PHOENIX

FINAL REPORT

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1.1
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EDITORS:

Enrique González Pino, Project Manager

Jesús Carbajosa Menéndez, Financial Administrator

AUTHORS:

CETEMAR, S.L., Spain

Jaime Leça da Veiga ______________________________

Bruno Della Loggia ______________________________

Ricard Marí Segarra ______________________________

APPROVAL:

Approved for release by:

Enrique González Pino ______________________________

Jesus Carbajosa Menéndez ______________________________

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FINAL REPORT

SUMMARY

The aim of the PHOENIX project is to apply a universal tool for the quantification of fire risk on ships that will allow us to cover a deficiency in the field of maritime transport.

With respect to the outbreak of fire, the project scientific objectives were to:

- Determine current ship condition directly related to fire risk.
- Provide awareness of the fire fighting capacity of the ship.
- Detect the absence of adequate procedure and method in the inspection system.
- Identify the significantly negative parameters that, on applying adequate preventive action, will effectively reduce the level of the risk.
- Detect and differentiate structural deficiencies in the organisation.
- To prepare a computer programme that facilitates the calculation process and the presentation of the negative aspects that affect the level of risk so determined.

From the research carried out, negligence is suspected to be the main cause for accidents. The situation in this sense reflects a great need for education and training. The consequences of the accidents studied, in the majority of cases, were not significant (44%). General cargo vessels would seem to be those most prone to developing a fire risk situation on board. Vessels over 15 years of age show a tendency toward high risk.. On the other hand, vessels to which the most recent amendments to SOLAS Chapter II-2 apply tend towards a lesser risk of fire on board. Vessels with a tonnage above 10000 but less than 50000 also show a tendency toward high risk. As it might be expected, the risk of accidents is higher when the vessel is under way. In this situation, the majority of fires started in the engine room. With regard to the importance of the variables in the analysis, these may be organised in the following way:

Size	15,08%;
Cause	14,06%;
Age	12,82%;
Type	11,80%;
Place of outbreak	11,19%
SOLAS	9,56%;
Flag	8,89%;
Condition	8,83%;
Position	7,77%

Risk analysis, information was collected from reliable sources such as the Institute of London Underwriters, the U.K. Marine Accident Investigation Branch, the International Maritime Organisation (Reports of the Sub-Committee on Flag State Implementation), and individual ship owners and maritime authorities in the participating countries.

Data related to the physical and chemical aspects of fire on board, ship types and flags, the human factor in the time span approaching the event was considered, together with an evaluation of measures taken as well as the protective devices installed. Finally, the resources available for fire fighting after the event and its evolution were considered. The consequences were measured by the level of seriousness.

In order to analyse the relationship between the incidence of the different flags and the individual number of vessels involved in fire accidents, more data was collected from Lloyd's Maritime Information. For the period under study, flag statistics (fleet dimension) were collected.

Two computer programs were developed in the form of checklists for analysis and prevention of fire on board ships. The checklists developed have been adapted to computer use for the user's convenience. Both programmes have similar structures and configurations. The first one is called General Fire Protection and offers information about prevention and control, and the second one offers information about the major causes of fire, negative influences and efficiency. This method allows an inspector to look for the adequacy of safety policies applied to fire prevention

For the Basis for other Applications, conclusions were reached that are applied to the different aspects of fire risk. This is so that technical and scientific links may be established that improve criteria on the choice and specifications of the equipment to be used for fire-fighting, whether at the first design stage of a ship or during later construction phases, or refitting.

A a case study of fire propagation on board ship was simulated. A typical room arrangement was defined, including complete outfitting, furniture and division bulkheads. The simulation output was represented by typical fire elements such as temperature and smoke rate.

2. EXECUTIVE SUMMARY

2.1 PHOENIX

This was an Identification and Case Study of the variables and parameters in the Human Domain in Evaluating Fire Risk on Board Ships that was carried out for Directorate General VII of the European Union Commission under Contract number: WA-97-SC.2201.

The contractors of the project were:

CETEMAR, S.L., Spain
FRESTI, Lda., Portugal
CETENA, S.p.A., Italy
DCEN-UPC, Spain

2.2 Scientific Objectives

The aim of the PHOENIX project is to apply a universal tool for the quantification of fire risk on ships that will allow us to cover a deficiency in the field of maritime transport. To achieve this objective the study is divided into eight parts with their specific objectives as follows:

- E.U. Statistics

The aim here is to build a database that incorporates information related to the outbreak of fire on board and includes data collected from reliable sources.

- Risk Analysis

This task is to analyse the database that is the result of WP100 collecting together the different aspects and conditions that have an influence on, or directly causes the outbreak of fire.

- Risk Determination

This part consists in the groundwork for preparing the methodology for the development of the fire evaluation method.

- Tools for Evaluation

The aim here is to provide an evaluation procedure for certain case studies of the outbreak of fire.

- Basis for other Applications

The aim of this part is to reach conclusions that may be applied to the different aspects of fire risk.

- Simulation

The aim here is to set up a design specification of a crisis management tool capable of aiding decision-makers in an emergency situation related to the propagation and behaviour of fire on board ships.

- Checklist

This part will offer detailed and complete checklists to be applied before and after a fire event. It is one of the central tasks of the Phoenix Project, since its main aim was to offer a deliverable consisting of detailed and complete checklists to be applied before and after a fire event on board ships. This was to be achieved on the basis of the information provided by all previous WP’s.

2.3 Exposition of Results

Negligence is suspected to be the main cause for the accidents. This situation reflects the great need for education and training. The consequences of accidents in the majority of the cases were small (44% of the cases). General cargo vessels are those which are most prone to developing a fire risk situation on board. The vessels with an age above 15 years show a tendency toward high risk.

It was discovered that vessels to which the most recent amendments to SOLAS Chapter II-2 apply have less risk of fire on board, contrary to those that the requirements of the 1981 amendments apply.

In reference to weight, it would seem that vessels with a tonnage above 10000 but less than 50000 also show a tendency toward high risk. As it might be expected, it was found that the risk of accidents is higher when the vessel is under way. In this situation, the majority of fires started in the engine room. Regarding the importance of the variables in the analysis, they can be organised in the following way:

- Size 15,08%;
- Cause 14,06%;
- Age 12,82%;
- Type 11,80%;
- Place of outbreak 11,19%
- SOLAS 9,56%;
- Flag 8,89%;
- Condition 8,83%;
- Position 7,77%

2.4 Means Used To Achieve The Objectives.

Information was collected from the most reliable sources such as the Institute of London Underwriters, the U.K. Marine Accident Investigation Branch, the International Maritime Organisation (Reports of the Sub-Committee on Flag State Implementation), in some cases individual ship owners and the maritime administrations in the participating countries.

Data related to the physical and chemical aspects of fire on board, ship types and flags, the human factor in the time span approaching the event was considered. Furthermore, one of the objectives was to evaluate any measures taken as well as the protective devices installed. Finally, the resources available for fire fighting after the event and its evolution were considered. The consequences were measured by the level of seriousness.

All the information was collected in order to carry out an in-depth statistical analysis covering those variables that were not taken into account and that turn out to be vitally important. This is particularly significant because it was our intention to obtain correct criteria on evaluating the response and preventive/protective factors that had an influence on the outbreak of the fire and its evolution/propagation.

In order to analyse the relationship between the incidence of the different flags and the individual number of vessels involved in fire accidents more data was collected from Lloyd's Maritime Information. For the period under study, flag statistics (fleet dimension) were collected. The main objective was to analyse the circumstances that lead up to accidents involving the outbreak of fire on board ships. The particular conditions that differentiate one case from another were taken into account and any aspect considered important for clarifying the real causes behind the outbreak of fire and its evolution on board

The variables considered were:

1. Year of event
2. Type of vessel
3. Age
4. Applicable SOLAS (74/78, 81, 83, 89, 91, 92 April, 92 December)
5. GRT
6. Flag
7. Condition
8. Position
9. Starting place
10. Cause
11. Action taken
12. Seriousness

After defining the variables, the next phase was the grouping of information.

Phase three consisted in the creation of a one dimensional variables analysis chart:

a. Variable 1 – Year of event. Relationship between year/casualties
b. Variable 2 – Ship type. Relationship between type of vessel/casualties
c. Variable 3 – Age. Relationship between age/casualties

d. Variable 4 – SOLAS. Relationship between SOLAS/casualties
e. Variable 5 – GRT. Relationship between GRT/casualties
f. Variable 6 – Flag. Relationship between Flag/casualties
g. Variable 7 – Condition. Relationship between condition (loaded/in ballast)/casualties
h. Variable 8 – Position. Relationship between position/casualties
i. Variable 9 – Starting place. Relationship between starting place/casualties
j. Variable 10 – Cause. Relationship between cause/casualties
k. Variable 11 – Action. Relationship between action taken/casualties
l. Variable 12 – Seriousness. Relationship between seriousness/casualties

All the data obtained up to this point had to be collated and analysed. With this information, two computer programs were developed in the form of checklists for analysis and prevention of fire casualties on board ships.

Procedures aiming at the evaluation of the success or adequacy of safety policies, in this case specifically those applied to fire prevention, protection and fighting, shall undoubtedly contemplate and be consequent with the following principles:

1. Analysis of ship condition before the accident (fire). The maximum number of parameters and elements that were present in the situation must be known: their condition, maintenance characteristics, actual use and degree of compliance with regulations, as well as requirements and limitations to which they were subject. The analysis of its condition previous to an incident sketches the scenario in which, and because of which, the incident was possible. This delimitation helps to establish an idea of the intact state, on which the human factor necessarily has a direct influence, since it manipulates, uses and modifies it. Eventually, either due to the tendency of the elements involved to decay, or to human error, they are so badly altered that an outbreak of fire becomes a natural consequence. The subsequent evolution of a fire might be accelerated by aspects derived from the previous condition, specific current conditions, the automatic intervention of installed protection systems or the human actions that were carried out.

> 1.1.. Information about ship condition can be obtained from procedures contemplated by safety inspections derived from a more or less exhaustive application of the Port State Control (MOU) requirements. One of their forms intends to do this with the checklist called “General fire Protection”.
>
> 1.2. The ship’s general condition and the probability / possibility that a fire may break out on board have already been described above.

2. Investigations of a standard type carried out after an accident, shall facilitate the maximum amount of information about aspects such as:

- The circumstances related to fire spreading,
- The conditioning, disturbing and damaging elements,
- Intervention procedures,
- Efficiency,
- Technical, equipment and human limitations, etc.

These elements, on a whole, will provide criteria on the "cause-effect-seriousness" and will highlight weak and strong aspects of each one of the stages of intervention, always obviously interacting with the condition of installations and available safety levels (previous condition).

The contents of the second checklist developed for the objectives of this study ("Checklist After Fire Incidents") might respond to this need and fill this gap.

The checklists developed have been adapted to computer use for the user's convenience. These two programmes have similar structures and configurations, and, therefore, the explanation given for one of them shall be extendible to the other.

3. MATERIALS AND METHODS

A co-operation agreement was signed by the CASMET and PHOENIX projects. To this end a meeting was held in Barcelona on the 1st April 1998. The CASMET project was represented by Mr. Piero Caridis of the National Technical University of Athens, who are the co-ordinators. The other partners of the project are:

Det Norske Veritas.
Instituto Superior Tecnico.
Marintek, Greece.
National Technical University of Athens, Greece.
TNO Human Factors Research Institute, Germany.
Marine Accidente Investigation Branch, UK..
Dutch Ministry of Transport, Holland.
Norwegian Maritime Directorate, Norway.

The main aims of CASMET are:

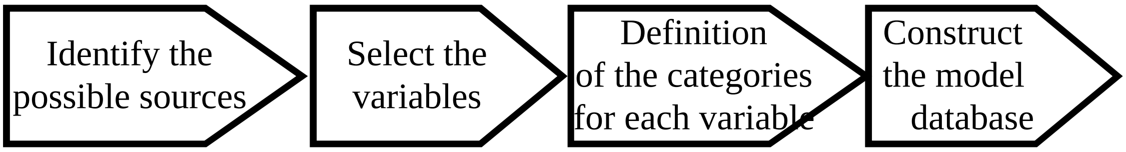
- Develop casualty analysis methodologies that will adequately address human and organisational errors (HOE).
- Develop a policy impact assessment tool that will address HOE.
- Demonstrate the results with a number of case studies.
- Develop a procedure for the investigation and analysis of marine casualties.

During the first 2 months of the PHOENIX project, FRESTI built a model database where the information related to the outbreak of fire was incorporated. The development of this database involved:

- Selecting the variables and the respective categories. Twelve variables were chosen by the study team according to the type of information and the existing database.
- Collecting the information from the most reliable and complete sources. The majority of the information was collected in the Institute of London Underwriters and more data was acquired from the Marine Accident Investigation Branch in Southampton and UK P&I Club. The Statistics of Lloyd's, specific ship owners and classification societies were also consulted.
- Collating all the information and doing the statistical treatment.

On examination of the information so collected, the categories for each variable were redefined and the non-significant ones were removed. It was then possible to build a final database.

The approach to creating the database can be seen below:



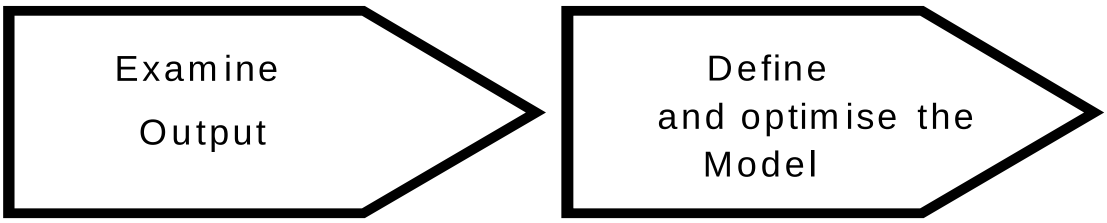
- To check from different sources the existent database
- To identify the type of information

- To select common variables from previous database
- Which variables we can add to our database to achieve the objective

- Definition of the categories for each variable

- To construct the database from the previous stages

All the information from the previous sub-task was grouped into action/reaction blocks during the different stages of the process and their statistical treatment.

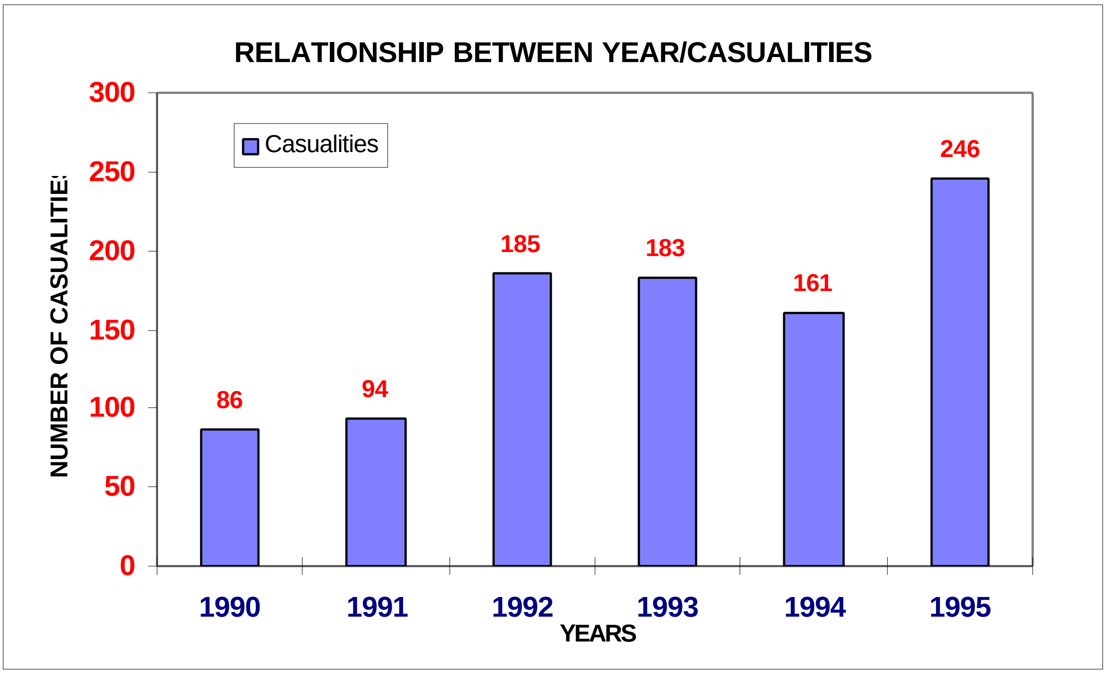


- Overall data of each vessel and casualty
- Lack of information for the same variables
- Predicted vs. Actual results

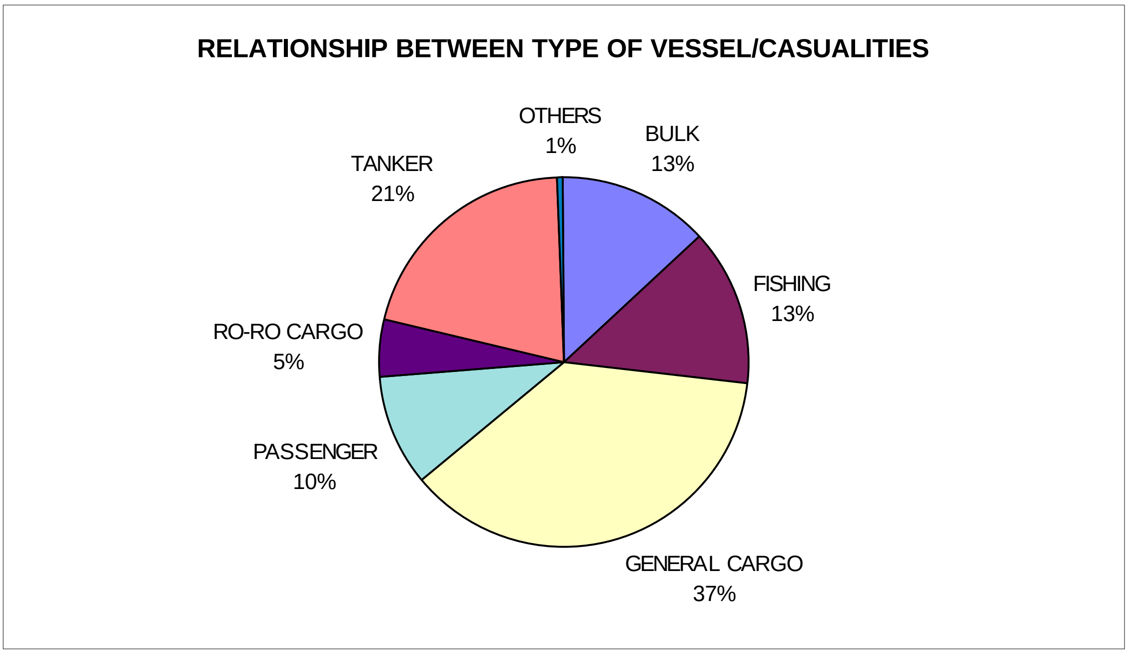
- Remove non-significant variables
- Redefine categories for each variable
- One-dimensional correlation

Some cases from which it was not possible to collect all the information were eliminated. With respect to the variable SOLAS the following amendments were considered: SOLAS 74, SOLAS 81, SOLAS 83, SOLAS 89, SOLAS 91, SOLAS 92 (April) and SOLAS 92 (December).
Special care was taken regarding the 1991 amendment. Two of the amendments apply to all ships. They affect regulations 20 and 21, which deal respectively with fire control plans and ready availability of fire extinguishing appliances. The remaining amendments concern passenger ships built on or after 1 January 1994. For this reason and in order not to affect the statistical treatment of the information this amendment was only considered as a variable for the passenger ships built on or after the above mentioned date.

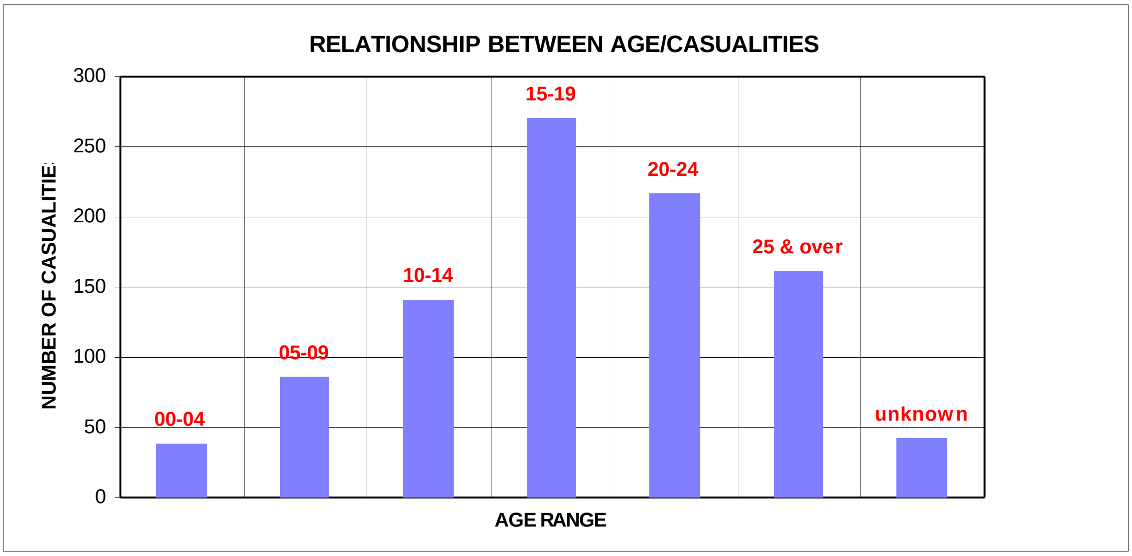
VARIABLE 1 - YEAR OF EVENT



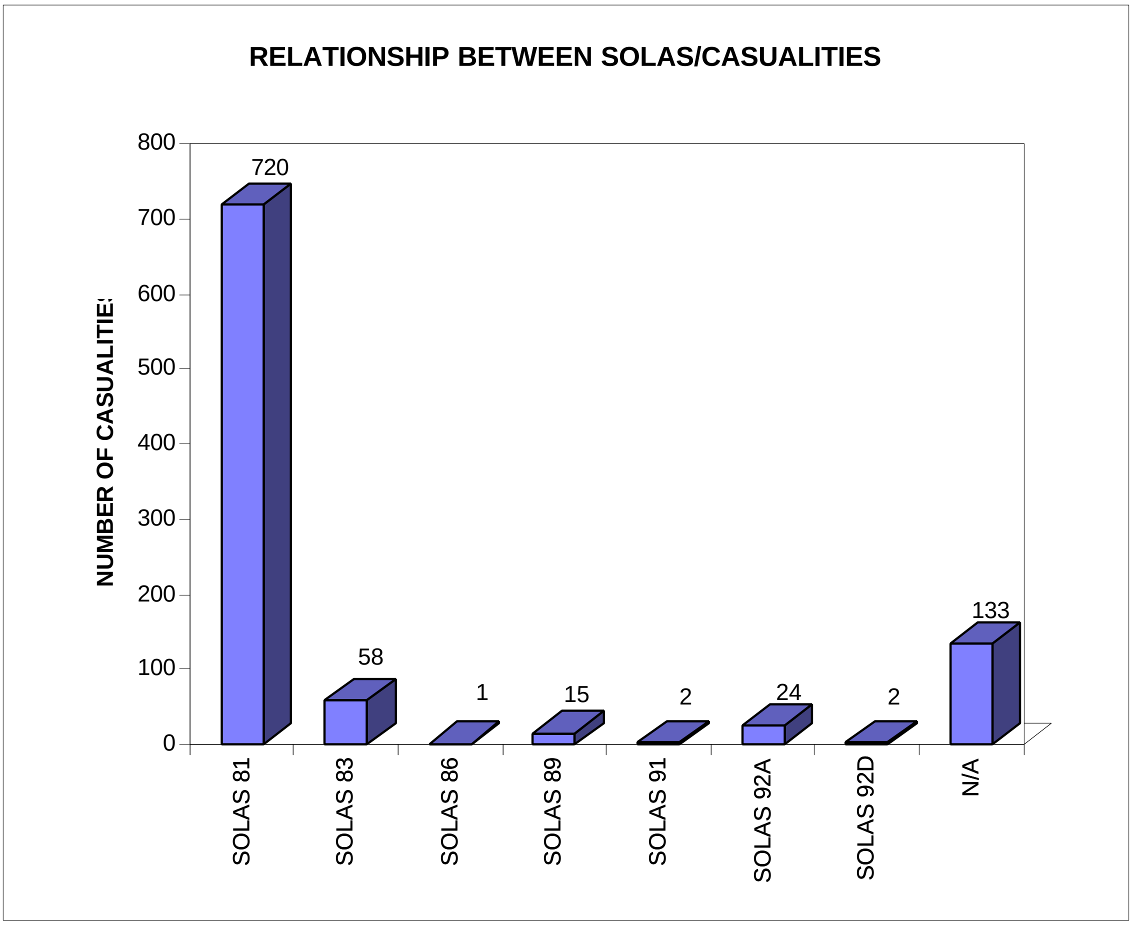
VARIABLE 2 - TYPE OF VESSEL



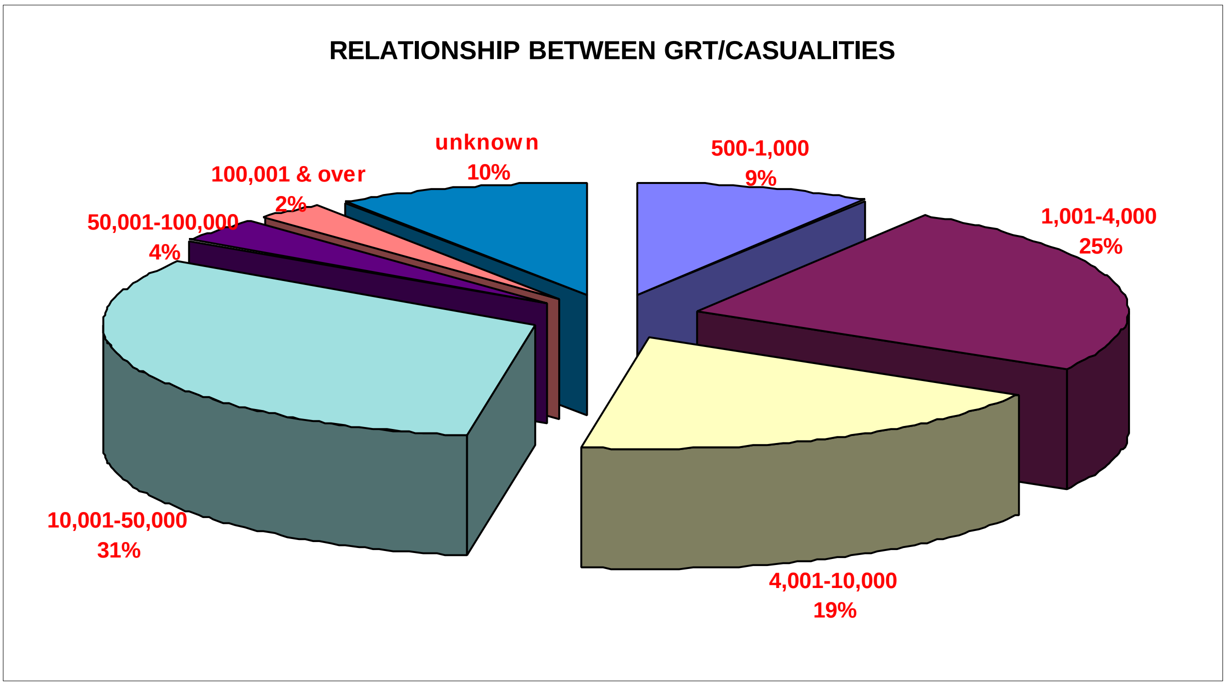
VARIABLE 3 - AGE


RELATIONSHIP BETWEEN AGE/CASUALITIES
NUMBER OF CASUALITIES
300
250
200
150
100
50
0
00-04
05-09
10-14
15-19
20-24
25 & over
unknown
AGE RANGE

VARIABLE 4 - SOLAS



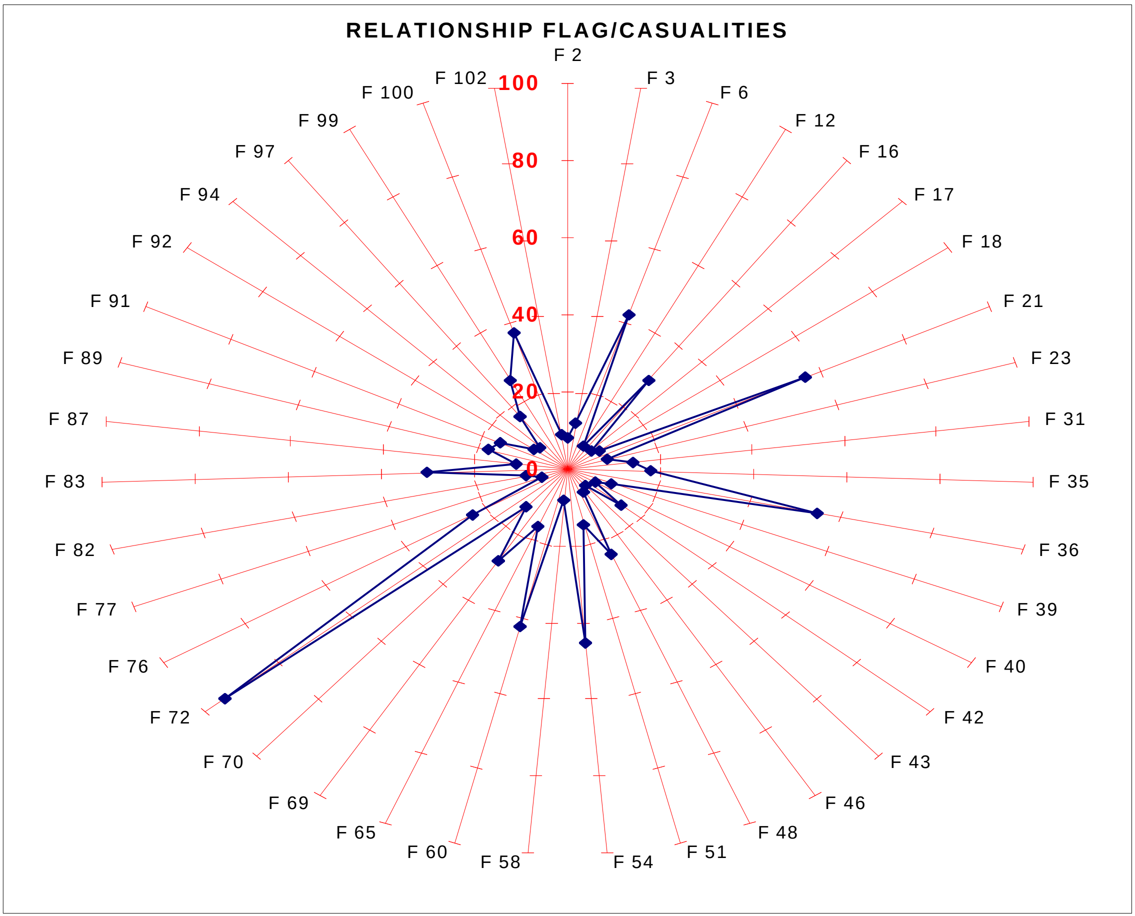
VARIABLE 5 - GRT



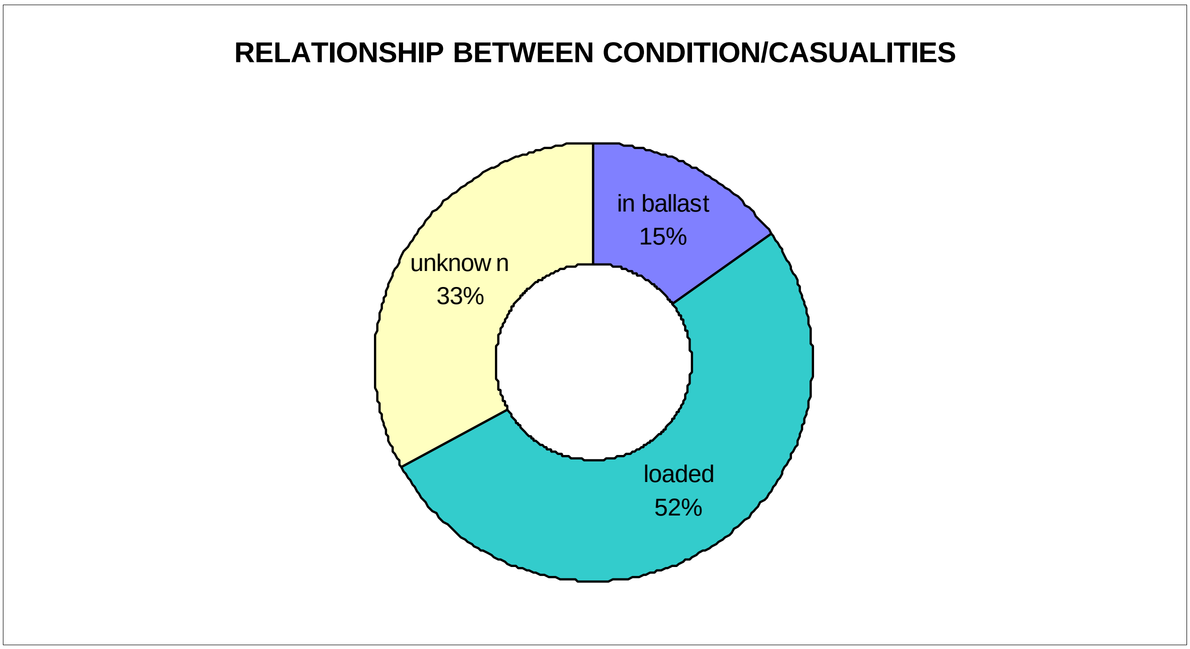
VARIABLE 6 - FLAG

Variable 6	FLAG	Total
Antigua & Barbuda	F 2	8
Argentina	F 3	12
Bahamas	F 6	42
Brazil	F 12	7
Canada	F 16	29
Chile	F 17	7
China	F 18	8
Cyprus	F 21	56
Denmark	F 23	9
France	F 31	14
Germany	F 35	18
Greece	F 36	55
Honduras	F 39	10
Hong Kong	F 40	7
India	F 42	15
Indonesia	F 43	6
Isle of Man	F 46	7
Italy	F 48	24
Korea, South	F 51	15
Liberia	F 54	45
Malaysia	F 58	8

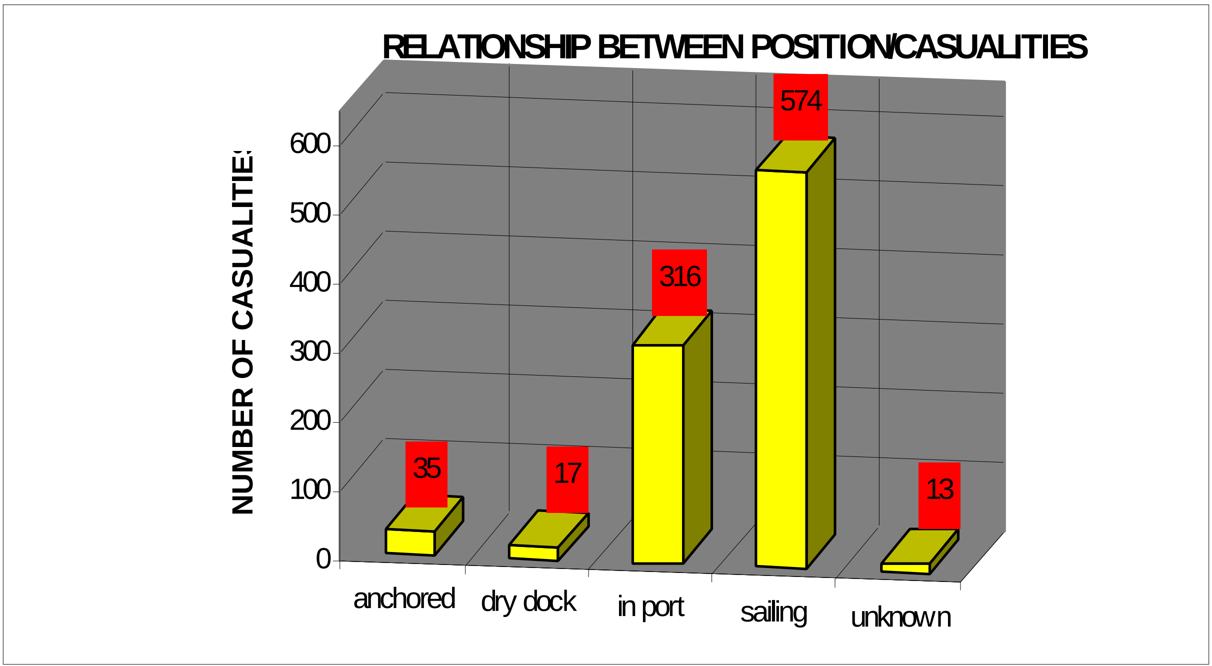
Variable 6	FLAG	Total
Malta	F 60	42
Netherlands	F 65	16
Norway	F 69	28
Norwegian Int. Register	F 70	13
Panama	F 72	95
Philippines	F 76	24
Poland	F 77	6
Romania	F 82	9
Russia	F 83	30
Singapore	F 87	11
Spain	F 89	18
St. Vincent & Grenadines	F 91	16
Sweden	F 92	9
Taiwan	F 94	8
Turkey	F 97	17
U.K.	F 99	26
U.S.A.	F 100	37
Vanuatu	F 102	9



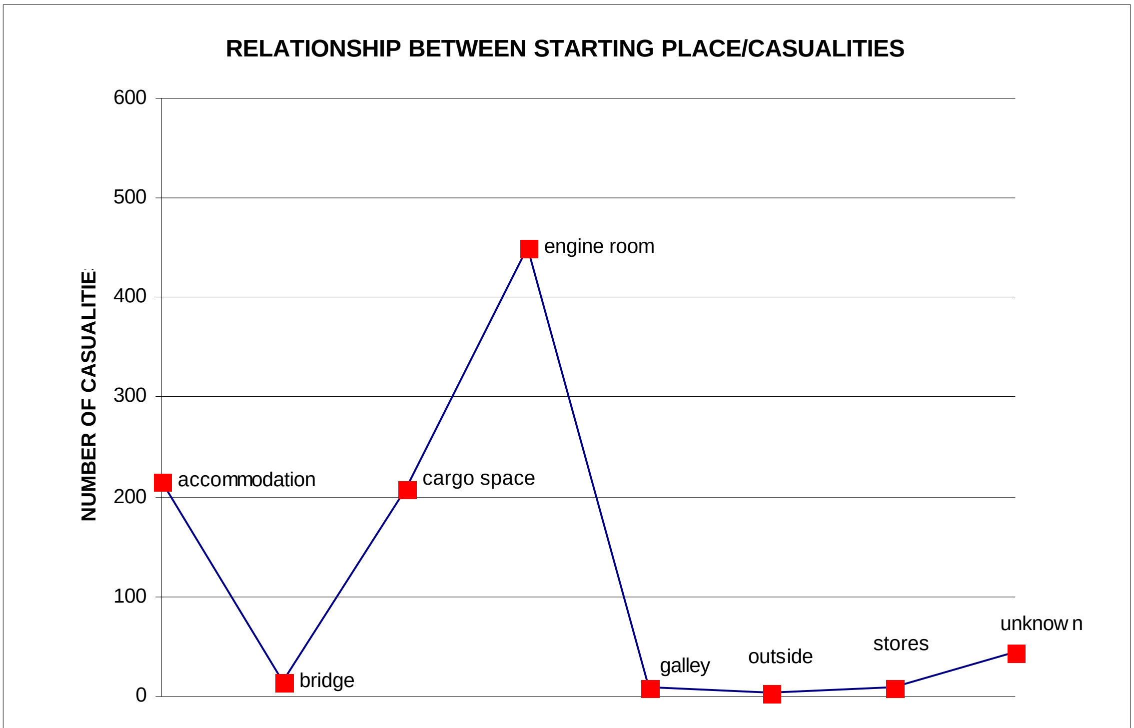
VARIABLE 7 - CONDITION



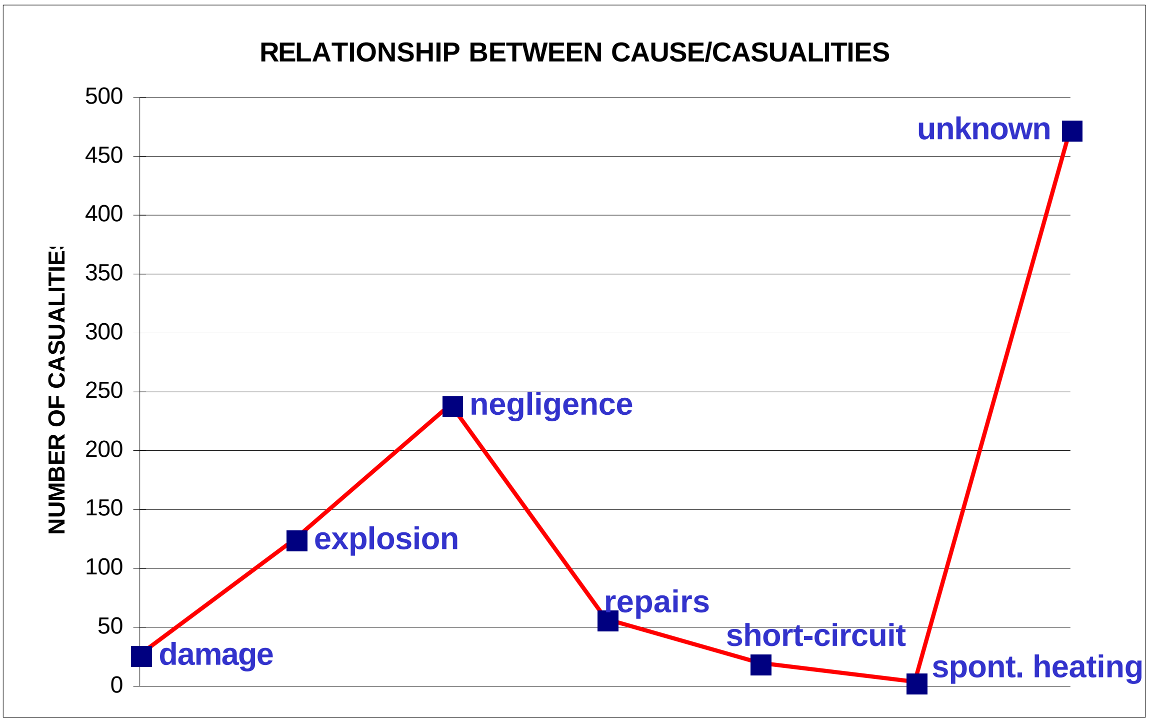
VARIABLE 8 - POSITION



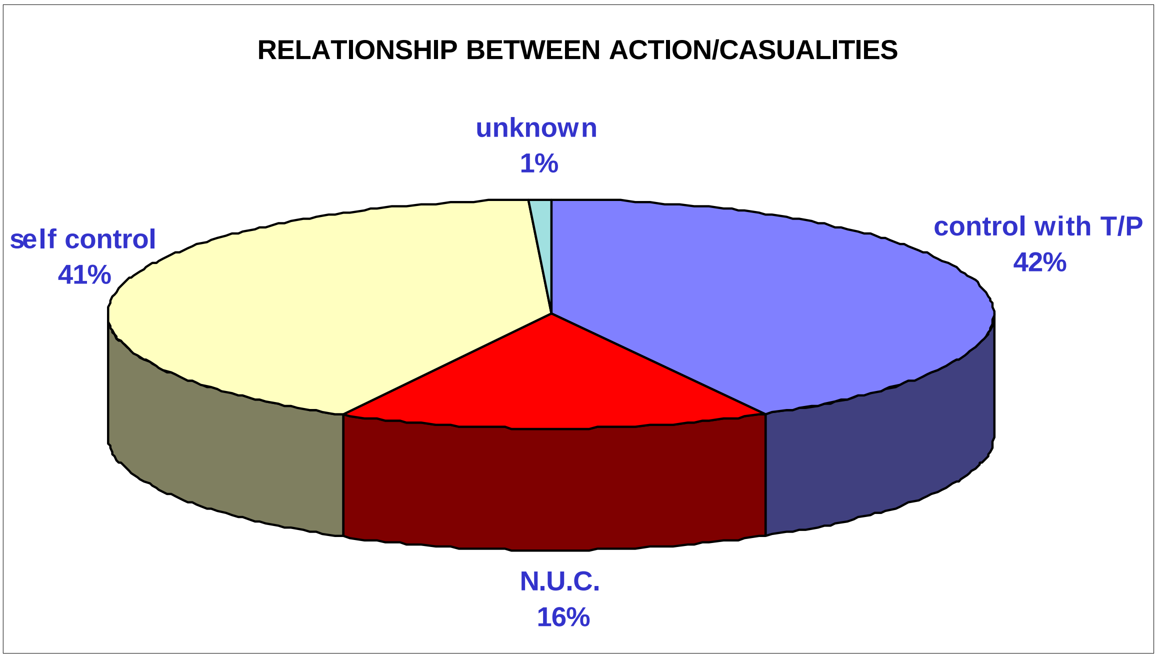
VARIABLE 9 - STARTING PLACE



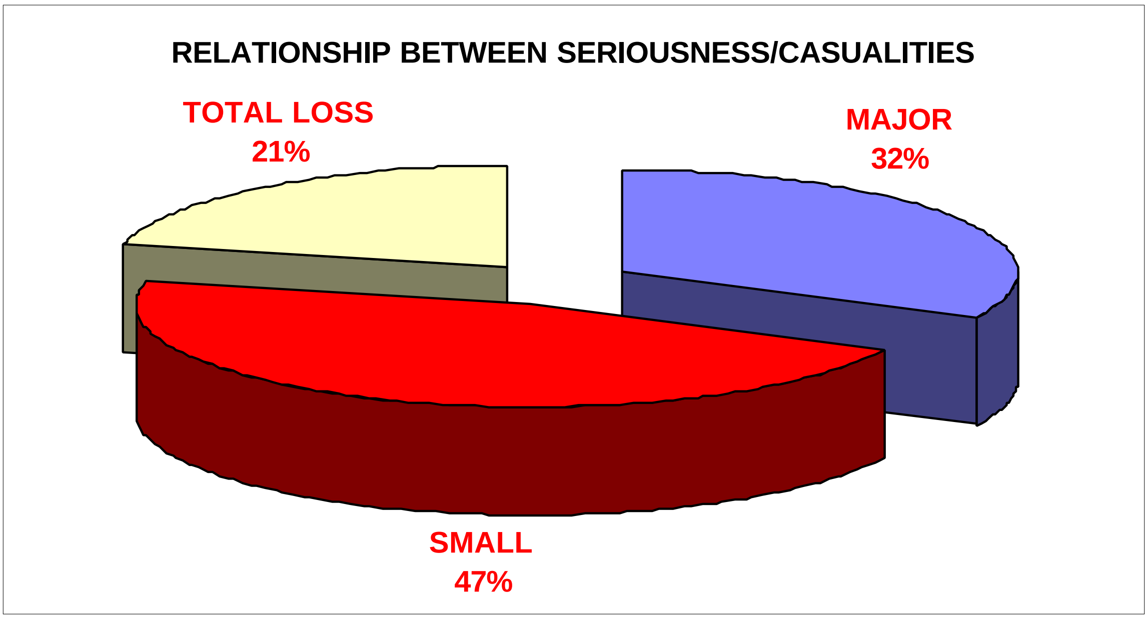
VARIABLE 10 - CAUSE



VARIABLE 11 - ACTION



VARIABLE 12 - SERIOUSNESS

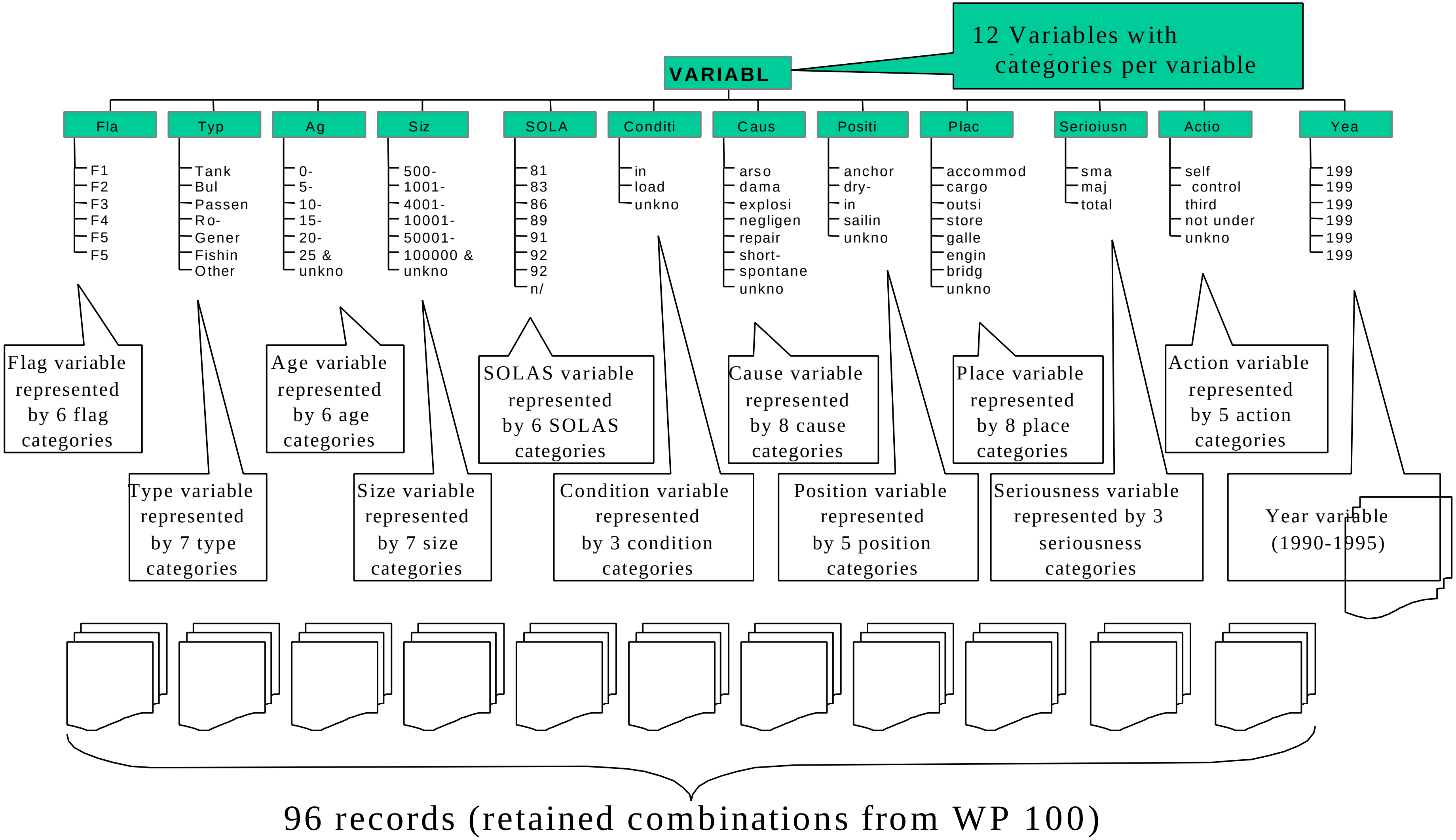


In order to analyse all possible relations between the fire accident variables, several databases of different resources collected:

- The database generated at the beginning of the project.
- The reports and data connected to fire accidents on board during the 6-year period from 1990 to 1996.
- The flag statistics from Lloyd's during the period under study.
- The criteria used in other industries.

When all data collection was completed, the relationship and different combinations were aggregated on the first database, considering the information and criteria of each resource when it was possible to import. Finally, a data analysis was developed, making it possible to establish some conclusions.

3.1.1 FIRE CASUALTY DATABASE STRUCTURE



3.1.2 FIRE RISK VESSEL VARIABLES

955 vessels in casualty data were transformed into 96 combinations of vessel variables.

- 12 vessel variables were selected
- Each variable was split into a logical number of categories e. g. Type - logical split into Tankers, Bulk, Passenger, Ro-Ro, General, Fishing and Others
- The combination of the various categories was computed against the seriousness of the casualties
- The risk analysis was conducted without the variables Year (already aggregated) and Action, as these variables don't deal directly with the fire risk analysis.

3.1.3 FLAG CATEGORISATION

96 Flags

Flag	Total Casualities	Total Cumulative Fleet (90-95)	Risk Fleet	Cumulutive %	Flag Code
Japan	4	59080	0,00007	0,00015	1
Peru	1	3801	0,00026	0,00057	1
Cuba	1	2291	0,00044	0,00095	1
Iceland	1	2286	0,00044	0,00096	1
Indonesia	6	12277	0,00049	0,00107	1
Vietnam	1	1894	0,00053	0,00115	1
China	8	14835	0,00054	0,00118	1
Nigeria	1	1632	0,00061	0,00134	1
Morocco	2	2868	0,00070	0,00152	1
Belgium	1	1416	0,00071	0,00154	1
Egypt	2	2425	0,00082	0,00180	2
Russia	30	35449	0,00085	0,00185	2
Latvia	1	1161	0,00086	0,00188	2
Faeroes Islands	1	1076	0,00093	0,00203	2
Senegal	1	1049	0,00095	0,00208	2
Australia	4	3964	0,00101	0,00221	2
U.S.A.	37	34521	0,00107	0,00234	2
Portugal	2	1856	0,00108	0,00235	2
Ukraine	5	4487	0,00111	0,00244	2
Korea (South)	15	12814	0,00117	0,00256	2
Iran	3	2487	0,00121	0,00264	2
Mexico	5	3821	0,00131	0,00286	2
Syria	1	750	0,00133	0,00291	2
Spain	18	12153	0,00148	0,00324	2
Honduras	10	6638	0,00151	0,00329	2
DIS	4	2638	0,00152	0,00331	2
Colombia	1	639	0,00156	0,00342	3
Bulgaria	2	1265	0,00158	0,00345	3
Poland	6	3674	0,00163	0,00357	3

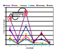
South Africa	2	1213	0,00165	0,00360	3
Thailand	4	2370	0,00169	0,00369	3
Bangladesh	3	1759	0,00171	0,00373	3
Singapore	11	6338	0,00174	0,00379	3
Maldive Islands	3	1630	0,00184	0,00402	3
Bahrain	1	538	0,00186	0,00406	3
Papua New Guinea	1	524	0,00191	0,00417	3
Brazil	7	3649	0,00192	0,00419	3
Belize	2	953	0,00210	0,00459	3
Lebanon	2	910	0,00220	0,00480	3
Ecuador	2	450	0,00222	0,00486	3
Tunisia	1	900	0,00222	0,00486	3
Malaysia	8	3451	0,00232	0,00507	4
Sweden	9	3843	0,00234	0,00512	4
New Zealand	2	846	0,00236	0,00517	4
Germany	18	7601	0,00237	0,00517	4
Libya	2	839	0,00238	0,00521	4
Denmark	9	3694	0,00244	0,00532	4
Finland	4	1616	0,00248	0,00541	4
Netherlands	16	6369	0,00251	0,00549	4
Italy	24	9272	0,00259	0,00566	4
U.K.	26	9726	0,00267	0,00584	4
Germany D.R.	1	372	0,00269	0,00587	4
NIS	13	4832	0,00269	0,00588	4
Philippines	24	8917	0,00269	0,00588	4
Qatar	1	365	0,00274	0,00599	4
India	15	5299	0,00283	0,00619	4
Chile	7	2452	0,00285	0,00624	4
Israel	1	345	0,00290	0,00633	4
Estonia	3	1028	0,00292	0,00638	4
France	14	4784	0,00293	0,00640	4
Saudi Arabia	5	1704	0,00293	0,00641	4
Panama	95	32265	0,00294	0,00643	4
Norway	28	9481	0,00295	0,00645	4
Turkey	17	5673	0,00300	0,00655	4
Hong Kong	7	2300	0,00304	0,00665	4
Korea (North)	2	656	0,00305	0,00666	4
Lithuania	3	962	0,00312	0,00681	5
Saint Vincent	16	5062	0,00316	0,00691	5
Venezuela	5	1549	0,00323	0,00705	5
Marshall Islands	1	301	0,00332	0,00726	5
Romania	9	2681	0,00336	0,00734	5
Algeria	3	892	0,00336	0,00735	5
Bermuda	2	563	0,00355	0,00776	5
Antigua & Barbuda	8	2120	0,00377	0,00825	5
Luxembourg	1	246	0,00407	0,00888	6
Argentina	12	2781	0,00431	0,00943	6
Canada	29	6398	0,00453	0,00991	6

Liberia	45	9852	0,00457	0,00998	6
Netherlands Antilles	4	866	0,00462	0,01009	6
Irish Republic	5	1075	0,00465	0,01016	6
Paraguay	1	213	0,00469	0,01026	6
Greece	55	11269	0,00488	0,01067	6
Sri Lanka	2	385	0,00519	0,01135	6
Vanuatu	9	1706	0,00528	0,01153	6
Austria	1	180	0,00556	0,01214	6
Gabon	1	179	0,00559	0,01221	6
Cyprus	56	8976	0,00624	0,01363	6
Ethiopia	1	153	0,00654	0,01428	6
Bahamas	42	6326	0,00664	0,01451	6
Pakistan	3	407	0,00737	0,01611	6
Malta	42	5444	0,00771	0,01686	6
Isle of Man	7	711	0,00985	0,02151	6
Georgia	2	184	0,01087	0,02375	6
Tuvalu	1	45	0,02222	0,04856	6
Equatorial Guinea	1	13	0,07692	0,16810	6
Haiti	2	20	0,10000	0,21853	6

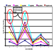
Sort on risk fleet
(Low to high)

3.1.4 Flag Risk by Type

3.1.5

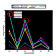


3.1.6 Flag Risk by Age

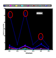


3.1.7 Flag Risk by Size

3.1.8

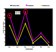


3.1.9 Flag Risk by SOLAS

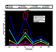


3.1.10 Flag Risk by Condition of the Vessel

3.1.11

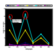


3.1.12 Flag Risk by Cause

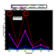


3.1.13 Risk Flag by Position of the Vessel

3.1.14



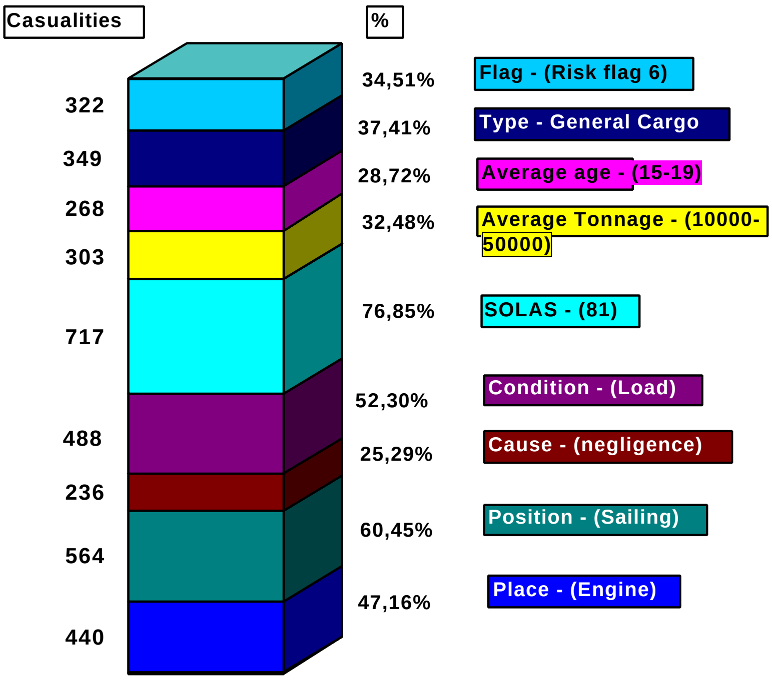
3.1.15 Risk Flag by Place of the outbreak fire



3.1.16 Higher Risk Categories per each Variable

Note: the Cause frequently found to explain fire outbreak was "unknown", but we suspect that this is really negligence. In order to maintain the consistency of the analysis we refer to only the known 25.29 % of negligence

Higher Risk Categories per each variable		
Importance categ.	Casualities	% Casualities
Risk Flag 6	322	34,51%
General Cargo	349	37,41%
Average age 15-19	268	28,72%
Average Ton.10001-50000	303	32,48%
SOLAS 81	717	76,85%
Condition Loaded	488	52,30%
Cause negligence	236	25,29%
Position sailing	564	60,45%
Place engine	440	47,16%



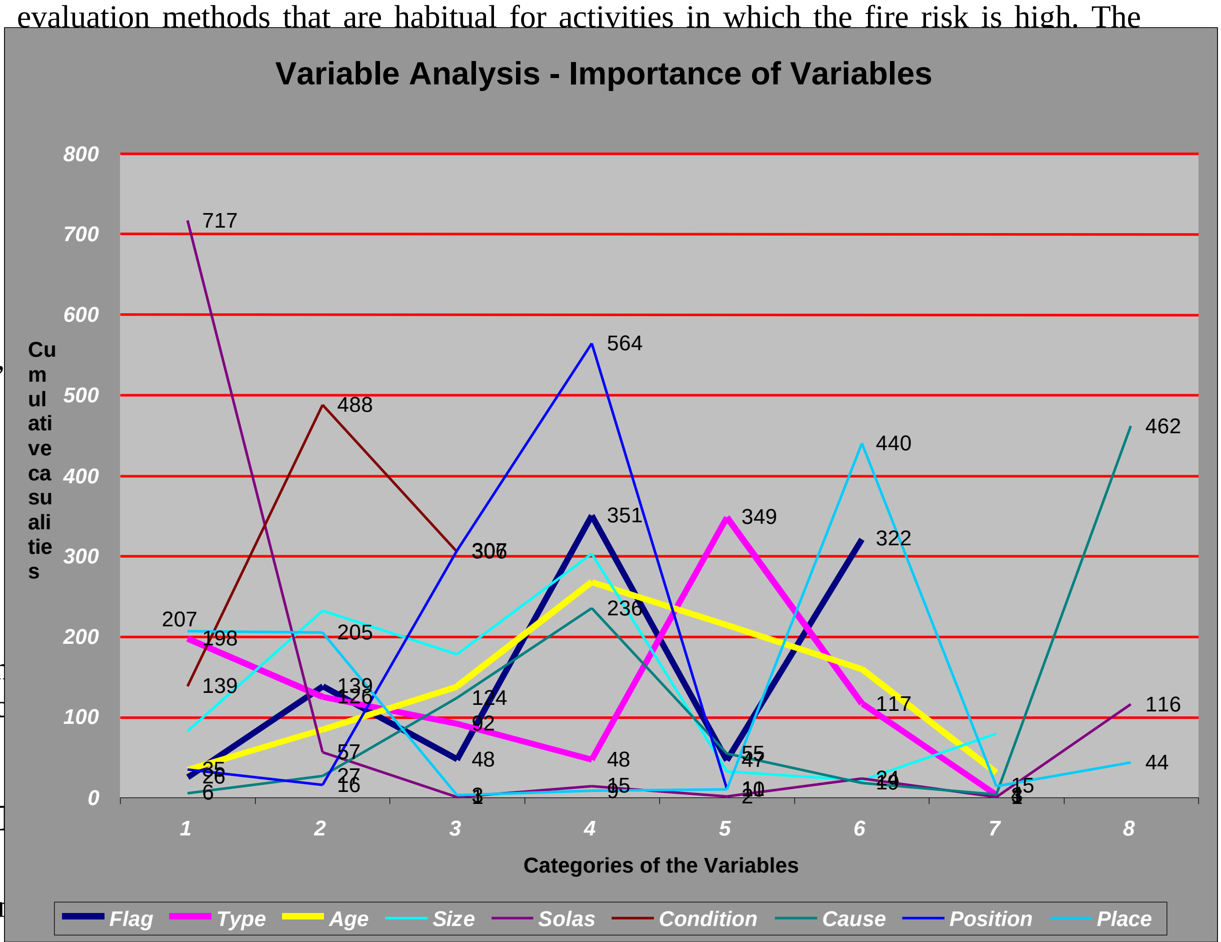
3.1.17 Variable Analysis

Variables	Categorie 1	Categorie 2	Categorie 3	Categorie 4	Categorie 5	Categorie 6	Categorie 7	Categorie 8
Flag	26	139	48	351	47	322		
Type	198	126	92	48	349	117	3	
Age	35	85	139	268	215	160	31	
Size	83	232	178	303	33	22	80	
Solas	717	57	1	15	2	24	1	116
Condition	139	488	306					
Cause	6	27	124	236	55	19	4	462
Position	35	16	307	564	11			
Place	207	205	3	9	10	440	15	44
Total	**1446**	**1375**	**1198**	**1794**	**722**	**1104**	**134**	**622**

3.2 Risk Detemination

This part of the project was divided into into two parts:

- Analyses criteria derived from general risk evaluation methods and regulations regarding fire accidents. The analysis has been made of the different procedures used by safety techniques to quantify fire risk, considering both occasional and common evaluation methods that are habitual for activities in which the fire risk is high. The



Then,

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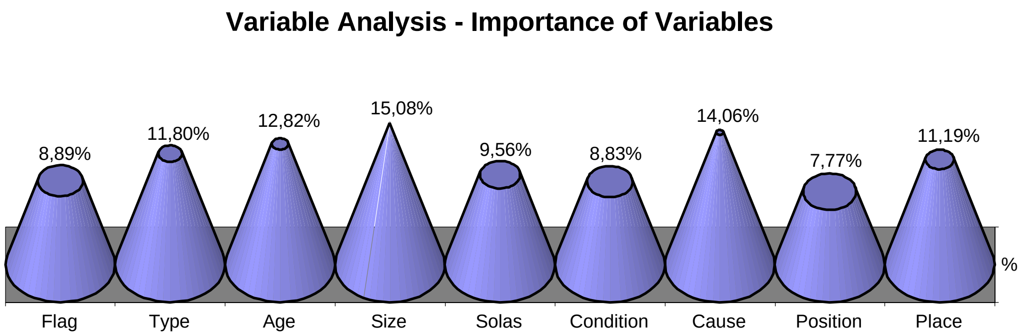
results, the workpackage was structured as follows:



- A mathematical treatment of the results of the questionnaire including the determination of the "N" coefficient, with application in this method, was developed and the variables were analysed.

All operations and important aspects of quantification of risk were considered and collated into the program: "HCFIRE – Fire risk Spreadsheet". This software allows the user to detect and identify deviations in regard to the fulfilment of the items and to apply preventive measures.

3.4 Basis for Other Applications

In this workpackage a description of the main rules of the SOLAS Convention, Chapter III was developed. All the aspects of safety on board of ships, the materials, the fire division bulkheads, the alarms plants, the detection plants, the fixed and portable extinguishing equipment and all the escape means were analysed. In the treatment of these points, the main aspects of fire-fighting were analysed:

- Basic principles.
- General requirements.
- Means to reduce the risk of fire outbreak and propagation.
- Main technical rules for fire detection and extinction.
- Escape and evacuation.

In order to comply with the safety rules, all ships existing and under construction, are requested to be equipped with suitable systems for its own protection and of the people it carries against the risk of fire. All the materials on board, the fire division bulkheads, the alarm systems, the detection systems, all the permanent and portable extinguishing equipment and all the means of escape must comply with the existing rules.

All the aspects of safety on board of ships are treated by the rules of the SOLAS Convention and its chapters II and III are entirely dedicated to the description of all the requirements for every ship in order to be able to travel safely over the oceans.

In particular Chapter II is mainly devoted to safety aspects linked to the buoyancy of the ship and its intact and damage stability, Chapter III is devoted to the safety aspects related to the fire protection of passenger ships, cargo ships and tankers.

3.4.1 Conventional Ships

3.4.1.1 Fire Fighting On Board Of Ships

Fire is one of the most dangerous situation a ship and the people it carries on board might experience. Therefore, the main goal of everybody involved in fire-fighting is to avoid the loss of both the ship and human life.

The efforts of ship designers are led in two different directions:

1. to reduce the risk of fire outbreak

2. to reduce its propagation if it does break out.

In order to achieve these goals, the basic principles adopted for fire fighting on board are the following:

- restricted use of combustible materials on board;
- minimisation of possibility of ignition of flammable fluids.
- division of ship into main vertical zones by thermal and structural boundaries;
- separation of accommodation spaces from other zones of the ship by thermal and structural boundaries;
- protection of means of escape or access for fire fighting;
- detection of any fire in the space of origin;
- containment and extinction of any fire in the space of origin;
- ready availability of fire-extinguishing appliances;

Rules regarding the fire-fighting depends on a lot of parameters that include:

- category, size and type of ship (i.e. passenger ship, dry cargo ship, tanker, special purpose ship, non self-propelled craft);
- fire hazard involved with the cargo carried (explosive mixtures, flammability, heat produced by combustion, speed of variation over time of thermal power produced, dangerous substance production in the case of fire, etc);
- structure of the ship related to cargo movement (lift on/lift off, roll on/roll off, etc);
- characteristics of ship service.(i.e. long haul, short haul, national voyages)

For each ship, taking into account these parameters, the specific rules for fire protection defines the requirements of:

- structural fire protection
- water fire-fighting system (fire pumps, hydrants and fire hoses)
- permanent gas fire-extinguishing systems
- fire extinguishers
- fire protection arrangements in machinery spaces
- automatic sprinklers, fire-detection and fire-alarm systems
- permanent fire-detection and fire-alarm systems
- arrangements for oil fuel, lubricating oil and other flammable oils

Fire Bulkheads

The first means of passive defence consists of dividing the ship (hull, superstructure and deckhouses) into main vertical zones. Each zone is delimited by two structural and thermal bulkheads.

The Convention defines 3 different types of fire bulkheads:

- “A“ Class divisions, formed by bulkheads and decks which comply with the following:

  (a) constructed of steel or other equivalent material;
  (b) suitably hardened;
  (c) constructed so as to be capable of preventing the passage of smoke and flame after a one-hour standard fire test;
  (d) insulated with approved non-combustible materials such that the average temperature of the unexposed side will not rise above 140°C in relation to the original temperature. Nor will the temperature, at any one point, including any joint, rise more than 180°C above the original temperature, within the time listed below:

  – Class "A-60" 60 minutes
  – Class "A-30" 30 minutes
  – Class "A-15" 15 minutes
  – Class "A-0" 0 minutes

- “B” Class divisions, formed by bulkheads, decks, ceilings or linings which comply with the following:

  (a) constructed as to be capable of preventing the passage of flame to the end of the first half hour of the standard fire test;

  (b) have an insulation value such that the average temperature of the unexposed side will not rise over 140°C above the original temperature, nor will the temperature at any one point, including any joint, rise more than 225°C above the original temperature, within the time listed below:

  – Class "B-15" 15 minutes
  – Class "B-0" 0 minutes

  (c) constructed of approved non-combustible materials and all materials entering into the construction and erection of B Class divisions must be non-combustible.

- “C” Class divisions, constructed of approved non-combustible materials. They do not need to meet either requirements relative to the passage of smoke and flame or limitations relative to the rise in temperature.

The Convention states that for A and B Class divisions a specific test of a prototype bulkhead or deck in accordance with IMO Resolution MSC.61(67) “Fire Test Procedures Code” is required, in order to ensure that it meets the requirements for integrity and temperature.

For further information regarding “Definitions” see Annex I - Chapter 1.

Chapter 11 of Annex I includes the rules regarding the structural fire protection of passenger ships.

The Convention states the appropriate fire integrity standards to be applied to boundaries between adjacent spaces; these requirements are described in Tables 1, 2, 3 and 4.

As regards the openings in division bulkheads, the Convention states that all openings must be provided with permanently attached means of closing and that they must be at least as effective for resisting fires as the divisions in which they are fitted.

Means Of Escape

In the case of a fire breaking out in a room or a specific point of the ship, the people on board must be able to escape from the fire zone as fast and safely as possible.

For this purpose several means of escape are available on board of ships.

They consist of stairs, ladders and doors suitably fitted in order to allow passengers and crew to reach the embarkation deck.

The Convention defines in detail the means of escape both for passengers and cargo ships.

As regards general spaces, the rules states that stairways and ladders must be arranged to provide ready means of escape to the life-boat and life-craft embarkation deck from all passenger and crew accommodation and from spaces in which the crew is normally employed, other than engine spaces.

In particular, the rules state that:

- below the bulkhead deck two means of escape, at least one of which must be independent of watertight doors, must be provided from each watertight compartment or similarly restricted space or group of spaces..

- above the bulkhead deck there must be at least two means of escape from each main vertical zone or similarly restricted space or group of spaces at least one of which must give access to a stairway forming a vertical escape.

- at least one of the means of escape required by the preceding items must consist of a readily accessible enclosed stairway, which must provide continuous fire shelter from the level of its origin to the appropriate embarkation decks.

As regards engine spaces two means of escape must be provided from each space. In particular, where the space is below the bulkhead deck the two means of escape must consist of two sets of steel ladders as widely separated as possible, leading to doors in the upper part of the space similarly separated and from which access is provided to the appropriate life-boat and life-craft embarkation decks. One of these ladders must provide continuous fire shelter from the lower part of the space to a safe position outside the space.

In no case can lifts be considered as forming one of the required means of escape.

The rules also provide a calculation method for the dimensions of means of escape from accommodation and service spaces and control stations. The calculation method considers evacuation from enclosed spaces within each main vertical zone individually and takes into account all the persons using the stairway enclosures in each zone even if they enter that stairway from another main vertical zone.

For each main vertical zone the calculation must be undertaken for the night time and day time and the largest dimension from either case used for determining the stairway width for each deck under consideration. The calculation method determines the stairway width at each deck level taking into account three consecutive stairways leading into the stairway under consideration. The calculations of stairway widths is based upon the crew and passenger load on each deck. Occupant loads must be as rated by the designer for passenger and crew accommodation spaces, service spaces, control spaces and engine spaces.

The dimensions of the means of escape are calculated on the basis of the total number of persons expected to escape by the stairway and through doorways, corridors and landing.

The Convention states additional requirements for Ro-Ro ships; particular attention is drawn to the handrails or other handholds to be provided in all corridors along the entire escape route, so that a firm handhold is available every step of the way to the assembly stations and embarkation stations. Such handrails must be provided on both sides of longitudinal corridors more than 1,8 m in width and transverse corridors more than 1 m in width. Particular attention must be paid to the need to be able to cross lobbies, atriums and other large open spaces along escape routes. Escape routes must be provided from every normally occupied space on the ship to a muster station.

Simple "mimic" maps showing the "you are here" position and escape routes marked by arrows, must be prominently displayed on the inside of each cabin door and in public spaces. The plan must show the directions of escape, and must be properly oriented in relation to its position on the ship.

Cabin and stateroom doors must not require keys to unlock them from inside the room. Neither must any doors along any designed escape route require keys to unlock them when moving in the direction of escape.

For Ro-Ro passenger ships constructed on or after 1 July 1999, escape routes must be evaluated by an evacuation analysis early in the design process. The analysis must be used to identify and eliminate, as far as practicable, congestion which may arise during an abandonment, due to normal movement of passengers and crew along escape routes, including the possibility that crew may need to move along these routes in a direction opposite the movement of passengers. In addition, the analysis must be used to demonstrate that escape arrangements are sufficiently flexible to provide for the possibility that certain escape routes, assembly stations, embarkation stations or survival craft may not be available as a result of a casualty.

Fire Detection And Extinction

As described in Chapter 5.I.1, the first active defence against the propagation of a fire is accomplished by the detection of the fire in its space of origin. Fire-detection and fire-alarm systems must warn personnel about the outbreak of a fire by means of acoustic and optical alarms.

Fire detectors adopted on board are automatic or manually operated:

- the automatic detectors analyse the quantity of smoke and/or the level of temperature in the air of each controlled space and send an electrical signal to the control station.
- the manually operated fire-alarm systems are equipment directly acted by personnel on watch.
- detectors and fire-alarm systems allows both to warn about fire and to locate the fire origin.

The second action is the extinction of the fire in the space of origin.

Ships are generally provided with a fire extinguishing system made up by different systems, permanent or mobile, each equipped with different extinguishing agents (water, gas, foam, dust).

Foam is one of the most effective means to extinguish fires caused by the combustion of flammable liquids. The types of foam normally used on board of ships are two: low and high expansion and their use mainly depends on the volume of the room to be protected. The effect of the foam is double: reduction of the temperature and smothering of the fire.

Carbon dioxide is an effective means to extinguish a fire caused by flammable liquids and electrical short-circuits. The effect of CO_2 is the reduction of available oxygen.
Steam is no more employed on new buildings and halogenised hydrocarbon systems are prohibited on new and existing ships.

Dust has the effect of interrupting the chemical reaction of the combustion process.

Water used as a fire extinguishing agent has a lot of advantages for ships:

- economical convenience
- facility of finding large quantities
- absence of toxicity
- absence of toxic products given off during combustion
- high capacity of heat absorption

As regards the main fire-fighting system, this is made up of a permanent pipe system fed by sea water through dedicated pumps (fire-pumps) and kept under pressure by an autoclave. Sea water is sent to the fire hydrants through the pipes: the most common use consists of launching a water jet against burning solids in order to reduce their temperature.

In the spaces where a diesel engine or a boiler is fitted a water spray circuit is adopted ending in a number of nozzles capable of ejecting a misty spray.

Generally in accommodation rooms, decks, working places and all spaces open to the crew a sprinkler circuit fed by fresh water is adopted, characterised by detection and extinguishing actions: the sprinkler-head initially acts as a fire-detector and later as a mist ejector.

On board ships the components and equipment of the water fire-fighting system are strictly linked to the bilge and ballast systems. The SOLAS Convention firstly states the number and capacity of bilge pumps and then the rules state those of the fire pumps, but it does not mention water pressure at the hydrants.

Generally the fire fighting system consists of main and emergency fire pumps, of main and derived pipelines feeding the fire stations, the sprinkler system and the foam extinguishing system. In order to grant a fast and safe intervention in the case of a fire outbreak, the hydraulic circuit is always kept under pressure by an autoclave fed by compressed air and low capacity pumps.

For each fire pump the rules state capacity as being the function of the capability of the bilge pumps and in function of the ship type (passenger or cargo ship). Within the passenger ships the rules state the required number of fire pumps and the hydrants' minimum pressure as in function of the ship size.

Automatic sprinklers, fire-detection and fire-alarm systems

The SOLAS rules state that any automatic sprinklers, fire-detection and fire-alarm system has to be able to operate immediately at all times and no action by the crew is necessary to set it in operation. The system must be kept at the necessary pressure and have provision for a continuous supply of water.

Generally sprinklers are grouped into separate sections, each of which contains not more than 200 sprinklers. For passenger ships any one section of sprinklers cannot serve more than two decks and cannot be situated in more than one main vertical zone.

Sprinklers must be placed in an overhead position and spaced in a suitable pattern to maintain an average application rate of not less than 5 l/m_2 per minute over the nominal area covered by the sprinklers.

An independent power pump must be provided solely for the purpose of continuing automatically the discharge of water from the sprinklers. The pump must be brought into action automatically by the pressure drop in the system before the standing fresh water charge in the pressure tank is completely exhausted.

On passenger ships there must be not less than two sources of power supply for the sea-water pump and automatic alarm and detection system.

Permanent fire-detection and fire-alarm systems

The SOLAS rules state that any permanent fire-detection and fire-alarm system with manually operated call points must be capable of immediate operation at all times.

Power supplies and electric circuits necessary for the operation of the system must be monitored for loss of power or faulty conditions as appropriate. Occurrence of a faulty condition initiates a visual and audible fault signal at the control panel which must be distinct from a fire signal.

There must be not less than two sources of power supply for the electrical equipment used in the operation of the fire-detection and fire-alarm system, one of which must be an emergency source. The supply must be provided by separate feeders reserved solely for that purpose. Such feeders must run to an automatic change-over switch situated in or adjacent to the control panel for the fire-detection system.

Detectors and manually operated call points must be grouped into sections. The activation of any detector or manually operated call point must initiate a visual and audible fire signal at the control panel and indicating units. If the signals have not received attention within two minutes an audible alarm must be automatically sounded throughout the crew accommodation and service spaces, control stations and machinery spaces.

The control panel must be located on the navigating bridge or in the main fire control station. Indicating units must denote the section in which a detector or manually operated call point has operated. At least one unit must be so located that it is easily accessible to responsible members of the crew at all times, when at sea or in port except when the ship is out of service.

Clear information must be displayed on each indicating unit about the space covered and the location of the sections.

Detectors are operated by heat, smoke or other products of combustion, flame, or any combination of these factors. Flame detectors are only used in addition to smoke or heat detectors.

Manual call points must be installed throughout the accommodation spaces, service spaces and control stations. One manual call point must be located at each exit. Manual call points must be readily accessible in the corridors of each deck so that no part of the corridor is more than 20 m from a manual call point.

Smoke detectors must be installed in all stairways, corridors and escape routes within accommodation spaces.

A fixed fire-detection and fire-alarm system must be installed in periodically unattended engine spaces.

This fire-detection system must be so designed and the detectors so positioned as to detect rapidly the onset of fire in any part of those spaces and under any normal conditions of operation of the engine and variations of ventilation as required by the possible range of ambient temperatures. Except in spaces of restricted height and where their use is specially appropriate, detection systems using only thermal detectors are not permitted. The detection system must initiate audible and visual alarms distinct in both respects from the alarms of any other system not indicating fire, in sufficient places to ensure that the alarms are heard and observed on the navigating bridge and by a responsible engineer officer. When the navigating bridge is unmanned, the alarm must sound in a place where a responsible member of the crew is on duty.

Fire Protection Arrangements In Engine Spaces

The engine spaces containing oil-fired boilers or oil fuel units and machinery spaces containing internal combustion engines must be provided with any one of the following permanent fire-extinguishing systems all complying with the SOLAS rules :

- a gas system;

- a high expansion foam system, capable of rapidly discharging through fixed discharge outlets a quantity of foam sufficient to fill the greatest space to be protected at a rate of at least 1 m in depth per minute The quantity of foam-forming liquid available must be sufficient to produce a volume of foam equal to five times the volume of the largest space to be protected, casing included. The expansion ratio of the foam must not exceed 1000 to 1.

- a pressurised water-spraying system. The number and arrangement of the nozzles must ensure an effective average distribution of water of at least 5 l/m 2 per minute in the spaces to be protected. The system must be kept charged at the necessary pressure and the pump supplying the water for the system must be put automatically into action by a pressure drop in the system.

Furthermore engine spaces containing internal combustion engines must be provided with:

- a sufficient number of portable foam extinguishers or equivalent located so that no point in the space is more than 10 m walking distance from an extinguisher and that there are at least two such extinguishers in each such space.

Table 1

Bulkheads Not Adjacent To Either Main Vertical Zones Or Horizontal Zones

SPACES	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*
Control station (1)	*B0 [a]*	*A-0*	*A-0*	*A-0*	*A-0*	*A-60*	*A-60*	*A-60*	*A-0*	*A-0*	*A-60*	*A-60*	*A-60*	*A-60*
Stairways(2)		*A-0 [a]*	*A-0*	*A-0*	15. A-0	*A-0*	*A-15*	*A-15*	*A-0 [c]*	*A-0*	*A-15*	*A-30*	*A-15*	*A-30*
Corridors (3)			*B-15*	*A-60*	*A-0*	16. B-15	*B-15*	*B-15*	*B-15*	*A-0*	*A-15*	*A-30*	*A-0*	*A-30*
Evacuation stations & ext. escape route (4)					*A-0*	*A-60 [b][d]*	*A-60 [b][d]*	*A-60 [b][d]*	*A-0 [d]*	*A-0*	*A-60 [b]*	*A-60 [b]*	*A-60 [b]*	*A-60 [b]*
Open deck spaces (5)					-	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*
Accomodation spaces of minor fire risk (6)						*B-0*	*B-0*	*B-0*	*C*	*A-0*	*A-0*	*A-30*	*A-0*	*A-30*
Accomoda-tion spaces of moderate fire risk (7)							*B-0*	*B-0*	*C*	*A-0*	*A-15*	*A-60*	*A-15*	*A-60*

Accomoda-tion of greater fire risk (8)								*B-0*	*C*	*A-0*	*A-30*	*A-60*	*A-15*	*A-60*
Sanitary and similar (9)									*C*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*
Tanks & auxiliary mach.spaces - little or no fire risk (10)										*A-0 [a]*	*A-0*	*A-0*	*A-0*	*A-0*
Auxiliary machinery, cargo, tanks & similar - moderate fire risk (11)											*A-0 [a]*	*A-0*	*A-0*	*A-15*
Engine spaces and main galleys (12)												*A-0 [a]*	*A-0*	*A-60*
Store-rooms, workshops, pantries, etc........ (13)													*A-0 [a]*	*A-0*
Other spaces flammables stowed. (14)														*A-30*

Table 2

Decks Not Forming Steps In Main Vertical Zones Nor Adjacent To Horizontal Zones

SPACE below ¯ SPACE above ®	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*	*(12)*	*(13)*	*(14)*
Control stations ... (1)	*A-30*	*A-30*	*A-15*	*A-0*	*A-0*	*A-0*	*A-15*	*A-30*	*A-0*	*A-0*	*A-0*	*A-60*	*A-0*	*A-60*
Stairways ... (2)	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-30*	*A-0*	*A-30*
Corridors.. (3)	*A-15*	*A-0*	*A-0 [a]*	*A-60*	*A-0*	*A-0*	*A-15*	*A-15*	*A-0*	*A-0*	*A-0*	*A-30*	*A-0*	*A-30*
Evacuation stations and external escape routes (4)	*A-0*	*A-0*	*A-0*	*A-0*	-	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*
Open deck spaces (5)	*A-0*	*A-0*	*A-0*	*A-0*	-	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*
Accomoda-tion spaces of minor fire risk (6)	*A-60*	*A-15*	*A-0*	*A-60*	*A-0*	*A-0*	*A-0*	*A-0*	14.A -0	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*
Accomoda-tion	*A-60*	*A-15*	*A-15*	*A-60*	*A-0*	*A-0*	*A-15*	*A-15*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*

spaces of moderate fire risk (7)														
Accomoda-tion spaces of greater fire risk. (8)	*A-60*	*A-15*	*A-15*	*A-60*	*A-0*	*A-15*	*A-15*	*A-30*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*
Sanitary and similar spaces (9)	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*
Tank & auxiliary spaces having little or no fire risk .(10)	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0 [a]*	*A-0*	*A-0*	*A-0*	*A-0*
Auxiliary machinery, cargo, tanks and similar spaces of moderate fire risk(11)	*A-60*	*A-60*	*A-60*	*A-60*	*A-0*	*A-0*	*A-15*	*A-30*	*A-0*	*A-0*	*A-0 [a]*	*A-0*	*A-0*	*A-30*
Engine spaces and main galleys (12)	*A-60*	*A-60*	*A-60*	*A-60*	*A-0*	*A-60*	*A-60*	*A-60*	*A-0*	*A-0*	*A-30*	*A-30 [a]*	*A-0*	*A-60*
Storerooms, workshops, pantries, etc (13)	*A-60*	*A-30*	*A-15*	*A-60*	*A-0*	*A-15*	*A-30*	*A-30*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*
Flammable liquids are stowed. (14)	*A-60*	*A-60*	*A-60*	*A-60*	*A-0*	*A-30*	*A-60*	*A-60*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*

Table 3

Fire Integrity Of Bulkheads Separating Adjacent Spaces

SPACES	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*
Control stations. (1)	*A-0 [c]*	*A-0*	*A-60*	*A-0*	*A-15*	*A-60*	*A-15*	*A-60*	*A-60*	*	*A-60*
Corridors (2)		*C [e]*	*B-0 [e]*	*A-0 [a] B-0 [e]*	*B-0 [e]*	*A-60*	*A-0*	*A-0*	*A-15 A-0 [d]*	*	*A-15*
Accomoda-tion spaces (3)			*C [e]*	*A-0 [a] B-0 [e]*	*B-0 [e]*	*A-60*	*A-0*	*A-0*	*A-15 A-0 [d]*	*	*A-30 A-0 [d]*
Stairwais (4)				*A-0 [a] B-0 [e]*	*A-0 [a] B-0 [e]*	*A-60*	*A-0*	*A-0*	*A-15 A-0 [d]*	**	*A-15*
Service spaces (low risk) (5)					*C [e]*	*A-60*	*A-0*	*A-0*	*A-0*	*	*A-0*
Engine spaces of Category A.. (6)						*	*A-0*	*A-0*	14. A-0	*	*A-60*
Other machinery spaces. (7)							*A-0 [b]*	*A-0*	*A-0*	*	*A-0*
Cargo spaces. (8)								*	*A-0*	*	*A-0*

Service spaces (high risk). (9)									*A-0 [b]*	*	*A-30*
Open decks (10)										*	*A-0*
Special (11)											*A-0*

Fire Integrity Of Decks Separating Adjacent Spaces

SPACE below − SPACE above ®	*(1)*	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*	*(8)*	*(9)*	*(10)*	*(11)*
Control stations (1)	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-60*	*A-0*	*A-0*	*A-0*	*	*A-30*
Corridors. (2)	*A-0*	*	*	*A-0*	*	*A-60*	*A-0*	*A-0*	*A-0*	*	*A-0*
Accomodation spaces (3)	*A-60*	*A-0*	*	*A-0*	*	*A-60*	*A-0*	*A-0*	*A-0*	*	*A-30 A-0 [d]*
Stairways (4)	*A-0*	*A-0*	*A-0*	*	*A-0*	*A-60*	*A-0*	*A-0*	*A-0*	*	*A-0*
Service spaces (low risk). (5)	*A-15*	*A-0*	*A-0*	*A-0*	*	*A-60*	*A-0*	*A-0*	*A-0*	*	*A-0*
Engine spaces of Category A. (6)	*A-60*	*A-60*	*A-60*	*A-60*	*A-60*	*	*A-60 [f]*	*A-30*	14. A-60	*	*A-60*
Other machinery spaces. (7)	*A-15*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*	*A-0*	*A-0*	*	*A-0*
Cargo spaces (8)	*A-60*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*A-0*	*	*A-0*	*	*A-0*
Service spaces (high risk). (9)	*A-60*	*A-30 A-0 [d]*	*A-30 A-0 [d]*	*A-30 A-0 [d]*	*A-0*	*A-60*	*A-0*	*A-0*	*A-0*	*	*A-30*
Open decks (10)	*	*	*	*	*	*	*	*	*	*	*A-0*
Special category spaces (11)	*A-60*	*A-15*	*A-30 A-0 [d]*	*A-15*	*A-0*	*A-30*	*A-0*	*A-0*	*A-30*	*A-0*	*A-0*

High Speed Craft

Accommodation And Evacuation Measures

Special care is paid to the need of safe evacuation of people on board in case of emergency situations for high speed crafts. and the rules clearly deal with the different aspects involved in this problem:

- general ship design
- accommodation design and location
- role of crew
- communication and alarm systems

The rules state that the design of the craft must be such that all occupants may safely evacuate into survival craft under all emergency conditions, by day or by night.

A general emergency alarm system, audible throughout all the accommodation and normal crew working spaces and open decks, must be provided.

In order to ensure immediate assistance from the crew in emergency situations, crew accommodation, including any cabins, must be located with due regard to easy, safe and quick access to the public spaces from inside the craft. For the same reason, easy, safe and quick access from the operating compartment to passenger accommodation must be provided.

The positions of all exits which may be used in an emergency, and of all life-saving appliances, the practicability of the evacuation procedure, and the evacuation time to evacuate all passengers and crew must be demonstrated.

Public spaces, evacuation routes, exits, lifejacket stowage, survival craft stowage, and the embarkation stations must be clearly and permanently marked and well lighted.

Each enclosed public space and similar permanently enclosed space allocated to passengers or crew must be provided with at least two exits placed at opposite ends of such spaces. Exits must be safely accessible and must provide a route to a normal point of boarding or disembarking from the craft.

Evacuation Time

The provisions for evacuation must be designed so that the craft can be evacuated under controlled conditions in a time of one third of the structural fire protection time (SFP) provided in tables 5 and 6 for major fire hazard areas, after subtracting a period of 7 minutes for initial detection and extinguishing action.

$$\textbf{Evacuation time} = \textbf{(SFP - 7) / 3} \quad [\text{min}]$$

where **SFP** = structural fire protection time, in min.

An evacuation procedure, including a critical path analysis, must be developed for the information of the Administration in connection with the approval of fire insulation plans and for assisting owners and builders in planning the required evacuation demonstration.

The evacuation procedures must include:

(1) the emergency announcement made by the master;
(2) contact with base port;
(3) the donning of lifejacket;
(4) manning of life-boats and emergency stations;
(5) the shutting down of machinery and oil fuel supply lines;
(6) the order to evacuate;
(7) the deployment of life-boats and marine escape systems and rescue boats;
(8) the bowsing in of life-boats;
(9) the supervision of passengers;
(10) the orderly evacuation of passengers under supervision;
(11) crew checking that all passengers have left the craft;
(12) the evacuation of the crew;
(13) releasing the life-boats from the craft; and
(14) the marshalling of life-boats by the rescue boat where provided.

Achievement of the required evacuation time must be verified by a practical demonstration conducted under controlled conditions in the presence of the Administration, and must be fully documented and verified for passenger craft by the Administration.

Evacuation demonstrations must be carried out with due concern for the problems of mass movement or panic acceleration likely to arise in a emergency situation when rapid evacuation is necessary. The evacuation demonstrations must be carried out with dry shoes and with the survival craft initially in their stowed positions and be conducted as follows:

- The evacuation time on a category A craft must be the time elapsed from the moment the first abandon craft announcement is given, with any passenger distributed in a normal voyage configuration, until the last person has embarked in a survival craft, and must include the time for passengers and crew to don lifejackets.

- The evacuation time on a category B craft and cargo craft must be the time elapsed from the moment the order to abandon the craft is given, until the last person has embarked in a survival craft. Passengers and crew may be wearing lifejackets and prepared for evacuation, and they may be distributed among muster stations.

- For all craft the evacuation time must include the time necessary to launch, inflate and secure the survival craft alongside ready for embarkation.

The evacuation time must be verified by the evacuation demonstration which must be performed using the survival craft and exits on one side, for which the critical path analysis indicates the greatest evacuation time, with the passengers and the crew allocated to them. Furthermore the demonstration must be carried out under controlled conditions in the following manner in compliance with the evacuation plan.

- The demonstration must commence with the craft afloat in harbour, in reasonably calm conditions, with all machinery and equipment operating in the normal seagoing conditions.

- All exits and doors inside the craft must be in the same position as they are under normal seagoing conditions.

- Safety belts, if required, must be fastened.

- The evacuation routes for all passengers and crew must be such that no person need enter the water during the evacuation.

For passenger craft, a representative composition of persons with normal health, height and weight must be used in the demonstration, and must consist of different sexes and ages so far as it is practicable and reasonable.
The specific evacuation procedure followed during the craft's initial demonstration on which certification is based must be included in the craft operating manual together with the other evacuation procedures. During the demonstration video recordings must be made both inside and outside the craft which must form an integral part of the training manual.

Fire Safety

Keeping into account the category of craft and the potential fire hazard involved: the main criteria on which the fire safety regulations are based are the following:

- maintenance of the main functions and safety systems of the craft after fire
- subdivision of the passenger accommodation area for category B craft, in such a way that the occupants of any compartment can escape to an alternative safe area or compartment in case of fire;
- subdivision of the craft by fire resisting boundaries;
- restricted use of combustible materials and materials generating smoke and toxic gases in a fire;
- detection, containment and extinction of any fire in the space of origin;
- protection of means of escape and access for fire fighting
- immediate availability of fire-extinguishing appliances.

The main requirements for fire safety are based on the following conditions:

- Where a fire is detected, the crew immediately puts into action the fire-fighting procedures, informs the base port of the accident and prepares for the escape of passengers to alternative safe area or compartment or, if necessary, for the evacuation of passengers.
- The use of fuel with a flashpoint below 43°C is not recommended.
- The repair and maintenance of the craft is carried out in accordance with the requirements given in Chapter 18 and Chapter 19 of the Code for High Speed Crafts construction (here not included).
- Enclosed spaces such as cinemas, discotheques, and similar spaces are not permitted. Refreshment kiosks which do not contain cooking facilities with exposed heating surfaces

may be permitted. Galleys, if fitted, must be in full compliance with Chapter II-2 of the Convention.

- Passenger access to vehicle spaces is prohibited during the voyage except when accompanied by a crew member responsible for fire safety. Only authorised crew members must be permitted to enter cargo spaces at sea.

Classification Of Space Use

For the purposes of classification of space use in accordance with fire hazard risks, the following grouping must apply (see tables 5 and 6):

"Areas of major fire hazard" include the following spaces:

- Machinery spaces
- Open vehicle spaces
- Spaces containing dangerous goods
- Special category spaces
- Store-rooms containing flammable liquids.

"Areas of moderate fire hazard" include the following spaces:

- Auxiliary machinery spaces
- Bond stores containing packaged beverages
- Crew accommodations
- Service spaces.

"Areas of minor fire hazard" include the following:

- Auxiliary machinery spaces
- Cargo spaces
- Fuel tank compartments
- Public spaces
- Tanks, voids and areas of little or no fire risk.

"Control stations"

"Evacuation stations and external escape routes" include the following areas:

- External stairs and open decks used for escape routes
- Muster stations, internal and external
- Open deck spaces and enclosed promenades forming lifeboat and life-raft embarkation and lowering stations
- The craft’s side to the waterline in the lightest seagoing condition, superstructure and deckhouse sides situated below and adjacent to the life-raft‘s and evacuation slide’s embarkation areas.

"Open spaces" include the following areas:

- Open spaces locations other than evacuation stations and external escape routes and control stations

Structural fire protection

The structural fire protection times for separating bulkheads and decks must be in accordance with tables 5 and 6, and the structural fire protection times are all based on providing protection for a period of 60 min.

The hull, superstructure, structural bulkheads, decks, deckhouses and pillars must be constructed of approved non-combustible materials having adequate structural properties. The use of other fire-restricting materials may be permitted provided the requirements of fire safety are complied with (including a test procedure, developed by the Organisation, for structural strength of composites at elevated temperatures).

Fire-resistant divisions

Areas of major and moderate fire hazard must be enclosed by fire-resistant divisions.

Fire-resistant bulkheads and decks must be constructed to resist exposure to the standard fire test for a period of 30 min for areas of moderate fire hazard and 60 min for areas of major fire hazards.

Main load carrying structures within major and moderate fire hazard areas must be arranged to distribute load such that there will be no collapse of the construction of the hull and superstructure when it is exposed to fire for the appropriate fire protection time.

- If these structures are made of aluminium alloy, their installation must be such that the temperature of the core does not rise more than 200°C above the ambient temperature.

- If the structures are made of combustible material, their insulation must be such that their temperatures will not rise to a level where deterioration of the construction will occur during the exposure to the composite standard fire test to such an extent that the load-carrying capability will be impaired.

The construction of all doors, and door frames in fire-resistant divisions, with the means of securing them when closed, must provide resistance to fire as well as to the passage of smoke and flame equivalent to that of the bulkheads in which they are situated. Watertight doors of steel need not be insulated. Also, where a fire-resistant division is penetrated by pipes, ducts, electrical cables or for other purposes, arrangements and necessary testing must be made to ensure that the fire-resistant integrity of the division is not impaired.

Restricted use of combustible materials

All separating divisions, ceilings or linings if not a fire resistant division, must be of non-combustible or fire-restricting materials.

Where insulation is installed in areas in which it could come into contact with any flammable fluids or their vapours, its surface must be impermeable to such flammable fluids or vapours. The exposed surfaces of vapour barriers and adhesives used in conjunction with insulation materials must have low flame-spread characteristics.

Furniture and furnishings in public spaces and crew accommodation must comply with the following standards:

- In all cases the furniture must be constructed entirely of approved non-combustible or fire-restricting materials, except that a combustible veneer with a calorific value not exceeding 45 MJ/m^2 ; may be used on the exposed surface of such articles;

- all other furniture such as chairs, sofas, tables, must be constructed with frames of non-combustible or fire-restricting materials;

- all draperies, curtains and other suspended textile materials have qualities of resistance to the propagation of flame in accordance with standards [1] developed by the Organisation; *[1] Recommendation on test method for determining the resistance to flame of vertically supported textiles and films, adopted by the Organisation by resolution A.471(XII), and amendments to the recommendation adopted by resolution A.563(14).*

- all upholstered furniture must have qualities of resistance to the ignition and propagation of flame in accordance with standards [2] developed by the Organisation;*[2] Recommendation on fire test procedures for upholstered furniture, adopted by the Organisation by resolution A.652(16).*

- all bedding components must comply with the standards [3] developed by the Organisation; *[3] Recommendation on fire test procedures for combustibility of bedding components, adopted by the Organisation by resolution A.688(17).*

- all deck finish materials comply with the standards [4] developed by the Organisation. [4] *Refer to the Recommendation on improved fire test procedures for surface flammability of bulkhead, ceiling and deck finish materials adopted by the Organisation by resolution A.653 (16) and Recommendation on fire test procedures for combustibility of primary deck coverings adopted by the Organisation by resolution A.687(16).*

The following surfaces must be constructed of materials having low flame-spread characteristics:

- exposed surfaces in corridors and stairway enclosures, and of bulkheads, wall and ceiling linings in all accommodation and service spaces and control stations;

- concealed or inaccessible spaces in accommodation, service spaces and control stations.

Materials used in the craft, when exposed to fire, must <u>not emit smoke or toxic gases</u> in quantities that could be dangerous to humans as determined in tests of a standard developed by the Organisation.

Arrangement

Internal stairways which serve more than two decks of accommodation must be enclosed at all levels with smoke-tight divisions of non-combustible or fire-restricting materials, and where only two decks are served, such enclosures must be provided on at least one level.

Lift trunks (or wells) must be so fitted as to prevent the passage of smoke and flame from one deck to another and must be provided with means of closing so as to permit the control of draught and smoke.

In accommodation and service spaces, control stations, corridors and stairways air spaces enclosed behind ceilings, panelling or linings must be suitably divided by close fitting draught stops not more than 14 m apart.

Fire Detection And Extinguishing Systems

Areas of major and moderate fire hazard and other enclosed spaces in the accommodation not regularly occupied, such as toilets, stairway enclosures and corridors must be provided with an approved automatic smoke detection system and manually operated call points to indicate at the control station the location of outbreak of a fire in all normal operating conditions of the installations.

Main propulsion engine room(s) must in addition have detectors sensing other than smoke and be supervised by TV cameras monitored from the operating compartment. Manually operated call points must be installed throughout the accommodation spaces, service spaces and where necessary control stations. One manually operated call point must be located at each exit from these spaces and from areas of major fire hazard.

The main requirements of the permanent fire detection and fire alarm systems are the following:

- Power supplies of the system must be monitored for loss of power or fault conditions.

- There must be no less than two sources of power supply

- The activation of any kind of detector must initiate a visual and audible fire signal at the control panel and indicating units. If the signals have not received attention within two minutes an audible alarm must be automatically sounded throughout the crew accommodation and service spaces, control stations and machinery spaces.

- The control panel must be located in the operating compartment or in the main fire control station.

- Detectors must be operated by heat, smoke or other products of combustion, flame, or any combination of these factors. Flame detectors must only be used in addition to smoke or heat detectors.

- Manually operated call points must be installed throughout the accommodation spaces, service spaces and control stations. One manually operated call point must be located at each exit. Manually operated call points must be readily accessible in the corridors of each deck such that no part of the corridor is more than 20 m from a manually operated call point.

- Smoke detectors must be installed in all stairways, corridors and escape routes within accommodation spaces. Consideration must be given to the installation of special purpose smoke detectors within ventilation ducting.

- Areas of major fire hazard must be protected by an approved fixed extinguishing system operable from the control position which is adequate for the fire hazard that may exist. The system must be capable of local manual control and remote control from the continuously manned control stations.

- In all craft where gas is used as the extinguishing medium, the quantity of gas must be sufficient to provide two independent discharges. The second discharge into the space must only be activated (released) manually from a position outside the space being protected.

- Control stations, accommodation spaces, service spaces must be provided with portable fire extinguishers of appropriate types. At least five portable extinguishers must be provided, and so positioned as to be readily available for immediate use. In addition, at least one extinguisher suitable for engine space fires must be positioned outside each engine space entrance.

Fire Pumps

Fire pumps, and appropriate associated equipment, or alternative effective fire-extinguishing systems must be fitted as follows:

- At least two independently driven pumps must be available. Each pump must have at least two-thirds the capacity of a bilge pump but not less than 25 m^3/h.

- The arrangement of the pumps must be such that in the event of a fire in any one compartment all the fire pumps will not be put out of action.

- Hydrants must be arranged so that any location on the craft can be reached by the water jets from two fire hoses from two different hydrants

Protection Of Special Category Spaces

Boundaries of special category spaces must be insulated in accordance with tables 5 and 6. The standing deck of a special category space need only be insulated on the underside if required.

Indicators must be provided on the navigating bridge which must indicate when any door leading to or from the special category space is closed.

Each special category space must be fitted with [1] an approved fixed pressure water-spraying system for manual operation which must protect all parts of any deck and vehicle platform in such a space. *[1] Refer to the Recommendation on fixed fire-extinguishing systems for special category spaces, adopted by the Organisation by resolution A.123(v).*

<u>A continuous fire patrol</u> must be maintained in special category spaces unless a fixed fire detection and fire alarm system and a closed-circuit television surveillance system are provided. The fixed fire detection system must be capable of rapidly detecting the onset of fire.

Manually operated call points must be provided and one must be placed close to each exit from such spaces.

There must be provided in each special category space:

- at least three water fog applicators;
- one portable foam applicator unit
- portable fire extinguishers must be located so that no point in the space is more than approximately 15 m walking distance from an extinguisher, provided that at least one portable extinguisher is located at each access to such space.

The special category spaces must be provided with an <u>effective power ventilation system</u> entirely separated from other ventilation systems. The ventilation must be such as to prevent air stratification and the formation of air pockets. Means must be provided to indicate on the operating compartment any loss or reduction of the required ventilating capacity. Arrangements must be made to allow a rapid shutdown and effective closure of the ventilation system in case of fire, taking into account the weather and sea conditions.

In view of the serious loss of stability which could arise due to large quantities of water accumulating on the deck or decks consequent to the operation of the fixed pressure water-spaying system, scuppers must be fitted so as to ensure that such water is rapidly discharged directly overboard.

Additional Requirements For Passenger Craft

For category B craft the public spaces must be divided into zones according to the following :

- The craft must be divided into at least two zones. The mean length of each zone must not exceed 40 m.
- For the occupants of each zone there must be an alternative safe area to which it is possible to escape in case of fire. The alternative safe area must be separated from other passenger zones by smoke-tight divisions of non-combustible materials or fire-restricting materials extending from deck to deck. The alternative safe area can be another passenger zone provided the additional number of passengers may be accommodated in an emergency.

- The alternative safe area must, as far as practicable, be located adjacent to the passenger zone it is intended to serve. There must be at least two exits from each passenger zone, located as far away from each other as possible, leading to the alternative safe area. Escape routes must be provided to enable all passengers and crew to be safely evacuated from the alternative safe area.

Category A craft need not be divided into zones.

Control stations, life-saving appliance stowage positions, escape routes and places of embarkation into lieboats must not, as far as practicable, be located adjacent to any major or moderate fire hazard areas.

Public spaces and service spaces, storage rooms other than those containing flammable liquids, and similar spaces must be protected by a fixed sprinkler system. Manually operated sprinkler systems must be divided into sections of appropriate size and the valves for each section, start of sprinkler pump(s) and alarms must be operate from two spaces as wide apart as possible, one of which must be a continuously manned control station.

Plans of the system must be displayed at each operating station. Suitable arrangements must be made for the drainage of water discharged when the system is activated.

Table 5

Structural Fire Protection Times For Separating Bulkheads And Decks On Passenger Vessels

		A	*B*	*C*	*D*	*E*	*F*
Areas of major fire hazard	A	60[1,2] / 60[1,2]	30 / 60[1]	[3] / 60[1,8]	[3,4] / 60[1]	[3] / 60[1]	- / 60[1,7]
Areas of moderate fire hazard	*B*		30[2] / 30[2]	[3] / 30[8]	[3,4] / 60	[3] / 30	- / [3]
Areas of minor fire hazard	*C*			[3] / [3]	[3,4] / 30[8]	[3] / [3]	- / [3]
Control stations	*D*				[3,4] / [3,4]	[3] / [3,4]	- / [3]
Evacuation stations and escape routes	*E*					[3] / [3]	- / [3]
Open spaces	*F*						- / -

Table 6

Structural Fire Protection Times For Separating Bulkhead And Decks Or Cargo Vessels

		A	*B*	*C*	*D*	*E*	*F*
Areas of major fire hazard	A	60[1,2] / 60[1,2]	30 / 60[1]	[3] / 60[1,8]	[3,4] / 60[1]	[3] / 60[1]	- / 60[1,7]
Areas of moderate fire hazard	*B*		[2,6] / [2,6]	[3] / [6]	[3,4] / 60	[3] / [6]	- / [3]
Areas of minor fire hazard	*C*			[3] / [3]	[3,4] / 30[8]	[3] / [3]	- / [3]
Control stations	*D*				[3,4] / [3,4]	[3] / [3,4]	- / [3]
Evacuation stations and escape routes	*E*					[3] / [3]	- / [3]
Open spaces	*F*						- / -

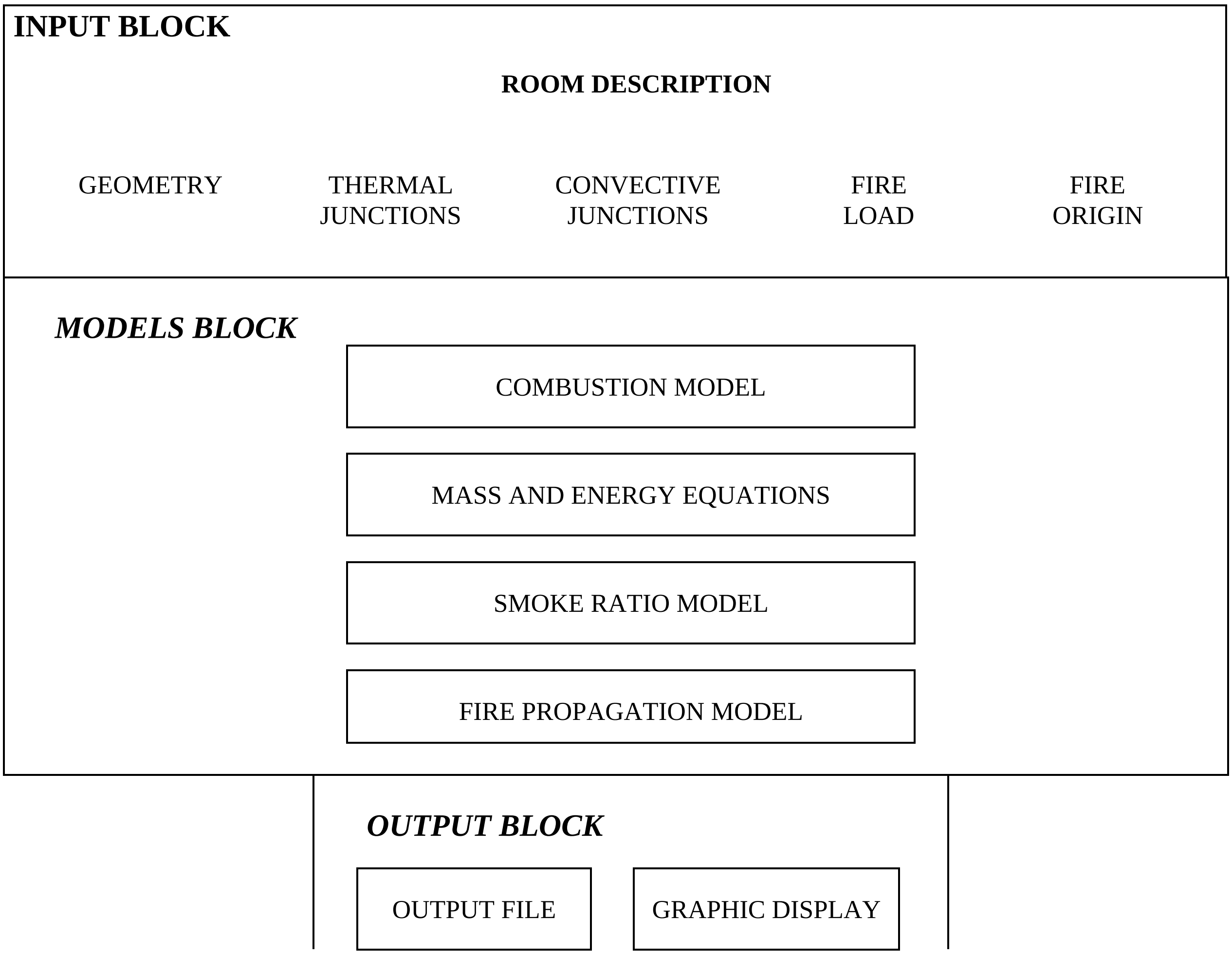
Simulation

CETENA carried out a simulation of a case study of fire propagation on board ship, adopting the code FIRST (FIRe Simulation Tool), developed by CETENA for the study of fire propagation in a complex system, such as a ship. This computer code was based on several models addressing the effect a fire has on the rooms adjacent to that where the fire originated. The outputs provided the evolution of the temperature, of the thermal power and the smoke ratio of each room in function of time. The results were drawn depending on various criteria of fire propagation. The fire development stages and the basic physical models were simplified to an extreme in order to allow for the simulation of the fire's influence on the rooms adjacent to where it breaks out.

Due to the above simplification, the code is not able to simulate detailed fire evolution inside each room taking into account the proper spatial arrangement of the furniture and other objects. However, the code output provides the evolution of temperature, thermal power and smoke ratio of each room in function of the time factor.

Structure Of The Code

The code flow chart is as follows:



The structure of the code is characterised by three main blocks:

- Input block : includes all geometric and thermophysical data of the rooms.
- Models block: includes the whole of the models able to simulate both fire development in the outbreak room and propagation to adjacent rooms.
- Output block: includes the routines of presenting the results both on output file and graphic display.

General Characteristics Of The Code

The rooms affected by the fire are schematised through simple geometric shapes: their volumes arranged one beside the other.

The volumes can be connected each other through two types of junctions:

- thermal junctions (bulkheads, ceiling, floor);
- convective junctions (doors, windows, openings);

Thermal junctions are responsible for heat exchange due to conduction, while convective junctions are responsible for mass exchange within adjacent rooms and of heat exchange due to convection.

Each volume is represented by a homogeneous mixture composed of air and combustion smoke; the mixture is characterised by an average temperature (T_g), a smoke ratio (X_f) and by a mass (M) consistent with the hypothesis of constant pressure within the volume. Furthermore each volume is identified by its fire load described as kilos of wood having an energetic content equivalent to the real energetic content of the room.

The mass balance equation related to convective junctions and the energy equation related to thermal junctions allow evaluating the inflows and outflows of mass within each room and also the wall temperatures. The temperature and the smoke ratio of each room are evaluated solving the mass and energy equations, once the thermal power released by fire is known. The code is able to evaluate the thermal power according to the growth rate of the fire.

The fire propagation from the outbreak room to an adjacent one occurs subject to one of the following conditions;

- the “waste basket ignition” temperature is reached on a thermal junction;
- the presence of openings in the room;
- the structural collapse temperature is reached on a thermal junction.

According to the first criterion, the fire is primed in the room adjacent to the one it broke out in when the temperature of the partition-wall, on the face belonging to the adjacent room, reaches the self-ignition temperature of an amount of paper contained in a basket near the wall itself (160 ^{0}C).

The second criterion is related to the condition in which the presence of openings in the partition-wall between the fire outbreak room and the adjacent one allows the flames to enter.

According to the third criterion, the propagation takes place when the high temperature of the room gives rise to an average temperature on the thermal junction higher than the structural collapse temperature of the thermal junction itself (540 ^{0}C for steel walls).

3.4.2 General Characteristics Of A Compartment Fire

Figure 1 shows a typical compartment fire, time related temperature; the figure also shows the various stages in which fire development is usually subdivided.

These stages are usually called:

1. Ignition
2. Growth
3. :Flashover
4. Fully developed fire
5. Decay:

Ignition :is the period in which the fire breaks out. This stage can be more or less time-extended and it depends on the type of material involved in the fire.

Growth: (also defined as preflashover) after ignition, the fire's growth depends on the characteristics of the type of combustible material available. The following figure shows the state of the compartment room during this stage.

Figure 2 shows two different zones within the room: the ’”hot gas layer” and the “cold gas layer”. Fire produces hot combustion smokes that move to the room ceiling thrust by the buoyancy forces. During the fire growth the hot gas layer increases its depth; if the room is connected to the external environment, hot gas leaves the room through the high part of the opening whilst the cold external air enter the room through the low part of the opening: the room is filled by hot gas in the upper and cold gas in the lower. If the quantity of fuel and of oxygen available is sufficient the fire keeps on growing giving rise to a temperature increase.

<u>Flashover:</u> generally the flashover is defined as the transition time between the growth period and the fully developed fire period in which all the combustible materials are involved.

<u>Fully developed fire:</u> (also defined as postflashover) during this period the power released by the fire reaches its maximum value because the high temperature in the room causes ignition and the rapid combustion of the entire fire load. Often not all the fuel in the room is burnt up because the combustion chemical reaction is limited by an inadequate quantity of oxygen. In this case combustion is defined as “ventilation controlled”. Fire power is limited by the room's ventilation and the possible excess of volatile fuel leaves the room and keeps on burning outside.
During this stage the room is completely enveloped by the flames and the depth of the hot gas layer reaches the floor of the room.

<u>Decay:</u> this stage begins when fuel exhaustion sets in. The released thermal power decreases in time and the combustion model can be “ventilation controlled” or “fuel controlled” in function of the thermophysical parameters in the room.

3.4.3 Basic Hypothesis

Considering a room, independent of the fire stage, the basic hypotheses are the following:

1. The pressure within the room is constant; this hypothesis is due to the fact the rooms are never totally insulated each other; in fact even small openings within the rooms are able to keep the pressure constant.

2. The content of each room is homogeneous; the hot gas produced by the combustion mix with cold air and forms a homogeneous mixture.

The consequence of the above hypothesis is that the mass of the gas contained in the room cannot be kept constant; in fact according to the ideal gas law, it is:

$$p\,V = n\,R\,T_g$$

where :

p = room pressure
V = room volume
n = number of moles of the gas contained in the room
T_g = gas temperature
R = universal gas constant

The temperature of the room increases because of the heat produced by the fire, so the pressure within the constant volume V can be kept constant if the number of moles decreases; it means that the mass of the gas in the room decreases.

The computation of the mass in the room is carried out as follows:

$$Mg = \rho\,(Tg) \times V$$

where Mg is the mass of the gas contained in the room, ρ (Tg) is the density of the gas as function of its temperature and V is the volume of the room.

3.4.4 The Algorithm Of The Code

Mass exchange within the rooms (connection equations)

Figure 2 shows a room in which the internal system is connected to the external environment through the openings of the room; Tg is the average temperature of the gaseous mixture inside the room and Te is the external temperature so that Te < Tg.

The fire produces hot gas rising to the ceiling of the room where it becomes stratified and increases its depth; this fact causes two effects:

- the high pressure in the upper side of the room and consequent expulsion of hot gas from the room (Mout);
- the depression in the lower side of the room and consequent recall of cold air from the external environment (Min).

The mass flows Min e Mout on the opening are caused by the difference of temperature and pressure between the room and the external environment. The balance equation of the gaseous mass Mg of a room is given by:

$$\frac{\Delta M_g}{\Delta t} = M_{in} + M_f - M_{out}$$

where M_f. is the burning rate defined as the variation of mass due to the physical conversion of the solid or liquid fuel into gas.

Under stationary conditions: $\frac{\Delta M_g}{\Delta t} = 0$

$$0 = M_{in} + M_f - M_{out}$$

and then:

$$M_{out} = M_{in} + M_f$$

Energy equation

The energetic balance equation is the following:

$$\frac{\Delta E}{\Delta t} = E_E - E_U + E_{BR} + Q_{FIRE} - Q_{LOSS}$$

where :

- E_E is the heat due to the air mass entering the room
- E_U is the heat due to the gas mass leaving the room
- E_{BR} is the heat due to the burning rate
- Q_{FIRE} is the thermal power produced by the combustion
- Q_{LOSS} is the energy lost by the room, due to various connection to the external environment
- $\frac{\Delta E}{\Delta t}$ is the energy variation inside the room

Balance equations for 1 room

$E_E = M_{in} \cdot T_a \cdot c_p$

$E_{BR} = M_f \cdot T_g \cdot c_p$

$E_U = M_{out} \cdot Tg \cdot c_p$

$$M_{in} \cdot T_a \cdot c_p + M_f \cdot c_p \cdot T_g + Q_{fire} - M_{out} \cdot c_p \cdot T_g - Q_{loss} = \frac{\Delta E}{\Delta t}$$

The variation of energy inside the room is evaluated according to the thermal energy of the gaseous mass M_g inside the room as:

$$\frac{\Delta E}{\Delta t} = \frac{\Delta T}{\Delta t} \cdot C_p \cdot M_g$$

where Cp is the specific heat defined as the quantity of heat required raising the temperature of a unit mass of each substance by one degree.

Balance equations for 3 rooms

Balance equation of the gaseous mass:

$$M_{21} + \frac{1}{2} \cdot M_f - M_{12} = 0$$

$$M_{31} + \frac{1}{2} \cdot M_f - M_{13} = 0$$

Balance equation of the energy:

$$M_{21} \cdot T_{g2} \cdot c_p + M_{31} \cdot T_{g3} \cdot c_p + M_f \cdot c_p \cdot T_g + Q_{fire} - \left(M_{12} + M_{13}\right) \cdot c_p \cdot T_g - Q_{loss_{12}} - Q_{loss_{13}} = M_g \cdot c_p \cdot \frac{\Delta T_g}{\Delta t}$$

Thermal power due to the combustion (Q_{fire})

According to experiences and trials carried out on various type of furniture, the following law can estimate the thermal power during the preflashover stage:

$$Q_{fire}(t) = \alpha \times (t-ti)^2$$

where :

- $Q_{fire}(t)$ is the thermal power released by the fire
- α is a parameter related to the release rapidity of the thermal power; the following table includes the numerical values usually adopted by the technical literature

FIRE TYPE	a [w / s^2]
slow	**2.90**
medium	**11.7**
fast	**46.9**
very fast	**187.6**

- ti is the ignition time of the fuel; usually ti = 0 and the law is Q_{fire} (t) = α t^2

The adoption of the law Q_{fire} (t) = α t^2 is equivalent to consider a condition of "free combustion" of the fire load: practically the combustion rapidity, and the consequent power release rapidity, is not conditioned by the geometric and ventilation characteristics of the room but by the fuel characteristics only: in this case the combustion is defined "fuel controlled".

The law Q_{fire} (t) = α t^2 is correct for the early stages of the fire because the size of the fire is still small compared to the room size, so the fire is not affected by the effects of the ceiling and of the walls, able to retain the smoke and to reduce the available quantity of oxygen in the room.

The combustion proceeds according to the law α t^2 during all the growth stage, whilst the type of law is completely different during the stages following the time t_1 corresponding to the maximum power value; in fact the stages following t_1 are deeply affected by the quantity of fuel and air in the room

After the time t_1 three different cases can be distinguished:

1. if the residual uncombusted fuel is less than 40% of the initial fire load and if the entering air flow is sufficient to warrant the minimum stoichiometric level of combustion, the thermal power reached level is maintained constant; the decay stage is delayed (fig 4)

2. if the residual uncombusted fuel is less than 40% of the initial fire load, but the entering airflow is not sufficient to warrant the minimum stoichiometric combustion, the value of thermal power is computed according to the following equation

$$Q_{fire}(t) = \frac{1}{r} m_{in} \cdot (1 - X_f) \cdot \Delta H \cdot h$$

where :

- r is the stoichiometric combustion ratio (air mass / combustible mass)
- $m_{in}\cdot$ is the cold air flow entering the room
- $m_{in}\cdot(1 - X_f)$ is the total cold air flow in the room
- ΔH is the wood heat of combustion
- η is the combustion efficiency

During this stage the thermal power released is strictly related to the room ventilation and the combustion is a typical “ventilation controlled” (fig 6)

3. if the residual uncombusted fuel is more than 40% of the initial fire load the power diagram is described by a linear decreasing equation corresponding to the decay stage (fig 7)

During the decay the thermal power released by the fire is related to the exhaustion of the fuel. The decay stage can occur during the preflashover or the postflashover: during the preflashover the decay occurs after the exhaustion of the 40% of the initial fire load; during the postflahover stage the decay occurs after the exhaustion of the 40% of the initial fire load.

Thermal power transfer (Q_{loss})

The heat exchange between a room and the external environment can occur according to conduction and or convection law. The fundamental law of conduction heat transfer is the following:

$$Q_{cd} = l \cdot A \cdot \frac{T_1 - T_2}{s}$$

where:

Q_{cd} = thermal power transferred by conduction
λ = thermal conductivity of the solid wall
A = surface area across which the heat is transferred,
$T_1 - T_2$ = temperature difference between two transfer surfaces
s = thickness of the wall across which the heat is transferred,

The thermal power transferred by convection between a surface and solid is estimated according to the following equation:

$$Q_{cd} = k_c \cdot A \cdot (T_1 - T_2)$$

where:

Q_{cv} = thermal power transferred by convection
k_c = heat transfer coefficient
A = surface area across which the heat is transferred,
$T_1 - T_2$ = temperature difference

3.4.5 Propagation Criteria

The fire propagation from the origin room to an adjacent one occurs according to one of the following conditions

1. reaching of the "waste basket ignition" temperature on a thermal junction;
2. presence of openings in the room;
3. reaching of the structural collapse temperature on a thermal junction.

Annexed figures are representative of above three conditions

- <u>Waste basket ignition</u>

The fire present in the room 1 spreads to the room 2 when the temperature of their partition wall, on the surface belonging to the room 2, reaches the self ignition temperature T_{wbi} of the paper contained in a basket placed near the surface itself (T_{wbi} = 160 ^{0}C).

- <u>Propagation from a room with openings</u>

The openings in the partition wall allows the passage of flames fire from room 1 to room 2 giving rise to the fire propagation to the whole room 2

- <u>Structural collapse temperature of thermal junctions</u>

The propagation of fire occurs if the high temperature of the room leads to a temperature value of the thermal junction higher than the structural collapse temperature of the junction (540 ^{0}C for steel walls). In this case the code eliminates the collapsed thermal junction so two adjacent rooms 1 and 2 initially separated become one unique room.

Annex I

3.5 Example Of Code Application

3.5.1 Case Study: Two Rooms With Openings

Annex 1 describes the practical application of the code to a case of fire propagation between two adjacent rooms.

Figure A1 includes the geometry of the rooms 1 and 2 separated by a partition wall having one door.

Room 1 has four openings: one door (P1), two windows (F1 and F2) and one door (P2) as connection to room 2; other junctions to the external environment are thermal.

The room 2 has four openings: one door (P3), two windows (F3 and F4) and one door (P2) as connection to the room 2; other junctions to the external environment are thermal.

The circled numbers on the drawing refer to the progressive number of each thermal junction.

Figures A2, A3, A4 and A5 refer to the input file of the code.

Figures A6 and A7 refer to the output of the code.

All sizes in meters

P: door

F: window

Height of the rooms: 3 m

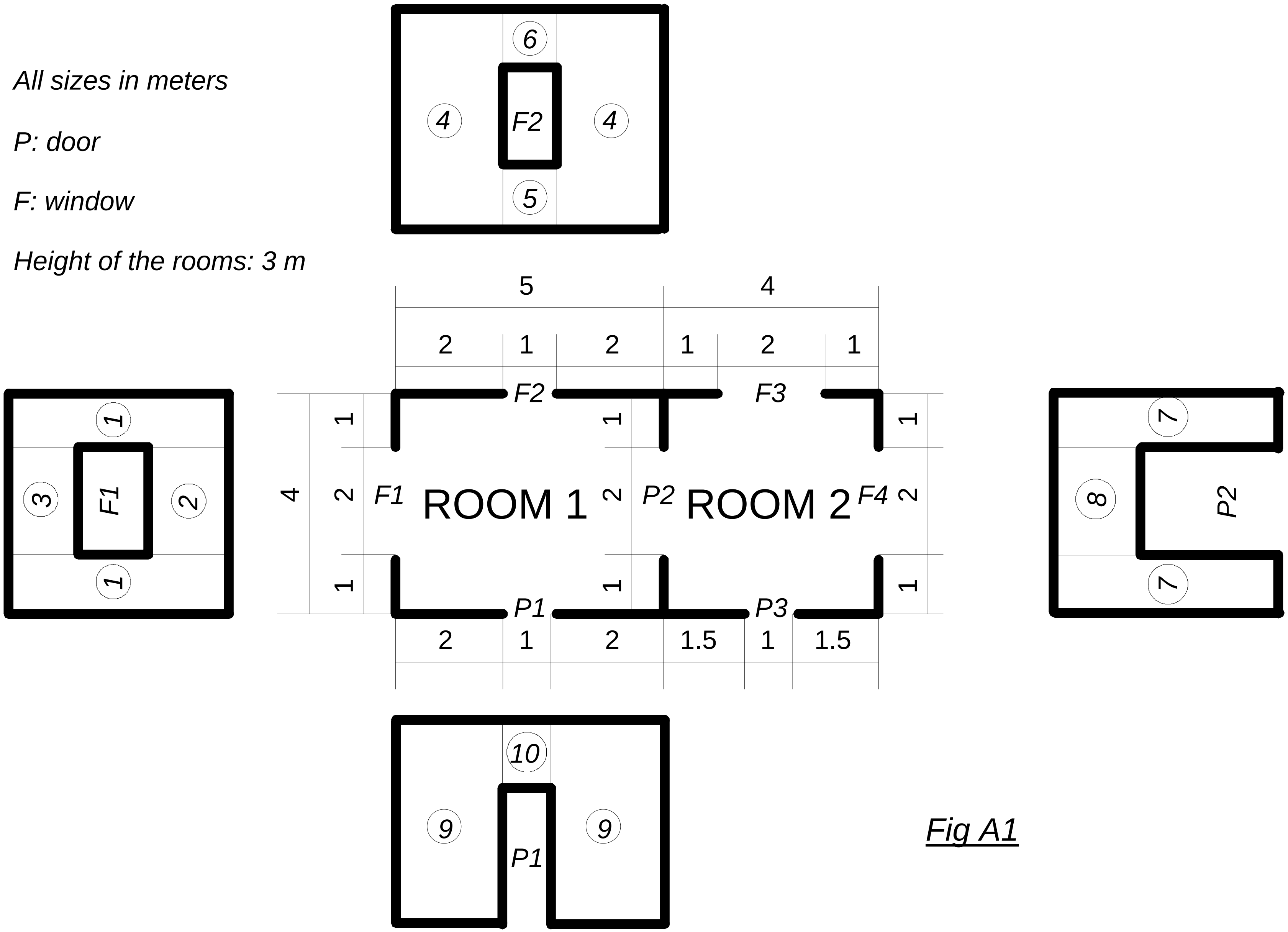


Fig A1

Fig A1 Code input form

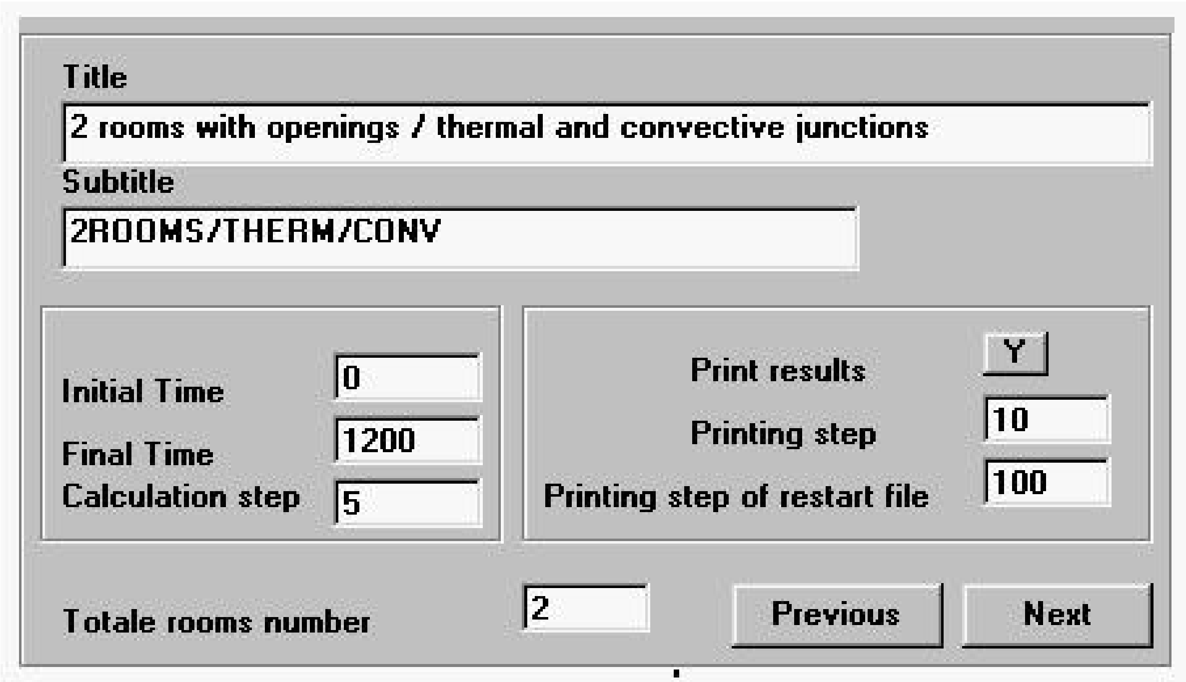


Fig A2 Code input form

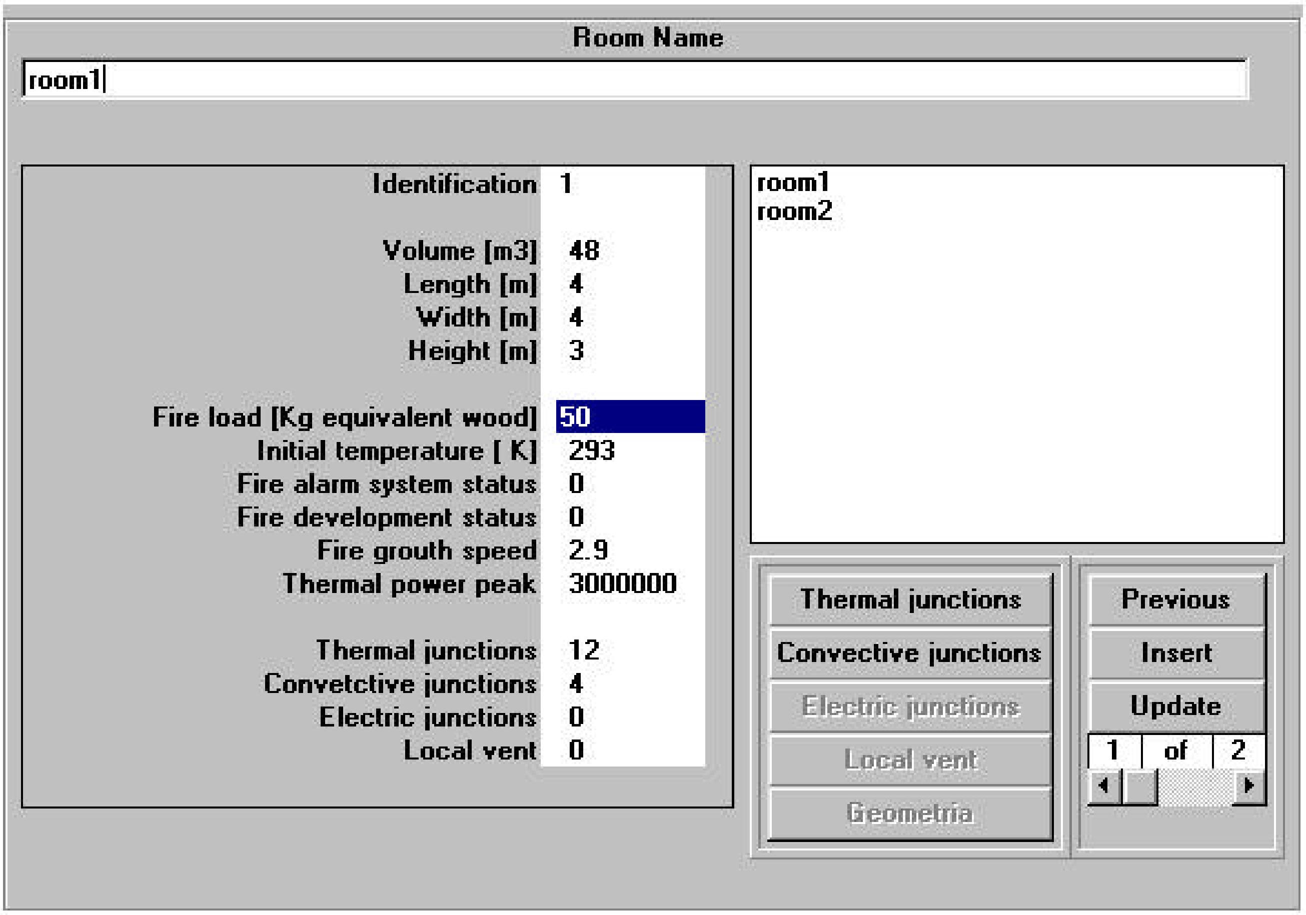
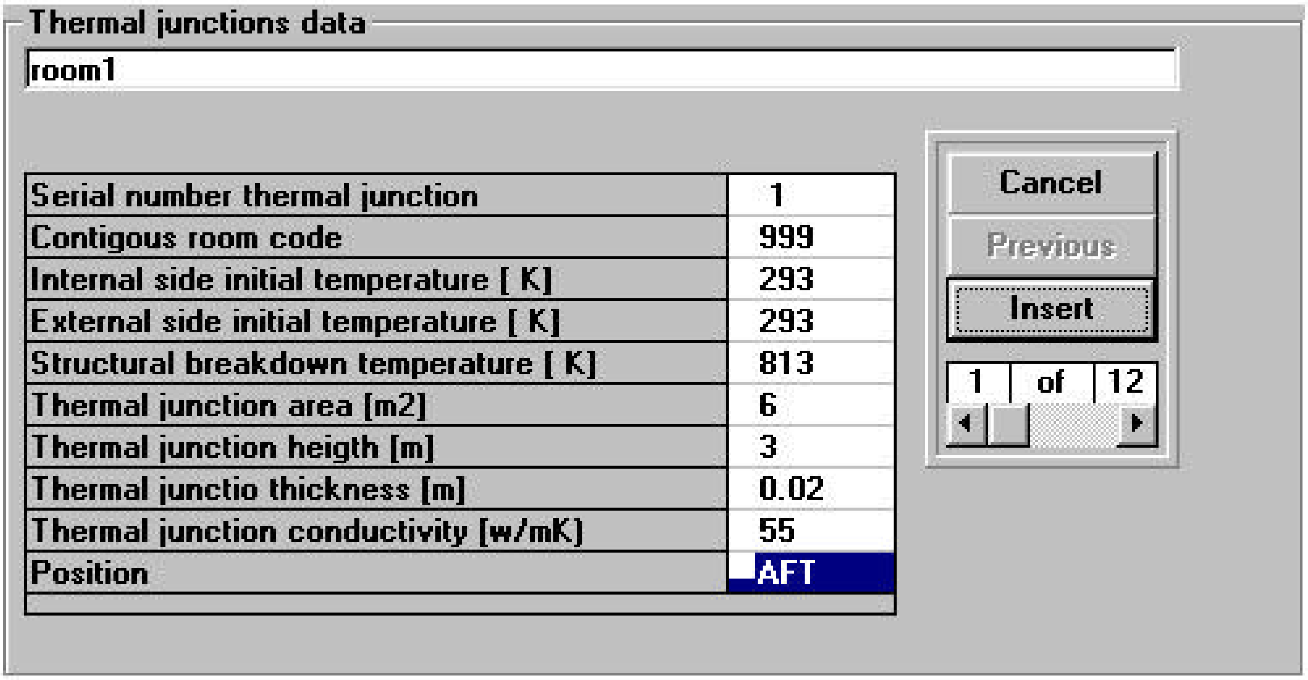


Fig A3 Code input form



Thermal junctions data

room1

Serial number thermal junction	1
Contigous room code	999
Internal side initial temperature [K]	293
External side initial temperature [K]	293
Structural breakdown temperature [K]	813
Thermal junction area [m2]	6
Thermal junction heigth [m]	3
Thermal junctio thickness [m]	0.02
Thermal junction conductivity [w/mK]	55
Position	AFT

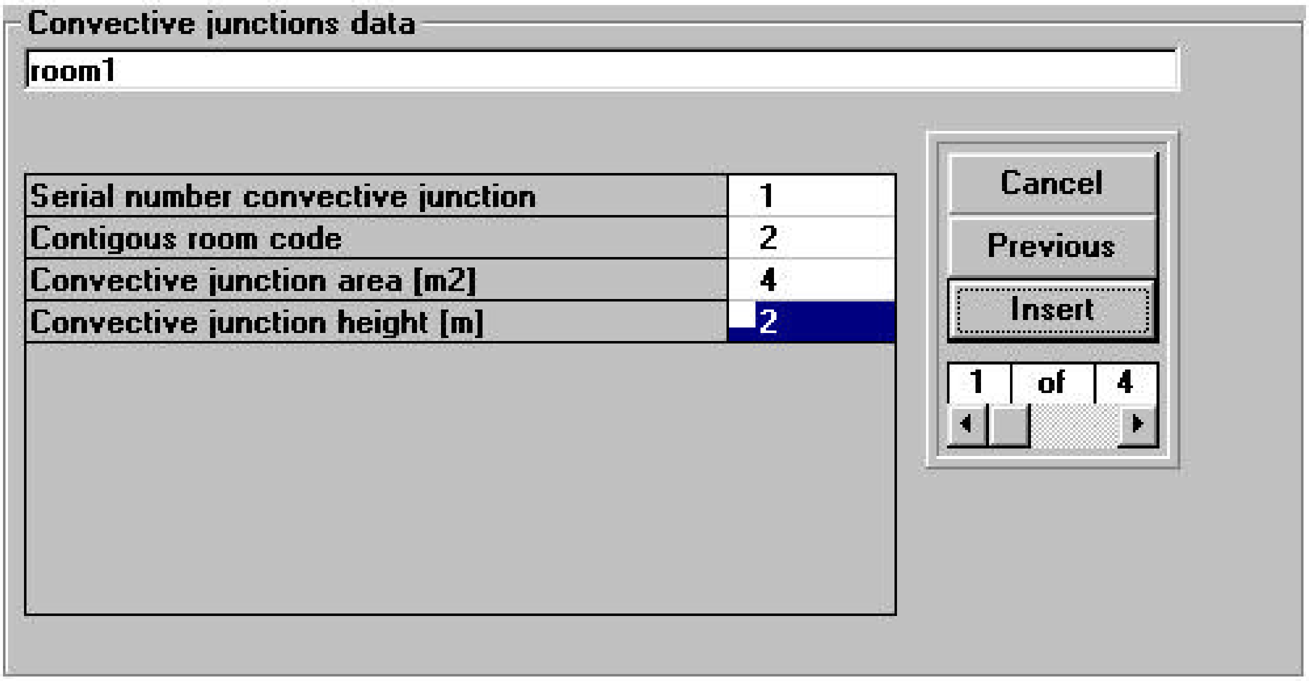
Cancel

Previous

Insert

1 of 12

Fig A4 Code input form



Convective junctions data

room1

Serial number convective junction	1
Contigous room code	2
Convective junction area [m2]	4
Convective junction height [m]	2

Cancel

Previous

Insert

1 of 4

Fig A6 Code output - Temperature

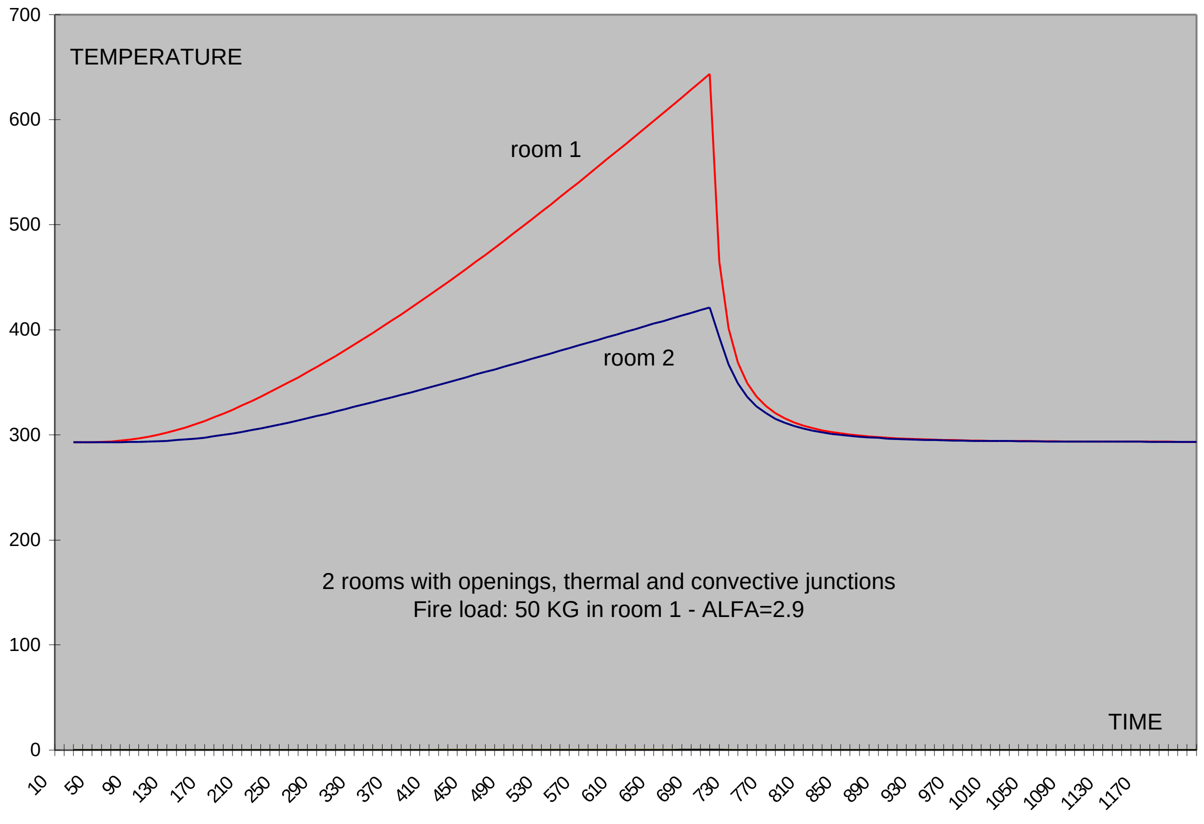
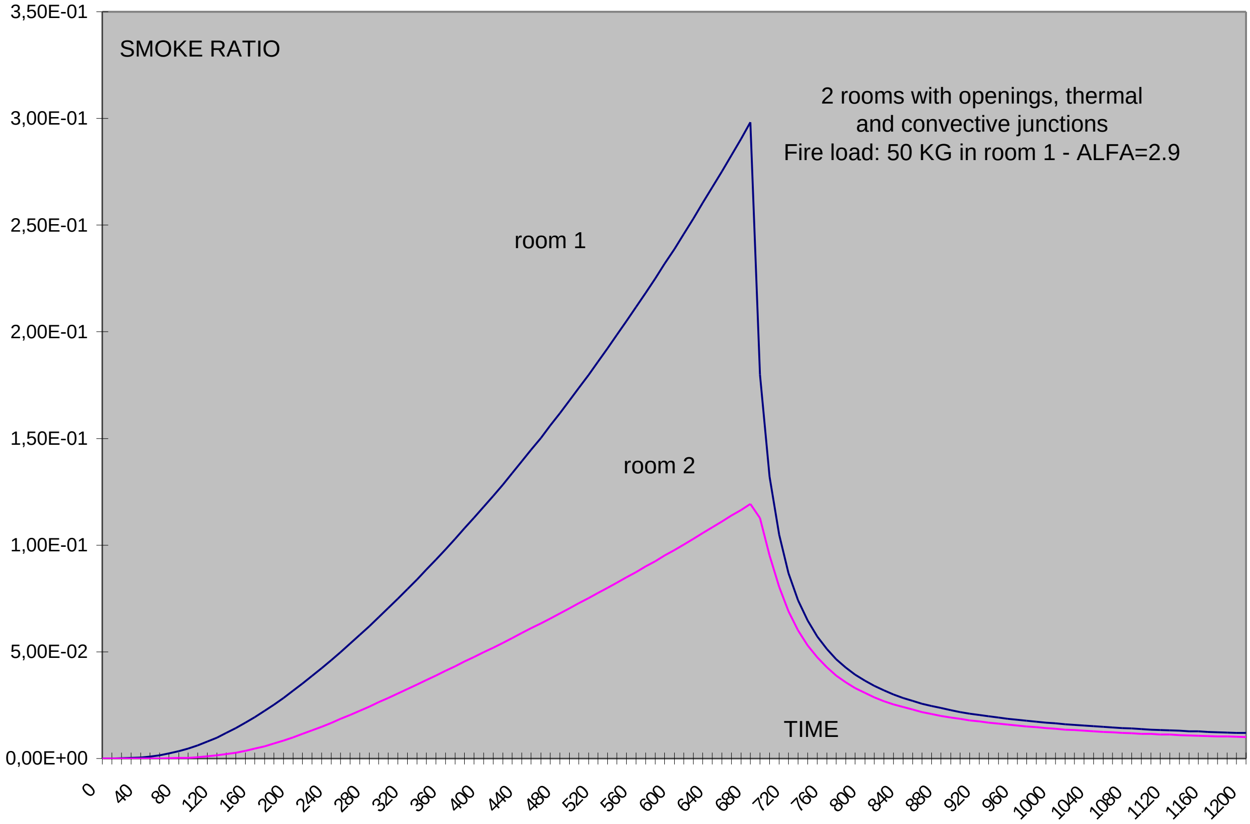


Fig A7 Code output – Smoke ratio



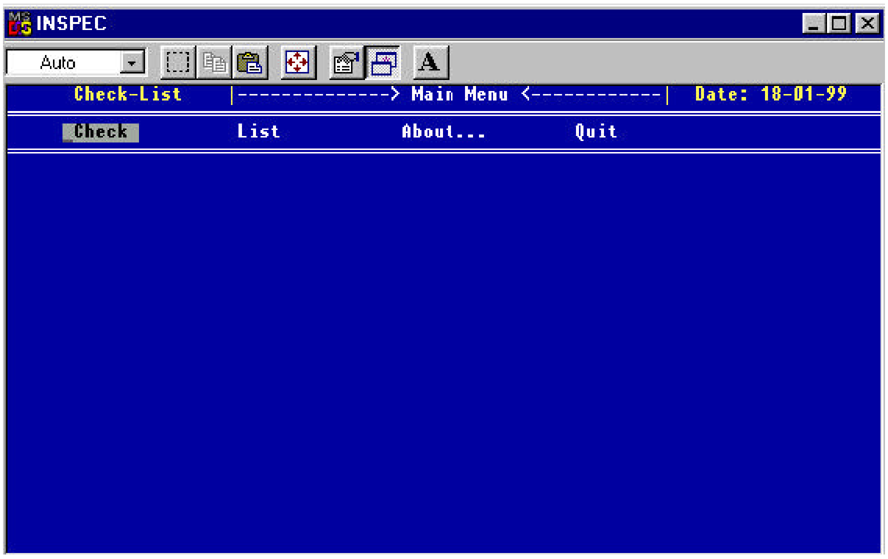
Two computer programs were created in the form of checklists, for the analysis and prevention of fire on board ships. The first one is called General Fire Protection and offers information about prevention and control, and the second one offers information about the major causes of fire, negative influences and efficiency. This method allows an inspector to look for the adequacy of safety policies applied to fire prevention, and is structured as follows:

- Analysis of condition previous to the fire, with the maximum number of parameters studied, such as: maintenance policies, actual use and degree of compliance with regulations, human factor, etc.
- Information about previous condition was obtained from procedures contemplated by safety inspections of the Port State Control.
- The ship's general condition and the level of probability of a fire outbreak has been described in the method to evaluate fire risk.
- Post-accident investigations describe the following aspects:
    - Circumstances of fire spreading
    - Conditioning, disturbing and damaging elements
    - Intervention procedures
    - Efficiency
    - Technical, equipment and human limitations, etc

The checklists developed were adapted to computer user's convenience, with similar structures and configurations.

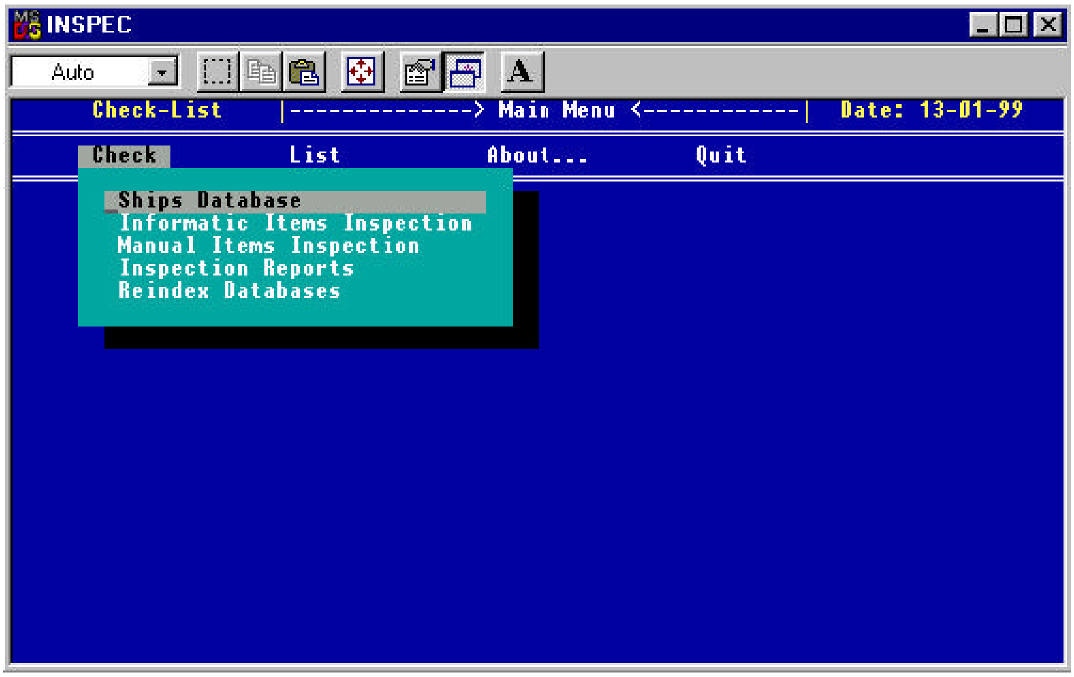
Once the program has been successfully installed on the PC and the application is running, the main window is displayed, showing the name of the application ("General Fire Protection", Figure 1). The following window introduces us directly into the programme itself (Figure 2) and contains all available functions in the form of pull-down menu entries.

Main functions



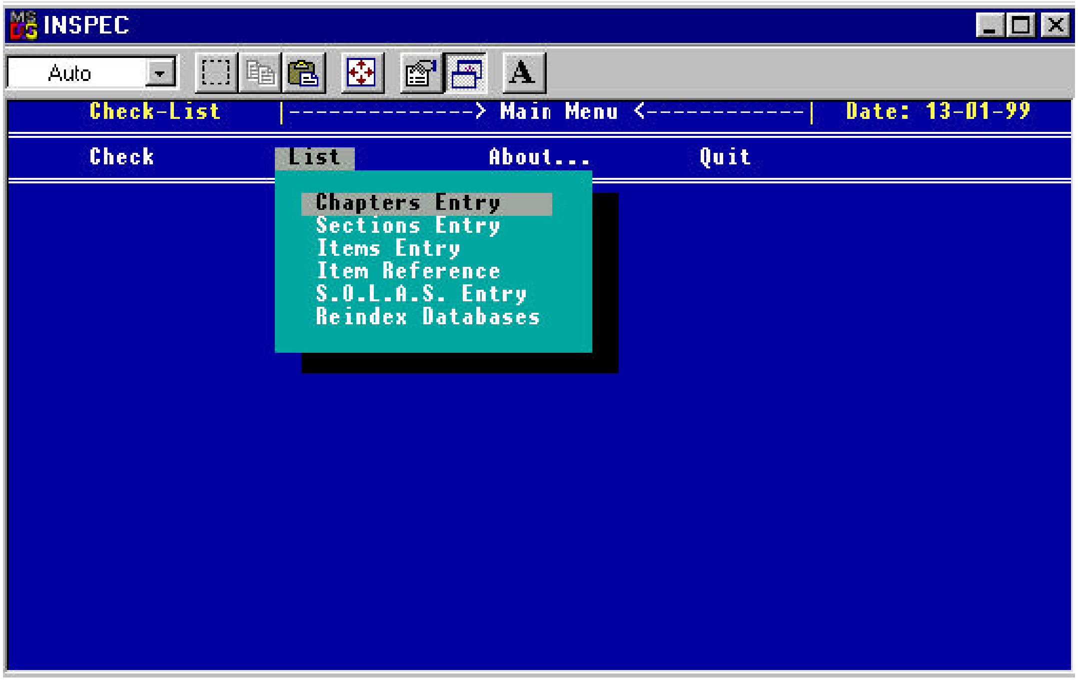
The pull-down menu Check contains the following options: Ships database, Computerised Items Inspection, Manual Items Inspection, Inspection Reports, Reindex Databases.

Contents of Check

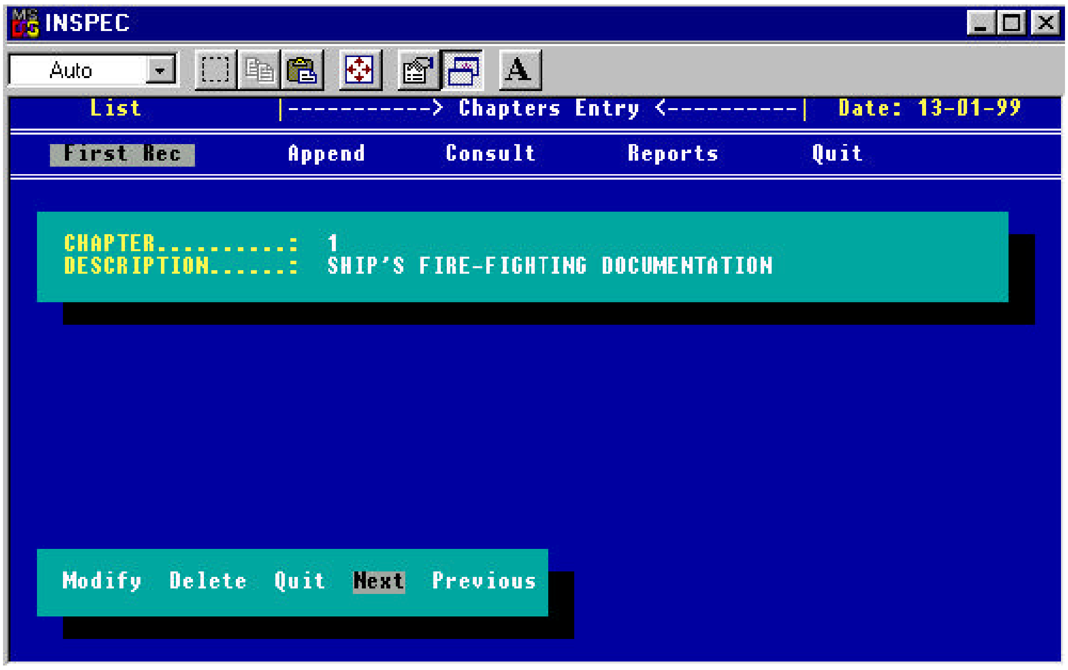


The pull-down menu List, contains the following commands: Chapters Entry, Sections Entry, Items Entry, Items Reference, S.O.L.A.S Entry, Reindex Databases.

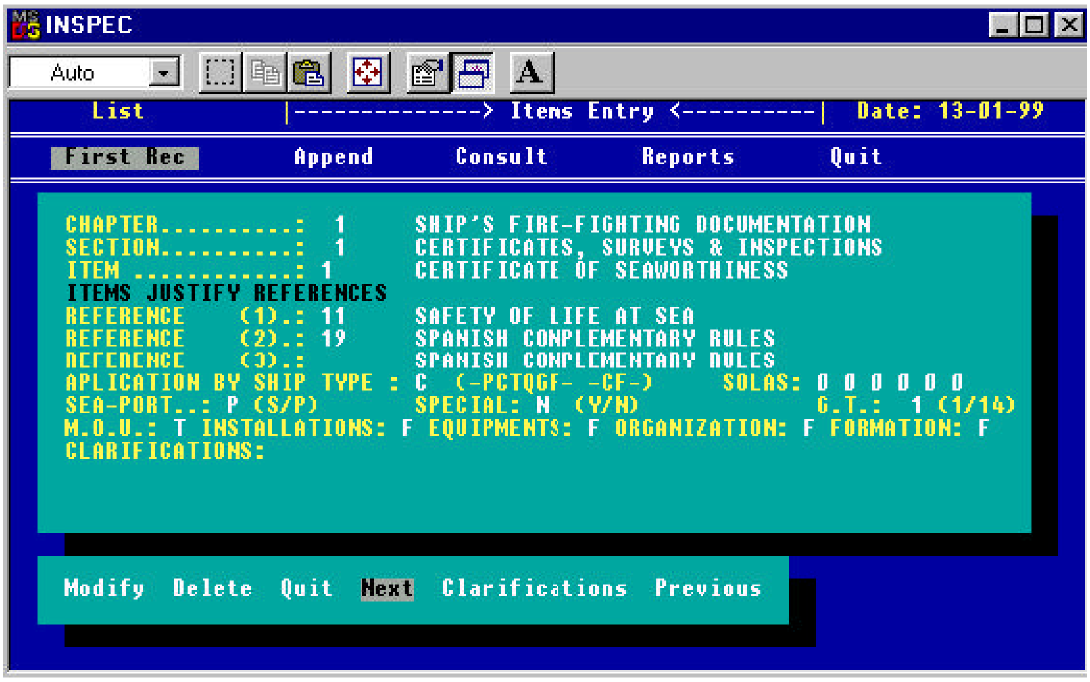
Contents of List



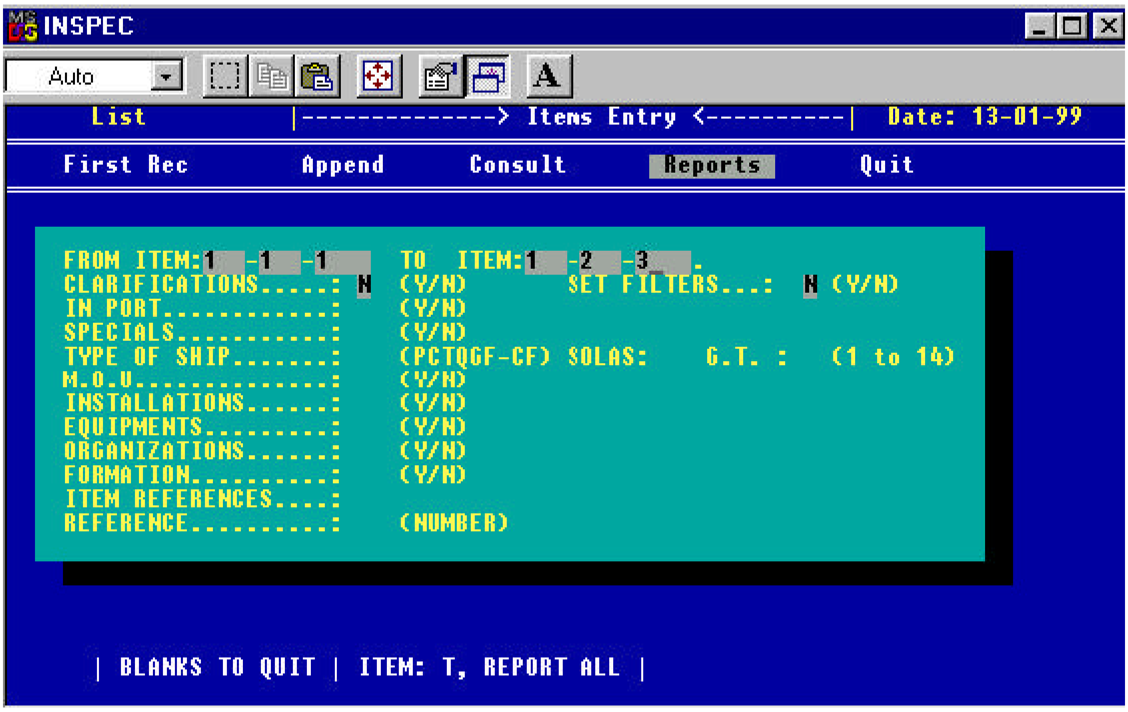
Database Records-Chapters Entry



Database Records-Items Entry



Reports-Items Entry



4. CONCLUSIONS

- The majority of the accidents occurred in vessels more than 15 years old and complying with the 1981 SOLAS amendments.
- The most common starting place was the engine room.
  - The majority of the accidents started when the vessel was at sea and loaded.
  - The worst GRT range for fire casualties is between 10.001 and 50,000.
  - The vessels, which have had more fires, were the general cargo.
  - The consequences of the accidents in the majority of the cases were small.
  - The general cargo vessels are those which are most prone to developing a fire risk situation on board.
  - The vessels with an age above 15 years are also in a group of high risk.
  - Vessels to which the most recent amendments to SOLAS Chapter II-2 apply have less risk of fire on board, contrary to those that the requirements of the 1981 amendments apply.
  - Vessels with a tonnage above 10000 but less than 50000 also have a high risk factor.
  - Most of the accidents are caused by negligence. Most of them, where the cause is unknown, may also derive that the main reason was negligence. This situation reflects the great need for education and training.
  - As it might be expected, the risk of accidents is higher when the vessel is under way. In this situation, the majority of fires started in the engine room.
  - Regarding the importance of the variables in the analysis, they can be organised in the following way:

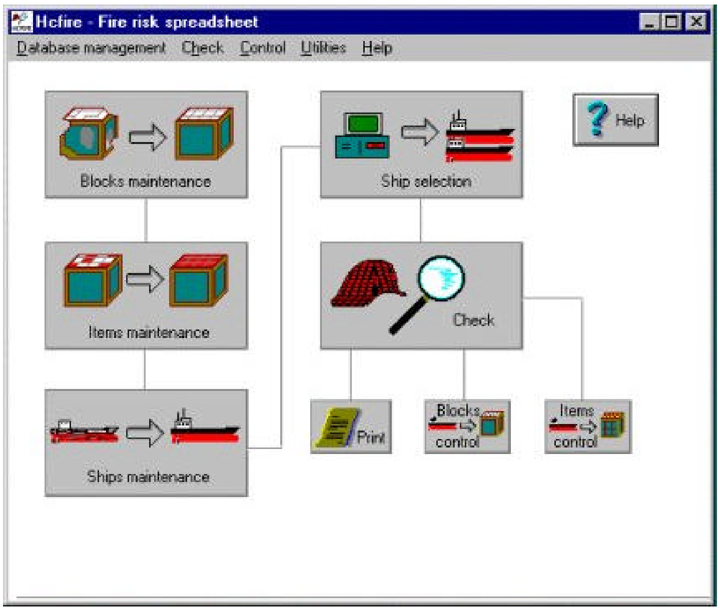
VARIABLE	**%**
Size	15.08
Cause	14.06
Age	12.82
Type	11.80
Place of outbreak	11.19
SOLAS	9.56
Flag	8.89
Condition	8.83
Position	7.77

Some initial possible variables had to be eliminated as there was no data available. One example is the difficulty to find out whether an engine was, for instance steam or motor driven. Another example was the difficulty in finding out the nationality of crew members. This is almost impossible from documentation and it would be necessary to make personal contact with the respective owners/managers.

Due to lack of adequate reports concerning the outbreak of fires on board ships and internal elements (existence of manuals, training of the crew, procedures in place) it is not always possible to import these criteria. It would be advisable to have common, standardised forms for the reporting of accidents where all this information could be obtained.

- Basic procedures in the identification of fire risk are:
  a) Reduction of combustible material
  b) Use thermal structural divisions into different sections of the ship
  c) Select high and low risk areas
  d) New organisation and training schemes for personnel

- The study of the general fire risk parameters like thermal load, fire resistance, combustibility, generation of smoke, etc, give the main criteria to achieve the best analysis of the fire risk.
- The developed evaluation method is fully appropriate according to criteria used in other industrial field activities.
- The program has been globally designed for its application to on board situations.
- It detects and identifies existing deviations in the fulfilment of the directions contained within the different blocks.
- The program also facilitates the application of preventive policies.
- One of the main characteristics of the evaluation procedure is its easy implementation by inspectors as well as non-specially trained personnel.
- The method also represents the great advantage of being capable of implementation on paper as well as by means of a portable computer.
- The method might represent the establishment of new criteria for the creation of a database with international projection.
- Contents and criteria can be continuously updated.



The Technical Report includes an analysis of the solutions adopted and a description of the main rules for conventional ships and for high speed craft on the issue of fire fighting and emergency.

The reason for this choice was due to the need to highlight the modern approach adopted by IMO for HSC to face the problem of fire fighting and emergency situations on board.

In fact, whilst conventional ships are requested to adopt solutions mainly related to the experience handed on form their history, high speed crafts are requested to comply with rules related to a modern approach that considers the craft as part of a whole system defined by; the craft itself, its mission profile, the marine environment, the capability and the skill of the crew, the resources available in case of an emergency.

- The code FIRST (FIRe Simulation Tool) is developed to simulate fire propagation for a typical ship layout.
- The code proved capable of simulating the free propagation of fire for complex systems.
- The output of the code is represented by the temporal evolution of temperature and smoke ratio for each room.

A computer code was applied to the study of fire propagation in a complex system, such as a ship is in this case and is based on several models. The fire development stages and the basic physical models were simplified to an extreme in order to allow for the simulation of the fires influence on the rooms adjacent to where it breaks out. Due to this simplification, the code is not able to simulate detailed fire evolution inside each room taking into account the proper spatial arrangement of the furniture and other objects. However, the code output provides the evolution of temperature, thermal power and smoke ratio of each room in function of the time factor. During the development of the code particular attention was paid to the implementation of various criteria of fire propagation.

5. FUTURE ACTION

Although work on this project is finished, as it was conceived in the proposal and the Technical Annex to the contract, the partners feel that the following would be logical projects to be taken on to further the conclusions of this current project:

- Develop a common European database for inputting information about shipping accidents involving fire on board.
- Define a specific method to unify fire risk evaluation
- Define new fire fighting training content
- Define a fire emergency Work Station to be integrated into emergency control equipment on board ship
- Use the checklists to adapt the ISM Codes to real needs.