PASSIVE FIRE PROTECTION FOR OFFSHORE PIPELINE RISERS

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In line with Cullen Recommendation 46 (i) many passive fire protection systems are now fitted to offshore pipeline risers where safety studies identify a potential fire threat requiring mitigation. The systems are often developed with fire resistance as the primary requisite and neglect other factors which could potentially cause degradation. This can occur to such an extent that fitness-for-purpose is lost and the system fails to provide adequate fire protection. To prevent this a specification for riser protection is required and this paper discusses details of considerations which must be made when specifying materials, types of systems, test methods to prove materials, and typical failures, all aspects which contribute to such a development.

Key Words: Offshore Safety, Pipeline Risers, Passive Fire Protection, PFP

INTRODUCTION

Recommendation 46 (i) of Lord Cullens Report (1) recommends that studies should be carried out 'To achieve effective passive fire protection of risers without aggravating corrosion'. Following safety studies operators have begun to protect risers using a variety of passive fire protection (PFP) methods in order to prevent the escalation of small fires by riser rupture and subsequent catastrophic loss of facilities.

A variety of PFP systems are available which exhibit different attributes. Many were originally designed for application to structural steelwork or for use in panelling systems and have been adapted for applications to risers. There are a number of particular considerations required when specifying PFP materials to protect risers since environmental, hazard and installation situations can vary significantly with fixity, and thus corrosion resistance, presenting a particular problem.

Fire resistance testing, with a number of exceptions, remains the principle means by which a PFP system is evaluated and achieves certification. In service the material may be subjected to a number of events and possible accident scenarios during its lifetime which could result in failure to reproduce the original fire resistance performance when required to do so.

Consideration will be given to sequences of events or scenarios in safety studies and it is appropriate therefore that testing should also employ a sequence of representative tests on specimens of a suitable geometry rather than individual tests on a small sample of the PFP material. It is the integrity of the complete riser system (PFP material, mechanism of fixity, riser pipe and supports) which is of importance rather than simply the fire resistance capability of the PFP material.

This paper identifies some of the more typical PFP materials, the events to which a riser may be subjected, the test methods used to evaluate PFP materials, examples of failures, and then proposes further work and the requirements for a specification which will cover the use of PFP materials applied to offshore pipeline risers.

RISERS

Offshore pipeline risers carry hydrocarbons to/from the platform topsides (as shown typically in Figure 1) and exhibit a number of different configurations which are dependent on platform type and layout. Bends and horizontal sections are present at the top of the jacket to route the riser to its terminal point, generally a pig trap (Figure 2). The riser is clamped at some point near to the top of the jacket and hung vertically or near vertically down to the sea bed thus imposing tension loads. In some instances compression may be introduced by supporting the riser at the bottom.

For a typical riser spans between supports of 5m are typical for horizontal sections and 10-15m for vertical sections. Pipe diameters can lie in the range 3" to 40" and are generally constructed of API 5L (2) steel tubes with grades X52, X60 or X65 being common. Joining between sections may be by bolted flanged connections or by welding and there may be the possibility of gaskets at these joints.

In some platforms of the caisson type, particularly concrete platforms, the vertical sections of the riser may not be exposed but may be contained within the body of the structure or possibly within a leg, caisson, or J-tube on a jacket structure.

RISER ZONES

From this brief description it may be deduced that a riser can pass through different regions of a platform. Seven areas have been defined which may or may not be applicable for a particular platform. Each zone will have different characteristic which, along with platform layout and function, will control the type of environment and hazard that the riser will experience and will thus influence the requirements of the PFP system. The regions are:

1 the continuously immersed area below lowest astronomical tide;
2 the splash zone where intermittent wet/dry conditions exist;
3 the area between the splash zone and cellar deck/spider deck level where saltwater spray levels are high and wetting could occur;
4 above deck where a reduced level of saltwater spray is experienced and equipment congestion may be light or heavy;
5 within modules and ESDV enclosures where a degree of protection to the marine environment will be provided;
6 within caissons or J-tubes which offer protection but are generally flooded;
7 in dry caissons such as [Condeep] platform legs.

PFP SYSTEMS COMMONLY APPLIED TO RISERS

Only generic material types are referred to in this paper and the descriptions apply to the use on risers only.

Sprayed epoxy intumescent coatings: Intumescent materials swell and form a char on the outer surface upon heating which produces a low thermal conductivity. Most of the produced gases are liberated in the very early stages of the fire below 300 °C. Materials of this form are lightweight and the epoxies naturally provide excellent corrosion resistance of the substrate along with good bonding characteristics. To prevent erosion during jet fire impingement, to provide adhesion, and to reduce cracking due to thermal expansion a mesh reinforcement, often pinned to the riser, is generally placed in layers within the material during spray application. Spray application means that the material may be applied in-situ.

Sprayed cementitious coatings: When sprayed onto risers the materials contain chemically bound in water of hydration or crystallisation which is converted to steam on heating. This action maintains the temperature of the PFP material at 100 °C until the water is removed after which the material reverts to a basic insulator and reflector. Once again the material may be applied in-situ and again the material is considered to be unsuitable for application in the wet zones.

Bonded elastomeric coverings: Coatings of this form are generally designed as corrosion coatings with extended abilities. Using chloroprene rubbers as a basis, they are bonded directly to the riser, often using a vulcanising process, and may then comprise a number of layers offering corrosion resistance, limited fire resistance, insulation, impact resistance, water resistance, and anti-fouling. The action is generally ablative, involving the sacrifice of material. Due to the vulcanising process the materials are usually applied to the riser in the factory before the whole assembly is shipped for installation.

Wound fibre composites: The systems are ablative in nature and formed from filament wound glass reinforced resin. The material is applied directly to the primed riser steel by rotating the riser and using a bobbin feed system although the material may be applied by hand. Due to the excellent bonding and water retardant properties the systems may be used on sections within the wet zone and the material has best results when factory applied.

GRP and FRP composites: Both materials have been used as PFP to protect risers but are generally not spray applied systems. GRP type materials employing chopped strand glass and epoxy resins are often faced with meshes to provide integrity and the FRP materials may be used in multiple layer composites which provide strength and fire resistance. Fire resistance can be provided by ablation or by the inclusion of an epoxy intumescent as a facing material.

Pre-formed half-shells or caissons: The tubular section of a riser lends itself to half shell sections which can be fabricated onshore and then shipped and applied in-situ. Half-shell systems have been developed for most of the materials covered above for use in retro-fitting existing risers. They are generally applied over a primed surface to provide corrosion resistance and require a suitable method for joining the half-sections together.

Box-type protection: The majority of systems are generally applied directly to the risers but box type systems have been used to enclose sections of risers, particularly in the above-deck regions. The systems make maintenance and inspection simple and may be fabricated and then assembled on-site for retro-fitting purposes. Box systems have been constructed from stainless steel skin with a high temperature or all-metallic in-fill or from GRP or FRP materials which can be either ablative or have an epoxy intumescent facing for fire protection. Such boxes have been widely used to protect ESD valves.

Blanket Systems: The blanket systems have occasionally been used to protect risers only in the above deck region since they exhibit no water repellent characteristics. Their ease of application and removal however does permit inspection. Weatherproofing can be improved by the use of external coverings and the integrity of such systems is very much dependent on the method of fastening, especially when subjected to blast loading and jet fire impingement.

The limitations of some of these systems for a particular environment have been realised, resulting in different combinations of materials along a riser to reflect the conditions experienced in the different zones.

RELEVANT FACTORS

A fire test performed solely on perfect PFP material which takes no account of actual riser geometries, or exposure to other possible offshore scenarios, will not give a representative indication of the ability of a material to retain its integrity during an offshore fire. It is unfortunate that the majority of tests are performed on virgin specimens applied under ideal conditions.

A number of conditions exist to which a PFP system on a riser could be exposed and which may require testing to prove the integrity of the system. Not all of the conditions highlighted will be applicable in all cases and indeed it may be discovered that some are irrelevant whereas others can be dismissed as unimportant for a particular situation.

Testing should be aimed at the complete PFP system, including a representative pipe, support conditions, and methods of fixity.

Application: When attaching the system to the riser methods should be used which ensure that no imperfections are introduced which could cause failure at some point in the future. Such imperfections could be introduced as a result of the location of the application, temperature during application, accessibility, environment, inadequate surface preparation, inadequately trained personnel, handling, or poorly made repairs and joints. All could be addressed by the use of QA procedures to ensure proper practice leading to good quality.

Ambient Temperatures: Temperature effects on the PFP system can be introduced by the environment and can include the maximum, minimum, thermal cycling and thermal shock effects of such parameters as sea and air temperature. There are also the effects of elevated temperature introduced by hydrocarbon import/export activities (Maximum of 120 °C) or extremely low temperatures introduced by rapid depressurisation. Elevated temperatures may also occur on sections of riser within enclosures or congested areas.

Weathering/Ageing: Weathering/ageing actions can cause a breakdown in mechanical and fire resistance properties by a change in chemical composition, by removal of constituents through leaching, by waterlogging, or by erosion. Exposure to UV light, the actions of saltwater spray, intermittent wet/dry conditions, and full immersion may render materials ineffective whilst the more mechanical actions of ice-wedging and spalling, or the erosive effects of wind, wave current, and high pressure sprayed hydrocarbon can act to enhance environmental weathering or deplete materials.

Impact: Damage caused by impacts leads to water ingress or often the removal of sections of PFP material. In some instances the primary function of a protective measure may not purely fire resistance but to protect the riser from the impact events as well. In addition to the types of impacts considered in safety studies which are generally due to dropped object, blast induced missiles or ship impacts, and which can result in both high and low energy impacts, there are also environmental considerations such as wave slamming and floating debris which can affect materials in the splash and immersed zones. It is unlikely that a riser will survive a full ship impact.

Blast: Blast effects can cause PFP materials to disintegrate, crack, or crush, placing particular emphasis on the mechanism of fixity to retain the materials. Factors of relevance are the blast over-pressure and blast wind velocity, the time history of the event, the response of the riser in terms of its deflection and any blast induced vibrations. The majority of blast parameters will be heavily influenced by the type of fuel and location of the ignition source within the platform and are thus zone dependent with high congestion and areas around vents producing more severe conditions.

Mechanical Properties: Although the riser steel will attract the majority of load the PFP will experience some form of loading and should be able, depending on the particular requirements, to demonstrate compressive and tensile strength, strain resistance under large deflection loading such as blast or impact, and fracture resistance, especially at low temperatures. Of particular interest is the performance of the fixing method or bond which will ultimately determine whether the PFP material detaches itself from the riser prior to a fire. The 'stickability' of a material, the ability to remain attached to the riser under the large deflections which could occur in a fire event, is of paramount importance, as is resistance to removal when fire-fighting operations such as hosing or deluge occur. Mechanical vibration experienced during normal operation may also cause disbondment over a period of time.

Fatigue: Three forms of cyclic loading are possible which could result in fatigue damage to the PFP system in the form of loss of bond strength or micro-cracking and they could be caused by wave action, thermal cycling or vibration. Location along the riser will determine the environmental conditions which will influence the fatigue performance, along with elevated temperatures.

Chemical Reactivity: The primary requirement is the provision of corrosion protection to the riser steel, but to ensure that the material does not degrade reactions should not occur between the PFP and production fluids, protective corrosion coatings, primers, existing CP systems for corrosion resistance, active fire protection systems, and existing PFP materials where over-coating has occurred.

Fire Resistance: The fire resistance requirements of both PFP and method of fixity should define the likely fire type and the fire parameters such as duration, heat flux, spread of flame, temperature of fire, and toxicity. It is essential that the type of test used to prove a PFP system should reproduce the severity of conditions which could be expected in the real fire event.

Thermal Properties: The design and specification of PFP systems for risers requires a knowledge of the thermal properties of a PFP material. Those of particular interest include the thermal conductivity, surface emissivity, absorptivity, rate of erosion, and the heat sink properties of the riser itself.

Post-Fire: Opinions differ as to the relevance of the post-fire condition of the material once a fire is extinguished. The intention is to ensure that re-ignition does not result due to smouldering char, but should this occur then escalation is not possible as adequate fire resistance remains. Resistance to hose stream testing and the provision of meshes to retain char are possibilities, along with a consideration of the smouldering characteristics of the material.

Inspection and Maintenance: The ability to detect defects will ensure that the PFP system performs as expected and demonstrated during test, and the riser pipe is not permitted to degrade by potential catastrophic factors such as corrosion or crack growth which could occur beneath the PFP material. Inspection should be able to detect the correct composition of the PFP material, its thickness, and any defects which may be present within the material or its reinforcement. Similarly there should be the ability to examine the riser material for corrosion and other defects. Maintenance is essential, especially when top coats are required to reduce the effects of weathering and improve waterproofing.

With these potential hazards and events in mind a number of tests have been developed to evaluate the PFP systems for the resistance properties. Definition of what constitutes a pass or fail during testing is of paramount importance.

DEFINITION OF ACCEPTANCE/FAILURE CRITERIA

One principal requirement when evaluating material under test is to define the nature of the pass/fail criteria. Three different levels have been identified:

1. Failure of the PFP material is deemed to occur when the critical value of one of the identified resistance requirements is exceeded.

2. Failure occurs as a result of the PFP material being unable to provide sufficient fire protection for the steel to prevent a critical temperature rise.

3. Failure of the complete system occurs which leads to an escalation of the fire event before evacuation of the platform can be achieved.

For condition 1 the failure criteria is based on the exceedance of a single parameter, be it mechanical or fire related, the result of which could render the PFP material ineffective in providing fire resistance. The criteria applies to the PFP material and not the system.

For condition 2 failure is based around a much broader criteria which considers the performance of the complete system and the ability of the PFP material to provide adequate fire resistance to prevent an escalation of the event.

For condition 3 the criteria is linked to the Safety Case assessment and the survival time required to permit the safe evacuation of the platform. The condition implies that failures of the type outlined in the first two conditions may occur as long as safe evacuation is possible.

Failure could occur by a means other than those expected in a fire test, for instance: degradation of material properties during weathering tests beyond a specified limit; excessive cracking, spalling, or disbondment during mechanical testing; inadequate thickness of material; defects discovered during inspection; corrosion of the riser steel; or failure of post-fire tests.

Failure criteria which could be discovered during a fire or fire test could include: Disappearance of protective materials; collapse of mechanical reinforcement; substrate temperature exceeds a recommended level; excessive reduction of yield or ultimate strength of the riser steel; allowable deflection limit of the riser steel is exceeded; failure of the specimen occurs by collapse or rupture; required survival time is not achieved; or complete failure and possible escalation occurs.

Clearly the ultimate criteria is that which allows the safe evacuation of the platform prior to an escalation of the event i.e. complete failure. The Safety Case assessment provides a time which is required to evacuate the platform and the failure criteria must reflect this. Failure criteria which are adopted during the specification stage must be linked to the practical situation and evaluated using representative tests.

CURRENT PFP TESTING

Weathering: Information from weathering tests performed on PFP is derived from two sources: Accelerated tests and long term tests. Accelerated tests aim to reproduce the severity of real conditions followed by a fire test, generally furnace testing. Typical examples are provided by Underwriters Laboratories UL1709 tests (3) or BS8202 Part 2 (4). The two methods are compared in Table 1.

Long term weathering tests were instigated by Shell in 1987 (5,6) with an anticipated programme length of 10 years. 30cm square specimens are exposed to marine conditions with a photographic record, weight gain, impact resistance, water content, and finally a furnace test being carried out on samples which are periodically removed.

Although accelerated tests are convenient to perform, calibration of the methods with real time weathering is required, and the final fire test should also consider jet fires.

Blast: No standard test methods exist for blast with most work being undertaken on an ad-hoc basis. Blast cells have been used to examine coated PFP specimens, with overpressures of 8 bar being possible. Details of blast test facilities may be found in Reference 7. In general PFP blast tests are performed using overpressures of less than 1.5 bar and usually involve tests on flat plate specimens.

A simulated explosion method has been devised by Haverstad (8) based on experience gained from gas explosion testing of PFP coated panels. The method reproduces the deflection performance of the panel during a blast using a hydraulic actuator. It does not however consider strain rate effects as the oscillation cycles during simulation are of the order of 2-3 seconds period, or the effects of blast wind or negative pressures.

Impact: Small scale impact testing of PFP material allows the evaluation of resistance to localised damage or fracture and is typified by such tests as Charpy or IZOD tests. Large scale impact testing has been carried out on flat panel specimens with the intention of examining the integrity of the entire panel. Inevitably the test results are not applicable to risers since the geometry and support conditions of the specimen influence the specimen response and thus damage experienced by the PFP.

Typical tests have considered pendulum tests such as the trawl board test (giving up to 17kJ impact energy) which is used for pipelines, and drop testing (giving up to 12kJ impact energy). Qualification testing has typically adopted 5kJ as a suitable impact energy, achieved using a 90° cone with an 8mm tip radius. This impact energy is based on a typical secondary missile picked up by a blast wind (9).

Fire Testing: Fire testing is carried out using two distinct methods: Furnace testing and jet fire testing. The hydrocarbon furnace test (for example Reference 10) providing the 'H' rating is a rapid rise test, based on temperature, which displays a time history which is distinctly different to a cellulosic fire test (See Reference 11) which provides the 'A' rating and reflects the combustion characteristics of hydrocarbons which ignite as pool fires. Such a rapid rise can subject the specimen to thermal shock. Peak temperatures of around 1100°C with heat fluxes of 225kW/m^2 are typical for a hydrocarbon furnace test. Most PFP materials have been tested in this manner.

Jet fire testing is not as clearly defined as the furnace test, and no 'J' rating exists, but studies are underway (12) to produce a standard test which will be published by the HSE as an OTO Report. Small scale jet fires have very limited use when considering practical high pressure gas releases. Medium scale fires have been developed by SINTEF (13) using a vaporised LPG flame with release rates of around 0.3kg/s, flame speeds of 20-60m/s and total received heat fluxes of 280 to 340kW/m^2 giving flame temperature of 1100-1200°C. The large scale tests developed by SHELL at the British Gas Spadeadam test site (14) develop flame lengths of 20m from release rates of 2-3kg/s of LPG or LNG. Received total heat fluxes of up to 350kW/m^2 have been measured at targets along with temperatures varying around 1100°C.

Due to the expense of jet fire tests only a few systems have been tested in this way, but the proposed standard test is based on the medium scale test and the current studies are aimed at showing correlation between medium and large scale parameters. This test is being produced at present and the results are out for discussion.

Mechanical Properties: Simple tests to determine tensile and compressive strength, elongation to break, fracture toughness, hardness and bond strength are generally available as standards and are applicable to individual material types such as elastomers, GRP products, resins etc.

Inspection: The importance of inspection has recently led to the development of methods which are capable of inspecting both the PFP and the coated substrate, which is of particular concern when considering corrosion. Such methods have included impedance testing, deep penetration eddy current, x-ray back scatter (15), and the development of an ultrasonic inspection downhole calliper (16) which can inspect the inner and outer surfaces of filled and unfilled risers and thus determine the degree of corrosion. GRP materials are currently being inspected using ultrasonic methods, with a change in attenuation indicating fracture, resin fibre slippage and fibre fracture (17). The results are being linked to damage tolerance and the significance of defects to determine the degree of damage before fitness-for-purpose is impaired.

Chemical Reactivity: Chemical reactivity is assessed in an ad-hoc manner using a variety of different methods which are normally based on chemicals and solvents found in onshore process activities. The activities often centre around the use of reactivity databases which consider the action on a component basis rather than the complete PFP system. Spot or immersion tests are performed at room temperature rather than the elevated condition. In some instance hydrocarbon production fluids have been used.

Combined Hazard Testing: Combined or sequenced testing has been applied to a few panel systems and has comprised: Blast followed by jet fire and furnace testing, simulated blast followed by furnace testing, weathering followed by furnace testing, impact followed by inspection, and fire followed by hose stream testing. The CEGB recognised the need for scenario-based testing and introduced a specification (18) for fire barriers which included wet-dry cyclic testing followed by impact followed by furnace testing followed by hose stream testing as a test sequence.

OPERATORS SAFETY CASE INPUT

The objective of the Safety Case approach is to allow the installation owner to demonstrate that the potential hazards have been identified, the risk therefrom evaluated, and measures taken to reduce those risks to as low as reasonably practicable (ALARP). The Safety Case approach is ***goal-setting***, allowing operators freedom to meet the safety objectives by whatever means they consider appropriate and can justify.

Safety studies will therefore determine whether or not the riser is a critical contributor to the risk to the personnel by examining any number of possible escalation scenarios. If the risk is considered significant then QRA techniques can be used to evaluate the potential reduction in risk that the use of PFP systems would provide.

The scenarios postulated in safety studies, and which the PFP would be expected to experience and resist, provide a basis for defining a test programme for a system. Unfortunately, with few exceptions, testing is concentrated on the fire resistance requirements only when the Safety Case scenarios, and a consideration of the other operational conditions, suggests a combination of factors would be more appropriate.

IN-SERVICE EXPERIENCE

The following gives some typical examples and comments on the performance of PFP materials based on both in-service experience and observations made during testing:

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Similarly, box or wrap-round protection may survive furnace or small scale testing but they are heavily dependent on the mechanical fastenings used to retain them which can undergo severe loading, including mechanical vibration, during jet fire impingement.

Mismatched thermal properties between riser, PFP and reinforcement can lead to cracking or bond failure under fire or other thermal loading as differential expansion occurs between the various layers.

Checks have revealed in some instances; incorrect thicknesses of materials, no reinforcement, reinforcement incorrectly positioned, lack of surface preparation and on a few occasions, incorrect materials or incorrectly mixed multi-part materials have been applied, some of which are not actually PFP materials. Checks on quality are essential.

REQUIREMENTS

The requirements for a riser PFP specification should be in the spirit of the goal-setting approach recommended by Lord Cullen and avoid an enveloping, prescriptive approach. The variability of the subject demands more flexible guidance which links Specification, Safety Case and Test Standard, with the emphasis on satisfying requirements on a case-by-case basis rather than a prescriptive set of rules and values to be achieved.

To accomplish this a set of valid tests are required, any of which can be selected to prove a PFP system against the likely conditions postulated during safety studies. This will ensure that a particular materials' attributes provide the necessary resistance to the likely through life conditions and hazards. This is especially true of offshore risers where conditions can vary in different zones and from platform-to-platform. Presenting a set of rigid design parameters such as impact resistance or blast overpressure would be inappropriate and would lead to error.

The specification must provide a Quality Assurance framework which covers all aspects of PFP material, from testing, through application procedures, to maintenance and in-service monitoring. Such aspects, other than incorrect specification of PFP systems, form the major reason for failures.

Additional work to enable the development of a specification, and test standard, should include:

- Development of a fatigue test to evaluate both material and bond under elevated temperature and saltspray conditions.
- Development of a tubular test specimen which allows the testing of the material, the method of fixity, site joints, and a typical repair. This specimen should be transportable between all tests (eg impact, fire, blast, weathering, etc.).
- Development of suitable methods for inspecting both PFP materials and protected substrate.
- Correlation between level of damage (possibly by impedance testing or sampling of bond strength) and reduction in fire resistance properties to permit in-place

materials to be evaluated for adequacy.

- Correlation between long term weathering and accelerated weathering test methods.
- Correlation between the various fire test methods (furnace, small-, medium-, and large-scale jet fires) and real fires.
- Interaction with active fire protection methods.
- Studies on the effect of vibration and riser response on the material performance.
- Development of a means of monitoring QA and maintenance procedures, including methods for checking application and materials properties, and methods for testing for long term degradation (possibly by retention of coupons).

CONCLUSIONS

1 This paper has highlighted a number of concerns related to the application of PFP material to offshore pipeline risers and gives some of the requirements that a goal-setting specification should consider.

2 The evaluation of PFP materials should encompass not only the PFP material itself but the method by which the PFP is retained and the response of the riser and its supports; in other words the complete system. This will determine the mode of failure and the failure criteria.

3 A number of generic types of PFP systems have been applied to offshore risers which could conceivably experience a variety of different environmental conditions and potential hazards.

4 Along the length of the riser a number of different environmental and hazard conditions may be found which the PFP system should be able to resist and then provide the required fire resistance. Such variability precludes the derivation of a set of fixed compliance parameters, and goes against the goal-setting approach.

5 Tests for a number of hazards have been performed on samples of PFP materials but there has been no significant testing which considers incident scenarios and thus sequences of tests to simulate those scenarios.

6 In-service experience of PFP materials demonstrates that close attention needs to be paid to Quality Assurance aspects, maintenance, adequate testing, and the specification of suitable materials for a particular requirement.

7 The key requirement is to ensure that adequately qualified materials are correctly applied to provide the required resistance parameters defined in the Safety Case with confidence that those properties will be provided over the life of the material to satisfy safety requirements.

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Test	Underwriters Laboratories	BS8202 Part 2
Heat exposure	6 months @ 60°C	270 days @ 70°C
Washing	Wash with soap, water and air dry with no rinsing. Cycle repeated 20 times	Wash with soap, water and air dry with no rinsing. Cycle repeated 20 times
Freeze-thaw	Water @ 0.7in/hr for 72 hrs. -40°C for 24 hrs. +60°C for 72 hrs. Cycle repeated 12 times.	-20°C for 24 hrs. +20°C for 24 hrs. Cycle repeated 10 times.
Sulphur dioxide	SO_2 @ 0.2 litres per 300 litres. Cycle repeated 20 times. (BS3900: Part F8).	1% SO_2 plus 1% CO_2 for 30 days @ 35°C.
Humidity	97-100% relative humidity @ 35°C for six months.	100% relative humidity and cycling between 42-48°C for 2000 hrs.
Weatherometer	Carbon arc lighting @ 20°C for 2000 hrs. (BS3900 Part F3).	Water spray and light for 3 mins and light only for 17 mins. Repeat cycle for 720 hrs.
Salt spray	5% salt solution @ 35°C for 90 days. (ASTM B117-3 1979).	Artificial seawater @ 20°C for 2000 hrs. (BS3900: Part F4).
Natural exposure	2 years minimum in a) industrial environment b) marine environment	
Acid environment		Fog spray of 2% by volume HCL in water for 5 days.
Solvent exposure		Toluene or acetone spray @ 21°C until excess runs off. Dry for 6 hrs, respray, dry for 18 hrs. Cycle repeated 5 times.

Table 1
Accelerated Weathering Tests

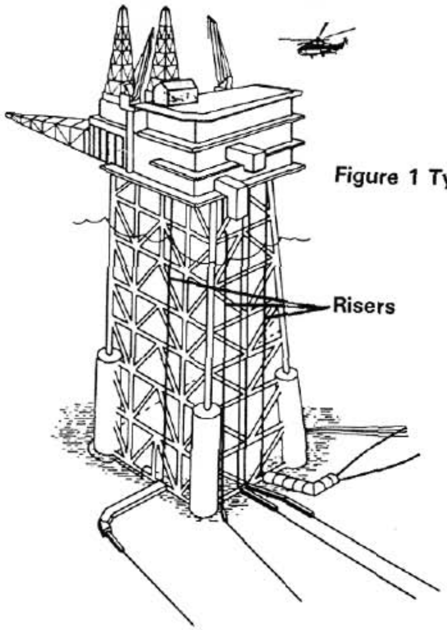

Figure 1 Typical Platform Showing Location of Risers

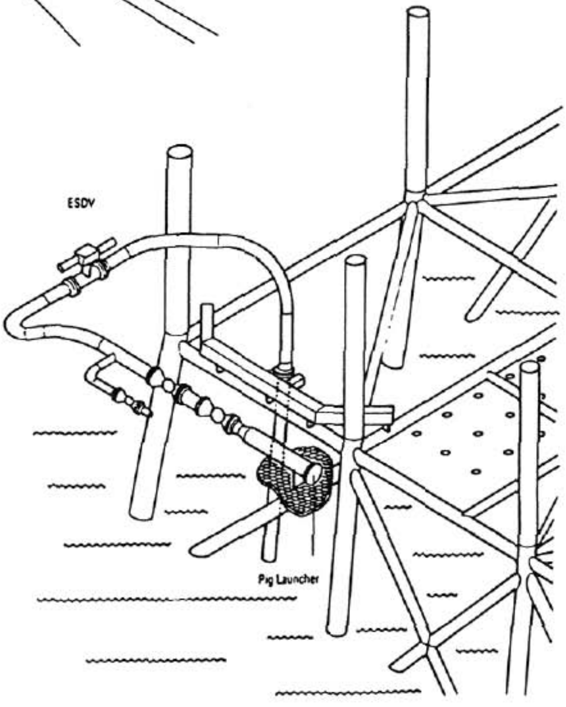

Figure 2 Typical Riser Configuration Above the Waterline