Trans IMarE, Vol 101, pp 211–224

Fire performance of electric cables

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SYNOPSIS

Fire hazards presented by cables have motivated the development of new insulating and sheathing materials.

Classification rules for many years required cables to be flame retardant. In 1984 it became a statutory requirement that they be installed in a way that did not impair their flame retardant properties. This requirement has been widely interpreted to mean that cables should not propagate fire when installed in bunches.

The test for flame retardance does not correlate, however, to the IEC 'bunch' test. The requirements for cables installed in bunches have been the subject of much international debate resulting in two solutions: fire stops, or cables made to IEC 332-3 standards.

LR initiated a research programme of fire tests in order to derive more satisfactory guidance for their use. These tests give clear evidence that cables which have satisfactorily withstood the IEC 332-3 test can fail in service when the cable installation geometry is changed.

LR is prepared to consider new products in advance of international standards. The problem when considering such products is that it is rare that a full specification of properties is presented, so that there is a risk that what is left unsaid can have greater significance than the claims being advanced.

INTRODUCTION

The author's detailed interest in electric cables arose from an interpretation by the International Electrotechnical Commission (IEC) Sub-Committee 18A (SC18A) of the International Maritime Organisation (IMO) of requirements relating to the flame retardance of installed cables which is published in IEC 92.[1]

In essence, the interpretation states that cable runs are to be so arranged as to prevent, as far as practicable, the propagation of fire, and this can be achieved by the use of fire stops or by the use of cables which have been satisfactorily tested for compliance with IEC 332-3.[2]

At the time, the requirements for fire stops did not seem to be unreasonable. However, queries from around the world soon dispelled that belief, with the result that an interpretation of an interpretation was being requested.

The use of cables that have been satisfactorily tested for compliance with IEC 332-3 is an attractive alternative to the use of fire stops, which resulted in an increase in the number of requests for Lloyd's Register (LR) approval from cable manufacturers. These requests posed a significant question as to the minimum number of necessary tests, representative of the range, to claim overall compliance with IEC 332-3.

Many of the cable types submitted utilised new materials [developed to overcome the disadvantages of traditional sheath materials such as chlorosulphonated polyethylene (CSP), polychloroprene (PCP) and polyvinylchloride (PVC), which produce dense smoke and harmful fumes under fire conditions]. Such developments are to be applauded. However, it must not be overlooked that the materials should also be adequate for meeting the rigours encountered during installation and service life of the cable. In this respect, current national and international standards give little or no guidance.

A further complication arose when trying to define what constituted a cable 'bunch'. This term has been the subject of much discussion, and there would seem to be as many definitions as participants in the discussions (see Table I).

Frank McCrudden worked for AEI and UK Consulting Engineers before joining Lloyd's Registers' Headquarters, London, in 1970.

Over the years he became well known, both in the UK and overseas, through his Chairmanship of the IACS Electrical Working Party (WP), the IEE Ships Regulations Tanker WP, and the IEE Offshore Recommendations WP. In 1977 he was appointed LR's Principal Surveyor for Electrical Engineering.

Frank died unexpectedly on Wednesday 4th January 1989. This paper has been compiled by a colleague at LR from his notes for the final draft as a memorium to his technical expertise, and personal kindness to so many, in the marine and offshore industries.

The nett result was that Lloyd's Register undertook to carry out a review to try and establish a practical yardstick for the testing and installation of cables.

FIRE PROPAGATION

IMO statutory requirement

IMO Resolution A 325, adopted in November 1975, included a requirement that stipulated 'All electric cables shall be at least a flame retardant type and shall be installed so as not to impair their original flame retardant properties'.

The first part of this requirement did not cause any concern at the time because it had been a long-standing classification requirement that cables should be of a flame retardant type.[3]

It was assumed that the objective of the second part of the requirement was to prohibit the contamination of cable sheaths by combustible materials after installation. Bearing in mind a common shipyard practice of paint spraying everything that doesn't move, it was anticipated that some difficulty would be experienced in implementing this part of the requirement.

Table I: Proposals for bunch definition from various Classification Societies

Number of cables touching	*Overall circumference*	*Quantity of combustibles per metre*	*Separation between single cables or groups*
≥ 2	C	–	< 1.6 C
> 6	–	> 7 litres	–
≥ 6	≥ 150 mm	> 1.5 litres	< 800 mm
≥ 5	≥ 250 mm	–	–
≥ 10	≥ 250 mm	–	-
–	> 195 mm	–	–

SOLAS interpretation

It is the author's opinion that the use of IEC 332-3 as the yardstick for the interpretation of SOLAS Ch 11-1, Reg 45.5.2, is not entirely satisfactory because the IEC 332-3 test cannot be compared with the original flame retardant test. Furthermore, it is considered that such an interpretation was not in the minds of the legislators when Resolution A 325 was published. This view is supported the following.

1. IMO was not advised of the work taking place within IEC (SC18A) until late 1980;
2. IEC 332-3 was not published until 1982.

IEC interpretation of IMO

By the time this requirement came into force on the 1st September 1984[4], the second part of the requirement had been interpreted to mean that 'cable runs shall be so arranged as to prevent as far as practicable the propagation of fire'. This interpretation was formulated by the IEC (SC18A) which went on to state: 'When cables are used which pass the test of IEC 332-1, but which do not pass the test in a bunched configuration, the following shall apply.

1. For vertical cable runs in enclosed or semi-enclosed spaces, fire stops shall be arranged at least at alternate deck levels, and with a maximum distance not significantly in excess of 6 m, unless installed in totally enclosed cable trunks.
2. For horizontal cable runs in enclosed or semi-enclosed spaces, fire stops shall be as specified in item 1 above. The maximum distance may be increased to 14 m'.

Fire stops

The fire stops proposed by the International Association of Classification Societies (IACS) for open cable runs are shown in Fig 1.

It was very quickly pointed out, as illustrated in Figs 2(a) and 2(b), that cable installations on board ships rarely, if ever, follow a neat geometric configuration, and it became apparent that further guidance was necessary.

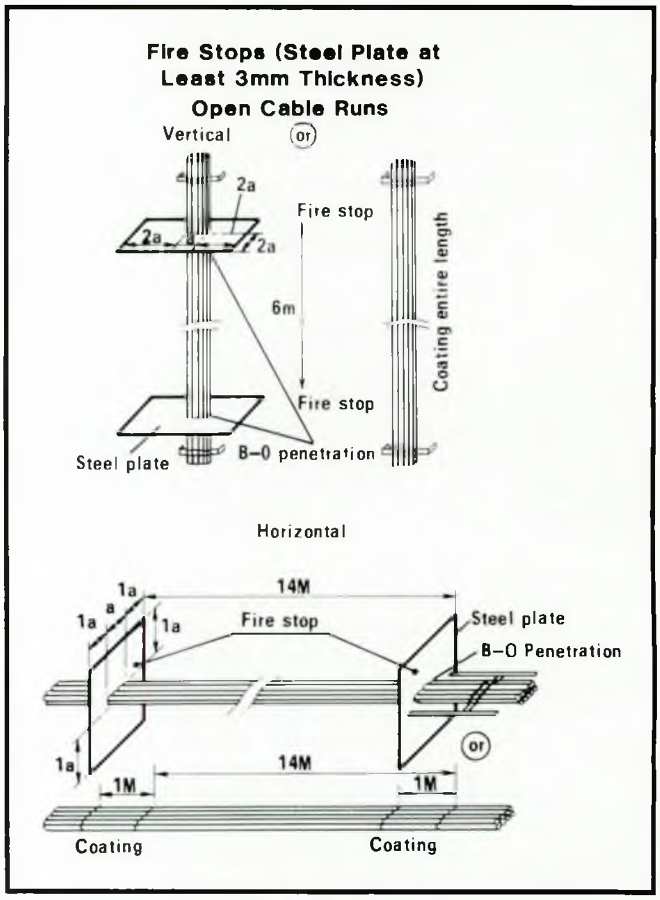

Fig 1: Fire stops

Cables complying with IEC 332-1

It is widely accepted that cables which meet IEC 332-1[5], are deemed to be flame retardant. This test is based on a single sample 600 mm long (see Fig 3), being self-extinguishing after being subjected to a gas burner flame for a period depending on the mass of the sample. Typical test times are given in Table II.

Cables complying with IEC 332-3

By contrast, IEC 332-3 is a test on bunched cables mounted on a vertical rack (see Fig 4), each cable sample being 3.5 m long. A 70 000 Btu/h burner plays on the base of the cables for 40 or 20 min, depending on the cable bunch category. The flame temperature is of the order of 800°C at a point 75 mm from the burner. The number of cable lengths are such as to give a total volume of combustible material of 7 litres/m for Category A, 3.5 litres/m for Category B and 1.5 litres/m for Category C. Cables with conductor cross-sections of up to 35 mm^2 are laid on the rack with the cables touching. Cables with larger conductor sizes are spaced by one cable diameter up to a maximum of 20 mm. The cables pass the test if the charred or affected portion does not extend beyond 2.5 m from the bottom edge of the burner.

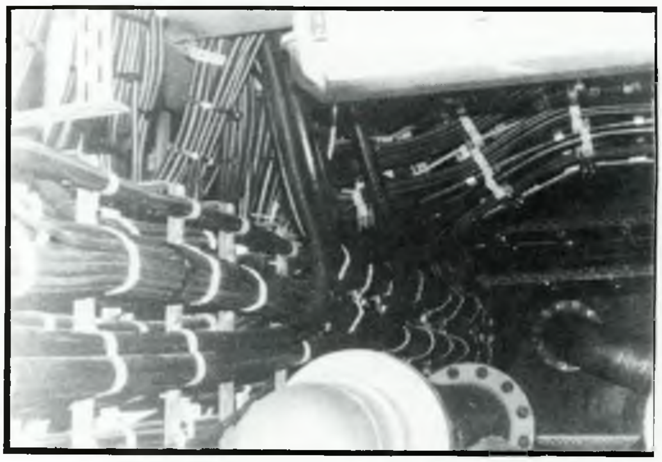

Fig 2(a): Typical cable installation

Table II: IEC 332-1 test times

Cable cross-section	*Cable type*	*Test time (s)*
3 x 25 mm^2	EPR/PCP/PVC	89
3 x 2.5 mm^2	EPR/CSP	71
3 x 2.5 mm^2	EPR/PCP	64

EPR = ethylene propylene rubber, CSP = chlorosulphonated polypropylene, PVC = polyvinylchloride, PCP = polychloroprene.

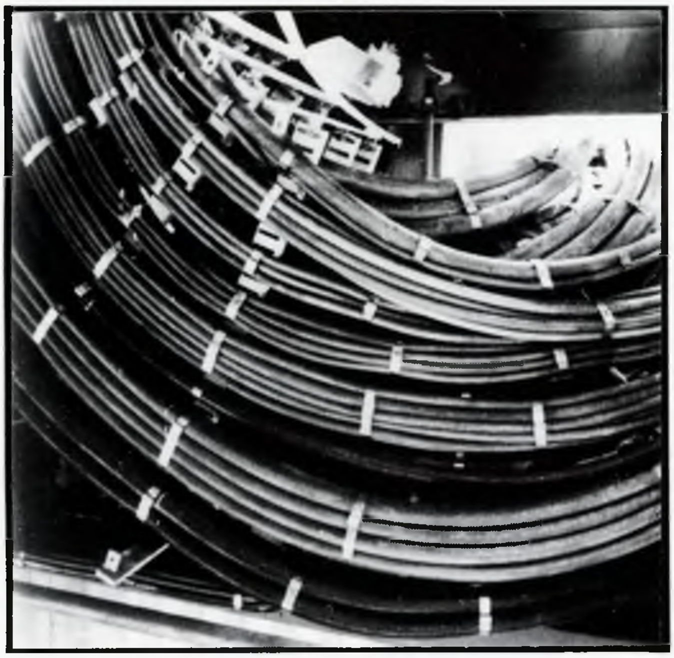

Fig 2(b): Typical cable installation

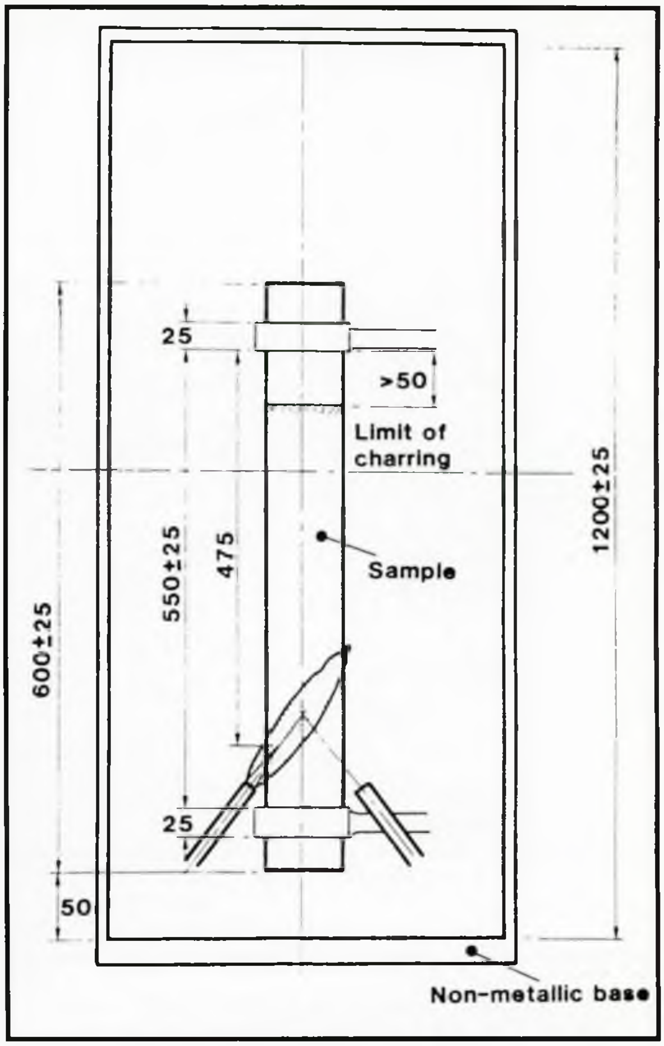

Fig 3: Flame retardant test IEC 332-1

IEC 92-352 and IEC 332-3 – 'The small print'

It is only fair to mention that both IEC 332-3 and IEC 92-352[6] draw attention to the fact that propagation of flame along a bunch of cables depends on a number of features such as:

1. the volume of combustible material exposed to the fire and to any flame subsequently produced by the cable;
2. the geometric configuration of the cables and their relationship to any enclosure;
3. the temperature at which it is possible to ignite any gases emitted from the cables;
4. the quantity of combustible gas released from the cables for a given temperature rise;
5. the volume of air passing through the cable installation.

IEC 332-3 goes on to state the following.

1. Details are given for a test where a number of cables are bunched together to stimulate a theoretical installation. There are three categories of varying volumes of combustible material per m of cable subjected to the test.
2. The test is primarily intended to classify cables and to give a guide to users on the relative merits of the three categories from the aspect of fire propagation under the conditions defined in the test. Consequently, this test method cannot provide a full assessment of fire risk under all of the conditions which may apply to a particular installation, and a constant awareness of the above factors 1 to 5 should be maintained.

With such conditions applying to a manufacturer's certificate, the electrical design engineer would seem to be in a 'no win' situation in that he is unlikely to have the specialised knowledge necessary to assess the above factors.

It is of interest to note that IEC had some reservations about the test in that IEC 332-3 was published as a report, ie it does not have the status of a standard, and that the above factors were published as an afterthought in 1987.

IEC 92-352 states that it is not intended at present that IEC 332-3 tests should be mandatory, but that the style and methods of tests should be adhered to, so that an increasing volume of experience can be gathered in a standardised manner.

Whilst he is agreed that this is a laudable statement, the practicality of being able to collate worthwhile information is questionable if the following factors are taken into account.

1. During the period 1977–86, the average percentage of fires per ship per year was 1.58 (see Fig 5). In other words, there were no reported fires on 98.4% of ships.
2. Of the merchant fleet, 88.6% are more than 4 years old (ie pre-1982 and will not have IEC 332-3 cabling).

It was this implied impracticality of obtaining statistical data, coupled with a small number of spectacular cable fires, where first hand evidence was available, that finally convinced LR to embark on their own test programme.

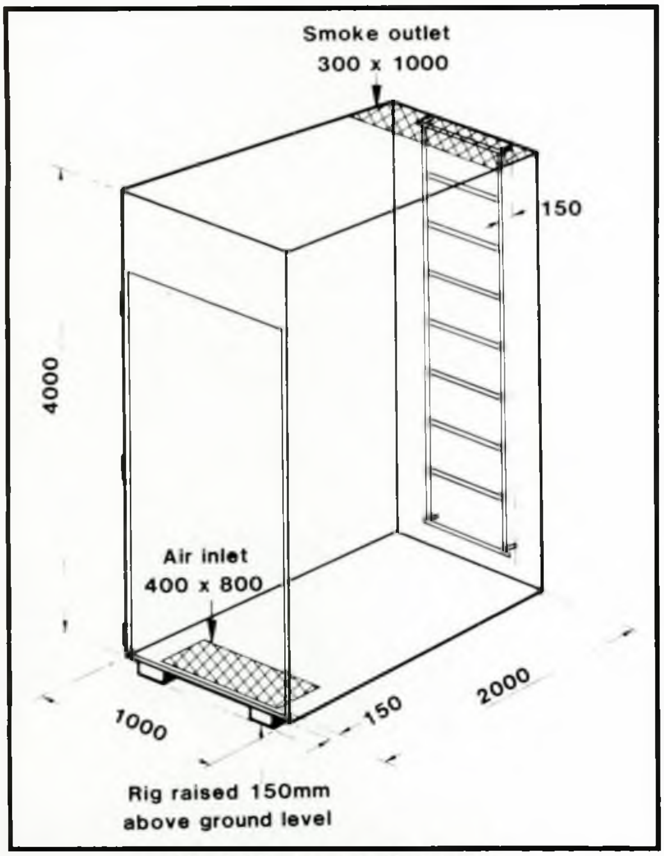

Fig 4: Fire test rig IEC 332-3

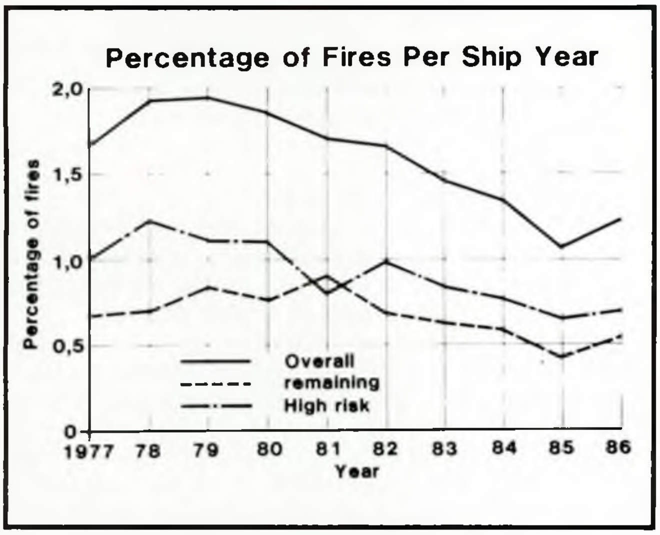

Fig 5: Percentage of fires per ship year

LR FIRE TESTS

Fire tests – phase 1

Test criteria

For phase 1 of the fire tests, which were carried out at the Leigh Laboratory of BICC Limited, it was decided that:

1. tests must be carried out using apparatus conforming with IEC 332-3;
2. the geometric configuration must be the only variable (ie the same number of cable lengths must be used for each test);
3. standard marine cable must be used which had already been demonstrated to meet IEC 332-1 and IEC 332-3;
4. the volume of combustible material must be in accordance with IEC 332-3 Category C so as to give the maximum 'free' space on the ladder to permit variations in geometric configurations.

Three-core 2.5 mm^2 ethylene propylene rubber (EPR)/CSP cable was selected for the tests which, for Category C, meant that 21 lengths of cable were required for each test.

Tests 1 to 3

Although the test cable had already met the IEC 332-3 Category C test, it was agreed that this test be repeated in order to establish a bench mark against which later results could be compared.

It was anticipated that the effect of varying the geometric configuration would be marginal. In order to allow these marginal differences to be recognised, two tests were preplanned using a technique of loading the ladder asymmetrically. This involved using the same bunch size across the cable ladder, but with the size of the gaps between the bunches on the left-hand side differing from the size of the gaps between the bunches on the right-hand side, as given in Fig 6, test 3. The results of these tests are given in Table III.

Test 1 was passed, as expected. However, using the criteria of IEC 332-3, tests 2 and 3 were failed. Indeed test 3 can be said to be a dramatic failure in that the test had to be terminated after 10 min. Given the pass result of test 1, the results of tests 2 and 3 were surprising, but the realisation that pass and fail results could be obtained by relatively minor alterations of the geometrical configuration of the cables was an important finding in itself.

Tests 4 to 6

To proceed two options emerged:

1. to use the same number and size of bunches as tests 2 and 3, but to continue increasing the gap size until a pass result was obtained;
2. to vary the size of the bunches in conjuction with the spacing.

After some consideration, option 2 was decided upon, and a plan of campaign was drawn up as shown in Fig 7. The objective was to make each subsequent test be more onerous if it passed, and less onerous if it failed.

On completion of tests 4, 5 and 6, it appeared that larger bunches of cables were less likely to propagate fire or smouldering combustion, and it was decided to explore this aspect further, which meant departing from Category C of IEC 332-3.

Test 7

For Category A, 96 lengths of cable would be required and in order to allow for the manipulation of the cable geometry, some bunches would need to be mounted on the back of the rack. Interested parties advised against mounting on the back of the rack because:

1. this would produce another order of difficulty for the tests;
2. such configurations would make it difficult to compare the results with those of the previous tests;
3. such configurations were not considered to represent realistic or typical installations.

TABLE III: Test results of phase 1 fire tests

Test number	Cable geometry	Test time	Result	Remarks
1.	21 cables mounted as one layer – cables touching	20 min	Pass	Char, 1.5 m front, 1.25 m back
2.	Seven bunches comprising three cables spaced 1 and 0.5 cm apart	20 min	Fail	Cables had to be doused after 20 min
3.	Seven bunches comprising three cables spaced 1.5 and 2.5 cm apart	20 min	Fail	Cables had to be doused after 10 min
4.	Three bunches comprising seven cables spaced 3 cm apart	20 min	Fail	Cables had to be doused after 20 min
5.	One bunch comprising ten cables and one bunch comprising 11 cables spaced 4 cm apart	20 min	Pass	Char 1.1 m, 20 min after-burn
6.	Three bunches comprising seven cables spaced 8 cm apart	20 min	Pass	Char 1.5 m, 12 min after-burn
7.	Three bunches comprising 16 cables spaced 4 cm apart	40 min	Pass	Char, 1.25 m front, 1.5 m back, 35 min after-burn
8.	Four bunches comprising five cables spaced 6 cm apart	20 min	Pass	Char 1.25 m, 3.5 min after-burn
9.	Seven bunches comprising three cables spaced 4 cm apart	20 min	Fail	Cables had to be doused after 12 min
10.	Five bunches comprising eight cables spaced 4 cm apart	40 min	Fail	Cables had to be doused after 22 min
11.	Five bundles comprising four cables spaced 5 cm apart	20 min	Fail	Cables had to be doused after 17 min
12.	Four bunches comprising ten cables spaced 4 cm apart	40 min	Fail	Cables had to be doused after 35 min

It was therefore decided to move to Category B for test 7, which entailed the use of 48 lengths of cable. Test 7 was passed and no arrangement more likely to propagate could be conceived.

Tests 8 to 12

Finding the limit of bunch size (between 7 and 16 cables) for three bunches did seem tempting at this point but it was decided that the test method was not precise enough to produce exact answers. Instead, it was decided to return to the effect of gap size, and tests 8 to 12 were carried out.

The results of the tests are given in Table III and are illustrated graphically in Fig 8.

Fire test – phase 2

Other manufacturers and cable types

It was appreciated that the three-core 2.5 mm² EPR/CSP cable represented only a small fraction of the types and sizes of cables encountered in the marine industry, and that further tests

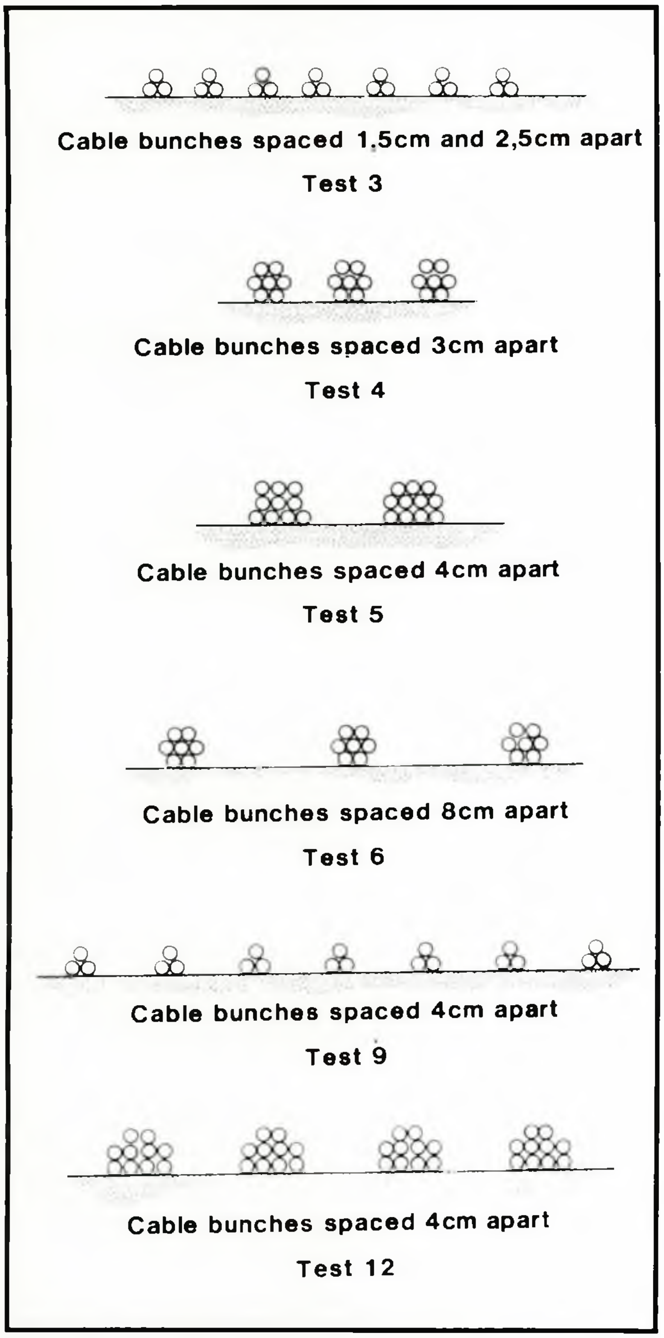

Fig 6: Plan view of cable arrangement on vertical rack

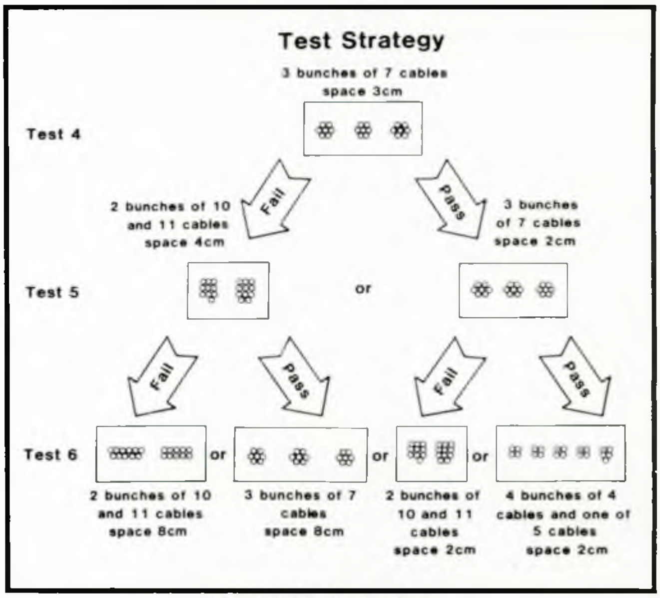

Fig 7: Test strategy

would be necessary before any firm conclusions could be reached.

A further series of tests were carried out at the Queen Mary College, Fire and Materials Laboratory, London. Tests 1, 3 and 12 were repeated using the following cable types supplied by members of the British Cable Makers Confederation (BCMC).

1. Three-core 2.5 mm², EPR insulated, CSP sheathed, unarmoured, of a different manufacturer to the first series of tests.
2. Three-core 2.5 mm², EPR insulated, CSP sheathed, steel wire braided with CSP outer sheath.
3. Single-core 10 mm², EPR insulated, CSP sheathed, unarmoured.
4. Three-core 2.5 mm², PVC insulated, PVC sheathed, unarmoured.
5. Three-core 2.5 mm², PVC insulated, PVC sheathed, steel wire armoured with PVC outer sheath.
6. Three-core 2.5 mm², EPR insulated, EVA sheathed, unarmoured.

The results of the test are given in Table IV.

Horizontal cable runs

Two further tests were carried out with the cable rack in the horizontal position, located in a tunnel and using the same burner as in the previous tests. For the first test 21 cables were mounted as one layer with the cables touching, and for the second test seven bunches comprising three cables were spaced 3 cm apart. In each case the test time was 20 min and the extent of the char did not exceed 85 cm.

COMBUSTION PRODUCTS

Smoke, toxicity and acid gas

Experience has shown that when traditional cable sheathing materials are subjected to a fire, they can:

1. release a large amount of dark obscuring smoke;
2. generate toxic and suffocating gases;
3. generate strong acids due to water or moisture in the atmosphere.

The cable industry has developed, and is still developing, new materials which considerably reduce these combustion products. Such developments are welcomed, but they have introduced the problem of how to quantify the improvements. Many papers have been written on the subject, which is an indication that there is a lack of agreement amongst the experts. Electrical engineers who have studied one or more of these papers, will appreciate the author's reluctance to go into detail on the subject. However, from a layman's view of some of the papers, it would seem that the following can be deduced.

1. There is a lack of international agreement on the techniques used to measure combustion.
2. The release of smoke and toxic gases is dependent on the rate of burning.
3. Cable configuration is a dominant feature not only of fire propagation but also of smoke emission.

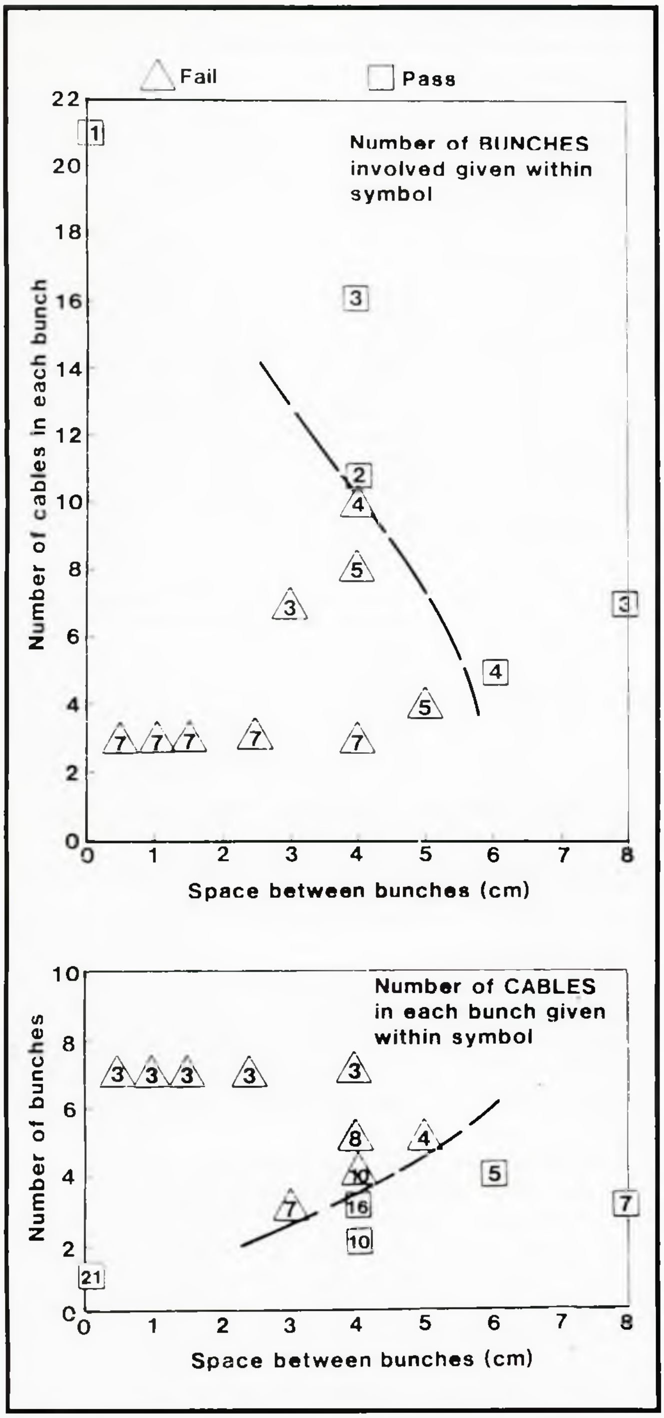

Fig 8: LR test results for 3 x 2.5 mm^2 EPR/CSP cable

4. All organic materials will produce carbon dioxide and carbon monoxide when burned.
5. Halogen acids are not the only corrosive acids.
6. The way a material burns can directly affect the smoke hazard. For some materials a relatively rapid burn under moderate temperatures (above 600°C) can give off less combustion products than when smouldering slowly at much lower temperatures.
7. Oxygen availability is an important factor.

It is evident that it will be some time before international agreement is reached on testing techniques and acceptable levels of smoke and toxic gases. However, it is encouraging to see that there is so much development and discussion in this field.

Thin wall insulation

It is readily apparent that the most obvious way of reducing the amount of smoke and other gases in a fire situation is to reduce the amount of organic material used. One method of achieving this is to use wiring developed for the aerospace industry.[7]

This incorporates less organic material with insulation thicknesses a fraction of those required by IEC 92 for comparable voltage ratings, which results in a lower ratio of combustible/non-combustible material.

However, in order to compensate for the reduced insulation, more stringent performance requirements are demanded of the insulation material. Such cables have the additional advantage of space and weight saving.

LR approval has been granted for these cables. This approval has also required that the users be made aware of the special techniques that must be adopted during installation and termination.

MATERIAL CHARACTERISTICS

General

LR has no desire to inhibit development and is prepared to consider the use of a new product in advance of either a national or international standard, provided that it can be demonstrated that the product is suitable for its intended purposes.

Hitherto, the practice has been to use the requirements of IEC 92-3[8] as the yardstick for the acceptance of new cable materials, the reasoning being that if the performance is equal to or better than established materials the new material should give a satisfactory service. This is fine until there is a significant difference between the old and the new materials.

The emphasis within the cable industry, quite rightly, is focused on the development of materials with improved fire performance. However, experience to date indicates that this improvement is being achieved at the expense of the mechanical properties as illustrated in Fig 9.

It is rare that anything approaching a full specification of properties is presented, so that there is also a risk that the improvement is being achieved at the expense of other characteristics that have been taken for granted in the past. Reference to standards such as IEC 92-3 and IEC 92-359[9] do not give sufficient guidance in that the test requirements for material characteristics are limited to the following.

Tensile strength/elongation without ageing (CSP/PCP/PVC)
Tensile strength/elongation after ageing in an air oven (CSP/PCP/PVC)
Tensile strength/elongation after ageing in oil (CSP/PVC)
Hot set test (PCP)
Pressure test at high temperatures (PVC)
Heat shock test (PVC)
Maximum loss of mass (PVC)
Behaviour at low temperatures (PVC)
Watertightness test (CSP/PCP/PVC) (when specifically agreed)

IEC 92-3 should be treated with caution, in that a number of amendments have been made and, as a result, it is not an easy matter to determine which of the test requirements are still valid.

Table IV: Test result of phase 2 fire tests

Cable geometry		*Cable sample* 3c 2.5mm² EPR/CSP Halogen < 5% Manf A	3c 2.5mm² EPR/CSP Halogen < 5% Manf B	3c 2.5mm² EPR/CSP SWB/CSP Halogen < 5%	3c 10mm² EPR/CSP Halogen < 15%	3c 2.5mm² PVC/PVC	3c 2.5mm² PVC/PVC SWA/PVC	3c 2.5mm² EPR/EVA Halogen < 0.5%
21 cables mounted as one layer – cables touching	*Result* *Test time* *Remarks*	Pass 20 min Char 1.5 m 12 min after-burn	Pass 20 min Char 1.4 m 12 min after-burn	Pass 20 min Char 0.7 m 7 min after-burn	Pass 20 min Char 1.9 m No after-burn	Pass 20 min Char 1.6 m No after-burn	Pass 20 min Char 2.4 m No after-burn	Fail 20 min Char 2.6 m 28 min after-burn
Seven bunches comprising three cables spaced 1.5 and 2.5 cm apart	*Result* *Test time* *Remarks*	Fail 20 min Cables had to be doused after 10 min	Fail 20 min Fire more intense after burner out. Doused at 33 min	Pass 20 min Char 1.3 m, 13 min after-burn	Pass 20 min Char 2.3 m, 1.5 min after-burn	Pass 20 min Char 2.2 m, 7 min after-burn	Pass 20 min Char 2.1 m, 11 min after-burn	Fail 20 min Flame advance approx 40 cm per 3 min after burner out
Four bunches comprising ten cables spaced 4 cm apart	*Result* *Test time* *Remarks*	Fail 40 min Cables had to be doused after 35 min	Fail 40 min Cables had to be doused after 40 min	Fail 40 min Cables had to be doused after 55 min	Pass 40 min Char No after-burn	Pass 40 min Char 2.3 m No after-burn	Pass 40 min Char 1.7 m, 5 min after-burn	Pass 40 min Char 1.4 m, 5 min after-burn

3c = three-core, Manf =manufacturer, EPR = ethylene propylene rubber, CSP = chlorosulphonated polypropylene, SWB = steel wire braid, PVC = polyvinylchloride, SWA = steel wire armoured, EVA = ethyl vinyl acetate.

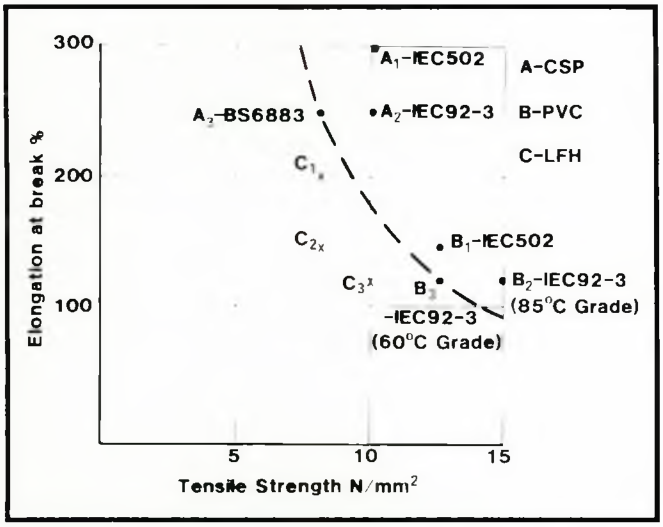

Fig 9: Cable sheaths – mechanical properties

The author has been advised that improved fire performance cannot be achieved without some 'trade-off' between the mechanical properties of a sheath and its fire performance, which imposes the big question as to how much trade-off one can accept. This is not an easy question to answer, which is illustrated by considering the variations in the permitted values of tensile strength and elongation without ageing for CSP, PCP and PVC. The values given in IEC 92-359 are shown in Table V.

The problem is further complicated if the above values are compared with those in national standards such as BS 6899[10] which, for CSP, gives the values shown in Table V.

Cable standards

Electrical cables form but a part of an electrical engineer's sphere of activity, and it is not realistic to expect a full understanding of the chemistry of the complex range of materials now on offer. The electrical engineer is, however, normally responsible for the selection of cables to be used on an installation.

When confronted with a new sheathing material, a non-cable specialist could be forgiven for comparing its characteristics with those of CSP, PCP and PVC. The author went through this exercise and came to the conclusion that the tests quoted in standards such as BS 6899 and IEC 92-359 were 'engineered' to meet the material characteristics. This conclusion may be unfair, but the limited range of test requirements and the variances in the acceptance criteria within IEC 92-359, and between this standard and BS 6899, mean that they do not give sufficient guidance for the acceptance of new materials. The acceptance criteria for tensile strength/elongation shown in Table V illustrate the point.

Table V: Acceptance criteria for cable sheaths

	Minimum tensile strength (N/mm²)		*Minimum elongation (%)*	
Type	IEC 92-359	BS 6899	IEC 92-359	BS 6899
CSP	10.0	8.0	250	250
PCP	10.0	–	300	–
PVC	12.5	–	150	–

These variances pose the question of how critical the individual values of tensile strength and elongation are, and what relationship between the two is needed to ensure that the sheath materials will be suitable for the marine industry.

It is interesting to note that the UK Ministry of Defence recognise the limitations of the current national and international standards and in their standard NES 518[11] they have introduced a wider range of tests which include the following.

- Tensile strength
- Elongation
- Tear resistance
- Thermal endurance
- Critical oxygen index
- Temperature index
- Toxicity index
- Halogen content
- Smoke index
- Resistances to fluids
- Ozone resistance
- Cold bend test
- Heat shock test
- Sheath compatibility
- Flammability

The author is not qualified to comment on the need for this range of tests nor on the acceptance criteria specified. However, the main aspects of concern have been covered, namely:

- resistance to mechanical damage;
- thermal endurance;
- resistance to fluids.

These aspects are worthy of further comment.

Resistance to mechanical damage

The principal criteria used as a measure of toughness and elasticity are tensile strength and elongation at break. The variation in acceptance levels of unaged test pieces is discussed above.

The materials age with exposure to atmosphere, and the process is accelerated by temperature, so international and national standards require these tests to be repeated after ageing. Again there are differences in test and acceptance criteria. Figures for IEC 92-359 and BS 6899 are shown in Table VI for comparison.

A further useful measure of sheath toughness is tear resistance. NES 518 has an acceptance criteria of 5 N/mm·min. Whilst BS 6899 has the same minimum value the test is only applied to the heavy duty (type RS 4) sheath. IEC 92-359 does not call for a tear resistance test.

Thermal endurance

NES 518 specifies that the sheath material should be subjected to a thermal endurance profile as determined in BS 5691 Part 1[12] to demonstrate that the sheathing material has a life exceeding 40 000 h at a continuous temperature of 85°C, it being assumed that the cable will be operating at their normal operating temperature of 85°C for one-third of their installed life, ie an allotted life of 15 years.

To obtain the thermal endurance profile it entails carrying out a number of heat ageing tests and noting tensile strength and elongation of the material samples in each test to see the extent, if any, of deterioration that has taken place. NES 518 suggests material samples should be heat aged for 7 days at 120, 140, 160, 180 and 200°C. By contrast, Underwriters' Laboratories reports submitted by American cable manufacturers for approval, show that the thermal endurance profile is obtained by carrying out heat ageing tests for 30, 60, 90, 120 and 150 days at an oven temperature of 92°C for cables having a conductor temperature of 85°C.

Table VI: Mechanical characteristics after ageing in an air oven

	IEC 92-359	*BS 6899*
Treatment temperature (°C)	100	127
Treatment duration (h)	168	42
Tensile strength, minimum (% non-aged specimen)	70	50
Elongation at break, minimum (% non-aged specimen)	60	50

The thermal endurance profile does not give a guaranteed life expectancy for a material for the simple reason that it is impossible to predict the conditions it will encounter during its life. Nevertheless, it is a technique that is widely accepted and it is considered that cable standards should make specific reference to this technique and should be made applicable to materials which have not previously been accepted for cable applications.

It is understood that the maximum conductor temperature allocated to a cable relates to the current that can be carried during the life of the cable without excessive degradation of the insulation and sheath materials. Unlike national and international standards, NES 518 gives guidance as to how this value of temperature is established.

Resistance to fluids

A significant portion of cabling in ships is exposed to oil and/or water during service life. IEC 92-359 and BS 6899 recognise this and require measurement of the mechanical properties (tensile strength and elongation at break) after 24 h ageing in hot oil at 100°C. The percentage reduction from unaged specimens is, in this case, the same at 60% minimum.

The author has been informed that improved fire performance is often at the expense of the resistance to fluids and this would appear to be borne out by the range of fluids required by NES 518 tests.

- Fuel oil
- Hydraulic fluid (two grades)
- Lubricating oil (three grades)
- Deionised water
- Water with $3^1/_2$% NaCl

These tests are conducted at lower temperatures than BS 6899 but are for a much extended period (28 days).

NES 518 also has acceptance limits on the volume swell of the sheathing materials. This aspect has been addressed in the draft revision of BS 6883[13] which was issued for public comment in February 1989. Typical values of swell from BCMC sample tests are shown in Fig 10.

CONCLUSIONS

Fire propagation

A prime requirement is the prevention of the spread of fire via the cabling system.

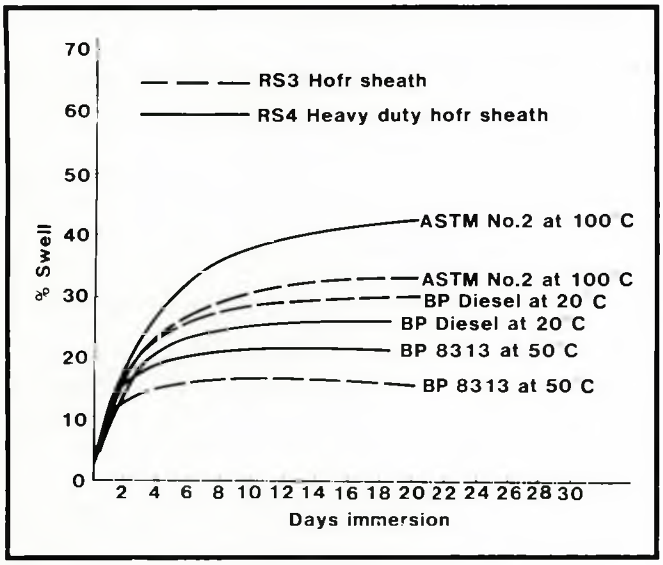

Fig 10: Oil resistance test – volume swell

The results of the LR fire tests lead the author to conclude the following.

1. The use of cables which have met the requirements of IEC 332, Part 3, does not guarantee that the cables will not propagate fire when installed in a ship.
2. Large bunches, eg 16 or more cables, are less likely to propagate fire.
3. Propagation of fire is less likely if the spaces between bunches are greater than 6 cm.
4. Propagation of fire is less likely if the number of bunches does not exceed two.
5. Propagation is less likely to occur along horizontal cable runs.

If the tests are to be meaningful, in that they can be related in some degree to an actual installation, it is essential that the cables be tested in a truly representative configuration. This may be possible for installation encountered in, for example, power stations, underground transport systems and the like but, taking into account worldwide shipbuilding practices, it is not considered possible to conceive such a configuration for the marine industry.

Specifying strict compliance with IEC 332-3 could result in the rejection of materials offering greater overall safety as illustrated by the results on PVC/PVC/SWA/PVC and EPR/EVA cables.

Other fire properties

Before any firm conclusion can be made concerning corrosive and toxic test methods, considerably more experimental work is required. There are still arguments about the correct fire scenario, since the intensity of irradiation, the concentration of available oxygen (which can change as the fire develops) and the presence or absence of flame early in the fire development all vary. Should the most onerous conditions be used for particular materials, or average conditions which permit easier comparisons between different materials?

The whole subject needs to be put into context. Whilst reduction in smoke from cables may seem important, does it really have much effect upon total smoke, a lot of which will come from the primary cause of the fire, eg burning oil? Similarly with toxic fumes, there may be other materials in the compartment, such as paints and varnishes, deck coverings and amenity products like foam mattresses, which will give rise to as much or more toxicity (and smoke) than the products of combustion of the cables.

It is true that IMO has tackled the specific problem of smoke from deck coverings. In 1971, Resolution A 214 (VII) specified a light obscuration test for smoke and also advocated the taking of samples of gases from the smoke test apparatus to be analysed. But no acceptability levels were proposed.

Mechanical properties

Reduction in flame propagation, emission of smoke, and emission of acidic and toxic gases, is usually achieved at the expense of mechanical properties. It is possible that in establishing standards with improved fire performance, it will be necessary to accept a trade-off between the mechanical properties of a sheath and its fire performance.

Mechanical damage most commonly occurs during installation, eg ploughing penetration and tear when the cable is pulled across a sharp point such as a bolt head, and liquid absorption whilst in service. These hazards occur on every ship whilst fire, we trust, occurs seldom, if ever, on a particular ship.

The acceptance of new technology cables will therefore depend on their cost. If they are no more expensive than existing cables there is no problem, but if they are more expensive, their acceptance will depend upon the overall improvement, which will require a value judgement.

The established process of looking at properties one by one has not worked too badly where the properties were separate and indicated independent aspects of performance. In the field of fire safety, however, it is obvious that the hazards of ignitability, flame spread, heat release, smoke and toxic effluents are highly interactive. Attempts to deal with these factors as if they were independent of one another cannot lead to safety decisions. No one wants a regulatory system which denies public use of materials offering greatest inherent safety and accepts those of lesser safety.

ACKNOWLEDGEMENTS

Thanks are due to individual company members of BCMC for the supply of cables for testing and to the Confederation for technical advice. Thanks are also due to Mr G T Reilly for technical suggestions for the test programme, to Lloyd's register for permission to publish information from their records and research and development programme, and to the Ministry of Defence (Procurement Executive) for permission to publish criteria from Naval Engineering Standards.

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Discussion

J M R Hagger (BCMC) The programme of work as detailed in the paper, presented by Mr J K Robinson, was carried out as a joint venture with members of BCMC. Many useful discussions were held with the late Mr Frank McCrudden during the programme with the idea of developing some of the aspects investigated.

The central theme of the paper and indeed of many of the discussions is the interpretation of the relationship between test parameters/data and the service performance.

In general, it has to be said that tests and their results can only be regarded as indicative of a performance characteristic which the 'test' has been designed to monitor, and not a definitive demonstration of service capability where the full hazard potential is not known.

The introduction of the IEC 332-3 vertical fire test has given the cable industry the opportunity to demonstrate that some cables have a greater resistance to flame propagation than others when tested in a given manner – for example armoured cables when compared with unarmoured ones of the same type. This has proven to be an effective tool in the development of cables, but its interpretation in isolation, in forecasting service performance, was not envisaged. The cable industry has used the test to obtain a relative performance indication, whereas it is the cable users that have used the test for definitive service performance requirements.

Tests specified in material standards are often used to define the performance of compounds which have been found to be satisfactory in service. They are not necessarily directly related to any service requirement. For instance, the difference in elongation at break (Table V of the paper) between 150% (PVC) and 300% (PCP) does not indicate any ranking of the materials, merely their different nature in a situation where the maximum extension likely to be seen in service is 20%.

In the cable industry, we carry out extensive testing and field trials in the promotion of new products or materials prior to introduction into the marketplace.

J K Robinson (LR) I agree with Mr Hagger's opening paragraphs and reiterate LR's thanks to BCMC for their valued assistance.

Whilst IEC 332-3 has given a procedure to demonstrate a degree of flame propagation resistance the formulation of the acceptance level has lead to a black/white situation (eg EPR/EVA – fail) which I feel is being over-emphasised in order specifications by some users.

With respect to mechanical characteristics I would agree that there is significant margin over the practical maximum extension of 20% liable to occur during installation. However I would prefer also to see a penetration/tear test along the lines proposed by Swingler (Bibliography ref 8 of the paper).

G T Reilly (Not representing any organisation) In chapter II-2 of SOLAS, eight basic principles which underlie the regulations of that chapter are given. These include:

Zoning (1 and 2)
Restrictions on the use of combustible materials (3)
Detection (4)
Containment (5)

Given these as the basis of the fire safety measures of SOLAS, the interpretation of the requirement that cables '... shall be so installed as not to impair their original flame retarding properties', resulting in the arrangements shown in Fig 1 of the paper, or in the use of cables which pass the test given in IEC 332-3, seems odd.

If it was intended that these types of arrangements were required, then they should surely have been included in chapter II-2 so as to have been part of the overall safety measures philosophy, rather than as a precaution added to the requirement for cables to be flame retardant.

If, as the paper suggests, the phrase was originally intended to mean that the cables should not lose their flame retardancy if painted or if they were liable to absorb oil, then time has been lost in considering that aspect, whilst the IEC 332-3 interpretation has taken us into a lengthy debate.

I feel that the effort involved in producing this paper will only be rewarded if the industry now realises that we have been barking up the wrong tree. If fire stops are needed in long cable runs as part of the fire safety philosophy then so be it, but let us not include them because of a poor interpretation of a separate requirement, and let us delete any reference to IEC 332-3 for marine applications completely.

On the more positive side, having had the privilege of seeing many fire tests, and having been impressed by the performance of many of the improved fire performance cables, I feel that the cable industry has made great progress in this field. I also feel however that the best overall solution would be to work within the philosophy given in chapter II-2 of SOLAS.

The design and manufacture of cables is an art of compromises, and if manufacturers are being required to sacrifice too many useful cable properties in order to try to attain the elusive and probably irrelevant goal of IEC 332-3 compliance, then we may be missing out on useful properties to no avail.

J K Robinson (LR) Mr Reilly draws our attention to the fundamental principles of fire protection behind SOLAS Chapter II-2. Personally I would like to see these amplified by specifying limits for the quantity, and the combustion smoke characteristics, of combustible materials within accommodation fire zones (as per MOD requirements).

Whilst I have some sympathy with his suggestion to delete reference to IEC 332-3 for marine applications, I would prefer to see a modified test protocol, eg results categorised by length of char.

With respect to fire stops, there are not many spaces in merchant ships where they would be required within fire zones; the 'cathedral' engine room and vehicle decks of ro-ros are the obvious examples. The use of metal plate on open runs appears impractical from a shipbuilder's point of view (not withstanding the fact that its effectiveness has yet to be demonstrated). The most obvious cost-effective solution for new construction or retrofit would appear to be a well-tested coating such as that described by Eiermann (ref 1 below).

J A Pownall [Ministry of Defence (Navy)]

1. The significant research work of this paper, demonstrating how cables arranged in accordance with the IEC 332 standard can be slightly altered in spacing and thereby change the fire propagation characteristics, fails to address an important aspect. How can the implied recommendations that will reduce on-board cable fire risks be implemented by Lloyd's on commercial ships?
2. The MOD is somewhat divorced from the economic

constraints of the commercial shipping world. However, I would suggest that Lloyd's and IEE rules, should give greater consideration to the 'system' approach defined in Naval Engineering Standards (NES) 518, 523, 525, 526, 713, 715, Def: Standard 59.71 etc.

3. This system approach ensures that fire barriers such as cable glands at bulkheads do not allow defined fire scenarios to penetrate to adjacent compartments or subsequently transmit water, air or smoke. It also ensures, for example, that:
   a. fire/temperature sensors alert the damage control centre to the extent of the fire.
   b. cables are supported and returned to their position during a fire so that they do not fall and impede access to firefighters.
   c. ship staff undergo training in simulators on how to fight a fire effectively.
   d. cables have polymers that limit the release of smoke, acid and toxic gases.
   e. cable sheaths and insulations have similar or enhanced physical characteristics to the present in-service types that have proven life survival under all environmental conditions.
4. One complex problem that has yet to be addressed is the effect of multiple combinations of cable sheath polymers, such as CSP, LFH, EPR, PVC, etc, on the fire propagation characteristics of those cables proven to pass the IEC 332 test with a single-polymer sheath.

J K Robinson (LR) LR is familiar with the range of NESs listed by Mr Pownall as we have classed the Royal Fleet Auxiliary ships for which these cables have been specified. I would say that we admire their comprehensiveness and fully support the aims that lie behind their formulation. One must also commend the British cable industry for developing products which meet these stringent standards without excessive cost. Unfortunately LR and the UK Flag fleet [for which the IEE Recommendations (ref 2 below) apply via UK Statutory Instruments] are under intense international commercial pressure which makes it difficult to demand any significant safety features, beyond those required by IMO, which would add to builders/owners costs.

P Waterworth (AEI Cables Ltd) A theme that has emerged in this very interesting paper is that the vast range of cables and cable materials available, allied to the types of bunching and cable installation techniques employed on board ships, means that there is no one simple solution or conclusion to be drawn.

The British Cable Makers Confederation is acknowledged in this paper as having lent advice and assistance. This organisation, the co-ordinating body for all cable majors, although at times criticised for the length of time taken to reply to questions and queries raised, is one of the few bodies that can give an authoritative answer based on the actual experience of its members, and first hand knowledge of the diversity of the potential solution available.

This knowledge is usually freely available to users of electric cable and their own associations or bodies, should they choose to ask.

The correct selection and installation of cable is of paramount importance to all. Solutions to problems posed are not easily found but a united approach with a free exchange of information will produce results.

J K Robinson (LR) I concur with all Mr Waterworth's comments.

D St J Seigne (Department of Transport) In my view this excellent paper is very accurate in reviewing the present position and throws up some problems which warrant serious consideration. Only yesterday I had further confirmation of this view – if that were necessary – when reading the current edition of a well-known electrical journal. In the journal it is stated some 400 km of recently installed low-smoke signalling wire is to be removed after discovering that the insulation of the wire is cracking. I wonder if this is the result of a wrong balance in the 'trade off' between improved fire performance and other characteristics, as highlighted in the paper.

J K Robinson (LR) The press report (ref 3 below) referred to by Mr Seigne gives no clue as to the cause of the insulation cracking and LR are not party to any further information in this instance.

We have had experience of insulation, from various manufacturers across the world, becoming too hard or too soft after periods from 1 to 5 years in service. The causes were identified as either inadequate quality control during batch manufacture or insufficiently comprehensive ageing type tests for new products.

J Giaever (The Norwegian National Committee of the IEC) The content of the 'Fire propagation' section of the paper may be understood to read that IEC SC 18A took the initiative for interpretation of the new IMO requirement that cables 'shall be so installed as not to impair their original flame-retarding properties'.

It was in fact not an IEC SC 18A initiative and I have sent the paper's presenter (Mr Kelvin Robinson) some information regarding this.

I would like to add two personal comments regarding technical matters.

1. The possible adverse effects of painting cables is mentioned in Mr McCrudden's paper. I would like to recount an interesting experience in this connection. In 1978 a newbuilding from a Norwegian shipyard had an engine room fire on its maiden voyage. The cause was oil leakage onto a hot surface. The surveyors reported severe fire spread along cable runs, and that all cable runs had been painted with ordinary engine room paint, which was combustible (on a polyurethane basis, if I remember correctly). The cables were of Norwegian ship cable type with outer PVC sheaths, and had passed the IEC Publ 332 test (in 1979 superseded by Publ 332-1). At this time the Norwegian Research Institute of Electricity Supply (EFI) worked on a project called 'Cable fires', and in this connection a special fire test was arranged with two vertical bunches of similar cables installed parallel to each other with a fire screen between. One of the bunches was painted with the suspect paint and according to the recipe received from the yard, the other bunch was unpainted. To our surprise the painted bunch burned much less than the unpainted one. The only explanation we could find was that PVC softeners first evaporate and burn when the cable PVC is set on fire, and this evaporation is retarded when the surface is covered by paint. Maybe the result would have been different with cables having another sheath material such as PCP or CSP.

2. In connection with the LR fire tests, as described in the paper, I am not very surprised that so many configurations failed to pass even though the cables had passed the IEC 332-3 test.
   Only small diameter cables had been used in the tests. At one of the meetings of IEC SC 18A WG 3 (with three members of TC 20 WG 12 also attending), one of our members maintained that it was possible for small diameter cables to pass the 332-3 but not the 332-1 test. As far as I can remember the reason he gave for this was that, according to the specifications of Publ 332-2, small diameter cables 'should be fixed to the front of the ladder in multiple layers with the cables touching one another'. In this way, smaller cables, which have a larger surface area/volume (of combustible material) ratio than larger cables, have their surface/volume ratio reduced to bring it into line with that for larger cables. The larger cables are spaced apart in the test.
   In the WG 3 draft, which was circulated as IEC document 18A (Secretarial) 53 of January 1983 we had proposed, among other things, that in type tests of cables according to Publ 332-3, it should be recommended that at least the size of cable with the largest volume of combustible material/volume of conductor material ratio, and the size with the largest volume of conductor material/volume of combustible material ratio, should be tested.
   This was among those of our proposals which were deleted during the discussions of the parent committee.

J K Robinson (LR) I would like to thank Mr Giaever for minutes of meetings and correspondence covering the interaction between IEC and IMO on flame propagation. From these it is clear that the IMO Subcommittee on Ship Design and Equipment had been aware of the IEC TC20 work (which subsequently became IEC 332-2) and had taken it into account in the final draft of SOLAS Chapter II-1, Reg 45.5.2. Also it is clear that the request for IEC SC18A to consider the type test specification and installation conditions to meet this regulation came from IACS.

The Norwegian tests on painted cables are noted. In the UK a major shipping company also carried out such tests and, whilst the results were not published, it was concluded that the paint contributed to flame propagation. It is generally poor practice to paint cables, as the oxidant (drying agent) in the paint will react with the anti-oxidant (ageing inhibitor) in the sheath.

The LR tests and other test information submitted by cable manufacturers lead one to conclude that the volume of combustible material per metre and the ratio of combustible to non-combustible material are of less significance than geometric configuration. The increased exposed surface area and 'chimney effect' of spacing, whether of individual cables or small bunches, necessary to maintain maximum current ratings results in much increased flame propagation. This prompts further criticism of IEC 332-3 for marine applications as the bulk of ship power cabling in use is below the 35 mm^2 cut-off for spacing during the test.

P T Chilman [Terasaki (Europe) Ltd] Whenever I consider fire and electric cables on ships I am immediately reminded of 10 May 1982 when *HMS Sheffield* was sunk by an AM39 Exocet missile. Many lives were lost in the fire caused by the fuel of the missile burning (not by it exploding). The loss of lives was put down to aluminium burning and cables giving off toxic gases on burning. The latter, to me, is perhaps the most important feature of cables installed in ships and also in other confined spaces such as underground railways. When PVC insulation burns, hydrogen chloride (or, as I learned at school, hydrochloric acid gas) is evolved.

The specification of the wiring of the two medium voltage, two high voltage and the emergency switchboards on *HMS Challenger* was such because of the Sheffield experience.

As Mr Scott of the MOD will confirm they were investigating this problem long before this. Since the replacements for the *Sir Tristram* and the *Sir Galahad* were completely rewired with thin walled, low toxicity cables, does this not point the way to the future?

Mr McCrudden's paper deals very clearly with the installation of fire stops to comply with IEC 332-2. Although fire stops are an aid to reducing fires, they will surely not eliminate them, and their effects must therefore be considered.

Unfortunately, the compounds which make insulating materials less toxic impair their flame retardant properties. I feel, however, that cable manufacturers have now resolved this problem.

I am a qualified naval firefighter and have been trained to deal with ship fires. I have entered a module containing a wood fire without breathing apparatus and have had the stress of considering if my air would last. I have then entered the module with an oil fire wearing breathing apparatus and was stunned by the shock of being completely disorientated because of the lack of any reference points as there was no light whatsoever.

The idea of having the two combined – risk of suffocation and no visibility – leaves me completely terror struck. I therefore feel that on ships the only cables allowed should be low toxicity on burning ones. Should Classification Societies lead the field in this matter and make it a rule requirement? Have any done so already?

Finally, as detailed in the paper, surely painting cables must impair their flame retardant properties. Is this the case?

J K Robinson (LR) The equipment wiring referred to by Mr Chilman is covered in the sub-section of the paper 'Thin wall insulation', and was a forerunner of NES 525 etc.

The use of Naval standards in commercial shipping and the painting of cables was commented on earlier.

With respect to toxicity, Murrell (Bibliography ref 7) points out that the majority of deaths occur from carbon monoxide poisoning. Toxicity is addressed in NES 713, and for enclosed environments, eg leisure submarines, LR have made low toxicity cables a Rule requirement (ref 4 below).

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