire safety objectives. Figure A1 represents only the upper elements of the tree; lower levels continue to breakdown the concepts through the use of more specific elements combined by AND/OR gates. As with other tree-based methodologies, the hierarchy goes from broader requirements,

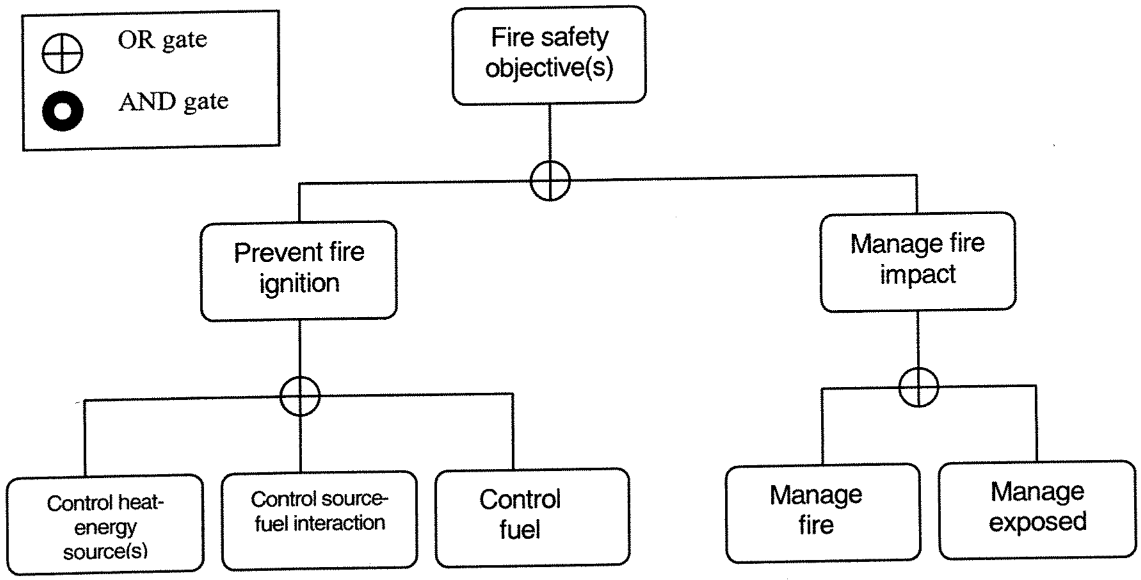


Figure A1 – Upper Levels of Fire Safety Concepts Tree.

near the top of the tree, to more specific means of accomplishing these requirements at the lower levels of the tree.

When used for fire safety design, the FSCT analysis starts at the top and works down through the elements. This approach is heavily dependent on defining the fire safety objectives at the outset of the analysis. Fire safety objectives commonly referenced in design include protection of life, property, and the environment, or ensuring the continuity of operations. While these objectives apply equally to the maritime industry, there was no need to define them or adopt them as part of this analysis, the group was focusing on documenting the current practices. In contrast to fire safety design, this analysis focused on "reverse engineering" the existing regulations. As such, the approach used for this analysis was to work from the bottom elements up, which corresponded to the more specific requirements typically found in the regulations.

A critical limitation of this tool for this analysis is the FSCT's inability to adequately address the interaction of fire safety concepts. Specifically, the FSCT does not consider multiple interactions of fire safety concepts, i.e., concepts that are inputs into more than one strategy. As an example, within this analysis the group found that for Subchapter K vessels, non-combustible structure was beneficial to both fire prevention and fire management. Thus if non-combustible structure is altered, the alteration affects multiple branches of the tree. When multiple branches are affected by the removal of one element, the OR relationship between these branches is invalidated, and the FSCT becomes limited in its ability to analyze and promote alternatives. While the Tree's inability to deal with multiple interactions did not prevent us from completing the analysis of Subchapter K, it does limit the application of this analysis for future equivalency determinations. The following section provides a brief narrative of how the methodology was employed to document the fire safety concepts in Subchapter K.

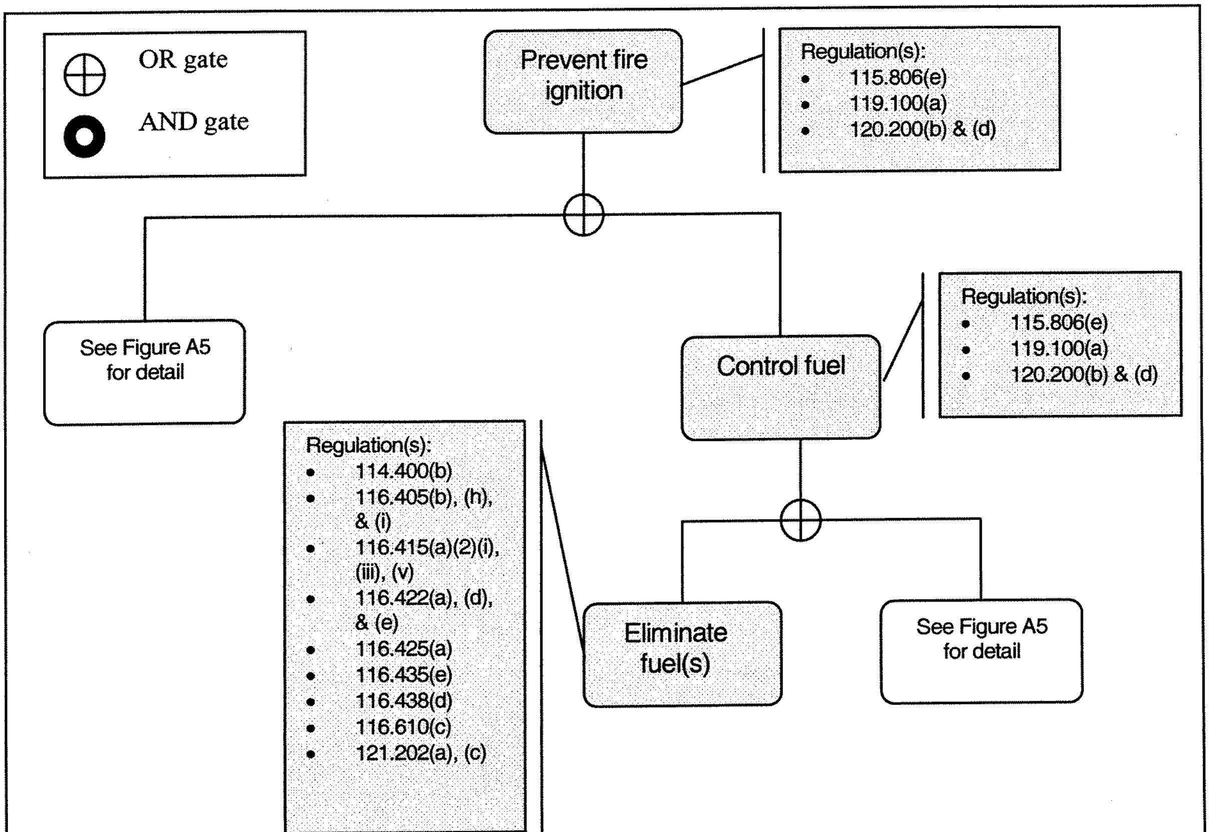


Figure A2 – Subchapter K Emphasis on Fire Prevention.

2.1 Fire Safety Analysis: Results

The following figures provide the most readily understandable depiction of how the fire safety regulations in Subchapter K are mapped to the FSCT. It is readily apparent from these figures that the regulations span all of the major branches of the tree. This widespread nature indicates that the fire safety regulations in Subchapter K are a complex balance of fire prevention and fire management. However, as anticipated, the regulations place particular emphasis on only a few elements in each major branch of the tree. These elements are thought to be the critical fire safety concepts in Subchapter K, as they have the greatest number of regulations associated with them. The following paragraphs discuss the critical fire safety concepts for fire prevention, fire management, and management of the exposure to passengers and crewmembers.

Fire prevention in Subchapter K spans all of the elements in this branch of the tree. There are regulations which prohibit heat sources from hazardous spaces, require separation between combustibles and heated surfaces, and which place restrictions on the type and amount of fuel in the space. Of these approaches to fire prevention, restrictions on the amount of fuel, are the most heavily emphasized by the regulations. As noted in Figure A2, the majority of the restrictions on fuel quantity come from the regulations in 46 CFR 116. These particular regulations focus primarily on restricting the amount of combustible materials in the vessel construction. The prevailing group opinion was that these particular regulations served two purposes: first, to reduce or eliminate the number of potential ignition sources, and second to restrict the spread of fire. Accordingly, these regulations are also included on the fire management branch of the tree.

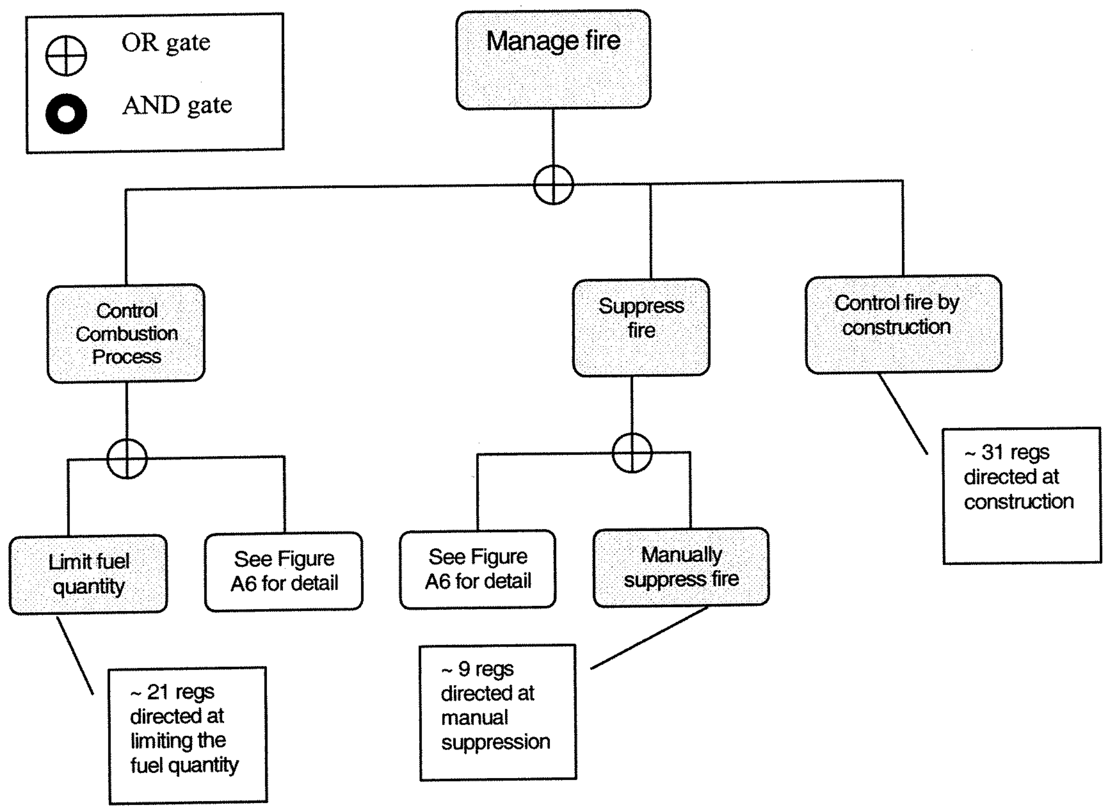


Figure A3 – Subchapter K Emphasis on Fire Management

Fire management can occur through controlling the combustion process, suppressing the fire, or controlling the fire by construction. As shown in Figure A3 above, the regulations in Subchapter K apply a balanced approach through limiting the fuel quantity, controlling the fire through the vessel construction, and relying primarily on manual suppression. The spread of regulations across this branch of the FSCT indicates that equivalency determinations dealing with fire management are not likely to be simple decisions. Instead, the equivalency determinations should be reviewed as a system wide equivalency that incorporates increased fire prevention and better management of the crew and/or passengers (shown as managed exposed in figures).

As anticipated, the passenger vessel regulations emphasize capacity and egress route access elements for management of the crew and/or passengers. In this respect, the Subchapter K regulations are similar to Subchapters H and T, in terms of specifying the number and dimensions of the means of escape in great detail. In addition to these requirements, Subchapter K regulations also emphasize providing a safe destination by requiring documented and protected areas of refuge. Although safe destinations are not emphasized in terms of the quantity of regulations, they are clearly one of the fire safety concepts that are inherent in Subchapter K.

Figure A4: Top Gate of Fire Safety Concept Tree

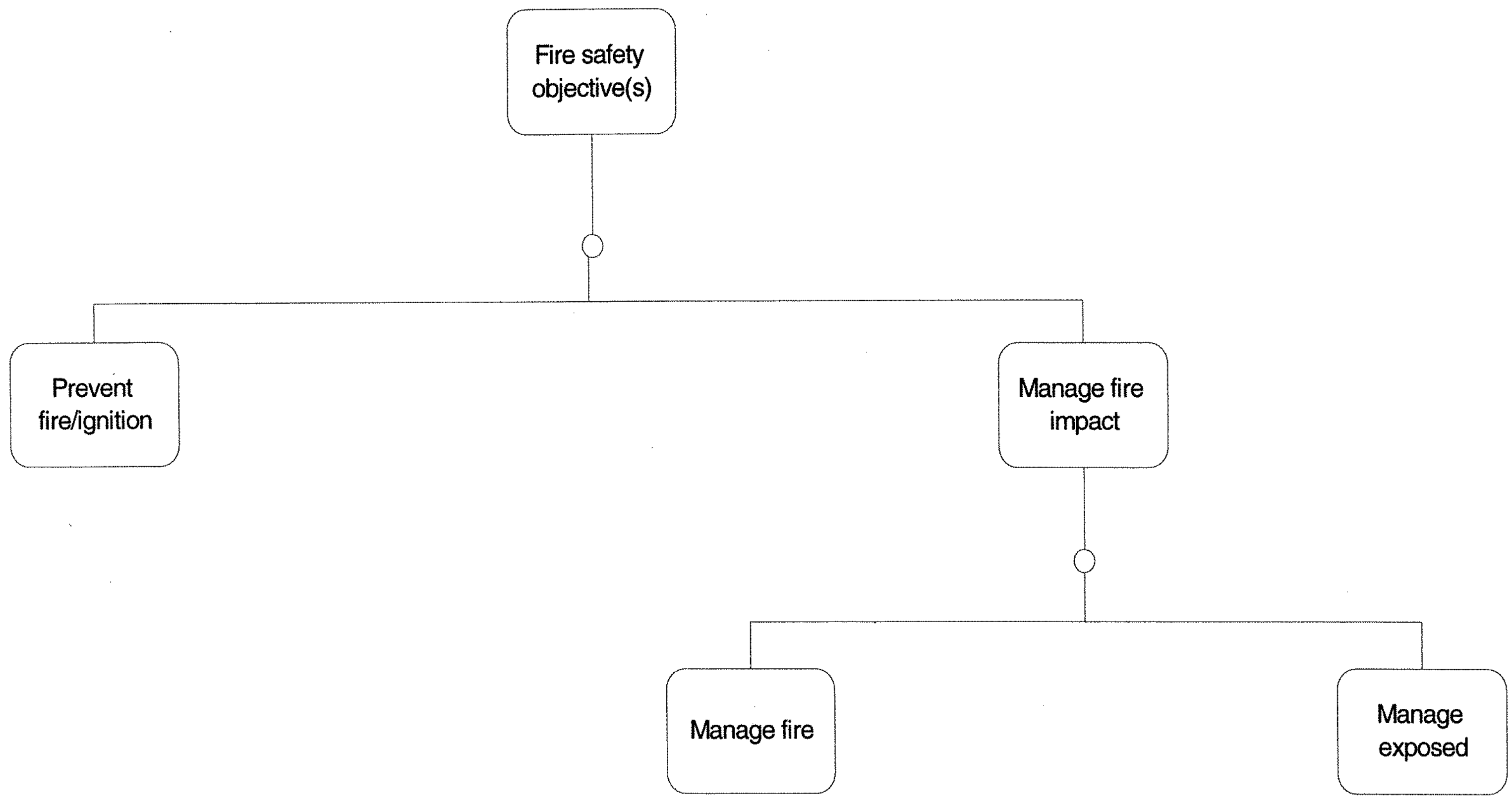


Figure A5: Prevent fire ignition branch of Fire Safety Concept Tree

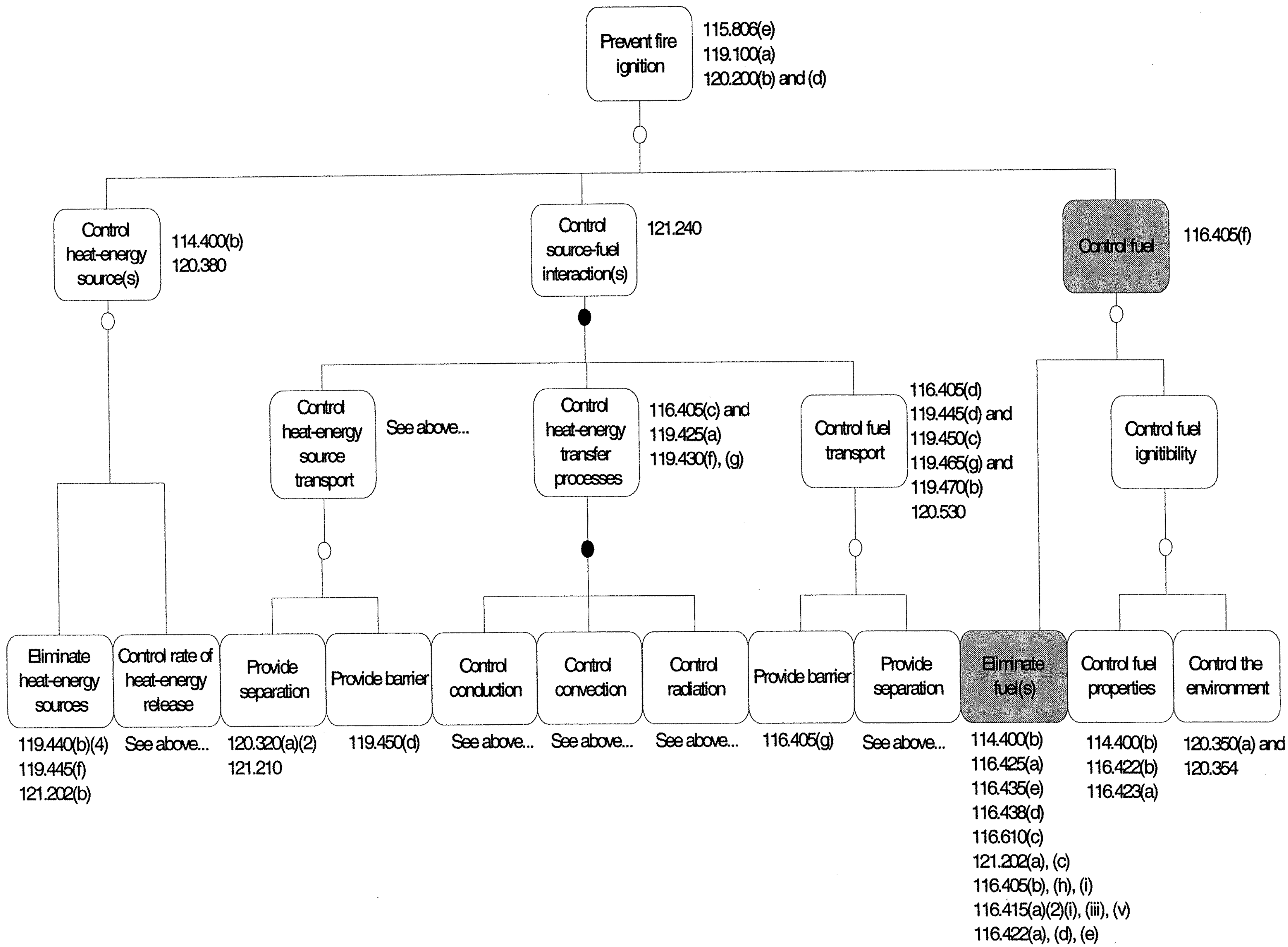


Figure A6: Manage fire branch of Fire Safety Concept Tree

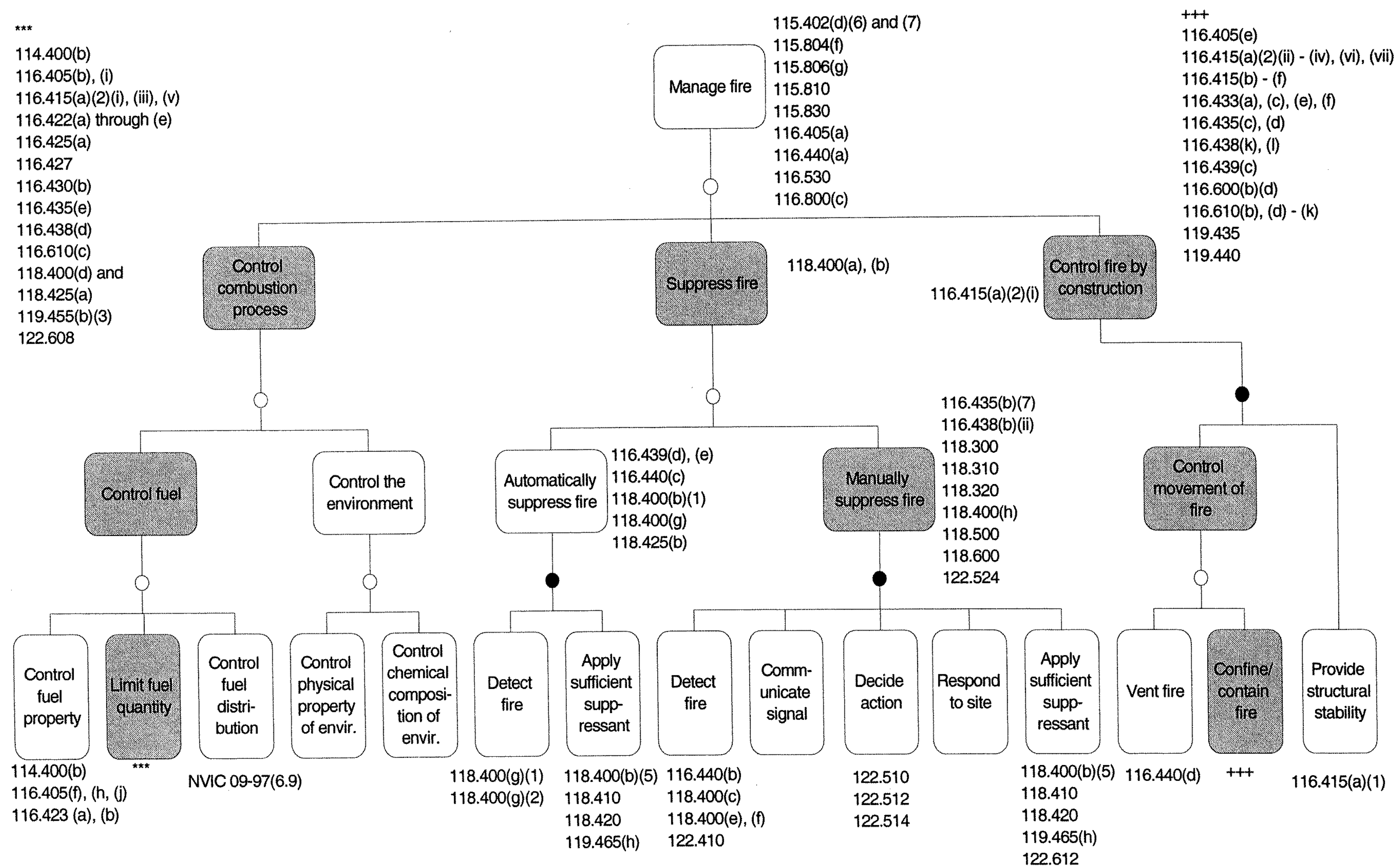
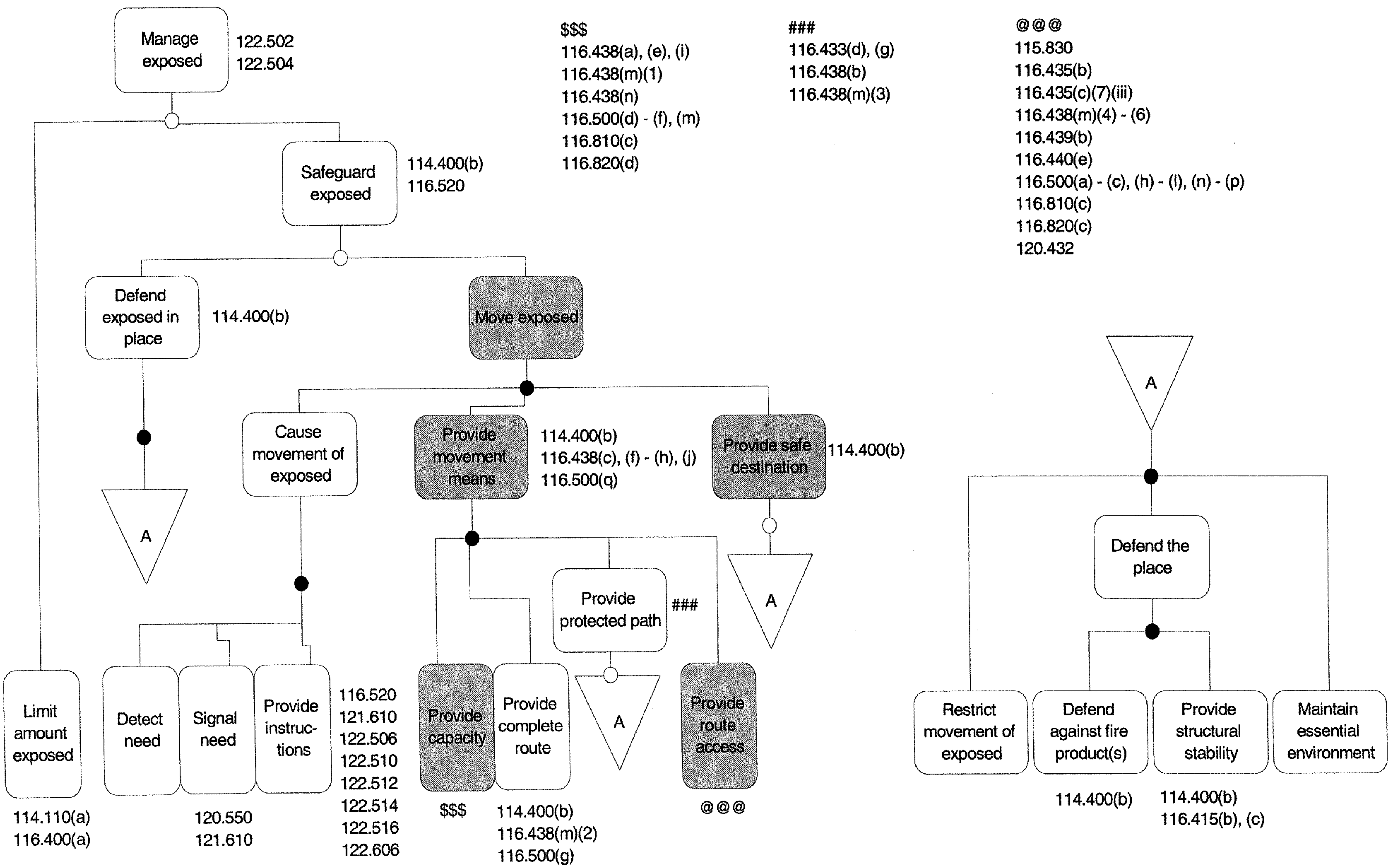


Figure A7: Manage exposed branch of Fire Safety Concept Tree



APPENDIX B: Design Fire Scenarios

The purpose of this appendix is to provide minimum design fires scenarios for evaluation of proposed designs. This is necessary to ensure a consistently applied "design load" (i.e. the minimum design fire that the vessel design should be able to withstand while meeting the performance objectives and criteria).

The approach used by the 2000 NFPA 101, "The Life Safety Code" is recommended for selecting and developing fire scenarios and deterministic modeling. This reference defines which type of scenarios are to be used and which major assumptions must be made. In all, eight scenarios are discussed where scenarios selected as design fire scenarios could include, but should not be limited to, those specified below.

Scenario 1. An occupancy-specific scenario representative of a typical fire for the occupancy. The scenario shall explicitly account for occupant activities, number and location; room size; furnishings and contents; fuel properties and ignition sources; and ventilation conditions. The first item ignited and its location shall be explicitly defined.

Scenario 2. An ultrafast developing fire (i.e. flammable liquid fire), in the primary means of egress, with interior doors open at the start of the fire. This scenario shall address the concern of reducing the number of available means of egress.

Scenario 3. A fire, starting in a normally unoccupied room, that can potentially endanger a large number of occupants in a large room or other area. This scenario shall address the concern of a fire starting in a normally unoccupied room and migrating into a space that can, potentially, hold the greatest number of occupants in the building.

Scenario 4. A fire originating in a concealed wall-or ceiling-space adjacent to a large occupied room. This scenario shall address the concern of a fire originating in a concealed space that does not have either a detection system or suppression system and the fire spreading into the room within the building that can, potentially, hold the greatest number of occupants.

Scenario 5. A slow developing fire shielded from fire protection systems, in close proximity to a high occupancy area. This scenario shall address the concern of a relatively small ignition source causing a significant fire.

Scenario 6. An ultrafast developing fire resulting from the largest possible fuel load characteristic of the normal operation of the vessel. This scenario shall address the concern of a rapidly developing fire with occupants present.

Scenario 7. Outside exposure fire. This scenario shall address the concern of a fire starting remotely from the area of concern and either spreading into the area, blocking escape from the area, or developing untenable conditions within the area.

Scenario 8. A fire originating in ordinary combustibles in a room or area with each passive or active fire protection system independently rendered ineffective. This scenario shall address the concern of a fire protection system or feature being either unreliable or unavailable.

The probabilistic elements should be integrated by requiring certain types of fires (e.g., ultrafast) and assumptions about operability of systems (e.g., detection and suppression system failure). This approach could be readily modified for shipboard use, and strengthened with respect to defined factors of safety and additional scenarios which require failure assumptions about other fire safety features (e.g., passive systems failure).

APPENDIX C: Technical References and Resources

Section 3 of the guidelines state that the fire safety engineering approach should be "based on sound fire science and engineering practice incorporating widely accepted methods, empirical data, calculations, correlations, and computer models as contained in engineering textbooks and technical literature." There are literally thousands of technical resources that may be of use in a particular fire safety design. Therefore, it is very important that fire safety engineers and other members of the design team determine the acceptability of the sources and methodologies used for the particular applications in which they are used.

When determining the validity of the resources used, it is helpful to know the process through which the document was developed, reviewed, and validated. For example, many codes and standards are developed under an open consensus process conducted by recognised professional societies, codes making organizations, or governmental bodies. Other technical references are subject to a peer review process, such as many of the technical and engineering journals available. Also, engineering handbooks and textbooks provide widely recognised and technically solid information and calculation methods.

Additional guidance on selection of technical references and resources, along with lists of subject-specific literature, can be found in:

- The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings, Society of Fire Protection Engineers and National Fire Protection Association, 2000. SFPE Publications can be ordered at this address:
  SFPE 7315 Wisconsin Ave, Suite 1225W
  Bethesda MD, 20814
  www.sfpe.org

- ISO/TR 13387-1 through 13387-8, "Fire safety engineering," International Standards Organization, 1999.

Other important references include:

- SFPE Handbook of Fire Protection Engineering, 2nd Edition, P. J. DiNenno, ed., The Society of Fire Protection Engineers, Boston, MA, 1995.
- Fire Protection Handbook, 18th Edition, A. E. Cote, ed., National Fire Protection Association, Quincy, MA, 1997.
- Custer, R.L.P., and Meacham, B.J., Introduction to Performance-Based Fire Safety, Society of Fire Protection Engineers, USA, 1997.
- NFPA 550, *Guide to the Use of the Fire Safety Concepts Tree*, National Fire Protection Association, 1995.

APPENDIX D: Basic Element Equivalency Process

Basic element evaluations will likely be used for most of the equivalency determinations. Thus the method presented in this Appendix serves primarily to formalize the current practices. Specifically, this includes describing the method, personnel, procedures, and documentation that must be followed when a basic element equivalency is sought.

1.1 Method

A simplified version of the entire engineering design process discussed previously is recommended for conducting a basic element equivalency. A diagram of this process is included as Figure D.1on page D-4.

1.2 Responsible parties

As the intent of the basic element equivalency is to provide a standardized process for procedures that are already in practice, the personnel will remain as per current practice. The basic element equivalency shall be performed between the Naval Architect and/or Owner requesting the equivalency and the appropriate branch within the Marine Safety Center who will be responsible for reviewing the equivalency. It is fully anticipated that these two parties will possess the knowledge and skill necessary to make an informed engineering evaluation of the issue. However, this should not preclude owners and architects from involving other parties, including professional fire protection engineers, from this process.

1.3 Preliminary analysis

The purpose of the preliminary analysis is two-fold: first, to identify and fully define the issue and second, to agree upon the performance necessary to demonstrate equivalency. Under most circumstances it is anticipated that the owner or naval architect will complete the majority of the preliminary analysis without the aid of the Marine Safety Center. Specifically, it is presumed that the owner or naval architect will perform all of the preliminary analysis before presenting the issue to the Marine Safety Center for review and comment. Thus the following guidance is aimed primarily at the naval architect or owner.

1.3.1 Identify the basic element for equivalency

Familiarity with general fire safety principles will lead many naval architects and owners to the right answer without the use of the FSCT. However, the structure still presents a useful common framework to enable discussion. Further, the regulatory mapping included in Appendix A provides a clearer understanding of how the basic fire safety concepts are incorporated into Subchapter K. Identification of the basic element for equivalency becomes a simple process of comparison and reverse engineering. Thus this process reduces to simple steps:

- Identify the regulation for which equivalency is sought.
- Use Appendix A to identify the node or branch that this regulation impacts.

Once the regulation (branch of the FSCT as discussed in appendix A) has been identified, both parties need to agree on whether the equivalency will be a substitution or a trade-off for the regulation/branch of the FSCT. Typically, only the designer or naval architect will know whether or not the design will be best served by performing either a substitution or a trade-off. A substitution implies that the designer will provide features that perform similar functions to those required by the regulations – i.e. substitution of an optical fire detector for a smoke detector. A trade-off implies that the designer will compensate for the regulatory requirements by providing additional features under an adjacent branch on the FSCT – i.e. providing automatic suppression in lieu of manual suppression. Regardless of the approach taken, the important point to remember is that both substitutions and trade-offs must be done at the same level within the FSCT for which equivalency is sought.

1.3.2 Define performance criteria

Once the regulation has been identified and the decision regarding substitution or trade-offs has been made, both parties should agree on the performance criteria required to demonstrate equivalency. In the case of a basic element equivalency, performance criteria may be able to be determined by a direct interpretation of the regulations, taking into consideration the fire safety objectives and the functional requirements. For a more detailed discussion of performance criteria see section 4.6 of this document.

1.3.3 Develop alternative design

For a basic element equivalency, the owner will already have an idea of or direction for the development of the alternative prior to beginning the Quantitative Analysis. In either case, the development of the alternative needs to be consistent with the objectives and performance criteria.

1.3.4 Document the preliminary analysis

Prior to performing the quantitative analysis, is critical that all parties agree to the scope of the project, level of analysis, and the performance criteria necessary to demonstrate equivalency. Further, it is in the interest of all parties that the agreement be clearly documented. However, for the case of the basic equivalency evaluation, the documentation need not be any more formal than a routine exchange of correspondence between the owner/architect and Marine Safety Center. Specifically, it is anticipated that the owner/architect would make a written proposal to the Marine Safety Center that contains:

.1 A clear definition of the scope of the equivalency, including a thorough description of the vessel and applicable operating conditions;

.2 The regulation for which equivalency is being sought;

.3 A review of the overall fire safety objectives affecting the regulation;

.4 Identification of trade-off or a substitution to be performed; and

.5 Performance Criteria, including safety factors, to demonstrate an equivalent level of safety.

It is foreseeable, that the owner/architect may not have all of the above information before making their initial proposal to the Marine Safety Center. If so, it is likely that the Marine Safety Center will be more involved in assisting the owner/architect with the development of the preliminary analysis. Alternatively, it is also foreseeable that the owner/architect will be able to complete even the quantitative analysis before involving the Marine Safety Center. Under the latter circumstances, the owner/architect will likely provide a fully quantified solution along with the above documentation. In either case, it is still important that both sides carefully review, agree, and document the above information, as this is the foundation on which the solution is built.

1.4 Quantitative analysis

In general, the purpose of the quantitative analysis is to use an engineering approach to demonstrate compliance with the performance criteria that were developed. The quantitative analysis may involve engineering calculations, scientific test procedures, computer modeling, probabilistic analysis, or a combination of these. Accordingly, a person who is familiar with fire safety engineering concepts and methodologies should conduct the quantitative analysis. As discussed in Section 5 of this document, quantitative analysis includes both the quantification and evaluation of the alternative design. For basic element equivalencies, it is foreseeable that these steps will be collapsed into a single combined step.

1.5 Document alternative

Because the equivalence design process will involve a deviation from the regulatory prescribed requirements, the process should be thoroughly documented. The documentation provides a record that will be necessary if future design changes to the vessel are proposed as well as providing much detail and information that may be adapted for use in future designs. In addition, the document may be necessary to demonstrate compliance or acceptance to other regulatory bodies and/or classification societies. The documentation should include both the required information and results of both the preliminary and quantitative analyses. Additionally, any operational constraints or additional maintenance and inspection procedures and the references used must also be clearly identified in the final documentation. At a minimum the information required by Section 6 of this document should be addressed.

USCG Basic Element Equivalency Process

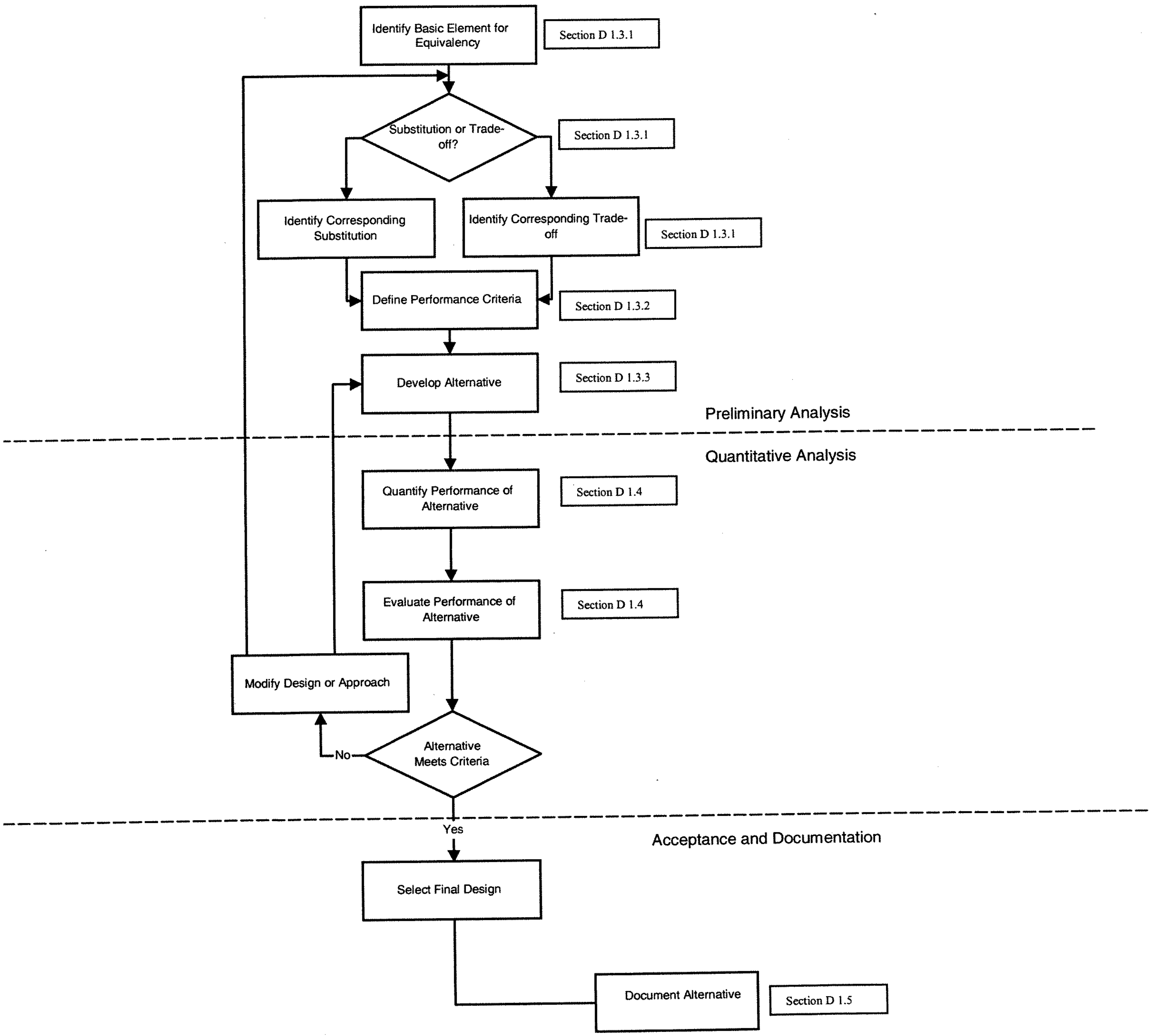


Figure D1