Lund University/Lund Institute of Technology
School of Fire Protection Engineering

Evaluation of the Fire Safety Level in High Speed Craft

- Problems, Improvements and Future Developments

Linus Eriksson Malmö 1998

SWEDISH MARITIME ADMINISTRATION

Sjöfartens Brandskyddskommitté
The Swedish Maritime Fire Protection Committee

Main report

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Title:

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Main report

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Abstract:

The study is an evaluation of the fire safety level of category B High Speed Craft built according to the High Speed Craft-Code. To verify the conclusions and results, four category B HSC have been selected and analysed. The fire safety evaluations of the craft are presented in separate reports. This report summarises the results from the evaluations with respect to the fire safety measures and the fire safety organisation on board.

Extensive short term and long term improvements are presented in order to achieve an fully acceptable total fire safety level, among which introduction of fire risk analysis in the design process and a performance based HSC-Code are the most important improvements. Finally, the need for increased fire safety competence within the maritime area is discussed.

Keywords:

Fire Safety Evaluation, High Speed Craft Code, Maritime Fire Engineering Design, Evacuation, Safe-area, Event tree, Risk profile, ALARP, Fire Risk Analysis, Performance based fire regulations.

FOREWORD

This study was initiated by the Swedish Maritime Administration in co-operation with the Swedish Maritime Fire Protection Committee and constitutes a graduate project at the School of Fire Protection Engineering, Lund Institute of Technology/Lund University, Sweden. The work has been carried out in Malmö, Sweden during spring and summer 1998 and was presented at Lund Institute of Technology 10 September 1998.

The purpose of the report is to produce a document useful in the future development and review of the seventh chapter of the International Code of Safety for High Speed Craft. My hope is also that this report and the sub-reports constitute good examples of the fire engineering approach to the maritime fire safety area.

To limit the extent of this report it is assumed that the reader is familiar with the HSC-Code and the maritime area.

I want to thank everyone who has been involved in the study. Thanks to: The crew and onshore managers of the analysed craft. Mr Magnus Arvidson and the staff at the Swedish National Testing and Research Institute for a valuable visit in Borås. Mr Matthew Marshall and Mr Philip Collins at the Institute of London Underwriters. Programme Officer Sven-Åke Wernhult at the World Maritime University for help with background material. Special thanks to: Mr Staffan Ålund, the Swedish Maritime Fire Protection Committee for being very helpful. Mr Krister Ingvarsson, the Swedish Maritime Administration for initiating this project. Mr Jörgen Carlsson for advice and late telephone fire-support. Mr Henrik Melkstam and Mr. Adrian De Almeida for help with the English language. My wife, Therese, for support during the work.

Finally, I would like to express my sincere gratitude to my supervisors Prof. Sven-Erik Magnusson at the Department of Fire Safety Engineering, Lund University and M.Sc. Jan-Åke Jönsson at the Swedish Maritime Administration.

Malmö September 1998

Linus Eriksson

SUMMARY

The report is an evaluation of the fire safety level of category B High Speed Craft built according to the High Speed Craft-Code, adopted within IMO in 1994. To verify the conclusions and results, four category B HSC have been selected and analysed. The fire safety evaluations of the craft are presented in separate reports. The analyses of the craft can be divided briefly into four phases: *Hazard identification*, where statistics, personnel and craft are each studied separately. *Risk analysis* of the consequences of fire on board. *Risk evaluation* where the existing safety level has been outlined in event trees mainly with regard to passenger safety and finally *risk reduction* including improvements presented in risk profiles.

Results:

The main conclusion of this report is that the HSC-Code does not achieve a fully acceptable fire safety level on board large High Speed Craft. An acceptable situation is where no persons are exposed to untenable conditions in the event of fire, or that there is a very low probability of only few persons being exposed and where all persons safely can evacuate to the life rafts.

- ***Fire in the accommodation:*** The fire safety level has to be improved in order to reduce the risk to a level *As Low As Reasonably Practicable* (ALARP). A lot of passengers can be exposed to untenable conditions before they are able to evacuate to the life rafts due to e.g. late sprinkler activation and only smoke tight separating constructions to the alternative safe area.
- ***Fire on the vehicle deck:*** The fire safety level is acceptable with regard to passenger safety since no passengers are expected to be exposed to untenable conditions. However, major material losses are expected since fire spread from a vehicle fire cannot be prevented by the existing sprinkler (drencher) system.
- ***Fire in the engine rooms:*** The fire safety level is acceptable since no passengers are expected to be exposed and the probability of major loss is low. Maintained fire safety level is of outmost importance in engine rooms on board aluminium HSC.
- ***The safety organisation:*** Where a fire is detected the crew immediately is expected to put into action fire fighting procedures. The education process needs to be reviewed where quality should be preferred instead of, as today, quantity.

Measures:

Extensive improvements are required in order to achieve a fully acceptable total fire safety level. The improvements are divided into two categories:

- Urgent *short term improvements*, where the most important improvement is the introduction of fire risk analysis within the design process. Other short term improvements, such as improved safe area qualities, automatic sprinklers and improved separating constructions to the safe area, are concluded in section 5.1.
- According to future demands within the High-Speed area and since the evaluation has revealed some important deficiencies not reducible within the framework of the existing regulations, performance based regulations have to be introduced as a *long term improvement*. By introducing performance based regulations a high and

uniform level of fire safety for all types of craft can be obtained in a cost-efficient way. Basic principles of a future performance based HSC-Code are proposed.

Increased maritime fire safety knowledge:

Most importantly, regardless of whether the measures in this report are implemented or not, knowledge within the maritime fire safety area, particularly for designers and surveyors, must be increased and used in order to achieve a fully acceptable fire safety design on board future HSC.

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1. INTRODUCTION

1.1 BACKGROUND

The demand for high-speed transportation at sea has led to the development of High Speed Craft (HSC). The possibility of carrying passengers and goods as fast as possible between two ports has become a competitive factor and therefore HSC constitute a rapidly developing sector of the shipping industry. The consequence of increased speed is increased fuel costs, and in order to reduce these costs new low-weight materials such as aluminium and composites are required. This has resulted in the development and adoption of a new Code called the International Code of Safety for High Speed Craft (HSC-Code) [/1/] within the International Maritime Organisation (IMO). The code was adopted in 1994 and is divided into 19 chapters among which chapter 7 deals with fire safety. The basic fire principles of the HSC-Code correspond with the principles of the traditional SOLAS 1974 [/2/] with the addition of two new principles where no enclosed spaces are permitted and the crew is expected to be put into action immediately where a fire is detected.

A new code within the maritime area has a direct impact on the safety-level and consequently on the fire safety level on board. The significant increases in numbers, size, speed and passenger capacity over the past few years have resulted in certain questions with regard to fire safety. It has been unclear as to whether the interpretation of the code results in an acceptable fire safety level. Especially since new technological developments within the fire safety area are applied on the already advanced craft. Another interesting subject is the concept of an alternative safe-area on board from which the passengers should evacuate via evacuation stations in the event of fire.

It is in order to evaluate the fire safety of HSC in support of future revisions of the HSC-Code, which should be done every fourth year, that the Swedish Maritime Administration in co-operation with the Swedish Maritime Fire Protection Committee has initiated this study.

1.2 PURPOSE OF THE STUDY

The purpose of this study is to answer the following question:

- Does the HSC-Code achieve an acceptable safety level with respect to fire safety and evacuation in case of a fire on board HSC?

If the answer is negative, the resulting questions are:

- Why is the fire safety level not acceptable?
- What improvements are necessary to achieve an acceptable fire safety level?

The analysis is an objective analysis of the fire safety solutions on board existing craft and is based on established fire engineering methods.

/1/ *The International Code of Safety for High Speed Craft*, IMO 1994
/2/ *Safety of Life at Sea*, SOLAS 1974 including latest amendments, IMO 1997

1.3 METHODOLOGY

The aim of this report is to review the fire safety level in the HSC-Code. To verify the conclusions and results, four category B HSC have been selected and analysed, in this report called Craft A-D. The fire safety evaluations of the craft are presented in separate reports, to which reference should be made for the details of the study. A brief introduction to the analyse of craft A-D is as follows:

All selected craft have a capacity of 700 passengers or more and have an operational speed of about 35-40 knots. These are all built of aluminium and the craft, which are both monohulls and catamarans, have varying flag-state, not only north European.

The work with the separate analyses of craft A-D can be divided briefly into four phases: /3/

1. *Hazard identification*

   - Visit to craft.
   - Interviews with shore-based managers and crew on board.
   - Collecting of data, drawings etc.

2. *Fire safety analysis*

   - Analysis of the consequences of outbreak and spread of fire for main fire scenarios on board.
   - Determination of evacuation times to safe-area and to the life rafts.

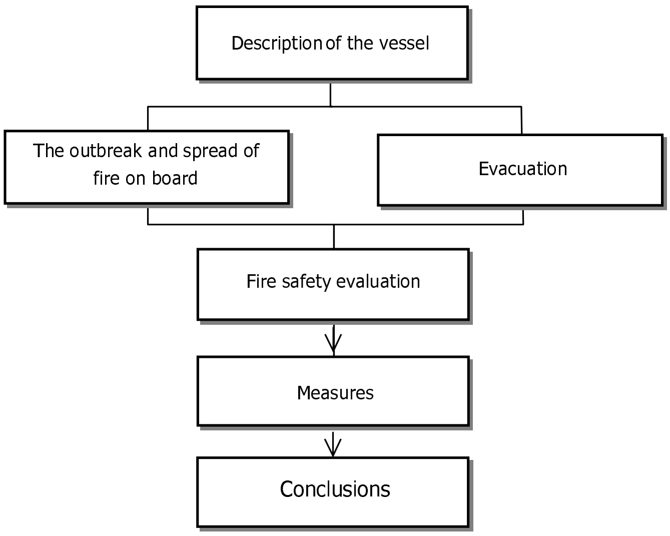

Figure 1.1 *Overview of the risk analyses of craft A-D*

3. *Fire risk evaluation*

   Risk is often divided into consequence and probability. By comparing the time to untenable conditions and the evacuation time from phase 2 the consequences can be determined. Thereafter, the existing safety level has been outlined by weighting these consequences and the probabilities of the existing safety systems in event trees with the classification of acceptable or unacceptable safety level, mainly with regard to passenger safety.

4. *Fire risk reduction*

   Where the existing solution is determined as unacceptable, it has been compared with an improved safety standard and this comparison is presented in risk profiles.

/3/ *Uncertainty and Risk Analysis in Fire Safety Engineering*, H.Frantzich, Department of Fire Safety Engineering, Lund 1998.

The aim of this main report is to conclude and summarise the results of each analysis in order to determine an average fire safety level of the HSC-Code, both regarding the fixed active and passive fire safety measures (see section 3) as well as the fire safety organisation (see section 4). The necessary improvements from the risk reduction phase are concluded in section 5 and should be treated as overall measures, necessary to future Category B HSC.

1.4 OVERVIEW OF THE MAIN REPORT

A comprehensive report might be difficult to overview and it is often a laborious task for the reader to find the specific results of interest. Therefore a short guide to this study is presented below to help the enthusiastic reader.

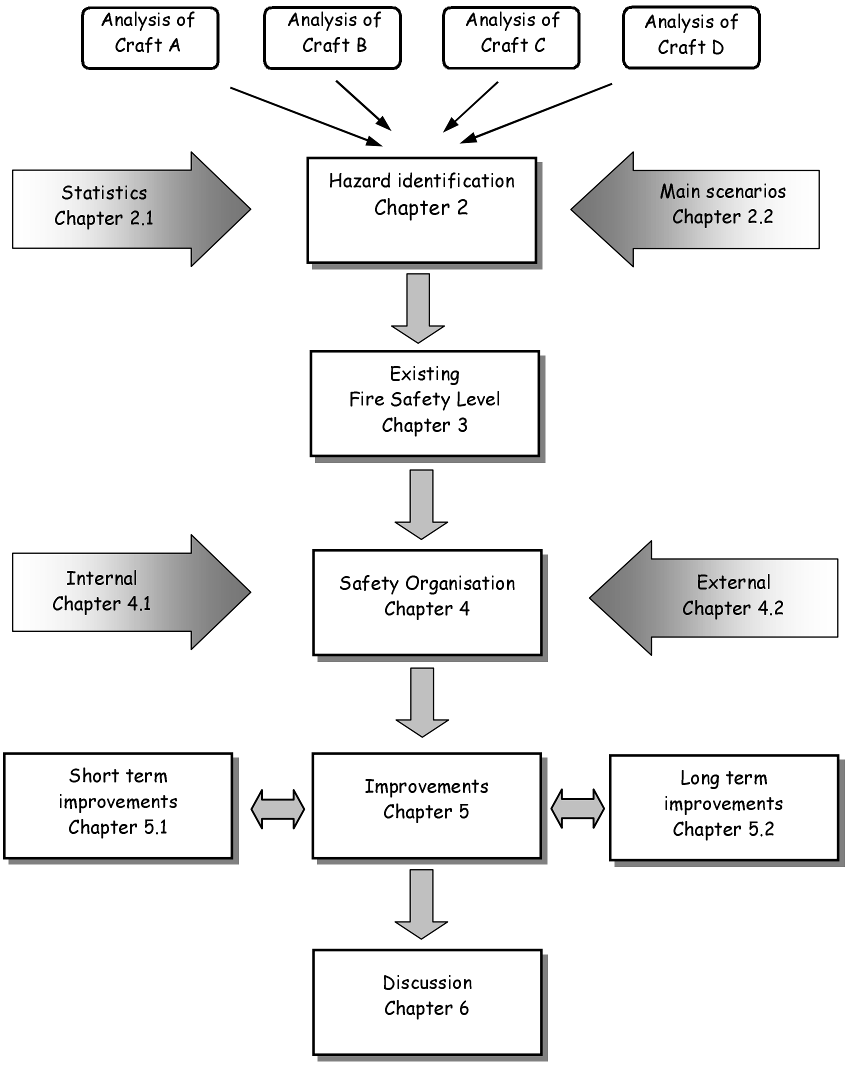

Figure 1.2 *Overview of the report*

1.5 LIMITATIONS

The report has the focus on "Category B Passenger craft", as defined in the preamble of the HSC-Code. Furthermore, the report is confined to the seventh chapter. The chapter is not analysed word by word, but rather the implementation of the seventh chapter on existing HSC as a whole. Consequently specific details are not analysed, for instance the fuel tank details or details of the detector system. Instead the main subject is to evaluate the general fire and evacuation safety level in case of a fire with respect to the passengers on board. Material and financial values are only considered where an obvious risk for large material and financial loss has been revealed. The specific life-safety appliances and arrangements used during evacuation are not in the scope of this analysis, consequently they are, when used in the evacuation process, assumed to work faultlessly. Realistic and reliable fire test procedures (FTP) are important when designing the fire safety on board. However, FTP are not in the scope of this analysis.

1.5.1 Accuracy

The reader should consider the fact that the used engineering tools and the presented values involve uncertainties and limitations. Nevertheless, the values show tendencies and approximate values useful when describing the situation on board as well as comparison between different solutions and different HSC.
Another fact that should be considered is that, since no reliable statistics on the outbreak of fire in large HSC are available, the probability of fire equivalent to the design fire is 1 in all scenarios. This is of course not true but it is a common assumption when evaluating, designing and comparing different fire safety measures. However, the fire scenarios used are considered realistic and probable, suitable when designing the fire safety on board.

1.6 ACCEPTANCE CRITERIA

The results have been defined as acceptable, ALARP or unacceptable. An acceptable situation is where no persons are exposed to untenable conditions, or that there is a very low probability of only few persons being exposed, during evacuation to or inside the safe-area and where all persons safely can evacuate to the life rafts. The opposite situation, where a lot of passengers are exposed to untenable conditions, is regarded as unacceptable. A third criterion, in between of the acceptable and unacceptable criteria, is the ALARP[/31/] (As Low As Reasonably Practicable) criterion implies that the risk is tolerable on condition that reasonable measures are considered. The risk should be reduced if it is practicable and cost-effective.

Untenable conditions have been defined as follows:

Smoke layer height:	Minimum 1.6+(0.1xH) meter, where H is the ceiling height
Visibility:	Sight-reduction of 1 obscura. (10 meters of free sight)
Temperature:	Maximum 80°C air temperature.
Toxic species:	CO concentration 100 ppm

Note: The values used are corresponding with the Australian Fire Engineering Guidelines[/11/] and the Swedish building code[/24/]. Untenable conditions result not necessarily in injuries or fatalities. The limits are rather limits directly inconvenient to be exposed to, over which the society cannot accept exposure.

/4/ *International Code for Application of the Fire Test Procedures*, Res. MSC.61(67)
/11/ *Fire Engineering Guidelines*, Fire Code Reform Centre, Sidney, 1996.
/24/ *BBR94*, Boverkets byggregler 1994, Karlskrona1994. (In Swedish)
/31/ *Evaluation of Risk*, Räddningsverket 1997, Karlstad. (In Swedish)

2. HAZARD IDENTIFICATION

As input to the risk analysis it is necessary to identify the fire hazards on board. By reviewing statistics (section 2.1) and experiences, different main scenarios (section 2.2) can be determined. These main scenarios are thereafter used in the fire safety evaluation process that is summarised in section 3.

2.1 STATISTICS

When evaluating an existing safety level it is of certain interest to monitor recent statistics. The statistics can, if they are interpreted in a proper way, answer the main question of this report, namely: Do we have a satisfactory safety level? With a deeper analysis we can also ascertain the most common fire casualties and from this form effective measures in order to improve the fire safety level.

Unfortunately, when examining existing statistics and safety records for HSC you will immediately run into problems. Since the HSC-code was published in 1994, the operational hours of large HSC have been too few to find reliable data and thereby recognise trends. However, some general conclusions can be drawn regarding fire frequencies, probable locations of outbreak and fire causes.

2.1.1 Fire frequency

Historical data 1981-1996, mainly for craft built according to the DSC-Code/5/ (Dynamical Supported Craft), present the following:

Accident Category	**Total Number of Accidents**	**Total Number of fatalities**	**Historical Accident Frequency** (per vessel operating year)	**Historical Fatality Risk** (per vessel operating year)	**Predicted Fatality Risk** (per vessel operating year)
Collision	104	14	0.067	0.012	0.065
Contact	84	0	0.047	0.0005	0.006
Grounding/Stranding	36	-	N.A	N.A	N.A
Fire	*16*	*0*	*0.007*	*0*	*0.004*
Loss of Hull Integrity	9	0	0.004	0	0.002
Other	45	-	N.A	N.A	N.A
Total	**301**			**0.00125**	**0.077**

N.A Not Assessed

Table 2.1 *Data for frequent accident categories. Only four categories assessed.* /6/

The statistics in table 2.1 are presented in the Formal Safety Assessment Trial application to HSC /6/ and includes all category A and B passenger HSC. The risk levels are derived from a combination of historical data and judgements from a group of experts familiar with HSC operation. The table 2.1can be summarised as follows:

/5/ *The Code of Safety for Dynamical Supported* Craft, IMO 1977
/6/ *FSA, trial application to High Speed Passenger Catamaran Vessels*, DE41/inf.7, MSC 1997

The historical fire frequency is one fire on every craft every 125 years and the predicted future equivalent fire fatality frequency is one fatality on every craft every 250 years. However, craft built according to the DSC-Code are often small and carry only seated passengers. The new large HSC, in the scope of this analysis, are intended to carry large numbers of passengers and have large areas that are difficult to survey. Therefore both the fire frequencies and the consequences of a fire will be higher than for the average sized DSC or HSC in the statistics in table 2.1. Nevertheless, considering the data some conclusions can be drawn: According to the historical statistics fire represents 5% of all accidents on board HSC. For comparison, on board traditional vessels 20% of the major and total losses are caused by fire.[/7/] Finally, the existing total risk is only one sixth of the predicted future risk, i.e. the total risk level and thereby also the fire risk is expected to increase in the future. [/6/]

All these values are long term averages over many vessels, and the probability is that most craft will not experience any fatalities or major fires at all, but some vessels may be involved in a serious fire with multiple fatalities. Thus, since fire often accounts for large and serious consequences fire safety on board must be of high priority, despite the rather low expected fire frequency.

Note: Since no reliable frequencies of fire in large HSC are available the probability of fire in the analyses are equivalent to 1 in all scenarios, i.e. fire is established. This is of course not true but it is a common assumption when evaluating, designing and comparing different fire safety measures. However, the fire scenarios used are realistic and probable, suitable when designing the fire safety on board.

2.1.2 Location of outbreak

To determine the probable locations of outbreaks in HSC we have to study traditional vessels and in particular traditional passenger vessels.

About 55 percent of all fires are referred to the engine spaces, 15 percent to the accommodation spaces and 4 percent to vehicle deck and galley. The statistics are a summary of the casualty database of the Institute of London Underwriters for the period 1989-1996. [/7b/]

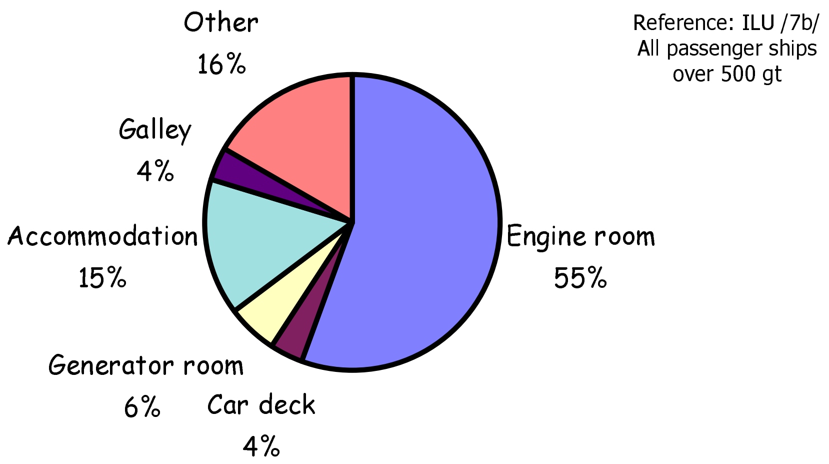

Figure 2.2 *Location of outbreak. Passenger ferries, all total and major losses 1989-1996.*

/7/ *Hull Casualty Statistics*, The Institute of London Underwriters, 1997.
/7b/ Extract from database for the period 1989-1996, The Institute of London Underwriters, 1997.

The Swedish Maritime Administration's database for Swedish passenger vessels/8/ contains details for the period 1990-1996 where 39 passenger ship fires (vessels over 500 gt) were reported. Only one fire was classified as a serious fire accident, all other were classified as incidents or small accidents. No fatalities were reported due to fire during the period.

The records according to the Swedish database show the same tendency as the international statistics where three main locations of outbreak are discernible easily:

- Accommodation,
- Engine room and
- Vehicle deck.

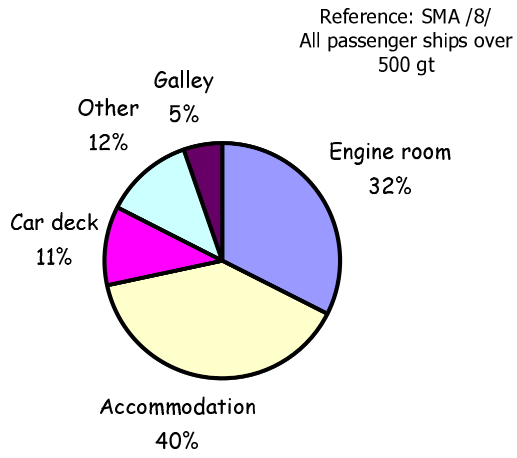

Figure 2.3 *Location of all fires on board Swedish passenger ferries 1990-1996.*

Note: There are differences of vital importance between the fire safety in large HSC and traditional SOLAS passenger vessels. Therefore, the data should only be used to monitor trends for passenger HSC.

2.1.3 Fire cause

The only available and reliable fire cause data are records from national databases. The Swedish statistics 1990-1996 can be summarised as follows:

Accommodation: (18 Fires)
According to figure 2.3 nearly 50 % stem from arson in the accommodation. 55 % of these were initiated in areas that have a counterpart in HSC (e.g. Restaurants, shops, passageways).

Engine room: (12 Fires)
Nearly 50% of all fires in the engine rooms are initiated by flammable liquid (e.g. fuel or lubrication oil) on hot surfaces.

Vehicle deck: (4 Fires)
All fires on vehicle deck were initiated by burning vehicles. (For instance truck cabin fires, short circuit and fuel leakage.)

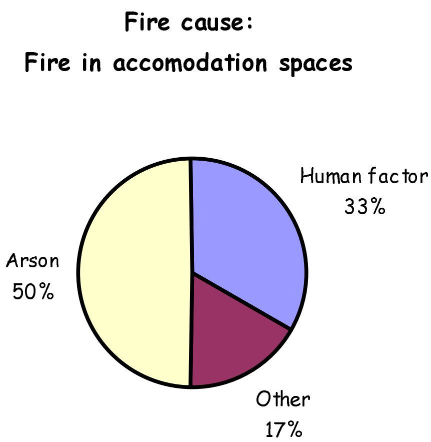

Figure 2.4 *Accommodation. Swedish passenger vessels over 500 gt, 1990-1996.* /8/

/8/ Database SOS (SjöOlycksSystem) 1990-1996, Swedish Maritime Administration, 1997.

As noted in section 2.1.2 the safety records for traditional vessels should be applied with caution on HSC since important differences exist. For instance, the basic principle where no enclosed spaces are permitted may influence the statistics in the accommodation since a pyromaniac will have a smaller chance to commit arson. The probability for arson increases with the size of the vessel and the number of subdivisions of the craft. However, all analysed HSC have more or less areas where arson definitely is possible. The statistics confirm this where pyromaniacs initiated nine of the eighteen accommodation fires presented in the Swedish statistics.[8] Five of these were initiated in areas that have counterpart on board HSC e.g. restaurants, shops and passageways. Thus, the probability for arson is decreased but not eliminated.

The vehicle deck on HSC is similar to those on traditional vessels, consequently the possibility for vehicle deck fire is equivalent. Finally, the probability for fire in the engine rooms of the analysed craft are lower than on traditional vessels since all craft are new and fitted with appropriate fire safety measures. However, when the craft get older the fire frequency will approach the records for traditional engine rooms.

2.2 MAIN SCENARIOS

From the statistics in section 2.1 three different main fire areas in large HSC have been discerned and used as input to the analyses of craft A-D, namely: *Accommodation* (passenger area), *Vehicle deck* and the *Engine rooms*.

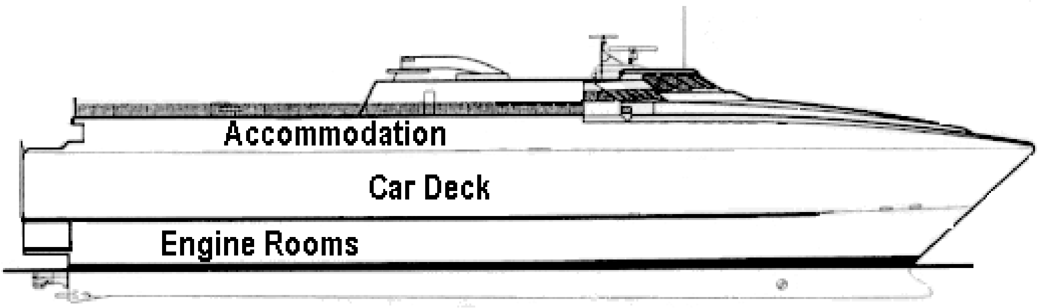

Figure 2.5 *Schematic overview of the main fire areas in a large HSC.*

2.2.1 Accommodation

Typical design fire:	Arson in passenger seats, garbage can or life-jacket storage. The arsonist is assumed to use a couple of litres of flammable liquid as initial fire. The same design fire has been used for all analysed craft (A-D).
Location:	Two different fire locations have been analysed for each craft where the design fires are located in different alternative safe-areas.

2.2.2 Vehicle deck

Typical design fire: Ignition in one car due to leakage or short circuit. The design fire, according to test results[9], will have a rapid development and cause fire spread to adjacent vehicles within the first few minutes.

Location: One passenger car fire, in the centre of the vehicle deck that spreads to adjacent cars, has been analysed for each craft.

2.2.3 Engine room

Typical design fire: Ignition of fuel due to a fuel pipe rupture close to a hot surface.

Location: The fire will be a pool fire on the bottom of one of the two main engine rooms.

2.3 THE RELEVANCE OF THE DESIGN FIRES

The design fires influence of course the outcome of a fire safety evaluation, where a too small design fire cannot reveal the possible deficiencies, but on the other hand, a too large design fire may result in too stringent and inappropriate measures. Therefore it is important that the design fires in a fire safety evaluation are suitable and applicable.

The level of the design fires used in this analysis (see section 2.2.1-3) should be considered neither as worst-case scenarios nor as the most probable scenarios. The scenarios represent rather a "plausible upper bound" level, as defined in M.E Paté-Cornell [26]. This level is common in design processes and often used as a basis in for example some building codes. Consequently, the scenarios are estimated to be suitable when evaluating the fire safety level of the HSC-Code and a good basis when designing future improvements.

3. EXISTING FIRE SAFETY LEVEL

3.1 INTRODUCTION TO THE FIRE SAFETY LEVEL RESULTS

The methodology of the fire safety evaluation is briefly divided into two steps, namely: Safe evacuation from fire area *to safe-area* (1) and thereafter safe evacuation from the safe-area *to the life rafts* (2):

(1) Evacuation to the safe-area

The passenger should be able to evacuate to the safe-area without being exposed to untenable conditions. Accordingly equation 1 should be fulfilled:

/26/ *Six Levels of Treatment*, M.E Daté-Cornell, Reliability Engineering and System Safety, 1996.
/9/ SP-Report 1997:03, *Water based fire protection systems for vehicle decks on RoRo passenger ferries*, M.Arvidson et.al, SP-Fire Technology,1997.

$$t_{evacuation} \leq t_{untenable} \quad (1)$$

Where t_e is the required evacuation time to the safe area and t_u is the time to untenable conditions.

(2) Evacuation to life rafts

The passengers should be evacuated via the MES-stations (Marine Evacuation System) before fire spread to the safe-area occurs. Of course it is not acceptable for passengers to be exposed to untenable conditions while in the safe-area. This results in the following expression:

$$t_{evacuation\ life\ rafts} \leq t_{fire\ spread} \quad (2)$$

Where t_{elr} is the required evacuation time to the life rafts and t_{fs} is the time for fire spread (i.e. smoke and heat spread) to the alternative safe area.

By using established fire engineering tools and experiences the time to untenable conditions, fire spread to the safe area and evacuation times have been determined for the different expected outcomes.

Application:	**Method:**
Visibility:	Hand calculations /27/
Temperature:	Computer model FAST 3.1.2 /28/
Toxic species:	Hand calculations /27/
Smoke layer height:	Computer model FAST 3.1.2
Detection:	Computer model DETACT-QS /29/
Sprinkler activation:	Computer model DETACT-QS
Evacuation times to safe area:	Hand calculations /27/ and computer model SIMULEX 2.0 /30/
Evacuation times to life rafts:	Tests and Hand calculations

Table 3.1 *Overview of engineering tools used in the analysis*

These time to untenable condition has been compared with the evacuation time in event trees and by using acceptance criteria according to section 1.6 the safety level has been outlined. The availability of the fire safety measures stem from present guidelines./10/11/12/ Different safety systems on board have been considered in the event trees as follows:

- Detection
- Sprinkler
- Door closing
- Separating constructions (smoke tight)
- Manual attack
- Extra fire safety measures if provided (e.g. CO_2, smoke management etc.)

The event trees are summarised as risk profiles. Risk profiles present the probability for exposure of X number of passengers provided the fire on board is equivalent to the design fire (see section 2.2.1-3). An event tree used in the analysis and the corresponding risk profile is presented as an example on the next page:

/10/*Fire Safety Engineering in Buildings*, BSi-guide, British Standards Institution, 1997.
/11/ *Fire Engineering Guidelines*, Fire Code Reform Centre, Sidney, 1996.
/12/ *Balanced Design Concepts*, R.Bukowski, NIST, 1997.

3.1.1 Introduction to Event trees and risk profiles

Procedure of evaluation:

Step 1: Forming of event tree, determination of unavailability.
Step 2: Determination of probability of outcome.
Step 3: Determination of time to untenable conditions. (Seconds)
Step 4: Determination of time for evacuation. (Seconds)
Step 5: Evaluation by using equation (1) or (2) and determination of the consequence in number of exposed passengers
Step 6: Presentation of results in risk profile (see figure 3.2)

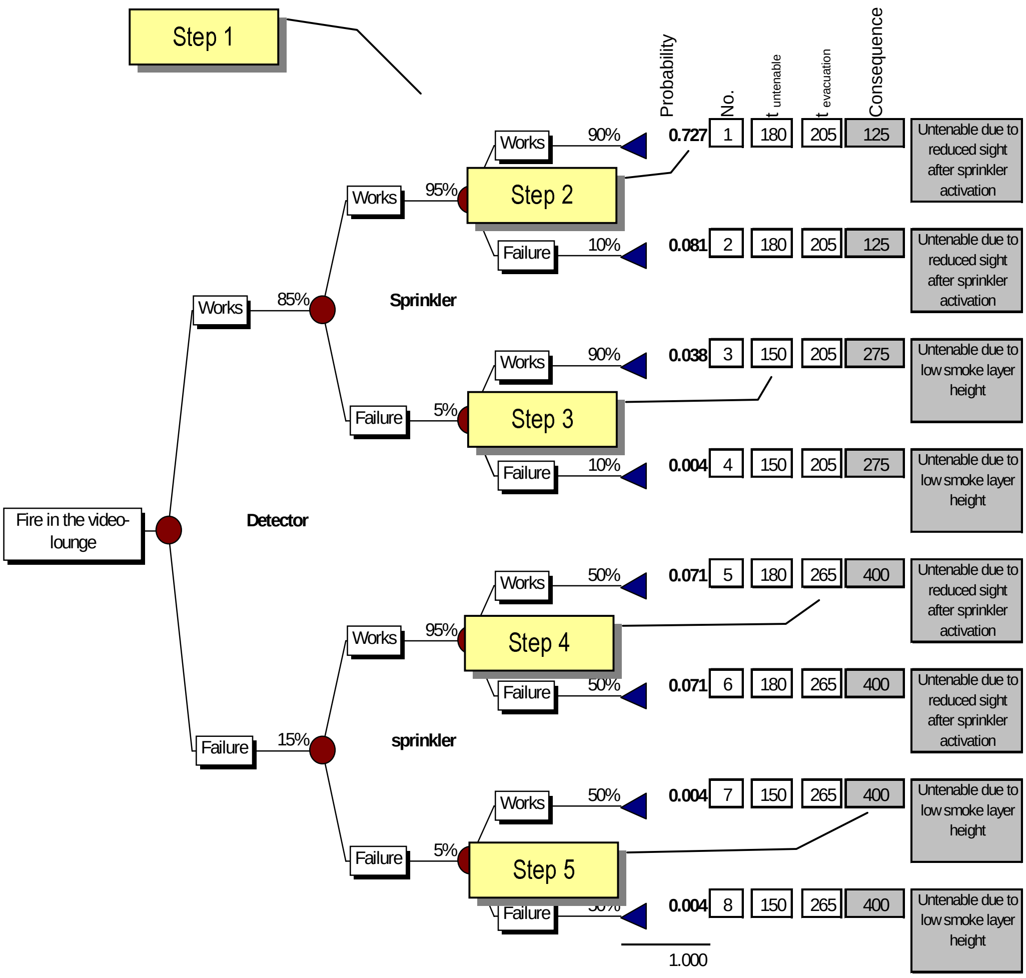

Figure 3.1 *Example of event tree[13] used for an accommodation fire, evacuation to safe area.*

Note: The event tree presents both the probability and the consequence of the outcome of a design fire on board.

/13/ Precision Tree, http://www.palisade.com, 1997.

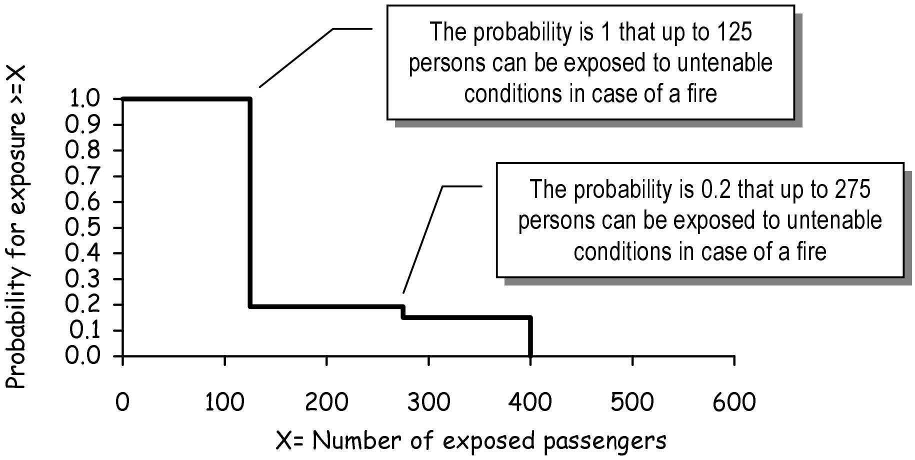

Figure 3.2 *Example of risk profile*[14] *corresponding to the event tree in figure 3.1. Exposure of untenable conditions during evacuation to safe area.*

It should be observed that the evacuation time, based on the structural fire protection time, in chapter 4.8 of the HSC-Code have not been used in the evaluation since this time is not valid in the event of an accommodation fire. Instead equation (1) and (2) have been used.

3.2 ACCOMMODATION AREA

For the accommodation area two scenarios have been analysed per craft, one design fire in the aft and one in the forward passenger area.

3.2.1 Evacuation to safe-area

Two scenarios show a fully acceptable safety level since the probability of exposure of untenable conditions is very low. This is mainly due to automatic sprinkler activation on board craft A and B. Automatic sprinkler activation is not required in the HSC-Code. Two of the scenarios are considered to the ALARP area (see definition section 1.6). Finally, four of the scenarios are not acceptable since too many passengers can be exposed.

It should be noted that the term exposure does not necessarily imply injuries or fatalities, but rather that X number of passengers are exposed to untenable conditions according to the definition in section 1.6. However, the values are suitable for comparison since they show the differences between the fire safety measures. For instance, figure 3.3 reveals that craft A and B, fitted with automatic sprinkler systems, show a significantly better fire safety level than craft C and D which are fitted with manual sprinkler in accordance to the HSC-Code requirement. If craft A and B should be fully acceptable, i.e. acceptable in both scenarios, automatic smoke management is necessary. Thus, the values should not be regarded as absolute values, but rather suitable for comparison.

/14/ BRAND, Tillämpning av Boverketsbyggregler, Rapport 1997:9, Karlskrona, 1997. (In Swedish)

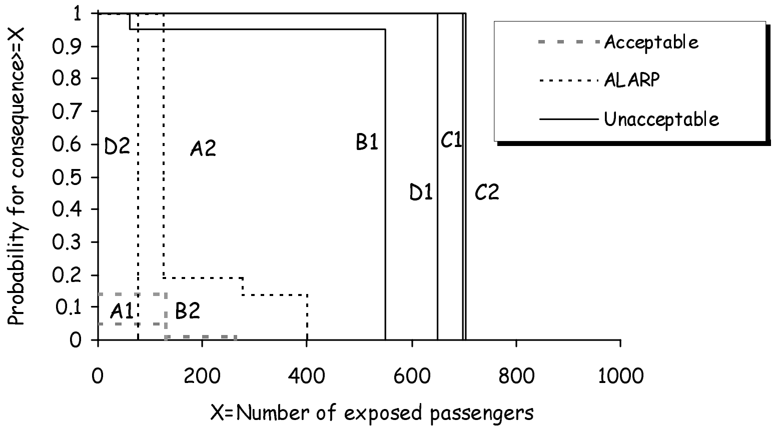

Figure 3.3 *Risk profile for the results of evacuation to a safe area. Two fully acceptable, two ALARP and four unacceptable fire safety levels.*

3.2.2 Evacuation to the life rafts

The results of evacuation to life rafts correspond with those in section 3.2.1. Two scenarios are fully acceptable since the fire will be constrained by the sprinkler system. Four of the scenarios are within the ALARP area since the probability of exposure or the number of exposed passengers is too high to be fully acceptable. Two of the scenarios are not acceptable since only smoke tight separations, manual sprinkler activation and no smoke management arrangements are provided.

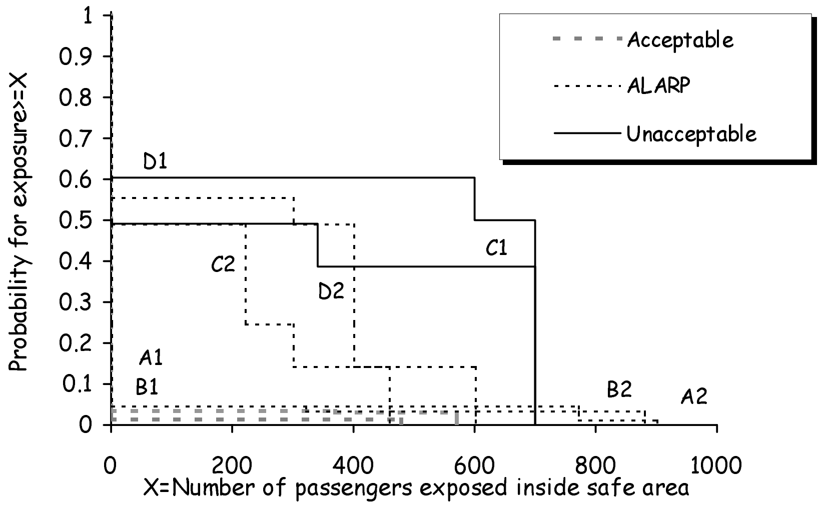

Figure 3.4 *Risk profile for the results of evacuation to life rafts. Two fully acceptable, four ALARP and two unacceptable fire safety levels.*

There is one main difference between the results in section 3.2.1 and the results of evacuation to life rafts. The passengers in the latter situation are exposed to a fire spread (dense smoke and heat but also flame spread) to the safe area before being able to leave the safe area. Consequently, the passengers will be exposed to heat and a very toxic environment and many fatalities can be expected.

3.2.3 Summary Fire Safety Level Accommodation area

The fire safety evaluation of the four craft reveals that the total fire safety level of the accommodation on board large HSC need to be improved. No craft have a fully acceptable fire safety design according to the analysed scenarios.

	Existing Fire Safety Level			
	Evacuation to safe area		**Evacuation to life rafts**	
	Fire in the forward area	Fire in the aft area	Fire in the forward area	Fire in the aft area
Craft A	Acceptable	*ALARP*	Acceptable	*ALARP*
Craft B	Unacceptable	Acceptable	Acceptable	*ALARP*
Craft C	Unacceptable	Unacceptable	Unacceptable	*ALARP*
Craft D	Unacceptable	*ALARP*	Unacceptable	*ALARP*

Table 3.1 *The results of every scenario analysed. No craft can show consistently acceptable fire safety levels.*

The results show that the requirements of the HSC-Code reviewed in order to achieve a fully acceptable fire safety level.

Note: The craft with acceptable sub-scenarios are fitted with extra fire safety measures, not required in the HSC-Code.

3.2.4 Summary deficiencies Accommodation

All craft are built according to the HSC-code and approved by the administration. Therefore the results are not mainly because of deficiencies caused by the ship owner or the designers. Instead the inadequacies should be pertained to the HSC-Code and the seventh chapter. Consequently, the deficiencies in the Code have been identified, listed and explained in table 3.2 on the next page:

Type of inadequacy:	**Consequence:**	**Valid for craft:**
Required in the HSC-code:		
Only manual sprinkler activation	Low availability and late activation	C,D
Only smoke tight separating constructions required between safe area and fire area	Smoke and heat spread to the safe area before evacuation is finished	A,B,C,D
Large amounts of combustible material inside the evacuation stations (Category E area)	Increased risk for arson and blocked MES station	C
Not required in the Code:		
No smoke management arrangements provided	No possibility for evacuation of Smoke and/or over-pressurisation of the safe-areas to prevent spread of smoke	B,C,D
Not automatic door closing	Low availability and facilitated smoke spread	C,D
Unsuitable design/arrangement:		
Insufficient available floor area inside the safe areas. Should not exceed 2-2.5 persons/net m^2.	The available safe areas cannot accommodate all passengers	C,D
Bad accessibility of the MES-stations	The evacuation procedure is prolonged and more complicated	A,D
MES stations inside passenger areas	A fire in the passenger area results in blocked MES-station	A,C,D
Restricted access to fresh air	Increased risk for panic	A,B,C,D
Low ceiling height	Fast smoke exposure	(C), D

Table 3.2 *Inadequate requirements and/or deficiencies on board the analysed HSC.*

Improvements to these deficiencies and inadequate requirements are assessed and presented in section 5 *Measures*.

3.3 VEHICLE DECK

A fire on the vehicle deck will probably never threaten the passengers on board since the evacuation time is much shorter than the time for the fire spread from the vehicle deck to the passenger areas. In only 4% of the outcomes are passengers left on board when the fire has spread (See figure 2.3). The situation is definitely acceptable in a passenger safety point of view.

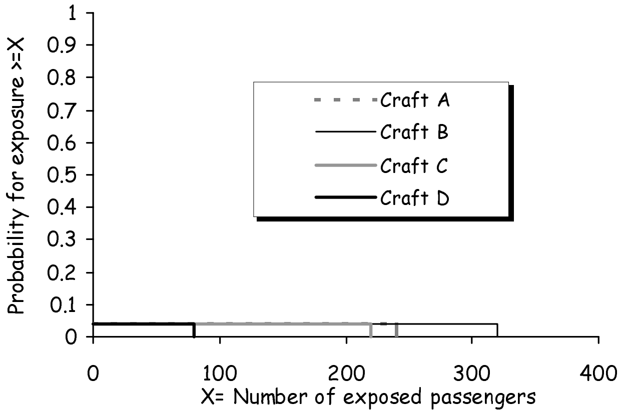

Figure 2.3 *Risk profile for fire spread from vehicle deck to passenger area.*

However, it should be noted that research collected and summarised in the SP-report 1997:03 /9/ and 1997:15/15/ reveals that a fixed (drencher) sprinkler system according to Resolution A.123(V)/21/ on Vehicle deck is probably unable to either extinguish or constrain the vehicle deck design fire according to section 2.2. This is mainly due to:

- Only manual sprinkler activation
- Too low water discharge density
- No foam additives in the sprinkler water.
- Shielding effect by the vehicles. (Sprinkler heads are not located with regard to the longitudinal flue space formed by the vehicles.)

Since the sprinkler system will have minor impact on the fire nearly 70% of the outcomes of the expected design fire result in major material and economical losses due to unprevented fire spread on board. The fact that the Code prescribes a solution only fully acceptable with regard to passenger safety should be avoided since the ship owner may think that the sprinkler system also prevents material losses. The existing fire safety level should be considered unacceptable, but only with regard to the risk for material losses.

A summary of the necessary improvements is given in section 5 *Measures*.

/9/ SP-Report 1997:03, M.Arvidson et.al, SP-Fire Technology,1997.
/15/ SP-Report 1997:15, *Large Scale RoRo Vehicle Deck Fire Test,M.Arvidson*, SP-Fire Technology,1997.
/21/ *Recommendations on fixed fire extinguishing systems for special category spaces*, Res. A.123 (V), IMO 1967.

3.4 ENGINE ROOM

Incident data presented in section 2.1 clarify that engine room fire is the most frequent fire on board. This is a well-known fact and therefore the fire safety measures are suitably designed on board the analysed HSC. An engine room fire threatening the passengers on board is unlikely because the evacuation time is shorter than the estimated time for fire spread to the alternative safe area for all evaluated craft.

The existing safety standard is acceptable in all crafts since no passengers are exposed to the fire, but some areas should be considered.

Three of the analysed craft are fitted with manual CO_2-systems where long activation times give rise to long pre-burning times and thereby risk for large material damage and increased risk for fire spread. This problem has been avoided in Craft B where measures have been taken in order to enable automatic activation of the CO_2-system with out any risk for the crew. Experiences show that short activation times of the extinguishing medium should be encouraged if the safety of the crew is considered. No craft is fitted with alternative gaseous extinguishing agents or only high-pressure water mist inside the engine room. An example of a suitable future alternative to the toxic CO_2 in the engine room is automatic high-pressure water mist with foam additives.

Improving measures are concluded in section 5 *Measures*.

4. SAFETY ORGANISATION

The human element is one of the most important factors in maritime fire accidents. A satisfactory safety organisation is therefore necessary to obtain a safe and successful operation of the craft. The safety organisation in this report is divided into two categories, namely *internal safety organisation* (section 4.1), which concerns the organisation on board such as education of the crew, and the *external safety organisation* (section 4.2) where, for instance, the surveying administration influences the safety on board.

4.1 INTERNAL SAFETY ORGANISATION

The evaluation of the internal safety organisation has been carried out by studying existing safety plans and interviews conducted with crew on board and shore-based managers.

It is stated in chapter 7.1.2.1 of the HSC-code: "*Where a fire is detected, the crew immediately puts into action the fire fighting procedures, …prepares for the escape of passengers to alternative safe area …or, if necessary, for the evacuation of passengers."*

According to the interview results the crew is expected to fulfil this requirement in the event of a fire on board. Consequently, the existing fire safety level of the crew is acceptable. This is because of the following reasons:

- All analysed craft were put into service during 1996-97 and the newly employed personnel were motivated and inspired by their new spectacular place of work.
- All personnel have participated in an introductory course where fire safety was one of the main subjects.
- Regular drills (at least one drill every month) have been introduced on board all analysed craft.

4.1.1 Maintenance of the fire safety organisation

The fire safety level of the crew should be maintained over the years. Therefore it is necessary to have routines and a well-planned fire safety organisation, especially since the fire safety for aluminium HSC need to be maintained more strictly than a steel vessel. A removed insulation board, for instance, may result in immediate fire spread and a disaster in case of a fire. [/16/]

The work with maintenance of the safety standard of the personnel within the safety organisation can be divided into four phases that should be under continuous development [/17/]: The safety work should be based on clearly defined *safety goals* formed by the needs within the organisation. In order to fulfil the safety goals and to compensate for the shortages an *education plan* should be developed and *implemented*. The standard of the personnel must be regularly *evaluated* in order to discover shortages within the organisation and to maintain the intended safety level.

/16/ *Fire in Aluminium and Composites on board HSC*, L.Eriksson,World Maritime University, Malmö 1997.
/17/ *Att planera utbildning*, B. Forsberg et.al. Student litteratur,1994. (In Swedish)

The work with maintenance of the safety organisation has been analysed with respect to the four main phases and the results are summarised in figure 4.1:

The process:	Example of application:	Valid for Craft:
Safety goals	Clearly defined designated tasks of the personnel on board	A,B,C,D
Education plan	Drill and education plan for all personnel within the safety organisation for the following year	A,D
Implementation	Regular drills, Annual fire exercises	A,B,C,D
Evaluation	A method for regular evaluation of the safety standard of the personnel, e.g. interviews, inquiries, forums.	—

Figure 4.1 *A summary of the education process and the extent of application on the analysed craft.*

It is obvious that all craft have regular drills, but without being assured if the drills correspond to the needs on board or give the expected result. This is probably due to the extensive and very detailed requirements in chapter 18 of the HSC-Code which require drills every week, no matter if these are necessary or not. It is necessary to re-consider the safety organisation and education of the personnel, especially for the fire-fighting unit on board. Quality should be preferred instead of, as today, quantity. The interviews show tendencies of over-trained personnel and thereby decreased motivation. A better solution would be fewer, but regular, high quality exercises adapted to the current needs, well planned and well prepared. These exercises should be implemented in realistic conditions and evaluated via forums and discussions on board in order to learn from the exercise and to develop the safety organisation to become more professional and efficient.

The interview results show that there is today little available time in the operational schedule. Drills early in the morning or late in the night should be avoided.

4.1.2 Measures internal safety organisation

The following measures should be considered on board:

- Review of the eighteenth chapter of the HSC-Code regarding the education process of the designated personnel.
- Introduction of requirements in chapter 7 of the HSC-Code regarding education, maintenance and inspections similar to the requirements of Life-Saving Appliances and Arrangements (chapter 8.9 in the HSC-Code).

4.2 EXTERNAL SAFETY ORGANISATION

The new large scale, Category B passenger craft embody new technology and are largely without an extensive historical basis of experience. This puts great demands on those involved in the development of the craft. Forming the design today is a process influenced by the ship owner and designer of course, but also by the national administration and the classification society. It is of certain interest as to whether this influence supports or restrains the fire safety on board.

The fire safety evaluation of the four craft presented in section 3 reveals insufficient fire knowledge of all parts involved, but definitely of the surveying administration which has accepted the existing solution. For instance, the important requirement of safe evacuation from the safe-area in the HSC-code chapter 7.11.1.3 is obviously not fulfilled in an acceptable way by the analysed craft. The ship owner also has a responsibility to utilise the required knowledge and make higher demands on the fire safety. However, observe that all craft are built according to the HSC-Code and approved by the administrations. The existing safety standard is not sufficiently good to be fully acceptable or to correspond with existing knowledge in the fire safety area. It is basically a lack of fire safety knowledge within the design process that causes the deficiencies on board. New craft require new knowledge.

4.2.1 The national administrations' influence

The administrations surveying the existing craft should consider the following matters:

- *Interpretation* of chapter 7. The ship surveyors have a tendency to look strictly to the specific requirements, but at the expense of the comprehensive view. For instance, the length of each fire zone is checked (should not exceed 40 m according to chapter 7.11.1), but no attention is paid to whether the zone can accommodate all passengers in case of an emergency or not.

- *Consistency*. Different administrations require different safety measures, which results in inconsistent solutions. International guidelines and directions need to be developed.

- *Equivalence*. The administrations are too conservative when considering alternative, equivalent fire safety solutions according to chapter 1.11. For example, automatic activation of smoke management system in the accommodation has been prohibited despite the fact that automatic activation has been proved necessary in order to maintain tenable conditions.

- *Inadequacy*. The evaluation has revealed some inadequate national requirements, apart from those in the HSC-code. For example regarding firemen's outfits, fire insulation of the floor of the duty-free shop and the design of the accommodation including the number of MES stations.

The traditional surveyors have successfully inspected the entire traditional craft. The administrations show great experience and competence regarding traditional solutions, but the complexity of the new analysed craft requires that experts are involved in the design process, for the fire safety as well as for other engineering areas. Today maritime fire experts are necessary within the administrations in order to involve the right fire safety measures and to achieve acceptable fire safety levels.

5. IMPROVEMENTS

According to sections 3 and 4 extensive improvements are required to avoid the identified problems and inadequacies within the seventh chapter of the HSC-Code and to achieve an acceptable fire safety level. The necessary improvements in this section are divided into two categories:

- Short term improvements, which are urgent improvements within the existing structure of the HSC-Code, and (see section 5.1)
- Long term improvements, necessary to meet future developments within the High-Speed area. (see section 5.2)

5.1 SHORT TERM IMPROVEMENTS

As mentioned in section 1.5 Limitations, chapter 7 in the HSC-Code is not analysed on detail level, but with respect to the total fire safety level of entire craft. Consequently the following improvements are not literal paragraphs ready to be adopted within the code. Instead, the exact formulations need to be further discussed. One general improvement is necessary with regard to the safety of the passengers on board.

General requirement *(chapter 7.1)*
Calculations or tests should demonstrate that the passengers are not exposed to untenable conditions in the event of fire. Calculations, if used, need to be based on established engineering relationships and equations.

5.1.1 Accommodation

The following measures are essential in achieving a safe accommodation area:

Fixed sprinkler system *(chapter 7.13 and Res. MSC.44 (65) Annex 27/18/)*
Only automatic wet/dry pipe, pre-action sprinklers or equivalent should be permitted in order to maintain tenable conditions and to prevent fire spread in case of a fire.

Structural fire protection *(chapter 7.4, table 7.4-1, and chapter 7.11.1.2)*
The structural fire protection between passenger zones and alternative safe areas should resist fire during evacuation to life rafts. (For Craft A-D this corresponds to thirty minutes' structural fire protection.)

Self-closing doors *(chapter 7.9.3 and chapter 7.11)*
The doors between passenger zones and the alternative safe area should be self-closing in case of a detected fire and capable of resisting fires the same length of time as the separating construction in which they are fitted.

/18/ Res. MSC.44(65), *Standards for fixed sprinkler systems for HSC*, MSC, 1995.

Smoke management *(no existing requirements)*
Where it is found necessary to evacuate smoke or prevent spread of smoke to the alternative safe area, suitable smoke management arrangements should be provided. Calculations or tests should demonstrate the need for and performance of smoke management systems.

Arrangement *(chapter 7.11)*
The following measures need to be adopted regarding the arrangement of the passenger area:

- *Alternative safe area should accommodate all passengers on board*. The safe area should be dimensioned on the basis of one person per seat and 2-2.5 persons per net remaining floor area.
- *Accessibility of evacuation stations*. The evacuation stations should be easily accessible from the served passenger areas where distance and familiarity should be taken into consideration.
- *Location of evacuation stations.* If evacuation stations are located inside passenger areas the risk for blockage in case of fire must be considered.
- *The amount of combustible material* must be limited inside and in the vicinity of an evacuation station and in evacuation routes.
- *Access to fresh air and light* should be considered.
- *Increased ceiling height* to prevent fast smoke exposure.

Note: The NFPA 101 Life Safety Code /19//20/ requirement regarding Area of Refuge, involves: Automatic sprinkler protection, self-closing and tight doors, suitable fire resistance rating and mechanical ventilation maintaining a minimum positive pressure of 25 Pa. This should be compared with the existing safe area qualities in chapter 7.11 of the HSC-Code where only smoke-tight divisions are required.

The measures above have been implemented on the analysed craft in order to determine their relevance. Figure 5.1 shows the results as a risk profile, comparable with the existing solutions (section 3.2). The improvement is between 10 to 30 times better where all solutions have acceptable fire safety levels. The improvement is significant for both the evacuation phases. The measure achieves a fully acceptable total fire safety level for the passenger area.

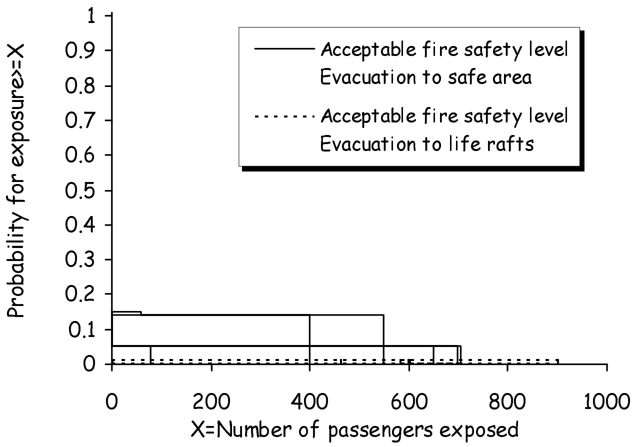

Figure 5.1 *Risk profile, improved fire safety level craft A-D. The improved fire safety level is acceptable.*

/19/ *NFPA 101 Life Safety Code*, National Fire Protection Association, USA 1991.
/20/ *Life Safety Code Handbook*, National Fire Protection Association, USA 1991.

5.1.2 Vehicle deck

In order to prevent major losses and to provide economic effectiveness of the fire safety on the vehicle deck the following measures need to be implemented:

Fixed fire-extinguishing system *(chapter 7.8.2 and IMO Res. A.123 (V)* [/21/]*)*
The fixed fire-extinguishing system in special category spaces must fulfil the following qualities [/9/15/]:

- Fully automatic activation
- Water discharge density equivalent to or over 15 $l/m^2 min$. As today the system need to be divided into zones in order to prevent overtaxing.
- Foam additive to the water where the foam additive should be capable of extinguishing both hydrocarbons and polar solvents.
- The sprinkler heads should be located with regard to the longitudinal flue space formed by vehicles, to provide water discharge in between them.

With these proposed measures the total fire safety level will be improved by a factor of ten compared with the existing safety level and will become accordingly acceptable.

5.1.3 Engine room

The safety level of the engine room is acceptable with respect to passenger safety, therefore no short term improvements are necessary. However, some measures could be considered:

- Improved entry procedures in order to achieve faster CO_2 -activation.
- Permission of automatic release of fire extinguishing medium on condition that the safety of the crew are considered. Examples of suitable extinguishing mediums are non-toxic alternative such as Halon-replacements or high-pressurised sprinkler with foam additives. *(chapter 7.7.6.1)*

The measures may increase the fire safety level about three times in the engine room.

5.1.4 Safety organisation

The following measures should be considered in the internal safety organisation:

- Review of the eighteenth chapter of the HSC-Code regarding the education process of the designated personnel.
- Introduction of requirements in chapter 7 of the HSC-Code regarding education, maintenance and inspections similar to the requirements of Life-Saving Appliances and Arrangements (chapter 8.9 in the HSC-Code).

For improvements of the external safety organisation, see section 4.2 *External safety organisation.*

/9/ SP-Report 1997:03, M.Arvidson et.al, SP-Fire Technology,1997.
/15/ SP-Report 1997:15, *Large Scale RoRo Vehicle Deck Fire Test,M.Arvidson*, SP-Fire Technology,1997.
/21/ *Recommendations on fixed fire extinguishing systems for special category spaces*, Res. A.123 (V), IMO 1967.

5.1.5 Cost analysis of the short term improvements

It is not in the scope of this analysis to present a complete cost-benefit analysis. However some comments, presented below, should be considered when evaluating the cost of the measures.

First, some of the present measures have been found insufficient in the event of a fire, for instance the manual *sprinkler system* as well as the *smoke-tight separations*. Consequently these measures are not cost-effective, but with some modifications the systems will fulfil their purposes and become both cost effective and fully adequate in case of a fire. For instance:

- The separating doors and walls in the accommodation should be fitted with appropriate joints and thermal insulation in order to resist a fire for at least thirty minutes.
- The sprinkler system should be redesigned in order to achieve automatic activation.

The existing Code may cause unprofitable investments since the ship owner spend money on required measures that do not achieve a satisfactory fire protection. For instance, the cost of an automatic sprinkler system with foam additives on vehicle is almost the same as the required manual system, but the difference in efficiency is significant in case of a fire.

Today there are no requirements regarding *smoke-management systems* in the HSC-code. However, immediate smoke management has been found necessary in order to attain safe evacuation of the passengers. This can be achieved by a number of different solutions, ranging from simple smoke evacuating openings in the ceiling to a complex over/under pressurisation system including mechanical smoke fans. Which of the solutions that is most cost-effective varies with the geometry and the amount of toxic gases produced.

Regarding the inadequacies in the *design and arrangement* it is necessary to make some improvements in order to achieve an acceptable solution. Therefore it is neither realistic nor economic to introduce these changes on board existing craft, but they are definitely necessary measures in future craft. The adoption of a new performance based design process, see section 5.2, will make it possible to avoid future design problems and achieve more cost-effective solutions.

When evaluating the cost of fire safety measures other costs should also be considered, such as those in case of a fire where the measures are not installed. The latent costs that occur in the event of a major fire due to standstill and the cost of lost public confidence should be considered. Another important factor is that good appropriate fire protection can reduce the insurance costs significantly. Finally, when evaluating cost effectiveness the cost should be considered for the entire period of operation. Some measures will result in increased initial costs but seen from a long-term perspective the measures will be cost-effective as well as efficient in case of a fire.

> Good fire-protection is always cost-effective
> and fully adequate in case of a fire.

5.2 LONG TERM IMPROVEMENTS

The short-term improvements will, if adopted, achieve an acceptable fire safety level for the studied craft. Nevertheless, the development of HSC is only in the beginning of its era where faster, larger and more advanced craft will be built in the coming years. Accordingly it is necessary to develop an HSC-Code adjusted for future demands within the High Speed shipping industry. Furthermore, this evaluation has revealed some very important inadequacies, not reducible or possible to be eliminated within the framework of existing regulations. For instance:

- *Inconsistency*. The fire safety level varies significantly between the four analysed craft. Even if all craft are built according to the HSC-Code craft A and B show a much better fire safety standard than craft C and D (see section 3.2.3).

- *No comprehensive view*. Designers and surveyors tend to look strictly to the specific requirements at the expense of the comprehensive view. For instance, all analysed craft have been approved by the administrations but the important requirement in chapter 7.11.1.3 where all passengers should be able to be safely evacuated from the alternative safe area is not fulfilled for any craft.

- *Cost-inefficiency*. The possibility of optimisation of the fire safety measures, even with the proposed short-term improvements in section 5.1 applied, is very low. For instance, a craft with 500 passengers would not require the same measures as a craft with 2000 passengers in order to obtain the same level of safety. The possibility of adjusting the fire safety to the specific hazards on board is restricted in the existing regulations, which results in too expensive solutions.

- *Inadequacy.* As an example, no enclosed spaces are permitted on board *(chapter 7.1.2)*. It is possible to achieve a solution with an acceptable fire risk level with enclosed spaces and consequently the requirement is inadequate and limits the use of the craft.

These inadequacies are mainly due to the following reasons:

- *Lack of fire safety knowledge.* The application of new knowledge, new engineering methods and mathematical models within the fire safety area is very limited in the regulations as well as in the design process.

- *Fire Risk Analysis.* The fire risk analysis is not used as a tool for fire hazard identification, fire risk determination, uncertainty analysis and fire risk reduction within the maritime high-speed industry.

The HSC-Code in its current performance does not take these factors into consideration. In order to rectify these inadequacies the HSC-Code must be developed or maybe replaced with regulations adapted to the situation within the present high-speed industry.

5.2.1 Performance based regulations

One way to meet the development of and demand for a new design, is to introduce a performance based High Speed Craft Code. Today there are two major approaches, namely prescriptive and performance based regulations.

The former approach prescribes in detail how different parts and systems should be designed. This approach puts low demands on the fire knowledge of the designer since he/she only has to follow the details in the regulations and craft are surveyed simply by checking that the detailed prescriptions have been followed./22/ (An example of prescriptive rules is chapter II-2 of the SOLAS-convention/2/)

In the performance based approach the goals are more important than the means by which they are accomplished. Instead of prescribing specific details the design should be acceptable according to predefined goals. For example: *A passenger space shall be designed so that the passenger can be safely evacuated in the event of fire.* How the designer fulfils this requirement will vary with the use of the vessel, number of passengers, amount of combustible material and so on. The performance based approach allows continuous adoption of new knowledge within the fire safety area and makes it possible to fit and optimise the fire safety to the specific fire hazards on board the specific craft since the total fire safety level of the craft is in focus rather than the details on board.

Furthermore, the performance based approach places high demands on the knowledge of the designer and the surveying administration since lot of knowledge is necessary to check the assumptions, technical methods and engineering judgements the design is based upon.

> By introducing performance based regulations a high and uniform level of fire safety for all types of craft can be obtained in a cost-efficient way.

Note: The performance based approach is further described in *"Performance Based Fire Safety Regulations for Ships"*, J. Wikman et. al 1994. /23/

The existing HSC-Code involves some performance based requirements but should be regarded as an prescriptive code since many details are prescribed, for instance the sprinkler systems and separating constructions on board.

What are the advantages and disadvantages of the two different approaches?

5.2.2 Comparison between the existing HSC-Code and a performance based HSC-Code

If you compare the application of a prescriptive code and a performance based code a lot of differences will be seen. In table 5.1 on the next page some of these are listed with respect to fire safety:

/22/ *Ship Fire Safety Engineering*, J.Wikman, The Department of Safety Engineering, Lund,1994.
/23/ *Performance based Fire Regulations for Ships*, J.Wikman et.al. Mariterm AB, Gothenburg, 1994.

Application:	Prescriptive regulations	Performance based regulations	Comments:
Financial optimisation	Difficult	Possible	Any design that fulfils the performance requirement is accepted. Consequently it is possible for the designer to find the most cost-effective solution.
Risk for over/under estimations	High	Low	This is because the prescriptive rules do not pay attention to the ship as a whole nor to the specific ship.
Uniform safety level of different ships	Difficult	Possible	Same reason as above.
Flexibility	Low	High	In the latter, new design is possible.
Introduction of new fire safety knowledge	Very slow	Possibly fast	The adoption of new knowledge into the prescriptive regulations is a very long process. The opposite applies to the performance based approach where the measure only has to be proven for one single craft.
Survey	Easy	Demanding	Prescriptive rules are relatively easy to survey since it is only the detail that should comply with the regulations. Performance based rules demand a lot of knowledge to check the assumptions, technical methods and engineering judgements the design is based upon.
Requirement of the user	Low	High	The safety level must be maintained during the life span of the ship.
Risk for cheating	Low	Medium	The administration should have the competence to survey a craft-design formed by a performance based code. Today it is possible to "prove" everything by calculations.

Table 5.1 *Comparison between prescriptive and performance based regulations. Based on ref. /23/.*

The use of performance based design does not exclude the use of common solutions. In the future many existing solutions will remain due to the fact that they often are simple and sometimes cheap to apply. Fundamental is however, that the ship is taken into account as a whole and that the fire safety designer can apply the latest knowledge in a professional manner.

/23/ *Performance based Fire Regulations for Ships*, J.Wikman et.al. Mariterm AB, Gothenburg, 1994.

5.2.3 The performance based design process

Performance based regulations are today in force in a number of countries. The design process differs somewhat between the countries, but, as a good example of one existing procedure, the performance based approach of the British Standard Code of Practice /10/ is described below. The process is split into four main stages as follows:

a) ***Qualitative design review**. (QDR)* The interaction of fire, craft and people give rise to a number of possible scenarios. The purpose of this stage is to review the architectural design and identify potential fire hazards and scenarios in more or less quantitative terms. In the QDR-stage the acceptance criteria are also established. It is desirable that a team including naval architects, surveyors and one or more fire protection engineers, carries out the QDR-stage.

b) ***Quantified analysis***. The identified scenarios have to be analysed with respect to initiation, smoke and fire spread, detection, activation and evacuation. Today there are a number of fire engineering tools to estimate and evaluate the consequences of a fire. Including frequencies and probabilities for each specific scenario it is possible to establish a risk level for the individual craft and the different fire safety measures. Also the cost-effectiveness should be analysed.

c) ***Assessment against safety criteria***. The results of the analysis and the established risk-levels should be compared with the acceptance criteria set during the QDR. If it is demonstrated that the design does not satisfy the specified criteria, the process should be repeated until a fire strategy has been found that satisfies the fire safety criteria and other design requirements.

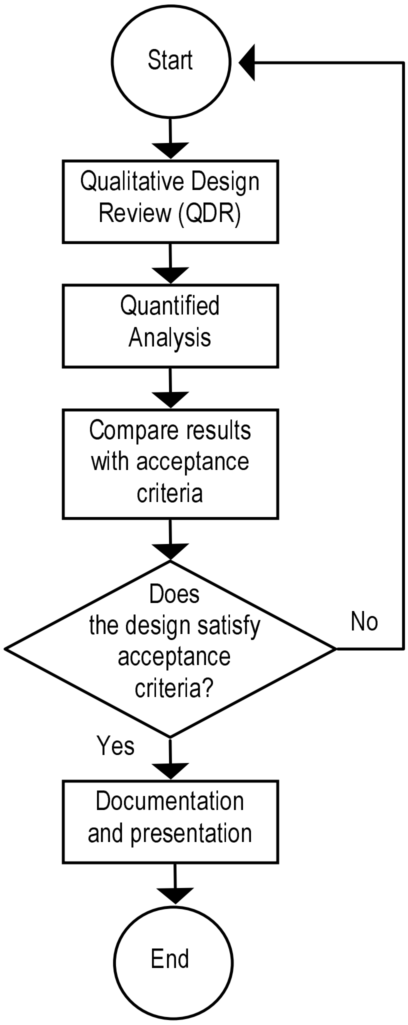

Figure 5.1 *Basic performance based design procedure*

d) ***Presentation and documentation.*** It is essential that the assumptions, methodologies and results of stages a)-c) are presented and documented in a form that can be clearly understood and checked by a third party, for instance the surveying administration.

Note: This design process is similar to the analysis process used in the evaluation of craft A-D, see section 1.3.

/10/*Fire Safety Engineering in Buildings*, BSi-guide, British Standards Institution, 1997.

5.2.4 Principles of a future performance based HSC-Code

This report has shown that there is a need for an extensive review of the HSC-code regarding chapter 7 and fire safety on board. The code must achieve a uniform fire safety level for all types of passenger craft, allow the adoption of new knowledge within the fire safety area and provide cost-efficient solutions. By introduction of performance based regulations, as described in this report, all these qualities can be obtained. However, some areas will need to be considered first:

- The existing design procedure has to be changed as well as the procedures of ship survey.
- Guidelines and handbooks have to be developed in order to establish validated and standardised methods of determination in the fire design process.
- The knowledge within the maritime fire area must be increased. Introduction and education of Maritime Fire Protection Engineers at established universities with fire protection engineer courses are definitely required. [/25/]

The introduction of a performance based chapter 7 can be carried out in two different ways, step-by-step or immediate transition. The step-by-step approach will be a softer transition, probably more suitable for the shipping industry. However, it will be nearly impossible to obtain a uniform fire safety level during the step-by-step transition, which also is the slowest way of introduction. Consequently an immediate transition is the best solution from a fire safety point of view. The introduction of performance based fire-regulations for buildings in Sweden confirm this conclusion. [/24/]

The basic principles of a future performance based chapter 7 in the HSC-Code can be stated briefly as follows:

1.	**General fire safety objectives and requirements**	
		Definitions
		Methods of determination
		Documentation
2.	**Evacuation in the event of fire**	
		Evacuation to Area of Refuge
		Evacuation to Life Rafts
3.	**Prevention of outbreak of fire**	
		Protection of ignition
		Detection
4.	**Prevention of spread of fire**	
		Protection of spread of smoke
		Protection of spread of flames
5.	**Structural fire protection**	
6.	**Fire extinguishing measures**	
		Manual equipment
		Automatic
		External

/24/ *BBR94*, Boverkets byggregler 1994, Karlskrona1994. (In Swedish)
/25/ Brandsäkerhet på fartyg och behovet av ökad ingenjörskompetens på området, R. Jönsson, Institutionen för Brandteknik, 1990. (In Swedish)

6. DISCUSSION

The main conclusion of this report is that the total fire safety level on board large High Speed Craft, built according to the HSC-Code, need to be improved. This is a remarkable, though not from a fire engineering point of view, unexpected result. Chapter 7 of the HSC-Code contains requirements that have to be reviewed to correspond with present fire safety knowledge. Compared with the DSC-code, the HSC-Code is a great step to a better fire safety standard on board HSC, but further improvements are necessary. I hope that this document constitute a good basis for future discussions and revision of the HSC-Code. I will also encourage the authors of the Code who have an obligation towards the designers and ship owners to form an adequate code. A craft built according to the HSC-Code should have an acceptable fire safety level and the ship owner should not be forced to install further measures in order to achieve a good fire safety level.

A noticeable result is the quality of education of the personnel on board. A regular drill today is too often that the crewmember should walk to his/her designated place and stay there until the drill is over. It is obvious that this results in low motivation on board and this in turn is probably due to lack of motivation, but also lack of competence in fire safety and education, of those who plan and conduct the education on board. Fewer, but regular, well-planned and well-prepared realistic high quality exercises are required.

The ship owner, who is responsible for the passengers on board, should not accept craft other than one fitted with the appropriate fire safety measures. It is ultimately the ship owners that have the possibility of boosting the fire safety development on board HSC, but also the administrations have to utilise the required fire safety knowledge in order to support the application of good fire safety solutions.

The fire risk analysis should and must be encouraged by the Maritime Safety Committee as a fundamental tool within the design process. Fire risk analysis can be immediately adopted within the framework of the existing HSC-code.

During the work with this report I have got several comments on the probability of fire in the accommodation area. The probability of a large fire in the accommodation is very low due to the area in most craft is easily viewable. However, the probability for example arson or late detection increases with the size and the number of subdivisions of the craft. Furthermore, the fire safety measures in a Code can not be based on the assumption that a fire never will break out. The Code and the fire safety measures must be adapted to the conditions on board HSC and be based on suitable design fires. The total fire risk is the product of the probability and the consequence. Thus, even if the probability is very low, the consequences of a fire in the accommodation can be so severe that the risk has to be considered and reduced within the framework of the Code.

The proposed improvements within this report confirm that it is possible and necessary to build HSC with a better level of fire safety. Most important is that the short term improvements be adopted but the work with a performance based HSC-code should begin as soon as possible. However, regardless of the measures in this report are implemented or not, knowledge within the maritime fire safety area must be increased and used.

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