



# **UKOOA FPSO DESIGN GUIDANCE NOTES**

## **FOR UKCS SERVICE**

**MARCH 2002**

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The purpose of these guidelines is to provide guidance on good practice for the design of FPSOs in the UKCS. These Guidance Notes are not a substitute for current statutory regulations.

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# **UKOOA FPSO DESIGN GUIDANCE NOTES FOR UKCS SERVICE**

## **CONTENTS LIST**

### **INTRODUCTION**

### **PART 1: GENERAL CONSIDERATIONS INFLUENCING FPSO SELECTION AND DESIGN**

- 1.1 LOCATION & ENVIRONMENT**
- 1.2 FPSO FUNCTION AND FIELD LIFE**
- 1.3 LAYOUT**
- 1.4 WEIGHT AND SPACE**
- 1.5 VESSEL SELECTION**
- 1.6 VESSEL MOTIONS**
- 1.7 CREW SIZE AND ACCOMMODATION**
- 1.8 REGULATORY FRAMEWORK**
- 1.9 CODES AND STANDARDS**
- 1.10 HEALTH SAFETY AND THE ENVIRONMENT**

### **PART 2: MARINE & STRUCTURAL**

- 2.1 INTRODUCTION**
- 2.2 HULL CONFIGURATION**
- 2.3 LOADS**
- 2.4 PRIMARY HULL STRUCTURE**
- 2.5 GREEN WATER**
- 2.6 BOW WAVE IMPACT**

- 2.7 SLOSHING IN CARGO TANKS**
- 2.8 COLLISION DAMAGE**
- 2.9 STRUCTURAL / PRODUCTION FACILITIES INTERFACE**
- 2.10 HULL DEFLECTION PATTERNS**
- 2.11 MOTION BEHAVIOUR**
- 2.12 MODEL TANK TESTING**
- 2.13 TURRET INTERFACES**
- 2.14 MOORINGS**
- 2.15 CRUDE OIL EXPORT**
- 2.16 BALLAST SYSTEMS**
- 2.17 THRUSTERS**
- 2.18 OPERATIONAL CONSIDERATIONS**

## **PART 3: PRODUCTION FACILITIES**

- 3.1 INTRODUCTION**
- 3.2 FRONT END ENGINEERING**
- 3.3 HYDROCARBON AND NON-HYDROCARBON SYSTEMS:  
CONTINGENT FACTORS**
- 3.4 DEVELOPMENT OF PHILOSOPHIES**
- 3.5 GLOBAL LAYOUT: DEVELOPMENT FACTORS**
- 3.6 LOCAL LAYOUT: DEVELOPMENT FACTORS**
- 3.7 FPSO MAJOR SYSTEMS INCLUDING INTEGRATION/ SEGREGATION**
- 3.8 FPSO SMALL UTILITY AND SUPPORT SYSTEMS**

## **REFERENCES**

# **UKOOA FPSO DESIGN GUIDANCE NOTES FOR UKCS SERVICE**

## **INTRODUCTION**

### **PURPOSE AND OBJECTIVES**

In the course of the Review of the Rules and Regulations for Floating Installations of three Classification Societies, UKOOA Study FPSO JIP 00/01 (ref 1) carried out by RM Offshore Ltd and Project Reviews Ltd, it became apparent that there is currently no single design guidance document or set of documents available to owners, operators and designers of FPSOs for UKCS service which is FPSO specific.

Classification Society Rules cover a variety of floating installations including drilling rigs, semi-submersibles, TLPs and SPARs and there is, inevitably, frequent cross reference to their rules for the classification of ships. Because FPSOs are ship shaped, the tendency is for designers to approach the design of an FPSO as though it is primarily a ship with production facilities as cargo. An FPSO is a floating offshore production and storage facility which happens to be ship shaped. Therefore there has to be a change in the approach to its design to ensure that it is considered as a single integrated entity, as is the case for a fixed jacket installation.

The major recommendation of the above study was that UKOOA should develop its own Design Guidance Notes for FPSOs to draw the attention of owners, operators and designers to the particular requirements of FPSOs, especially those operating in the harsh environment of the UKCS. The narrative of these Guidance Notes will in the first instance assist owners and operators in the early stages of a project, following the selection of an FPSO concept. It will also be of value to designers during front-end engineering and in the early stages of detailed design.

The input to UKOOA study FPSO JIP 00/01 was obtained from owners, operators, designers, constructors and consultants involved in FPSO developments. A number of common themes emerged where problems had been encountered in design, build and operation. These can be considered as Lessons Learned and have therefore been incorporated in these Guidance Notes in the hope that the problems will be avoided in future projects.

Both UKOOA and the Health and Safety Executive (HSE) have commissioned studies and issued a range of reports that are relevant to FPSO design and operation. Some of these reports are referred to in the Guidance Notes. It is recommended that FPSO owners, designers and operators familiarise themselves with the listings of UKOOA and the HSE to identify relevant topics and thereby ensure that findings and recommendations can be adopted, where appropriate.

The Design Guidance Notes have been divided into three parts. Part 1 covers the general considerations influencing FPSO selection and design. In Part 2 (Marine and Structural) and Part 3 (Production Facilities), specific issues are addressed in more detail, providing a lead-in to the detailed design of the FPSO.

## **LIMITATIONS AND EXCLUSIONS**

The Design Guidance Notes should not be considered either as a detailed design guide or as a form of textbook on FPSO design. Neither are they a substitute for current statutory regulations that prevail in the UKCS.

The Guidance Notes are not intended to replace the rules and regulations of the Classification Societies. They recognise that the Societies' rules play a valuable role in setting out good engineering practice gained over many years. Although an FPSO in the UKCS does not have to be classed by law, these rules still provide a wide coverage of the issues that have to be addressed to ensure the safety, operability and longevity of the FPSO.

The design of FPSOs involves the use of a large range of national and international laws, standards, codes of practice and specifications and so Guidance Notes, by definition, can refer selectively to only a very small number of these.

A field development using an FPSO involves subsea facilities, flowlines, risers, shuttle tankers and/ or export pipelines. While the Guidance Notes make references to these because of interfaces between them and the FPSO installation, guidance on these topics is outwith the scope of these Guidance Notes.

In the execution of a project, it is impossible to divorce the engineering of the facility from the management of the project itself. Project management decisions can have both beneficial and disruptive influences on technical decisions and on the progress of engineering. The Guidance Notes do not attempt in any way to set out project management guidelines. However, where appropriate, the Notes do indicate circumstances where informed and timely project management involvement can result in a more satisfactory technical and, possibly, commercial outcome.

# **UKOOA FPSO DESIGN GUIDANCE NOTES FOR UKCS SERVICE**

## **PART 1**

### **GENERAL CONSIDERATIONS INFLUENCING FPSO SELECTION AND DESIGN**

#### **CONTENTS LIST**

##### **1.1 LOCATION & ENVIRONMENT**

##### **1.2 FPSO FUNCTION AND FIELD LIFE**

- 1.2.1 Introduction
- 1.2.2 FPSO Hull Sizing
- 1.2.3 Sizing of Production Facilities

##### **1.3 LAYOUT**

- 1.3.1 Introduction
- 1.3.2 Turret
- 1.3.3 Living quarters
- 1.3.4 Helideck
- 1.3.5 Escape and Evacuation
- 1.3.6 Flares, Exhausts and Vents
- 1.3.7 Wind Tunnel Testing

##### **1.4 WEIGHT AND SPACE**

- 1.4.1 Weight control
- 1.4.2 Space control

##### **1.5 VESSEL SELECTION**

- 1.5.1 Selection factors

##### **1.6 VESSEL MOTIONS**

- 1.6.1 Human Response
- 1.6.2 Effect on Equipment
- 1.6.3 Helicopter operations
- 1.6.4 Model tank testing

## **1.7 CREW SIZE AND ACCOMMODATION**

1.7.1 Basis for Crew Sizing

1.7.2 Accommodation Facilities

## **1.8 REGULATORY FRAMEWORK**

## **1.9 CODES AND STANDARDS**

1.9.1 International Codes and Standards

1.9.2 Use of Classification Societies' Rules

1.9.3 Client and Classification Society Roles

## **1.10 HEALTH SAFETY AND THE ENVIRONMENT**

1.10.1 Introduction

1.10.2 Design for Safety

1.10.3 Design for Health

1.10.4 Design for the Environment

# **UKOOA FPSO DESIGN GUIDANCE NOTES FOR UKCS SERVICE**

## **PART 1**

### **GENERAL CONSIDERATIONS INFLUENCING FPSO SELECTION AND DESIGN**

#### **1.1 LOCATION & ENVIRONMENT**

FPSO-based developments in UKCS now number fourteen and these are located in a range of water depths from 70m in central N Sea to 450m West of Shetlands. Possible future developments in the Faeroes-Shetland trough could take the water depth to 1,000m. These extreme water depths introduce the challenges of designing cost-effective mooring and flexible riser systems which will freely allow vessel motion in waves but constrain riser top-end displacements within its design limitations.

The design of FPSOs in UKCS is also highly governed by the harsh environment. This influences:

- Requirement for a turret mooring to allow the FPSO to weathervane and minimise environmental loads on the mooring system.
- Selection of suitable hull size and form with good motion characteristics.
- Freeboard
- Production facilities design to minimise motion downtime.
- Hull size to provide adequate buffer storage to minimise shuttle tanker offloading downtime.
- Hull structure design (strength and fatigue)
- Environmental performance
- Marine installation design and procedures

An additional important requirement is the desirability for the FPSO to remain on station for the duration of field life, without dry-docking for inspection, maintenance or repair. This is because of potential difficulties in riser and mooring disconnection and reconnection in the harsh environment and the economic penalty of lost or deferred production. This is especially important for long field life FPSOs with high production throughput and complex riser systems.

Service in the NW Atlantic region of UKCS places even higher demands on FPSO design. The more onerous wave climate imposes higher hull loads and requires extensive upgrading of existing hulls to achieve strength and fatigue performance. The fatigue requirement, in particular, coupled with the problem of in-situ repair, strongly encourages the use of new-build custom-designed vessels for this area.



## **1.2 FPSO FUNCTION AND FIELD LIFE**

### **1.2.1 Introduction**

The function of an FPSO is determined by the type and quantities of the fluids that it has to process and export, and by the storage requirements for its crude oil product. The size of the reservoir, in terms of recoverable reserves and its producibility, will influence both the size of production facilities and the time the FPSO will be in the field. The export route will generally determine the storage capacity of the FPSO.

However, when an existing vessel as opposed to a new, purpose-built vessel is considered for a specific development application, it may well be that the storage capacity, the available deck space and load bearing capabilities along with the remaining fatigue life of the hull will determine the function and the field life.

The two following sections on the sizing of the hull and on the sizing of the production facilities identify the principal issues for consideration by FPSO owners, operators and designers in selecting a suitable unit to develop a field.

### **1.2.2 FPSO Hull Sizing**

The main drivers for hull sizing are:

#### **Crude oil storage**

For new-build custom designed FPSOs, hull size is driven usually by the crude oil storage requirement. This is sized on the peak oil production rate and is sufficient to cover the shuttle tanker cycle time between each offloading. The cycle time comprises:

- Loading time at field
- Sailing time to/from port (including weather delay en-route)
- Port discharge duration
- Connect/disconnect times to FPSO
- Waiting on weather time to cope with a specified winter storm. This is dependent on the wave height and wind speed thresholds for connection and disconnection.

Other practical factors may influence the crude storage volume. For instance, if the shuttle tanker is part of a pool arrangement with a common size of tanker, the FPSO storage can be the same volume, to avoid the shuttle tanker sailing with part-filled tanks or leaving part of the parcel behind.

For high throughput fields, it may be more economical to provide additional shuttle tanker(s) to give more frequent offloading during peak production, instead of enlarging crude oil storage on the FPSO. Towards the end of field life, when production rates have

declined, the frequency of shuttle tanker offloading can be reduced and it may be economic to have a pool arrangement with other fields for sharing shuttle tanker utilisation and operating costs.

Hull sizing should also provide sufficient segregated ballast capacity to ensure adequate ballast draft to avoid bottom slamming forward and provide required sea-keeping performance and stability.

On converted tankers, it is usually not possible to obtain a tanker that matches the optimum crude storage requirements outlined above. If the selected tanker has less than the required storage volume, the shuttle tanker offloading frequency can be increased during peak production, and vice-versa where storage is greater than required. Tankers that are greatly oversized for their FPSO role will have a cost penalty in heavier moorings.

Where crude oil is exported via pipeline or there is a separate FSU, there is no need for crude oil storage unless some buffer storage is specified to cover outage of the pipeline or FSU. The hull size can be reduced commensurate with a reduction in crude oil storage, provided there is sufficient deck space for production facilities and adequate sea-keeping performance.

### **Deck space**

Hulls sized for the crude oil storage requirement provide adequate deck space for deck mounted production facilities for small/medium-sized fields. On large throughput FPSOs, where production facilities may be complicated with water injection and gas processing, the hull may not be large enough to provide enough deck space for a workable single-level PAU layout with adequate lay-down area and future tie-in space. For new-builds, it may be economically attractive to increase hull size rather than constrain topsides deck area.

### **Availability of tanker hulls for conversion**

The size of converted tankers is governed by the availability of suitable tanker hulls for conversion. The technical criteria are:

- Structural condition and fatigue design
- Reasonable size to minimise cost of mooring system in harsh environment
- Adequate crude storage and ballast capacity with appropriate tank layout to minimise sloshing
- Adequate deck space and payload

To obtain a suitable hull, it may be necessary to compromise on a non-optimum size of vessel for a particular field. The most suitable size for UKCS service has historically been in the range 92,000 - 105,000 dwt, irrespective of oil production throughput.

## **Sea-keeping performance**

Good sea-keeping performance is important in the harsh environment to ensure:

- Crew safety and operability
- High production uptime
- Reliable helicopter operation
- Riser top-end motion is within limits

Sea-keeping is a function of size and shape of vessel.

Generally, conventional hull shapes can be expected, from experience, to give good motion performance with minimal production facility downtime provided attention is paid to motion sensitive facilities (separator design, gas turbines etc.)

Small or novel hull forms require detailed examination of their motion characteristics at an early design stage.

### **1.2.3 Sizing of Production Facilities**

The key factors which influence the main deck load which the FPSO has to carry in the form of production facilities are:

- The number of major systems
- Reservoir characteristics
- Choice of export route
- Single or twin production trains
- Possible redeployment on another, different field

#### **Major systems**

The main systems which will have a significant bearing on the size and configuration of the FPSO's production facilities are:

- Crude oil separation
- Gas processing (dehydration and compression) and possible export
- Produced water treatment and handling including re-injection
- Seawater treatment and injection
- Crude oil export via shuttle tanker or pipeline
- Main power generation i.e. size and numbers of units

#### **Reservoir characteristics**

As stated above, field reservoir characteristics have a major influence and the facilities designer therefore needs to have good quality information on:

- Production profiles for oil, gas and produced water
- Likely duration of the production plateau i.e. flat or peaked
- Potential for and timing of future satellite reservoir development which might extend plateau production
- Reservoir pressure and extent of reservoir pressure support to determine amount of water and gas re-injection.
- Gas-oil ratio and possible requirement for gas lift
- Properties of produced fluids e.g. wax content, sourness, viscosity, specific gravity
- Fluid arrival temperatures at the FPSO

Water injection support may be needed early in advance of significant quantities of produced water being available for re-injection. In this case, seawater treatment facilities such as de-aeration units will have to be sized accordingly.

High confidence levels in reservoir data and predicted performance are desirable to:

- minimise the possibility of late design changes and hence their impact on project schedule and budget
- reduce the risk of production constraints due to systems or equipment being subject to conditions for which they were not originally designed.

However, FPSOs may also be used in areas of low reservoir confidence as short-term production systems to improve reservoir understanding and prepare for an optimised long-term production system.

### **Export System**

The choice of crude oil export system will also influence facility sizing in that not only will flow rates to a pipeline and a shuttle tanker be different but also the levels of separation in the oil processing train to achieve the different crude oil specifications for each route. In the case of heavy, viscous or waxy crudes, low fluid arrival temperatures may require extensive heating facilities involving, among other items, waste heat recovery units on gas turbine drivers.

### **Single or Dual Production Trains**

The FPSO owner has also to decide if the production profiles require single or dual trains of crude oil separation and of gas compression. The owner has to weigh up the loss of revenue arising from a protracted outage of a single 100% production stream against the additional cost associated with the provision of two 50% streams.

Should a single production stream be chosen then a judicious selection of spared equipment within the train has to be made in order to ensure as high a level of system

availability as possible. Suitably sized test separation facilities can be utilised to give a degree of spareage as well as well as affording more efficient management of the wells.

### **Redeployment**

Where the FPSO is to used on a field with a short field life of, say, five to seven years, the owner has to decide whether to design the production facilities for that field life or to make provision for the possible redeployment of the FPSO to another reservoir, in another location. In such cases, perceived potential marketing opportunities may well determine facilities configuration, the extent of in-built flexibility to process a range of fluid types, and production rates and space and weight provisions for the addition of modules or extra piecemeal equipment.

## **1.3 LAYOUT**

### **1.3.1 Introduction**

The layout of an FPSO will probably depend on whether the vessel is a new, purpose-built vessel or a new intercept vessel or an existing unit. With a new, purpose built vessel the designer has two main decisions to make which will influence the overall layout, namely the position of the living quarters and the position of the turret. In the case of an existing vessel, there is probably only one decision to be made namely the location of the turret as the living quarters will have already been fixed.

The following sections consider the principal issues which affect layout. First and foremost, the main considerations are those of the safety of the crew and of reducing their exposure to the hazards encountered on an offshore installation storing and processing hydrocarbons. Whatever configuration is used, the scale of the hazards reduces towards the living quarters, the temporary refuge and the principal points of evacuation.

### **1.3.2 Turret**

All turret/swivel positions in UKCS are internal to the hull to minimise accelerations on flexible risers, for structural support of the turret, protection of the swivel and accessibility for maintenance.

There is a choice of turret position:

#### **a) Forward**

A forward location provides natural weathervaning of FPSO with use of minimal or no thruster power. This is the more common system in UKCS and is used on vessels with a high-pressure swivel which permits unrestricted rotation.

A forward turret is structurally preferable as it is removed from the central highly stressed part of the hull and less longitudinal reinforcement is needed. This is especially important on converted tankers.

The acceptability of riser top-end motions and accelerations needs to be checked at an early stage for forward turrets because of the high combined heave and pitch vertical motions close to the bow.

#### **b) Just forward of amidships**

This location requires vessels with substantial thruster power to control weathervaning. Where this type of turret is used, the vessel has a wind-on system of high pressure transfer hoses which permit rotation of approximately 270 degrees before the system must be “unwound”.

The turret opening close to amidships introduces major structural reinforcement problems on a converted vessel but is more easily incorporated at the design stage on a new-build vessel.

### 1.3.3 Living quarters

On converted vessels, the existing LQ is usually retained in its aft position. On a new-build vessel, the LQ position is largely determined by the position of the turret.

For forward turrets, the LQ is placed at the stern to maximise the separation between the LQ and the major hazards of the swivel and the production facilities.

For amidships turrets, the LQ is placed at the bow upwind of the major hazards. The acceptability of motions for crew and helicopter operability should be checked at an early stage in the design because of the high combined heave and pitch vertical motions at the bow.

The advantages and disadvantages of each position are as follows:

Position of LQ	Advantages	Disadvantages
Forward	<ul style="list-style-type: none"> <li>• LQ/helideck is upwind of major hazards and fire or smoke in an emergency</li> </ul>	<ul style="list-style-type: none"> <li>• High vertical motion at bow may affect crew comfort and helicopter operations.</li> <li>• Natural weathervaning of FPSO is difficult to achieve without placing HP swivel close to LQ.</li> <li>• An amidships turret achieves separation between LQ and HP swivel but requires substantial thruster power to weathervane the FPSO.</li> </ul>
Aft	<ul style="list-style-type: none"> <li>• Reduced vertical motion (compared to bow) for crew comfort and helicopter operations.</li> <li>• Natural weathervaning of FPSO can be achieved without thrusters.</li> <li>• Large separation of LQ from HP swivel.</li> </ul>	<ul style="list-style-type: none"> <li>• LQ/helideck is downwind of major hazards and fire or smoke in an emergency. However thrusters could be used to rotate FPSO clear of fire/smoke and create a lee side for lifeboats.</li> </ul>

### **1.3.4 Helideck**

Helideck design should meet the requirements of UK CAA CAP 437 Offshore Helicopter Landing Areas: A Guide to Criteria, Recommended Minimum Standards and Best Practice (ref.2). The siting of helidecks on FPSOs will generally be above the living quarters for logistics and safety reasons, and will therefore be at the forward or aft end of the FPSO. The positioning of the helideck should take account of the wind environment around the FPSO, particularly turbulence, vertical component of wind velocity and hot gas plumes from flares or turbine exhausts, both at the helideck and on the approaches. The height of the helideck and the air gap between it and the living quarters below should ensure as clean a flow of air as possible and should be determined using wind tunnel testing.

Helideck layout should allow for either parking of a broken-down helicopter or platform craneage should have helideck coverage and capacity to permit helicopter removal.

Design for operations is covered by UKOOA - The Management of Offshore Helideck Operations 1.27, 1997 (ref.3).

### **1.3.5 Escape and Evacuation**

#### **Escape**

During layout development studies of the FPSO main and production decks the location of the main or primary escape routes from these areas to the living quarters and the Temporary Refuge (TR) can have a major influence on the overall layout.

In the case of a large FPSO with substantial production facilities covering the main deck, the “free” open deck area may be considerably smaller than on a large vessel with small production capacity. It is therefore important to assess the escape route requirements at a very early stage to ensure that rapid escape from the more congested areas is not compromised.

One or more escape tunnels can be used to provide direct, protected access from the process and utility areas on the main deck into the TR, usually located in the living quarters. The escape tunnel has to be sized to take account of the range of credible scenarios of major incidents and the personnel likely to be involved. The tunnel should be capable of withstanding credible explosions and fires to permit personnel to escape within a defined time and to allow fire-fighting and rescue crews to gain access if and when it is deemed prudent to undertake these activities.

The position of the tunnel will be determined by the fire and explosion scenarios but it is most likely to be on the outside edge of the main deck running the length of the production facilities, as a minimum, and possibly the entire length of the main deck. It is unlikely to be located within the production areas unless safety studies indicate



otherwise. The tunnel may be totally enclosed and positively pressurised or it may be open on the seaward side.

There will be intermediate access points from production and utilities areas into the tunnel and layout studies must ensure that the access into these access points is as direct as possible and clear of obstructions.

The principles of direct, unobstructed escape access apply equally to enclosed areas in the hull, (i.e. the bow section and in the aft machinery spaces or in any superstructure), to the production areas and to the main decks where the congestion factors due to cargo tank pipe-work will be greater.

Attention should be given to secondary escape routes which may have to be used if primary routes are not available. Both primary and secondary routes should be provided with clear route markings.

## **Evacuation**

The main evacuation methods from the FPSO will be via helicopter, subject to proximity and availability of helicopter services and to weather conditions, or via lifeboat. The access requirements to the helideck are set out in CAA guidelines CAP 437 (ref.2). Whether a freefall or a davit-launched TEMPSC is chosen, lifeboat access will be close to the TR. Covered access may or may not be provided depending on the outcome of fire scenario studies with input from the wind tunnel tests.

Consideration has also to be given to secondary means of evacuation such as liferafts or other proprietary methods in situations where it may not be possible for personnel to gain access to or be able to use the escape tunnel. The position of and access to these secondary evacuation points must be included in the overall layout development studies.

### **1.3.6 Flares, Exhausts and Vents**

#### **Flares**

The position of the flare structure will be determined largely by the position of the living quarters. A bow-mounted living quarters will give rise to a stern mounted flare and vice versa. Once a location has been selected, account will have to be taken of the flare stack in relation to the main flare headers and knockout drums to achieve satisfactory pressure drops in the flare system.

The height of the stack will be chosen after careful consideration of flare radiation levels and the recommended human exposure guidelines. Those given in Section 44.6 (Thermal Radiation) of the now defunct Department of Energy's Offshore Installations: Guidance on Design, Construction and Certification Fourth Edition-1990 (ref 4) are still valid. The radiation levels on adjacent structures and equipment will also have to be taken into

account. The potential for liquid carry over and ignited droplets should also be considered to avoid the occurrence of “flaming rain” and its fall out on production areas.

The flare structure will probably also carry a low pressure hydrocarbon atmospheric vent, discharging at an intermediate point up the structure. The interaction of the plume from the vent outlet with surrounding structures and work places has to be considered in any layout assessment. The risk of ignition of the plume by the flare in still air conditions has also to be checked. The outputs from wind tunnel test should be used.

## **Exhausts**

The exhausts which dominate the main deck skyline are those from the main turbo-generators and from any gas turbine drivers used on compressor trains. Although fixing the location of the turbines themselves may be straightforward, the routing of ducting and selection of the final discharge location may not be as simple. Turbines providing main electrical power will be located in the least hazardous area of the main deck. Where the living quarters are aft, the generators will be relatively near and so the hot exhausts could have an adverse interaction with the helideck. Wind tunnel tests will assist in the selection of the optimal location of the exhaust outlet.

In the case of a vessel conversion, the existing in-deck generators may be retained to provide main power. Again the routing and the discharge points of these exhausts have to be carefully considered to avoid interactions with adjacent structures and work areas.

## **Vents**

In addition to the atmospheric vent discussed above, the other large vent discharge point to be considered is that of the cargo tank venting system. This can be incorporated into the main flare structure but may discharge at some intermediate elevated location along the main deck. The wind tunnel test programme should include a check on the main tanks’ vent outlet. Still air conditions should also be taken into account.

### **1.3.7 Wind Tunnel Testing**

Wind tunnel testing of a scale model of the FPSO will allow the designer to visualise the flow patterns of air, smoke, gas, hot and cold flare plumes, turbine exhausts and cold vents over and around the principal structures on the main deck. A comprehensive programme of tests covering a wide range of wind speeds and direction will usually address:

- air flows around the helideck to establish safe limits of operation
- air flows around the flare structure, turret and turbine inlet and exhaust support structures to detect possible vortex shedding

- smoke and gas dispersion within and around deck modules, around escape routes, lifeboat and life raft embarkation stations, air inlets of turbines and HVAC units
- areas of low air circulation within modules for possible build up of gas and other fumes
- hot plume flows from flares and turbine and other engine exhausts and their effect on the helideck, other elevated work areas e.g. turret/swivel and adjacent equipment
- dispersion of discharges from cold vents or the flare following a flame-out

Wind tunnel tests may be used in conjunction with appropriate computational fluid dynamics programmes to complement the outputs of such programmes. Still air conditions should also be examined to assess the dispersion of “lazy” plumes.

There are several establishments in the UK and in Europe which can undertake testing and their past experience in testing both fixed and floating offshore structures will provide a guide to the best scale of model to be used and the wind tunnel with the most appropriate characteristics. Further guidance can be found in section 6 of HSE report OTO 00:123, Review of Model Testing Requirements for FPSOs (ref 50).

## **1.4 WEIGHT AND SPACE**

### **1.4.1 Weight control**

FPSO weight is dominated by the weight of the crude storage and hull steel weight. Production equipment represents only a small proportion, typically 5-7% of total displacement, and therefore, in contrast to other types of floating structure, weight of production equipment is usually not a critical feature of FPSO design from an overall ship stability viewpoint. Stability constraints on FPSO operation have only occurred on two UKCS FPSOs.

Production equipment weight control is however important in design of the PAU structure and deck reinforcement and from a lifting viewpoint during fabrication.

The weight monitoring system should allow for tracking during design and fabrication of weight and vertical, horizontal and longitudinal centres of gravity of all items on-board. It is useful to group items by system and/or by PAU, and within each system by equipment and bulk materials. The monitoring system should record the margins set on each item and track how these margins are used up during the project. Visibility is also required on the status of each item's weight information i.e. AFC, vendor data, results of weighing or plate gauging.

The first objective is to arrive at the “lightship” weight and centres of gravity i.e. vessel with empty tanks and production equipment on board but no fluids in production/utility systems. The accuracy of this lightship weight/c of g estimate can be checked once the FPSO is reasonably complete and afloat by the “inclining experiment” which uses draft measurements and stability checks to produce FPSO as-built weight/c of g.

The “lightship” data is used as the basis for producing the various “ship conditions” with different tank contents and fluids in production equipment, mooring loads, etc. which check draft and stability information against design and regulatory constraints.

It is important to set up the weight monitoring program and weight budget at an early stage in the project since this information feeds into vessel, structural and lifting design.

### **1.4.2 Space control**

The large deck area on FPSOs has facilitated the use of single-level PAUs from cost and safety points of view, and has led to the view that FPSOs are not space-limited. This is generally the case on simple, lower throughput topsides but space control has become a problem on complex, high capacity topsides. This is manifested in poor lay-down areas and access for maintenance. Utility equipment e.g. switchgear, may be relegated to within the hull and this can cause problems during construction and hook-up. Alternative locations e.g. within the forecandle space, may put critical equipment in a location which may be more vulnerable to wave damage.

Deck space may be increased on custom-designed vessels by an increase in hull length and /or breadth or by 'double-decking' some of the facilities, depending on which is the most cost-effective option, and on whether vessel dimensions have been 'frozen'.

Space control should include early review of draft topside layouts by safety and operations before hull sizing and topside structural strategy is finalised. Design should designate free space to allow for future de-bottlenecking or tie-in with minimum additional piping runs or interruption to existing production.

Global layout and local layout are discussed in more detail in sections 3.5 and 3.6.

## **1.5 VESSEL SELECTION**

### **1.5.1 Selection factors**

Vessel type selection is field-specific and also depends on future use potential. The choice is driven by:

- Technical factors (size of facilities, environmental loads)
- Commercial considerations
- Field Life
- In-situ inspection, maintenance and repair issues (especially for long field life vessels)
- Availability of suitable vessels for conversion

Vessels can be selected from the following three categories:

#### **a) New-build vessels**

New-build vessels offer the opportunity to custom-design the vessel for the particular field application. This offers the following advantages:

- Optimised hull size with savings on hull/mooring cost
- Optimised hydrodynamic performance (motions, green water, bow wave slam)
- Structure/ systems designed for long-term FPSO duty
- New structure/ systems - minimum operating costs
- Optimised for life cycle benefits

New-build custom-designed vessels may be required where conversions are unsuitable e.g. insufficient capacity/ space for large throughput production facilities, or where the amount of upgrading for long field life and severe environment is found to be uneconomic.

#### **b) Converted trading tanker**

Converted trading tankers offer a minimum capex and project schedule solution which may be most appropriate for small/medium size fields where the field life is short/medium term. This does not exclude converted tankers from longer field life and severe environment applications, provided suitable durability upgrades are carried out.

The primary selection criteria for suitable vessels are:

- Structure and systems to achieve the necessary durability and field life.
- Feasibility of executing a life extension program.
- Reasonable size to minimise cost of mooring system in harsh environment UKCS.
- Adequate crude storage and ballast capacity and suitable tank layout to minimise sloshing.

- Adequate deck space.

Issues arising from tanker conversion to FPSO and technical guidance on these are covered in DNV Conversion of Tankers to Oil Production and/or Storage Vessels (ref.5).

### **c) Converted intercept tanker**

Converted intercept tankers minimise project schedule by procuring a tanker hull part way through the design and construction process. The other benefit is a new vessel and, depending on the design and fabrication status, the opportunity to upgrade the structure and systems for FPSO duty.

The selection criteria for intercept designs are similar to converted trading tankers. Since they are new vessels, intercept tankers have the advantage of not having already utilised part of the structural fatigue life.

## **1.6 VESSEL MOTIONS**

### **1.6.1 Human Response**

The FPSO is constantly in motion, even in the most benign weather conditions. It is therefore important that crew selection should take account of the susceptibility of personnel to motion sickness, not just in moderate to severe sea states but also in calmer conditions.

A crewmember arriving on the FPSO from the helicopter has no time to acclimatise to the moving environment and so the individual is expected to function as near normally as possible in terms of decision making and performing routine tasks. Even though an individual may not be susceptible to motion sickness, he or she still has to maintain balance while moving around to avoid bumping in to equipment and fittings. As FPSO motions become more pronounced the need to preserve balance becomes greater and so the individual's attention becomes more focussed on self-protection and injury avoidance.

Motion sickness may range from mild nausea to severe nausea and emesis, where the individual will probably be confined to bed. In the case of mild nausea, a crew member may be able to continue to work "normally" with or without appropriate medication, but in these circumstances, it has to be recognised that decision making may be impaired.

Studies have been carried out by the HSE in conjunction with a number of medical research bodies in to the physical and psychological effects of motion sickness. HSE reports OTO 99: 036 Human Factors Review of Vessel Motion Standards (ref.6) and OTO 99: 066 Effects of Motion on Cognitive Performance (ref.7) address this. Section 3 (Standards) of OTO 99:036 discusses a range of vessel motion frequencies which can influence human performance. It is important that FPSO owners and operators take account of the key findings and recommendations of such studies in considering the welfare and capabilities of the on-board work force during the complete range of sea states likely to be encountered on station.

It is recommended that a Human Response Analysis is performed which takes account of the motion characteristics of the particular FPSO, the effect on individuals and the subsequent effects on the safe operation of the installation. Particular attention should be paid to any novel hull shapes where the possibility of more extreme vessel motions may be greater than in the case of larger, more conventional ship shaped FPSOs which are considered to be more stable.

The Human Response Analysis should be carried out at an early stage in the project to avoid surprises later. The analysis should be refined and updated as the project proceeds and in conjunction with the development of the Operations Safety Case to ensure that the risks arising out of motion sickness are clearly identified and the effects managed.



While there is no acclimatisation period for those arriving on the FPSO, there is also no acclimatisation period for those returning onshore after a spell of duty. Appropriate advice should be given to help individuals to readjust in performing “routine” land based tasks such as driving motor vehicles or cycles.

### **1.6.2 Effect on Equipment**

On a fixed offshore platform, the production and utilities equipment is effectively static in terms of the motions which it might experience from, say, wave slam on the jacket structure. On an FPSO, the equipment is moving all the time, following the roll, pitch, yaw, heave, surge and sway of the hull.

It is therefore essential that before the specifications are drawn up for each item of equipment, the specifying engineer has a comprehensive understanding of the subtleties of these motions and their implications. The specifications should then fully identify the motions and the accelerations which the equipment can be subjected to. If possible, specific local conditions should be taken into account. All sea states which the FPSO can experience must be addressed, and while in severe weather conditions equipment may be shut down, some items such as pressure vessels, tanks and towers may still contain liquid inventory.

All rotating equipment, (centrifugal and reciprocating pumps and compressors along with their drivers, turbines, diesel engines and cranes) should be considered. Reservoirs for lube oil, seal oil and hydraulic oil should be checked to ensure that excessive sloshing of liquids, which might lead to damage to internal baffles or loss of pump suction, does not take place. Bedplates and holding down bolts should be designed accordingly.

In the case of pressurised equipment, such as separator vessels and coalescers, sloshing of liquid inventory has to be taken into account to ensure that internals are robust enough to withstand the liquid loads likely to be experienced. (A number of research institutions have scale models and simulator facilities to test different internals configurations).

Level control systems, especially on long horizontal vessels, have to take account of liquid levels not being the same at opposite ends of the vessel. Set points of process alarms need to be considered to avoid nuisance and override action. Instrument and electrical control panels and cubicles should be of robust construction and adequately supported to withstand motion forces and any associated vibrations.

Packed columns and stripper towers should also be checked for movement of packing, trays and demisters and potential loss or degradation of function. Support rings, foundations and holding down bolting should be designed accordingly. In the case of towers and columns, the higher over turning moments have to be taken into account. The motion effects on the flare tower structure should also be considered.

Forces on pipe-work, especially larger bore, liquid lines at higher elevations above main deck, should be examined. The location of large valves in vertical piping loops should also be checked and loads calculated.

On fixed platforms, flare headers can be run sloping towards the flare knock out drums, the falls permitting free draining of any liquids in the headers. On FPSOs, while the design can call for a fall towards the flare drum, the hull pitch and roll motions and vessel trim (especially if trimmed by the stern) may affect the drainage of any liquids. The process engineer has to consider the implications of any liquid hold up on header blow down capacity and any back pressure effect on the discharge capacity of relieving devices.

Trim and heel of the vessel can also affect the drainage of liquids in the various liquid drains systems and may also create unacceptable accumulations of water on decks and walkways unless these effects are addressed at an early stage in the design.

The design of pedestal cranes must recognise that the cranes will be subject to hull motions while operating and allowances have to be made for the effects of these movements on the hook load.

### **1.6.3 Helicopter operations**

Helicopter operations may be affected by vessel motion, especially those at wave frequency. The limiting factors for a Puma/Tiger are:

Roll	Max 3 degrees (half amplitude)
Pitch	Max 3 degrees (half amplitude)
Vertical motion	Max 5 metres (combined heave and pitch)
Wind speed	Max 35 knots cross wind

### **1.6.4 Model tank testing**

Model tank testing should be performed for all developments to confirm loads and motion behaviour predicted by analytical modelling. This is especially important for vessels with small or unusual hull forms, where there is a shortage of service experience and where analytical models lack calibration with model tank test results.

Ideally, model tank tests should be timed as soon as possible after conceptual design of the vessel and topsides is defined and mass properties and layout are available. This enables the tank test results to be incorporated in the detailed design of the vessel, topsides, turret, mooring and risers.

In addition, for small or novel hull forms, preliminary model tests are recommended early in concept design to identify any unacceptable motion behaviour and possible remedial measures.

Technical requirements for models and tank test facilities are covered in section 2.12.

## **1.7 CREW SIZE AND ACCOMMODATION**

### **1.7.1 Basis for Crew Sizing**

It is the general objective of FPSO owners and operators to have a minimum crew size that is consistent with maintaining the highest standards of safety, environmental performance, field uptime and the preservation of asset integrity.

Crew size will be driven by several factors, not the least of which are the size and complexity of the production facilities. The maintenance strategy, e.g. batch maintenance, will also influence crew numbers.

#### **Operations input to Engineering**

Planning for the production phase should start at the same time as preliminary engineering studies. In this way, operations representatives can provide input to matters of layout, process engineering and choice of equipment, for example. In addition the operations and maintenance strategies can be developed at the same time as the engineering so that whole life issues can be identified, agreed and addressed in design and manning levels can be firmed up.

#### **Steady State and non-Steady State Operations**

As well as planning for day-to-day operations and maintenance activities, the operations representatives have to consider, among other things:

- short and long term maintenance
- integrity inspection programmes
- duration and frequency of planned shutdowns
- extent of ongoing support from specialist technicians and engineers
- need for ongoing support for subsea operations
- reservoir engineering support
- possibility of unplanned shutdowns and resources to deal with them

All of these and other factors will influence crew size, which must obviously include all the marine activities associated with an FPSO and attendant shuttle tanker operations.

#### **Provision for FPSO installation, commissioning, major repairs**

There has been a tendency to design accommodation for steady state operations in the belief that keeping the size of the living quarters to a minimum will result in cost savings to the project. Such an approach may not prove to be cost effective in the long run as there are, in addition to the items above, other factors such as installation and commissioning of the FPSO to be considered as well as the possibility of future major repairs, upratings and modifications.

While many FPSO's can achieve fully or near fully commissioned status prior to sail away from the outfitting yard or prior to installation in the field, it has to be remembered that the hydrocarbon processing systems for gas, oil and produced water cannot be said to be fully commissioned until the subsea facilities have been operated and well fluids have been introduced on to the FPSO.

Should major problems arise in this phase of start-up which require additional manpower resources, it may not be possible to introduce temporary accommodation in the short term. It is not possible to bring flotel facilities alongside the FPSO as with a fixed platform and so personnel may have to be shuttled in, either from shore or from a nearby support facility. The costs of shuttling may exceed the initial capital cost of adding more accommodation over and above the levels considered appropriate for steady state operations.

### **1.7.2 Accommodation Facilities**

Once manning levels have been established along with provision for the contingencies outlined above, consideration is given to the facilities within the living quarters. The living quarters will very likely contain

- the temporary refuge along with fire fighting equipment provisions
- emergency control and response room(s)
- control rooms, radio room, offices and meeting rooms
- dining, recreation and leisure facilities and locker rooms
- galley, laundry facilities and stores
- HVAC plant rooms and battery rooms
- sick bay and medical rooms
- helicopter reception facilities

The owner will have to decide on whether to provide single or two person cabins and the possible temporary conversion of two person cabins into three person cabins for short, clearly defined periods such as a planned shutdown. Before any decision on temporary upmanning provision is taken, reference should be made to the HSE's A Guide to the Integrity, Workplace Environment and miscellaneous aspects of the Offshore Installations and Wells (Design and Construction, etc) Regulations 1996, notes 114 to 120 (ref.8). Consultation with the HSE may also be advisable. Provision has also to be made for male and female crew members.

Normally moveable fittings such as tables and chairs may have to be secured in position because of the movement of the FPSO in heavy weather.

## **1.8 REGULATORY FRAMEWORK**

There are numerous Acts of Parliament and Statutory Instruments which apply to FPSO developments in the UKCS, covering a wide range of issues including health, technical safety, work place safety, lifting operations, environmental protection and pollution prevention and control.

The main item of legislation is The Offshore Installations (Safety Case) Regulations, SI 1992/2885 (ref.9). The Safety Case Regulations are 'goal-setting' regulations made under The Health and Safety at Work Act, 1974 (ref.10). The key requirement of the Safety Case Regulations governing design is that all hazards with the potential to cause major accidents are identified, their risks evaluated, and measures taken to reduce risks to persons to as low as reasonably practicable (ALARP).

The Safety Case Regulations are backed up by The Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations, PFEER, 1995 (SI1995/ 743) (ref.11), the Management of Health and Safety at Work Regulations (SI1999/3242) (ref.12) and by The Offshore Installations and Wells (Design and Construction) Regulations, DCR, 1996 (SI1996/ 913) (ref.13).

The main item of legislation dealing with environmental issues is the Offshore Petroleum Production and Pipelines Act (Assessment of Environmental Effects) Regulations 1999 (SI1999/360) (ref.14). The Merchant Shipping Act 1979 (ref.15) and the Merchant Shipping (Prevention of Oil Pollution) Regulations 1996 (SI 1996/2154) (ref.16) apply the requirements of MARPOL 73/78 (ref.17) on matters of marine pollution with additional UKCS-specific instructions.

General health, safety and environmental requirements are discussed in section 1.10 of these Guidance Notes.

It is important to note here that the Design and Construction Regulations require design to be based on current good engineering practice, which is appropriately risk-based. Compliance with existing codes, standards and guidance may not be sufficient to meet the regulatory requirements.

## **1.9 CODES AND STANDARDS**

### **1.9.1 International codes and standards**

Several international design codes for floating production systems are undergoing final review or have recently been released:

The API Recommended Practice for Planning, Designing and Constructing Floating Production Systems RP 2FPS (ref.18) has the widest scope, covering ship-shaped, column stabilised and spar unit design. It also covers the complete floating production system including production facilities, risers and subsea, and export system design. The code is a high-level document and relies heavily on reference to appropriate sections of existing API codes, classification society rules and United States Coast Guard/ Mines & Minerals Service documents to provide the detailed design guidance. Use of the API document for UKCS guidance would need to recognise the special requirements of (a) the UKCS harsh environment and (b) the UKCS legislative framework.

ISO/WD 19904 Offshore Structures - Floating Systems (ref.19) and NORSOK Standard N-004 Design of Steel Structures (ref.20) both focus on structural and marine design aspects. A review and comparison of API and these design codes has been carried out by the HSE under Review of API RP 2FPS, OTO 2001-006 (ref.21).

Other codes for specific areas of design are covered in the relevant sections of this document.

### **1.9.2 Use of Classification Societies' Rules**

Classification is not mandatory for an FPSO in the UKCS since design is governed by the Safety Case, PFEER regulations and DCR Guidance. However most FPSO owners choose to build their vessel to classification society (CS) standards and some also choose to maintain class in service for insurance, mortgage and marketing purposes.

The following classification societies have recently issued new rules for the classification of floating production units:

Lloyds Register of Shipping (LR): Rules and Regulations for the Classification of a Floating Installation at a Fixed Location, July 1999 (ref.22).

American Bureau of Shipping: (ABS) Building and Classing Floating Production Installations, June 2000 (ref.23) and Guide for Building and Classing Facilities on Offshore Installations, June 2000 (ref.24).

Det Norske Veritas (DNV) Offshore 2000 Rules for Classification of Floating Production and Storage Units, OSS -102, January 2001 (ref.25).

Classification can use either:

- a) Prescriptive approach, where the class rules are based on the results of many years operating experience. These rules are useful in providing a framework for rapidly generating an initial design and have the additional advantage of being familiar to shipyards. This design can then be subject to more rigorous analyses and risk assessments.
- b) Risk-based approach, which can be based on the Safety Case information. All three societies LR, ABS and DNV are prepared to provide risk-based classification and have recently issued guidelines on this viz.
  - LR: Part 1A of the above Rules
  - ABS: Guidance Notes on Risk Assessment Application for the Marine and Offshore Oil and Gas Industries, June 2000 (ref.26).
  - DNV: Classification using Performance Criteria determined by Risk Assessment Methodology, OSS-121, January 2001 (ref.27).

It is important for the owner/duty holder to advise the classification society at the outset which of the above approaches is being used and agree the way in which the risk based assessment will be conducted and the results applied to the design of the FPSO.

Class can be applied to the complete floating production system or just to the hull and critical marine systems. In the latter case, the production systems can be designed to internationally recognised codes. The classification societies' rules address marine and structural areas in better detail than production/utilities system areas. This is to be expected because of the societies' background in ship classification.

A review of classification society rules was carried out in UKOOA Study No. FPSO.JIP.00/01, November 2000 (ref.1).

LR and DNV also provide guidance notes e.g.

LR: Ship-Type FPSO Hull Structural Appraisal, OS/GN/99002, June 1999 (ref.28).

DNV: Guidance and Classification Notes, July 1999 (ref.29).

### **1.9.3 Client and Classification Society Roles**

The role of the classification society needs to be clearly defined at project commencement viz. advisory only, full or part classification, whether classification is during construction only or also in service, and whether the CS is to assist in preparing the safety case. This decision will depend on the expected benefits from the classification society and the following factors:



- Advantages of a classed vessel viz. obtaining a marine mortgage, for insurance purposes, marketing the vessel for subsequent use outside the UKCS or for general comfort factor.
- Owner's hands-on/hands-off approach to project management.
- Strength of the owner's technical design and construction supervision staff.
- Contracting strategy and its impact on need for supervision.
- Experience base and capabilities of classification society.

It should be noted that using classification society rules does not absolve the owner from preparing clear design philosophies, basis of design and functional specifications. Classification society rules and guidance are useful in providing a good starting point which is familiar to designers and shipyards, and which reinforces owners' functional specifications. This is especially important in dealing with shipyards where functional specifications and performance standards are not widely understood.

Potential difficulties in using CS rules are that they concentrate on what is safety-critical but not what is production-critical and they do not encourage designers to think about long-term life-cycle issues which are especially important in harsh environment UKCS. Some difficulty may also arise over conflicts between prescriptive CS rules and the outcome of safety cases. The resolution of these may be difficult if the vessel is to be classed.

## **1.10 HEALTH SAFETY AND THE ENVIRONMENT**

### **1.10.1 Introduction**

The prime considerations in the design of any project, large or small, short term or long term, are:

- the safety and welfare of all those involved in the construction, installation, commissioning and operation of the facility.
- minimum impact on the natural environment around the facility during its life and following its decommissioning and removal.

The legislation applicable to offshore installations is extensive and it is the responsibility of the owner, through the project management team and compliance specialists, to ensure that the legislation is adhered to at a high level. Within the legal framework, through the application of best engineering, construction and operating practices, based on recognised codes and standards, the integrity of the facility and care of the environment is the responsibility of those designing, building and operating it.

The notes which follow, however, are directed at design activities only.

### **1.10.2 Design for Safety**

#### **Familiarity with key legislation**

It is recommended that at the earliest opportunity key members of the project management and engineering teams on an FPSO project familiarise themselves with the Introduction sections of the Safety Case Regulations (SCR), the Design and Constructions Regulations (DCR) and the PFEER Regulations, as a minimum (see section 1.8). In this way, they will gain a better understanding of the principal requirements of each set of regulations and how these three pieces of legislation relate to one another.

While the SCR and the PFEER regulations may be considered by some to be in the province of safety and loss control engineers, sections of them are relevant to the activities and responsibilities of all the design disciplines to a greater or lesser extent. All disciplines have a responsibility for integrity of the design and so they should review Regulation 4 (General Duty) and Regulation 5 (Design of an Installation) of the DCR to consolidate their understanding of their responsibilities.

A principal feature of DCR is the identification of Safety Critical Items, whose design and performance are essential to the overall safety of the installation. The identification activity and the development of associated performance standards are very much part of the design phase. UKOOA have issued a joint industry guide in the form of Guidelines for the Management of Safety Critical Elements (ref.30).

## **Concept Safety Evaluation and Preliminary Risk Assessment**

Once an FPSO has been selected as the preferred field development option, a concept safety evaluation should be performed along with a preliminary risk assessment.

At this stage it is likely that a Statement of Requirements will exist, based on preliminary engineering study work leading up to concept selection. The overall size of the production facilities will be known and a vessel size and type will have been determined. Indeed, a particular vessel may have already been chosen. Layout studies will have indicated the number, size and position of on deck modules and/or skids and the location options for the turret, living quarters and flare will have probably been reviewed.

The high-level safety evaluation should be carried out to identify the significant hazards and potential major accident scenarios which could have an effect on the integrity of the FPSO and the safety of the crew. By performing the evaluation and risk assessment at this early stage, it will be possible for the design team to identify any fundamental deficiencies in the outline design of the selected concept. It will also be possible to identify particular areas which have to be targeted during the various phases of design to prevent the occurrence of hazardous events or, if prevention is not possible, to detect events, and control and mitigate their effects. Changes can be more easily implemented before detailed design gets underway. The evaluation and assessment process can be repeated to test the effectiveness of any safety improvements which might be made subsequently.

Providing the evaluation has been comprehensive, the Basis of Design will reflect more accurately the requirements and aims of the overall design. Furthermore, a good foundation will have been laid for the preparation of the Design Safety Case.

## **Risk Based Assessments and Classification**

In the UKCS, the Safety Case Regulations require the duty holder to demonstrate that “major accident hazards have been identified, their risks evaluated, and action taken to reduce the risks to as low as reasonably practicable (ALARP)”. While “it is expected that the design of an installation will be based on current good engineering practice ..... compliance solely with existing codes, standards and guidance may not be sufficient to meet the regulatory requirements”, (HSE Guidance on DCR Regulations, regulation 5). Demonstration that risks have been reduced to ALARP will therefore require a risk assessment.

Outside the UKCS, the legislation of other countries may not require an FPSO installation to undergo such an assessment and it may be quite in order for an owner/operator only to provide a demonstration of compliance with the Classification Rules of a recognised Classification Society. Classification Societies do recognise that Risk Based Assessment and demonstration of ALARP is an acceptable alternative to compliance with the requirements of a particular Class notation.

As it is internationally recognised that Classification Societies Rules are based on sound engineering practice, it is accepted that designers will frequently refer to the Rules and will apply relevant sections regardless of whether the FPSO is to be classed in accordance with Rules alone or classed on a Risk Based Assessment. In the UKCS, it is likely that a rigorous Risk Based approach and demonstration of ALARP will not only secure HSE acceptance of a Safety Case but will also secure Classification Society approval of the design. However, as stated above, it should not be assumed that full compliance with Classification Society Rules will secure Safety Case acceptance.

### **1.10.3 Design for Health**

The well being of the offshore workforce is not just the responsibility of Operations management. Decisions made in the course of the design can and do affect the workforce's health.

The attention of designers should be drawn, for example, to many of the provisions of Schedule 1 for Regulation 12 of the DCR, which not only cover matters of safety but also matters which can have an influence on the working environment and hence on the health and welfare of crew members.

Awareness of the principal provisions of the Control of Substances Hazardous to Health Regulations COSHH 1994 (SI1994/3246) (ref.31) and associated approved codes of practice and guidance will assist designers in the correct selection and specification of materials to ensure that the health of those coming into contact with these materials in the course of their everyday tasks is not affected

### **1.10.4 Design for the Environment**

It is no longer acceptable to regard the seas, the oceans and the atmosphere as convenient dumping grounds for waste products from industrial activities. The increasing awareness of the environmental impact of offshore developments and the introduction of legislation in the form of the Offshore Petroleum Production and Pipelines Act (Assessment of Environmental Effects) Regulations 1999 (SI1999/360) (ref.14) now requires operators to demonstrate to the UK Government, stakeholders and the public in general that their current and future activities will have neither short term nor long term effects.

For a new FPSO installation, the development of an Environmental Strategy for the FPSO will help to provide a clear direction to the designers of the targets and hence measures to be taken to minimize environmental impact. The strategy will also form the basis of the Environmental Management System to control, monitor and report on environmental performance once in operation.

The emissions and discharges from offshore installations include products of flaring, exhaust gases from prime movers, oily water discharges from slop tanks or produced water which cannot be reinjected, sewage etc. Routine flaring is no longer considered to be environmentally acceptable and wherever possible only emergency flaring should be carried out.

The environmental threats are compounded by the risk of loss of containment of crude oil and gas leading to a major spillage. In the case of an FPSO, with its large volume of stored crude oil product and the attendant shuttle tanker operations, the risk of leaks and spills are perceived to be greater than on a fixed platform.

The integrity of the FPSO hull over the entire field life along with its cargo handling, product transfer and production systems are dependent on sound design and sound operating practices and procedures. The storage volume of the hull is significantly greater than the inventories of the oil and gas processing facilities. Consequently, hull fatigue life and its ability to survive credible collisions, impacts, explosions and fires are of prime importance in the prevention of pollution.

National legislation together with international protocols such as MARPOL 73/78 (ref.17) dictates the levels of pollutants which can be continuously discharged from an FPSO. Operating companies each have their own corporate environmental policies to limit or eliminate pollution. The design of the FPSO must therefore satisfy both the statutory and corporate requirements as a minimum or whichever is the more stringent. It is expected that the best available technologies will be used to limit or prevent pollution and that over the life of the field, steady year on year improvement in environmental performance can be demonstrated.

# **UKOOA FPSO DESIGN GUIDANCE NOTES FOR UKCS SERVICE**

## **PART 2**

### **MARINE & STRUCTURAL**

#### **CONTENTS LIST**

##### **2.1 INTRODUCTION**

- 2.1.1 Design objectives
- 2.1.2 Hull design process

##### **2.2 HULL CONFIGURATION**

- 2.2.1 Hull size and form
- 2.2.2 Stability requirements
- 2.2.3 Structural configuration

##### **2.3 LOADS**

- 2.3.1 Environmental data
- 2.3.2 Wind
- 2.3.3 Waves
- 2.3.4 Currents
- 2.3.5 Temperature
- 2.3.6 Snow & ice
- 2.3.7 Marine growth
- 2.3.8 Design environmental conditions
- 2.3.9 Operational wind and wave data

##### **2.4 PRIMARY HULL STRUCTURE**

- 2.4.1 Design methods
- 2.4.2 Finite element analysis
- 2.4.3 Fatigue Design
- 2.4.4 Local strength
- 2.4.5 Reliability based design
- 2.4.6 Material Selection
- 2.4.7 Welding and structural detailing

## **2.5 GREEN WATER**

- 2.5.1 Introduction
- 2.5.2 Current prediction methods
- 2.5.3 Avoidance measures

## **2.6 BOW WAVE IMPACT**

- 2.6.1 Introduction
- 2.6.2 Calculation of bow wave impact pressure
- 2.6.3 Measures to minimise bow wave impact
- 2.6.4 Full rounded v sharp bow

## **2.7 SLOSHING IN CARGO TANKS**

- 2.7.1 Introduction
- 2.7.2 Pressure prediction
- 2.7.3 Avoidance measures

## **2.8 COLLISION DAMAGE**

- 2.8.1 Introduction
- 2.8.2 Supply boat operation
- 2.8.3 Shuttle tankers
- 2.8.4 Passing traffic collision

## **2.9 STRUCTURAL / PRODUCTION FACILITIES INTERFACE**

- 2.9.1 Packaging of production facilities
- 2.9.2 Structural support of facilities
- 2.9.3 Design loads

## **2.10 HULL DEFLECTION PATTERNS**

- 2.10.1 Introduction
- 2.10.2 Calculation of hull deformation
- 2.10.3 Static v dynamic deformations

## **2.11 MOTION BEHAVIOUR**

- 2.11.1 Introduction
- 2.11.2 Design values

## **2.12 MODEL TANK TESTING**

## **2.13 TURRET INTERFACES**

- 2.13.1 Introduction
- 2.13.2 Structural/bearing interface
- 2.13.3 Mooring interface
- 2.13.4 Riser interface
- 2.13.5 Interface with production equipment

## **2.14 MOORINGS**

- 2.14.1 Design considerations for FPSOs
- 2.14.2 Mooring analysis
- 2.14.3 Anchor design

## **2.15 CRUDE OIL EXPORT**

- 2.15.1 Introduction
- 2.15.2 Export by shuttle tanker
- 2.15.3 Crude oil pumping and transfer hoses
- 2.15.4 Shuttle tanker operations

## **2.16 BALLAST SYSTEMS**

## **2.17 THRUSTERS**

- 2.17.1 Applications
- 2.17.2 Design considerations

## **2.18 OPERATIONAL CONSIDERATIONS**



# UKOOA FPSO DESIGN GUIDANCE NOTES FOR UKCS SERVICE

## PART 2

### MARINE & STRUCTURAL

#### 2.1 INTRODUCTION

##### 2.1.1 Design objectives

The key objectives of hull design are:

##### a) Reliability

FPSO hull design has to take account of the more onerous FPSO duty compared to a trading tanker:

- Increased hull loading resulting from weathervaning in harsh environment with no weather avoidance possible and the effects of non-collinear environment.
- Economic requirement to stay on station for the field life, in some cases 20-25 years, and the problems of performing hull maintenance and repair in-situ.
- High economic penalty of lost/deferred production during shutdown.
- Environmental consequences of a major hull structure failure.
- Variable cargo and draft level.

There is therefore a strong case on safety, environmental and economic grounds for robust and reliable hull design. The FPSO should be treated as an 'Offshore Installation' rather than as a trading tanker in terms of design for reliability.

The UKOOA study (ref.1) investigated where problems have been experienced in UKCS FPSOs. The results showed reliability has generally been good but some problems have occurred mainly with green water on deck, bow wave impact and shuttle tanker offloading incidents.

This finding has been confirmed by an HSE study to investigate reliability levels for different hull/turret/swivel limit states, entitled OTO 00:097 Rationalisation of FPSO Design Issues (ref.32). The conclusion was that FPSO reliability was generally satisfactory compared with norms for large projects but reliability for the three areas - green water, bow impact and collision - needed improvement. These areas are the subjects of on-going studies to improve knowledge and guidance.

### **b) Performance**

Performance is measured in terms of overall FPSO uptime, comprising production facility uptime and export system uptime. The economic penalty of weather downtime is high. Hull design (mainly through hull size) needs to minimise downtime by providing a stable platform for production facilities and sufficient buffer storage to cover probable shuttle tanker disconnected periods.

### **c) Flexibility for expansion**

Hull design should recognise possible future needs to develop satellite fields which will require additional riser slots and possibly extra modules. Additional payload, space, turret and structural supports are cheap to provide at the initial design stage but extremely difficult and expensive to perform later offshore.

### **d) Design for operations**

Hull design should also recognise the special in-situ inspection and maintenance needs of an FPSO on long-term deployment. This topic is discussed in section 2.18.

## **2.1.2 Hull design process**

The FPSO hull design process (for a new build vessel) is shown in greatly simplified form in figure 2.1.1. This is an iterative process where the results of analysis and model test are used to update the basis of design and provide a new starting point for re-analysis. In this respect, FPSOs are less sensitive to weight change than other floating systems and should therefore require few iterations of the design cycle. Key elements in minimising the number of design loops are (a) working from a broadly similar design as a basis (b) avoidance of design changes and (c) timely execution of model tests to feed into design.

A detailed description of analysis methods is given in the textbook *Floating Structures - A Guide for Design and Analysis*, CMPT publication 101-98, OPL (ref.33).

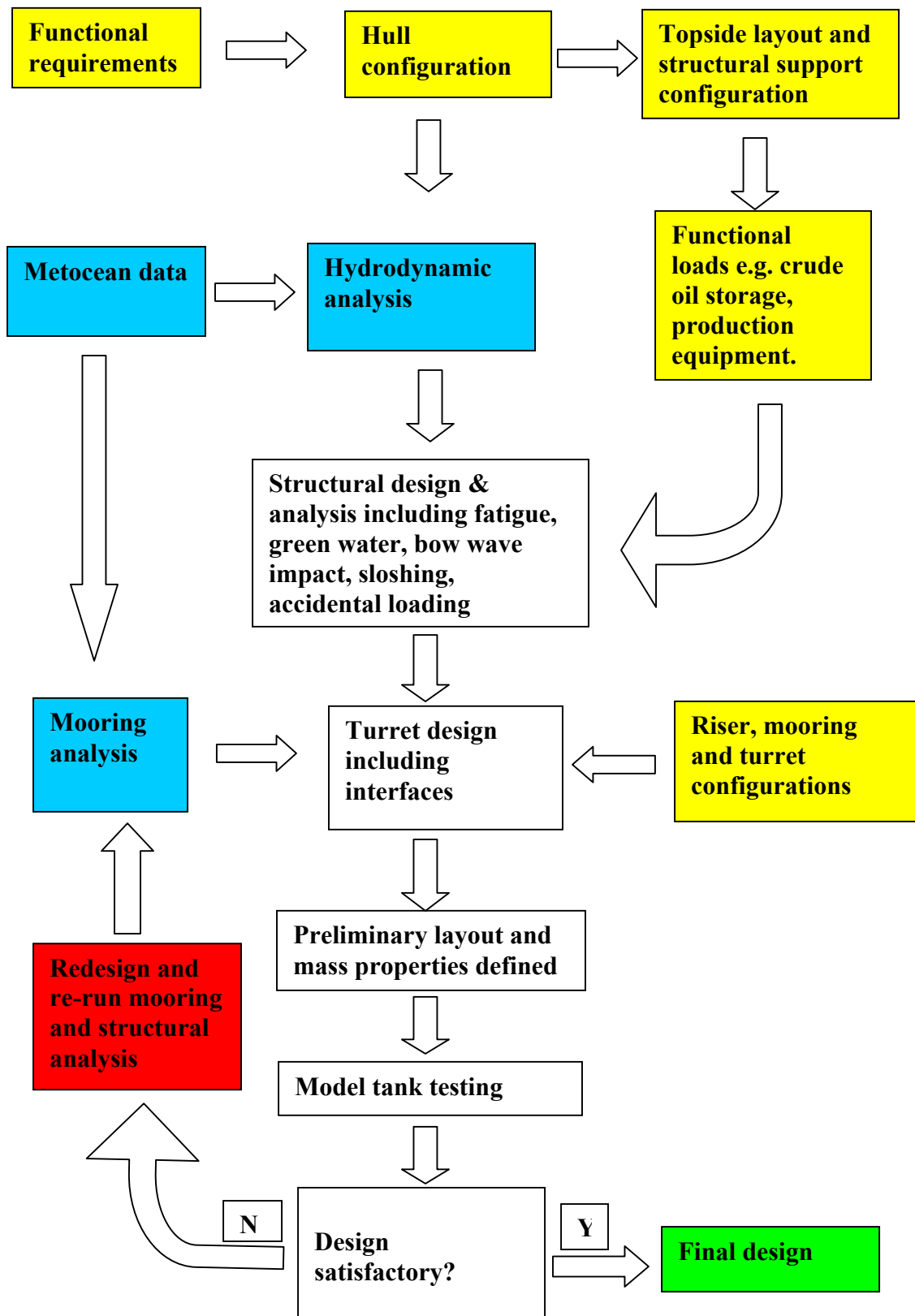


Fig.2.1.1 - Simplified hull design process

## 2.2 HULL CONFIGURATION

### 2.2.1 Hull size and form

The major requirements governing hull size are discussed in section 1.2.2.

- Crude oil storage
- Deck space
- Availability of tanker hulls for conversion
- Sea-keeping performance

The overall weight (displacement) of the FPSO is a function of steel weight, topside weight and crude oil cargo deadweight. Typically hull steel weight (excluding topsides) is 13-16% of displacement and cargo deadweight is approximately 75%. The hull must also have sufficient volume to accommodate crude oil storage and segregated ballast tanks to achieve the required ballast drafts and avoid bottom slamming forward. Typical ballast capacity is 35% of displacement.

The hull form should be optimised to produce the most economic design possible within the design constraints. Major factors are shown below in table 2.2.1.

Parameter	Function of
Hull steel weight	Length/depth ratio of hull & hull size
Deck space	Length x breadth
Mooring loads	Breadth/length
Stability	Breadth/depth
Sea-keeping (primarily pitch)	Length
Green water on deck	Freeboard
Bottom slamming forward	Ballast capacity
Bow wave impact	Bow fineness

Table 2.2.1 - Main hull design parameters and their dependencies

In general, length is the most expensive dimension and should be reduced as much as possible, but consistent with achieving adequate deck space, acceptable sea-keeping and not attracting high mooring loads. Breadth should be reduced to avoid high mooring loads and excessive stability causing high roll accelerations, within the constraints imposed by stability and deck space. Increase in depth has the benefits of increased freeboard against green water and improved hull section modulus for longitudinal strength and fatigue durability. Hull fineness should be a balance between minimising bow wave impact loads and minimising hull steel weight.

For initial design, typical dimensions and ratios for UKCS FPSOs that have performed successfully are given in table 2.2.2.

Parameter	Range from successful UKCS experience
Length	209 - 246 m
Length/breadth	5.0 - 6.5
Breadth/depth	1.6 - 2.0
Draft (max operating)/depth	0.73 - 0.74
Draft (ballast)/depth	0.47

Table 2.2.2 - Typical UKCS FPSO hull parameters

### **2.2.2 Stability requirements**

Hydrostatics and stability are part of the HSE Formal Safety Assessment where it is necessary to prove with a site and operations specific risk assessment that the stability characteristics result in a safe vessel, with low risk to health and safety of those on board. The safety case should cover intact and damaged stability, and also integrity of watertight openings and the possibilities of internal flooding from ballast piping, valves and pumps. The particular hazards from loading and off-loading at sea should be considered.

To assist in demonstrating that the above goal has been achieved, guidelines have been issued by IMO and classification societies. These guidelines differ in requirements and the user is advised to check that the most recent and relevant information is applied. The suitability of the referenced guidance should be considered in the risk assessment. Such guidance was not specifically designed to consider the hazards from tandem off-loading to shuttle tankers.

#### **Intact stability**

Intact stability requirements are governed by IMO recommendations for intact stability and weather criteria referred to in resolution A.749 (ref.17):

- Initial metacentric height (GM)
- Righting lever (GZ)
- Range of stability
- Dynamic stability limits on roll angle and down-flooding (due to wind gust)

Intact stability is also governed by IMO MODU codes which compare wind heeling curves with righting moment curves to ensure a reserve of dynamic stability.

The requirements of operations and crew comfort and safety also need to be taken into account in deciding limits on heel angle and stability.

Free surface effects on FPSOs can be large because of the requirement to have several slack cargo tanks (to minimise hull shear and bending). During offloading operations, the ballast tanks will also have free surfaces and these will be large where double bottom tanks are fitted. This will require close examination of stability during the tank filling and emptying sequences and possible restrictions on the number of slack tanks. It is suggested that stability be investigated at 10% increments in tank filling when verifying that loading conditions comply with stability criteria. Smaller increments should be used where there are sudden changes in free surface width.

### **Damage stability**

Damage stability is governed by MARPOL 73/78 (ref. 17) with additional guidelines from the HSE which require the following damage to be examined:

- a) Peripheral damage of depth 1.5m and minimum 14.5m length extending vertically upwards from the bottom.
- b) Flooding of any one compartment

Following this damage, IMO requires no progressive flooding at the equilibrium position.

### **2.2.3 Structural configuration**

#### **Double sides / bottom**

Double sides are required on UKCS FPSOs to minimise risk of oil spillage due to collision. The spacing from the outer hull should be sufficient to reduce the risk of major oil spillage from foreseeable collisions to an acceptable level. MARPOL (ref.17) requires 2m width of wing tank for trading tankers.

Single bottoms are acceptable in UKCS. However, there are practical and economic arguments for single v double bottoms as listed below. It should be noted that the low risk of grounding for an FPSO removes one of the most powerful arguments in favour of fitting double bottoms on trading tankers.

#### Advantages of double bottoms

- Flush inner bottom for ease of drainage and cleaning
- Ease of inspection of structure from double bottom
- Security against tank leakage

#### Disadvantages of double bottoms

- Higher first cost
- Loss of cargo volume
- Higher centre of gravity of cargo
- Higher pressure head in cargo tanks relative to outside sea with more loss of cargo if cargo tank is breached.

An analysis of the trade-off of operational benefits of double bottom v higher first cost is needed to arrive at the optimum solution for a specific development.

### **Bulkhead spacing**

Bulkhead spacing in cargo tanks is governed by:

- 1) Minimising free surface effects of part-filled tanks.
- 2) Limits on maximum tank size to keep oil spillage below a certain volume in the event of tank rupture.
- 3) Avoiding sloshing during filling and discharge of cargo tanks at sea - see section 2.7 of these Design Guidance Notes.
- 4) Structural support of production/utility system PAUs.
- 5) More tanks to allow safe inspection and maintenance while not interrupting operations.

Typically, the cargo tank region is subdivided by a centre-line bulkhead and four or more transverse bulkheads. Deleting the centre-line bulkhead may cause unacceptable free surface effects and require restrictions on tank filling/emptying sequences to meet stability requirements.

## 2.3 LOADS

### 2.3.1 Environmental data

Environmental loading plays a major part in the design of hull, mooring and risers. The following environmental data should be obtained from recognised sources for design purposes.

- Extreme events for wind speed, significant wave height and current. Directional data and angular separation for extreme wind, wave and current.
- Wave spectral shape
- Current speed and direction variation with depth (tidal and background)
- Wave scatter diagram
- Wind and wave persistence tables
- Water depth and tidal/pressure variations
- Air / sea temperature
- Ice and snow data

A range of wave height and period combinations should be considered to determine the most severe loading case. It is important to recognise that the various maximum responses will occur for differing wave periods.

Prior to site-specific information being generated, the following data may be used:

### 2.3.2 Wind

Wind speed estimates (m/s) are given in table 2.3.1 below:

Wind speed (m/s)	Return period (years)	Central N Sea	Northern N Sea	West of Shetlands
1 hour mean	100	37	38	40
10 min average	100	40	41	43

Table 2.3.1 - Omni-directional design wind speeds

Wind speeds for return period of 10,000years are 16% greater than the corresponding value in table 2.3.1.

The wind speed variation with height above sea level and mean period is covered in NORSOK Standard N-003 Actions and Action Effects, February 1999, section 6.3.2 (ref.34).



The wind force on each part of the FPSO (including suction on back surfaces) is calculated by:

$$F = 0.0625 A V^2 C_s \text{ (kgf)}$$

where A = projected area (m<sup>2</sup>)  
C<sub>s</sub> = shape coefficient

Shape	C <sub>s</sub>
Spherical	0.40
Cylindrical	0.50
Large flat surface (hull, deckhouse, smooth under deck areas)	1.00
Exposed beams or girders under deck	1.30
Isolated shapes (cranes, booms, etc)	1.50
Clustered deck houses	1.10

Table 2.3.2 - Values of shape coefficient

### 2.3.3 Waves

Wave information should cover a range of wave height / period combinations to ensure that maximum responses are obtained and that the most severe loading on the FPSO as a whole and also other limit states is identified. These include bow wave impact in shorter steeper seas. In addition, the distribution of wave encounters for all periods that the FPSO will encounter is required for hull fatigue calculations.

#### Extreme wave height data

Indicative values of significant wave heights are given in table 2.3.3 below:

Location	Central N Sea	Northern N Sea	West of Shetlands
Significant wave height H <sub>s</sub> (m)	14	16	18

Table 2.3.3 - 100 year return significant wave heights

The 10,000year significant wave height is 25% greater than the corresponding 100year value in table 3 above.

The associated mean zero up-crossing period T<sub>z</sub> lies in the range:

$$3.2 (H_s)^{1/2} < T_z < 3.6 (H_s)^{1/2}$$

where  $H_s$  is in m and  $T_z$  is in seconds. In shallower water areas, the wave period is water depth dependent.

The period of the 10,000year wave is 5% greater than the 100year wave period.

The expected (most probable) maximum wave height can be derived from

$$H_{\max} = 1.86 H_s$$

There is a 1% risk that a wave with  $H_{\max} = 2.5 H_s$  will be encountered.

The range of associated wave periods with maximum wave height is:

$$1.05 T_z < T_{\text{ass}} < 1.4 T_z$$

The effect on FPSO structural design should be considered for all values within the range.

Wave induced responses consist of:

1. First order motions at wave frequency (heave, surge, sway, roll, pitch, yaw)
2. Low frequency motions particularly surge and sway near the natural frequency of the vessel and mooring system
3. Steady or mean drift force

The wave-induced responses can be derived from model test results (see section 2.12) or from motion analysis computer programs using diffraction theory or, for initial design, 2D strip theory as an approximation.

### **Bow wave impact data**

In addition, short steep waves need to be considered for bow wave impact (section 2.6) and green water effects (section 2.5). Guidance on the design wave height and period relationship is contained in NORSOK (ref.34).

### **Fatigue data**

Wave data required for fatigue design consists of a cumulative frequency diagram (exceedance diagram) of the heights of all individual zero up-crossing waves likely to be encountered during a year as an omnidirectional data set (for weathervaning FPSOs) together with representative wave periods for each wave height.

This should be derived from a scatter diagram of significant wave height v mean zero up-crossing periods for the specific location.

For initial guidance in the absence of site-specific data, the frequency distribution can be calculated from the following relation from the former Department of Energy 4<sup>th</sup> Edition Guidance Notes (ref.4):

$$h = D(\ln N_y - \ln N_h)$$

where         $h$  = wave height  
                $N_h$  = number of waves exceeding  $h$  in one year  
                $D$  = distribution parameter  
                $N_y$  = total number of waves in one year

Values of  $N_y$  and  $D$  are given in table 2.3.4.

Location	Central N Sea	Northern N Sea	West of Shetlands
$N_y$ (/10 <sup>6</sup> )	5.9	5.6	3.8
$D$	1.13	1.51	1.52

Table 2.3.4 - Parameters for determining wave height exceedance

The associated average wave period  $T$  for each value of  $h$  can be determined from the relationship above in this section.

### 2.3.4 Currents

Surface currents alone are covered here since design of risers is outside the scope of these Design Guidance Notes at present.

Current measurements should be made at or close to the site for at least one year and preferably longer to build up an accurate picture of current strength and direction. In the absence of this data, the following typical values may be used:

Location	Central N Sea	Northern N Sea	West of Shetlands
100 year surface current speed (m/s)	1.03	0.99	2.00
1 year surface current (m/s)	0.88	0.89	1.64
Direction (approximate)	N/S	N/S	NE/SW

Table 2.3.5 - Surface current data

In the absence of model test data, current forces on FPSOs may be calculated using coefficients presented in OCIMF report Prediction of Current Loads on VLCCs, 1994 (ref.35).

### **2.3.5 Temperature**

The lowest observed daily mean air temperature for UKCS locations is minus 5 degrees centigrade.

### **2.3.6 Snow & ice**

The maximum expected wet snow accumulation on horizontal surfaces for UKCS locations is 200mm with a density of 100kg/m<sup>3</sup>. In practice, this is unlikely to occur on deck because of the heat transfer from crude oil storage tanks and production/utility equipment on deck.

### **2.3.7 Marine growth**

Very little marine growth has been reported on the hull except some weed at waterline and some growth in sea chests. There has been a case reported of mussel growth in a topsides seawater cooling system. Treatment of seawater and firewater systems by chemical dosing is addressed in section 3.7.3.

### **2.3.8 Design environmental conditions**

Guidance on the design environmental conditions and combinations are provided by ABS (ref.23). The design environmental conditions to be considered to determine the most severe loading condition are:

- a) 100 year wind and waves with associated 10 year current
- b) 100 year current with associated 10 year wind and waves

For weathervaning vessels, both collinear and non-collinear directions for wind, wave and current are to be considered. The angular separation for non-collinear conditions is to be based on site-specific environmental studies. If this is not available, the following combinations are to be considered as a minimum:

1. Collinear wind, waves and current.
2. Wind and current collinear and both at 30 degrees to waves.
3. Wind at 30 degrees to waves, and current at 90 degrees to waves.

### **2.3.9 Operational wind and wave data**

Operational wind and wave data are required to plan weather-sensitive operations and assess the likely downtime. UKCS data is available in the HSE report Wind and Wave Frequency Distributions for Sites around the British Isles, OTO 2001:030 (ref.36).

Recent studies have shown evidence of cyclical changes in wave climate in the Northern N Sea but not in the Central or Southern N Sea. The trend in mean significant wave height has been from 3.5m in 1985 up to 4.3m in 1995, based on a 5year average for the January to March period. This trend has now reversed back to a current value of 3.8m. In contrast, the October to December part of the winter has exhibited a reasonably constant mean significant wave height.

## **2.4 PRIMARY HULL STRUCTURE**

### **2.4.1 Design methods**

It is recommended that the structural design be based on the Limit State approach. The limit states to be covered are:

- Ultimate limit state (ULS) using a 10,000 year return period environmental load (see 2.3.2 and 2.3.3 for wind and wave estimates).
- Serviceability limit state (SLS) to assure service performance and habitability.
- Fatigue limit state (FLS) using wave data from 2.3.3.
- Accidental limit states (ALS) following credible accident scenarios.

Guidance on application of the limit state approach and partial factors is given in DNV OS-C102 Structural Design of Offshore Ships (ref.37).

A starting-point design may be based on the following classification society rules for trading tankers with the scantlings increased as necessary for FPSO duty e.g. fatigue, sloshing, green water on deck, bow wave impact.

- LR Rules for Ships (ref.38) - part 4, chapters 9 & 10.
- ABS Steel Vessel Rules (ref.39) - part 5, chapter 1.

The scantlings should also be verified by strength analysis as follows.

### **2.4.2 Finite element analysis**

#### **Modelling**

The FEA model should include a representative cargo tank including the boundary transverse bulkheads and one-half of the tanks forward and aft of this tank. A separate model should be made of the turret area. Finer mesh models should be constructed of localised areas of high stress and typical design details e.g. support detail for topsides, longitudinal / transverse web intersection and cutout.

Details of structural analysis and loading cases to consider are typically given in LR (ref.22) Part 4 chapter 4 section 4.2.

#### **Determination of load**

From experience, the loading cases that should be examined are:

1. Transit condition with 10year seasonal environmental condition for the tow route.
2. Installation condition

3. Design environmental condition with tank contents and external pressure heads selected to produce maximum differential pressure heads and maximum hog / sag bending effects, coupled with the maximum survival wind / wave / current forces.
4. Design operating condition with tank contents and external pressure heads selected to produce maximum differential pressure heads and maximum hog / sag bending effects, coupled with the maximum operating (typically 10 year) wind / wave / current forces.
5. Accident conditions, and after remedial action together with 1 year environmental condition.
6. Insulation conditions

### **Permissible stresses and buckling strength**

The permissible stresses are given in the above LR (ref.22) Part 4 chapter 5 section 2. Buckling strength of plates and stiffeners is given in Part 4 chapter 5 section 3 and of primary members in section 4.

### **2.4.3 Fatigue Design**

Fatigue design is an important factor because of the high cyclic loads from the harsh environment and the cost / difficulty of detecting and repairing fatigue damage in-situ. This means that a rigorous fatigue assessment, taking account of fabrication quality and details, should be performed for the site-specific environmental parameters with the FPSO weathervaning into the environment.

For converted tankers, allowance should be made for previous usage. The designer should ensure that fabrication details and fatigue analysis are consistent with the required service upgrade.

The areas where fatigue causes problems on an FPSO are:

- a) Fatigue design of longitudinals in the side shell in the operating draft range where there is fluctuating water pressure due to wave action. This may require fitting an extra bracket or collar at each longitudinal to transverse web frame connection to improve fatigue lives when modifying an existing tanker design. The problem is worst when the vessel is sitting at a constant draft in the case of oil export by pipeline or via FSU.
- b) Hull girder bending. Increased thickness of deck and bottom plate may be necessary when modifying intercept tankers to improve hull girder modulus and reduce cyclic bending stresses.
- c) In topsides supporting structure, due to transmission of hull bending stress into topside PAUs.

Guidance on fatigue design and analysis is provided by Classification Societies as follows. The required target fatigue life is 20 years or field life if longer, multiplied by a factor of safety (see below).

LR (ref.22) Part 4 chapter 5 section 5 includes:

- Factors which influence fatigue
- Sources of cyclic loading
- Structural areas to be examined for fatigue
- Fatigue damage calculations (using Miner's summation)
- Joint classifications and S-N curves (see Appendix A)
- Factors of safety on fatigue life (depending on accessibility for inspection/repair, and consequence of failure)

ABS (ref.23) Chapter 4 section 2.13.5 covers fatigue analysis.

ABS (ref.39) Section 5 -1 - 5/7 covers the extent of fatigue analysis.

DNV are managing the FPSO Fatigue Capacity JIP. The first phase examining fatigue performance of butt welds is summarised in HSE report OTN 2001:015 (ref.40). The second phase will examine fillet weld performance and will include a comparison with the earlier MARIN Structural Integrity JIP.

#### **2.4.4 Local strength**

Formulae for local strength are given by LR (ref.22) part 4, chapter 6:

- Design heads
- Watertight shell boundaries
- Deck structure
- Helicopter landing areas
- Wheeled vehicle loading
- Bulkheads
- Double bottom structure
- Superstructures and deckhouses
- Bulwarks and other means for protection of crew

#### **2.4.5 Reliability based design**

Recent work by HSE in OTO 98:164 has examined Reliability Based Design and Assessment of FPSO Structures (ref.41). This has adopted the approach to reliability design of fixed jacket structures where statistical data on loading, materials, fabrication and rigorous analysis methods are applied. The approach has been used on a recent UKCS FPSO to assess the extreme loading states the vessel will encounter and a non-linear finite element analysis, incorporating post-yield and post-buckling behaviour of



elements, has been performed to assess the ultimate capability of the structure under this loading.

#### **2.4.6 Material Selection**

Steel grade is of course predetermined for conversion of existing or intercept tankers. For new-build custom-designed FPSOs, it is possible to optimise steel grade for the particular requirements of FPSO duty. The choice lies between a completely mild steel hull (yield stress = 235 N/mm<sup>2</sup>) and a hull where the deck and bottom is high tensile steel (yield stress normally 355 N/mm<sup>2</sup>) and sides and longitudinal bulkhead in mild steel.

The issues affecting material selection are as follows:

- High tensile steel produces a lighter hull (subject to the other constraints below) and allows greater crude oil cargo deadweight to be carried. This is normally of benefit for dense crude oil where the crude oil capacity is limited by deadweight. For lighter crude oils, especially where a double bottom is fitted, the crude oil capacity is limited by volume and therefore a saving in hull weight may not be directly beneficial.
- Fatigue is a major design issue for harsh environment FPSOs and the use of high tensile steel may produce greater cyclic stress ranges than the structural details permit for fatigue. This constraint may not permit the full advantage of reduced scantlings and structural weight from HTS to be realised.
- HTS hull is more flexible (reduced modulus) so that more care needs to be taken in topside/piping design for hull flexibility.
- Weldability requirements for HTS are more onerous than mild steel.

#### **2.4.7 Welding and structural detailing**

Welding requirements and structural detailing are covered in detail in classification society rules e.g. LR (ref.22) Part 4 Chapter 8.

It is important to note that due to the difficulty of in-situ structural repair, high standards of welding and structural detailing are required to prevent initiation of fatigue cracks. Particular attention should also be paid to quality of field welds between block sub-assemblies where problems have occurred in the past.

## **2.5 GREEN WATER**

### **2.5.1 Introduction**

Green water i.e. unbroken wave crests inundating the deck of the FPSO, is a major consideration because of the production equipment mounted on deck. This equipment is mounted on a raised production deck (typically 2.5m above main deck) and this minimises the effect of green water. However damage has been sustained by UKCS FPSOs to cable trays, walkways and stairs, and containers have been lost from the production deck. Items which are at most risk are those under the production deck e.g. drains vessels, and these must be designed for green water loading.

Green water may be experienced over the bow (especially since the FPSO weathervanes) and this requires the fitting of a forecastle or breakwater to protect turret/swivel and production equipment.

Green water may be experienced over the sides especially in non-collinear wind/wave/current. This requires adequate freeboard and height of PAU/module above deck to avoid green water on the production deck.

Green water may also be experienced at the stern, particularly with vessels without a poop deck, due to vessel pitching down at the stern coupled with a wave crest passing. However, this is not considered to be as high a risk as bow or side green water loading.

### **2.5.2 Current prediction methods**

Green water behaviour for a particular design should be studied using model tank tests. For preliminary design guidance, the results of the JIP "F(P)SO Green Water Loading" conducted by MARIN and the computer design tool 'GreenLab' can be used by participants in the JIP. This predicts green water exceedance and corresponding pressures along the FPSO.

This program has been used by HSE in Analysis of Green Water Susceptibility of FPSO/FSUs on the UKCS OTO Report 2001:005 (ref.42) which was subsequently reviewed by MARIN in HSE Research Project 3794, MARIN Review of HSE Greenwater Study, completion 2000 (ref.43). This investigated the susceptibility but not the consequences of green water on deck for UKCS FPSO/FSUs. The analysis indicated that:

- Nearly one-half of these vessels were exposed to high bow green water susceptibility.
- Most of the vessels were exposed to high green water susceptibility at side in a 30 degree heading to waves.
- Freeboards at maximum draughts are generally insufficient to prevent green water occurring on deck.

- More green water is likely to occur at lower wave height/period (typically 12 seconds), corresponding roughly to the one-year wave, than with the design maximum condition.

The investigation also examined damage incidents in service. This correlated with the results of the above analysis and indicated a frequency of 1 incident per installation per 3.6 years.

Freeboard requirements to avoid/minimise green water are obviously installation and site-specific. Preliminary guidance on green water height is summarised in fig. 2.5.1, from which freeboard requirements can be deduced.

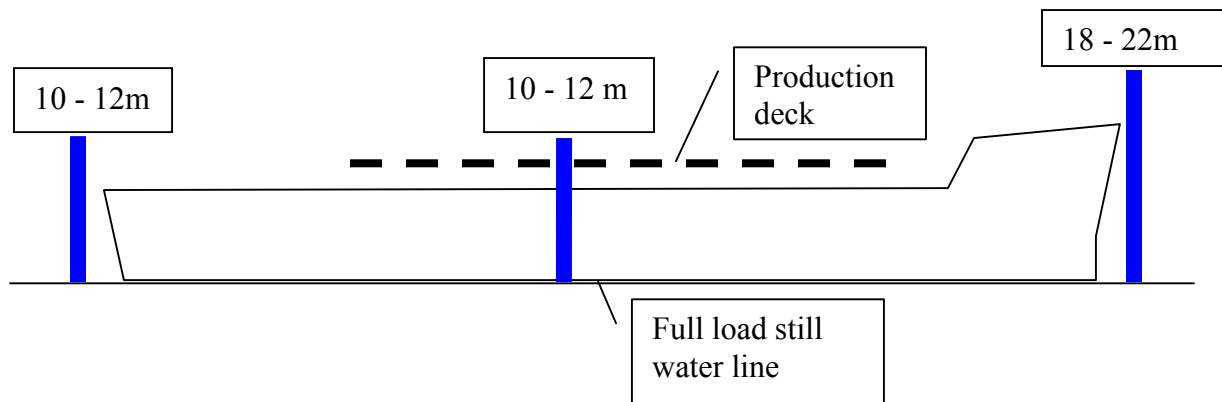


Fig. 2.5.1 - Elevation of Green Water above still water level

Additional guidance on green water behaviour will be available from HSE Research Project 3959 FPSO Response in long and short crested seas, due for completion April 2002 (ref.44) and from the 'FLOW' (Floater Loading by Waves) JIP.

The pressure due to green water inundation on deck is available for JIP participants from the GreenLab computer program at the fore perpendicular, 10m and 20m aft of the F.P. An alternative source for green water pressure is ABS (ref.23), appendix 2, section 3.

### **2.5.3 Avoidance measures**

At the bow, there are two measures used to minimise green water:

- a) Extending the bow upward to form a forecastle. This structure must be designed for high bow wave impact pressure (see section 2.6).
- b) Fitting lower bulwarks at the forward end and allowing green water to come aboard but prevented from flowing further aft over production equipment by a breakwater. Any structure in this forward end must be reinforced for local green water pressures.

At the sides, the main defences are to ensure adequate freeboard and height of production deck to raise production equipment above green water level. Bulwarks may be fitted (typically 1.4m high) at the deck edge to hinder green water inundation, but these should have freeing ports to permit rapid drainage of green water and the structural design should avoid transmitting hull bending to bulwarks. It should be noted that bulwarks may have the effect of increasing blast overpressure.

At the stern, a raised poop deck may be fitted.

Equipment should be sited as far as possible above green water inundation areas. If this is not possible, the equipment e.g. drains vessels, cabling, piping, stairs should be designed for green water pressures.

Green water susceptibility appears to be highest in January and February and it may be more economic to restrict operation to lighter than maximum draught during this period to increase freeboard and decrease green water loads rather than design freeboard for this onerous period.

## **2.6 BOW WAVE IMPACT**

### **2.6.1 Introduction**

Recent incidents have highlighted the need to consider bow wave impact at an early stage in FPSO design. In one incident, plating in the forecastle was torn and deck and shell stiffeners and in less than 10 minutes, forecastle plating was buckled.

Factors increasing the susceptibility of FPSOs to bow wave impact (relative to trading tankers) are:

- Exposure to severe UKCS weather conditions with no means of weather avoidance.
- Weathervaning, which exposes bow area to weather, noting that non-collinear environments can also expose bow sides.
- Full rounded bow shape of many FPSOs (especially new-build).

Bow wave impact is attributed to the celerity of water in the wave crest causing high stagnation pressures at the point of impact. Investigation has shown that the maximum pressures occur in short, steep seas e.g. in the first incident above, in 20m wave height and 10-12 second period i.e. much less than the design wave condition. Since this is a wave crest phenomenon, high pressures can be experienced in the upper bow and forecastle, exacerbated by bow pitching downwards.

The above incident has shown that particular attention should be paid to the end attachments of shell plating stiffeners, to preventing stiffeners tripping and to field weld attachments of forecastles to the hull. Care should be taken to avoid siting safety / production critical items within forecastles where possible.

### **2.6.2 Calculation of bow wave impact pressure**

HSE Report Review of Greenwater and Waveslam Design and Specification for FPSO/FSUs, OTO 2000:004 (ref.45) examined the Classification Society requirements on wave slam and the approaches adopted by leading FPSO designers. The conclusion was that much of the guidance is based on empirical formulae and requires more scientific research to extend trading ship experience to FPSOs.

ABS (ref.23) appendix 2, section 4 provides a formula for calculating bow wave impact pressure distribution, taking account of bow shape and position on bow from waterline and freeboard deck. A first principles design approach is given in the above HSE Report (sections 10.6 & 10.7) to calculate the wave crest velocity and stagnation pressure for given wave height and period, and the resulting impact pressures for local plate panels and larger areas.

More work is underway to quantify bow impact pressure in the Flow JIP, conducted by MARIN.

### 2.6.3 Measures to minimise bow wave impact

Bow wave impact pressures are highest on full rounded bow shapes with raised forecastles and bulwarks as in fig. 2.6.1 below, where the philosophy is to minimise the amount of green water that overtops the bow.

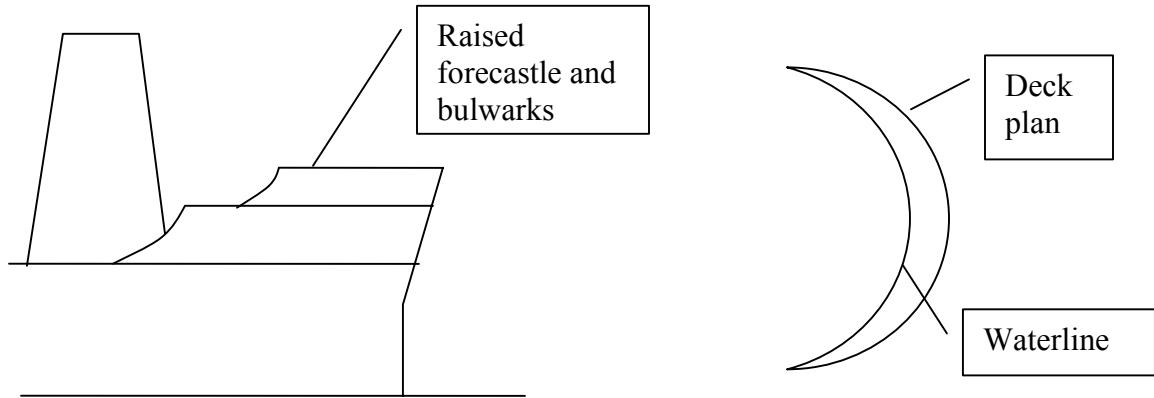


Fig. 2.6.1 - Full-rounded bow shape with raised forecastle and bulwarks

An alternative is to fit a lower forecastle and/or bulwark as in fig.2.6.2, which minimises the area of bow structure exposed to wave impact. The greater amount of green water which overtops the bow is deflected by a breakwater further aft in front of production equipment. The wave pressure at the breakwater (and front of turret if exposed) is however considerably reduced from bow front impact pressures.

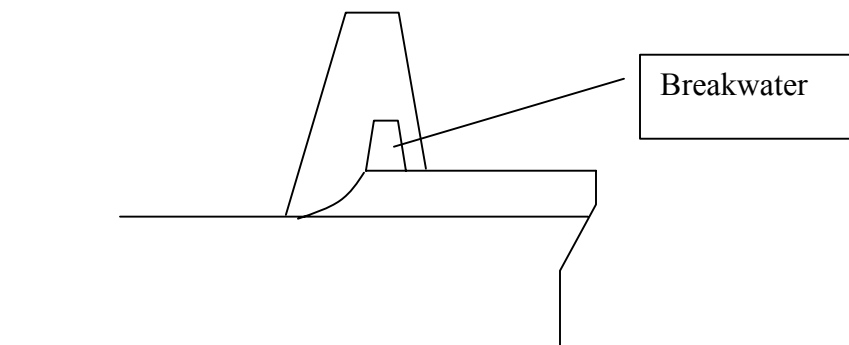


Fig. 2.6.2 - Alternative bow design incorporating breakwater

#### **2.6.4 Full rounded v sharp bow**

For converted trading tankers, the bow shape is of course pre-determined. For a new-build, bow shape in plan may be either full rounded (or semi-ellipsoidal) or a sharper bow with or without a rounded extremity. The choice requires a trade-off study of first cost versus a number of technical factors below:

The full rounded bow provides maximum buoyancy for minimum steelweight due to its low surface area. It minimises the 'dead space' forward of the turret and maximises the natural weathervaning action of the vessel. It also maximises the buoyancy in the bows to aid the bows rising to meet wave crests.

However the rounded bow presents a large amount of almost flat surface to wave impact loads and this must be strengthened. Also, waves meeting this surface will be deflected upwards with more probability of green water overtopping.

The sharper bow minimises bow impact forces (although wave impact in oblique seas due to non-collinear environment needs to be considered). It also reduces mooring forces. The sharp bow is however more costly to construct and provides less space for a forward-mounted turret.

## **2.7 SLOSHING IN CARGO TANKS**

### **2.7.1 Introduction**

Sloshing in oil storage and ballast tanks of FPSOs is an issue because of the need to fill and empty tanks at sea, possibly in severe weather conditions. Resonance between the tanks' natural sloshing period during filling/emptying and the periods of roll and pitch of the FPSO could result in high dynamic sloshing loads on the tank boundaries. The problem may be exacerbated by the smooth surface of the inner bottom when a double bottom is fitted.

A sloshing analysis should be performed for anticipated tank fillings to determine if the natural period of the tank contents is close to the vessel natural pitch and roll periods. If the tank natural periods approach the pitch or roll periods, then additional analysis is required to determine sloshing pressures and degree of structural strengthening of tank bulkheads.

### **2.7.2 Pressure prediction**

Sloshing pressures can be derived from:

- LR (ref.38) Part 3 chapter 3.5
- ABS (ref.39) Section 5 - 1 - 3/11

### **2.7.3 Avoidance measures**

If high dynamic sloshing pressures are predicted, it may be more economic to reduce the size of the tank by closer bulkhead spacing or by fitting partial slosh bulkheads. This will remove the tank natural period from the hull resonance range, and may be more economical than increasing the tank boundary scantlings.



## **2.8 COLLISION DAMAGE**

### **2.8.1 Introduction**

FPSOs by nature of their duty do not have to be designed for grounding damage. The principal cause of damage is collision risk due to the following sources:

1. Supply boat
2. Shuttle tanker
3. Passing ship traffic

Type 1 and 2 damages are likely to be low energy damage with no loss of life or risk of vessel loss unlike type 3 damage which could be a high energy collision from a large passing ship.

The objectives in designing for collision damage are firstly to avoid collision by well thought out design and procedures for offloading operations which have been subject to HAZID and HAZOP studies. Secondly, the design should minimise the consequences of collision viz. spillage of crude oil, loss of buoyancy or stability, damage to production equipment causing explosion/fire risk, damage to LQ.

The immediate aim is reducing risk to life and environment with the secondary aim of reducing the economic impact of damage on production by facilitating in-situ repair.

The topic is the subject of an on-going HSE Research Project 3397-Collision Avoidance Management (ref.46). This will examine previous research, legislation and incidents and present an overview of the causes and consequences of collisions due to in-field vessels and passing traffic. It will also review the effectiveness of different collision control and avoidance systems.

### **2.8.2 Supply boat operation**

Generally in the UKCS, supply boat operations are conducted on DP with the supply boat positioned adjacent to the FPSO cranes in the amidships region. The main risk is a failure of the DP system although if the FPSO is free to weathervane, the supply boat will probably drift clear. An impact, if it occurs, is most likely on the side shell amidships. This is in a double hull area so there is minimum risk of cargo tank damage but it is also in the hull area with highest stresses so any damage will probably mean shutdown awaiting repair.

Classification Society Rules e.g. LR Rules (ref.22) Part 4, chapter 3, 4.16.1 call for the unit to be capable of absorbing impact energy of 14MJ for sideways collision and 11MJ for bow and stern collision, corresponding to a supply vessel of 5,000te with a speed of 2m/s.

HSE Report Collision Resistance of Ship-shaped Structures to Side Impact, OTO 2000:053 (ref.47) contains methods of analysing collision damage and calculating the energy required to deform and/or fail the side structure of the FPSO.

### **2.8.3 Shuttle tankers**

Collisions between shuttle tankers in UKCS have occurred because of the inability of shuttle tankers to react quickly enough to follow sudden weathervaning of FPSOs on their spread mooring and because of loss of DP target for maintaining separation between the vessels.

The primary risk is collision of the shuttle tanker with the hose reel and aft end structure of the FPSO (commercial risk) and danger to personnel on the aft end of the FPSO.

The suggested safeguards and mitigating measures are:

- Crew competency and well thought out shuttle tanker approach/loading procedures.
- Providing a 'dead space' at the stern of the FPSO with voids or water tanks in the hull, and ensuring that helidecks, hose reels and fuel tanks are set back from the stern to avoid damage.
- A 'crumple zone' has been proposed to absorb likely energy impacts without compromising the watertight integrity of the FPSO or causing production to be shut down. Design of the FPSO stern should ensure that damage from the bow of a shuttle tanker (including bulbous bows) occurs above water level to facilitate repair.
- Thrusters on the FPSO are useful to optimise/stabilise FPSO heading during shuttle tanker approach/offloading.
- Perform a failure modes and effects analysis on power, control and thruster systems to ensure redundancy against failure.

UKOOA FPSO Committee has formulated Tandem Loading Guidelines - Volume 1 - FPSO/Tanker Risk Control during Offtake (ref. 48) which reviewed current UK practices, the implications of UK legislation, existing industry guidance and international initiatives. The study concluded that tandem off-loading incident rate warranted reduction by improved practices and the guidelines are intended to reduce the incident rate and the inherent risks of a major accident.

### **2.8.4 Passing traffic collision**

The probability of collision between passing traffic and an FPSO is increased because the length of the FPSO (and possibly a shuttle tanker attached) presents a much larger 'target' than a fixed platform. Such a collision could have very large safety and environmental consequences.

The main counter measures are to prevent collisions taking place in the first place:

- Monitoring the course of passing traffic to detect collision courses, with enhanced detection systems in high traffic areas.
- Audible warning on attendant vessels
- Emergency disconnection and sail away of shuttle tanker when a dangerous situation has been detected early enough.
- Rotation of FPSO to minimise 'target' as far as possible in prevailing weather if thrusters are fitted.
- Crew muster

## **2.9 STRUCTURAL / PRODUCTION FACILITIES INTERFACE**

### **2.9.1 Packaging of production facilities**

Production facilities are usually located on a production deck (typically 2.5m above main deck) to minimise the impact of green water, to remove topsides from zone 1 areas associated with the vessel, and as a safety measure in case of explosion or fire in topsides to minimise the risk to the vessel's crude oil tanks.

The two main choices for structural packaging of production facilities on FPSOs are pre-assembled units (PAUs) or structural pancakes and larger modules, more typically used on fixed jacket topsides.

The trend for cost reasons towards issuing functional specifications to equipment suppliers (including the supply of structural PAU) has led to adopting a larger number of PAUs on recent FPSOs. This has sometimes led to problems due to suppliers' unfamiliarity with the structural design aspects on a moving, flexing vessel. Small PAUs also have greater potential for interface problems between different suppliers' PAUs and inter-module hook-up problems late in the project. This can be avoided by using larger modules but at the expense of a number of drawbacks (see below).

The main factors to consider for module size optimisation are listed below.

#### **Support arrangements**

Very large 'module' type structures impose high point loads on the vessel structure and it is difficult to reinforce the under-deck structure of converted tankers to take these. New build vessels can be designed at the outset for these loads.

Support of 'rigid' PAU/module on the flexing deck of the FPSO must also be considered. For small PAU/modules, which span a short length of deck, the flexing movement is small enough to allow 'hard' supports to be used.

Large rigid modules, spanning a significant length of deck, need to have some flexibility built into their supports to prevent high hull stress levels being transmitted into the module.

For all support arrangements, it is important to fully consider fatigue due to hull flexure and inertia loads on PAU/modules in the design of supports.

#### **Structural weight**

The structural weight of large three-dimensional modules is significantly greater than for flat pancake PAU construction. Fig. 2.9.1 illustrates this for a typical large FPSO topsides (11, 000te).

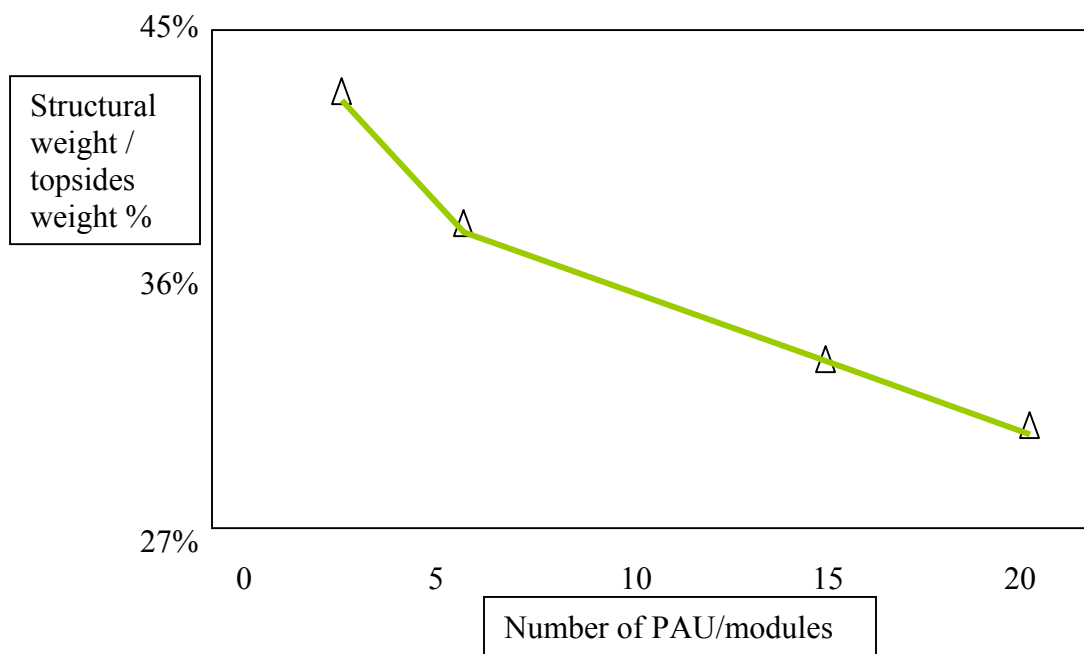


Fig. 2.9.1 - Variation in structural weight (including supports) with number of PAUs

### **Lifting facilities at fabrication site**

The lifting facilities need to have height and reach capable of lifting the PAUs/modules onto the deck of the FPSO that is at a light outfitting draught. Typical lifting capabilities in this role are:

Large mobile land crane	600t
Floating sheer legs	1,500t
Heavy lift crane barge	3,000t

### **Layout/space requirements**

PAU pancake-type construction is on a single level. This maximises safety but often uses all available deck space to the detriment of lay-down area. Module-type construction can incorporate two or more levels and leave spare space for future expansion and ample lay-down areas. Safety is still equivalent to that of a fixed platform's topsides. Stability should be checked for the higher centre of gravity of the topsides.

## Inter-module hook-up

The number of process and utility piping connections, electrical and instrument loop connections is greatly reduced by using larger modules (see fig. 2.9.2). This is a major advantage since these connections are made late in the project at the HUC yard and any problems would impact the project schedule.

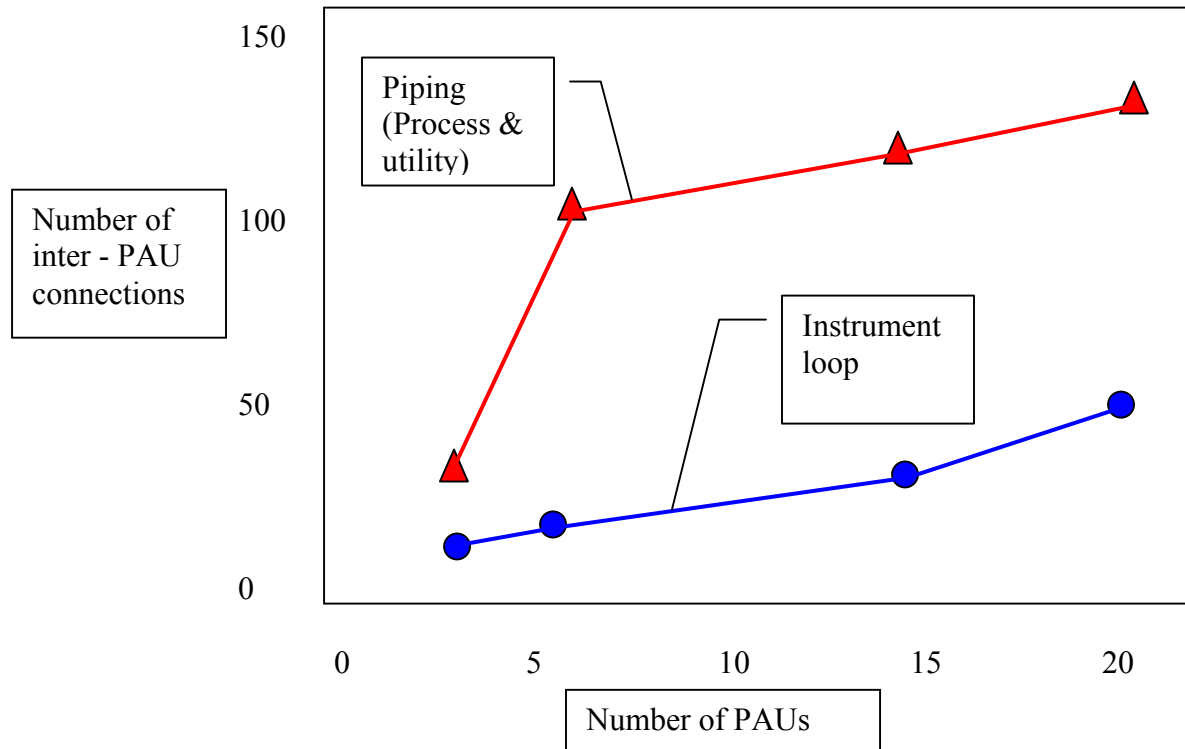


Fig. 2.9.2 - Variation in inter-PAU piping and instrument connections

## Contractual arrangements

The module split will also depend on whether a single topside contractor is appointed who may prefer to adopt the large module route or a functional specification is issued to a number of equipment vendors who will produce their own smaller PAU.

The above factors need to be weighed up for each particular project to arrive at the optimum module split.

## 2.9.2 Structural support of facilities

Typical structural support arrangements are shown below. Attention is drawn to the need for careful fatigue detailing of the supports.

### Individual pillars

Individual pillars from the PAU down to meet a pad or stool on the vessel's deck as shown in fig. 2.9.3. This is a simple, light and cheap solution. Provision must be made for misalignment of the pillar relative to the deck support. It is also important to have the attachment weld some distance above the deck to avoid damaging internal tank coatings. Some fatigue damage has been experienced due to either longitudinal hull bending being transmitted through the supports to the PAU or bending from transverse loads on topsides from roll motions.

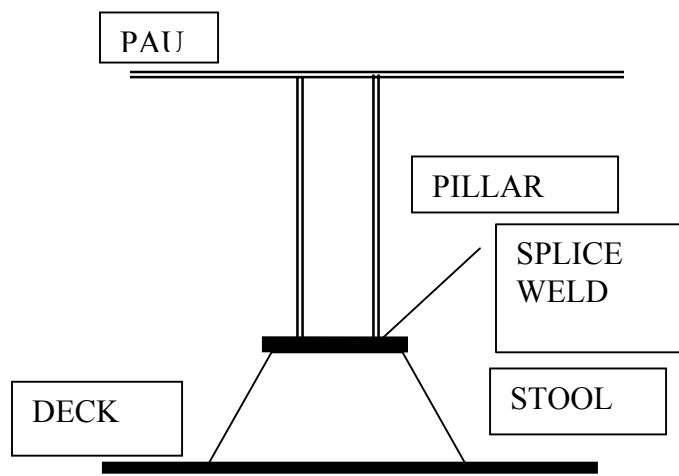


Fig. 2.9.3 - Individual pillar support

### Transverse T - beams

Transverse T-beams mounted across the ship's deck with the PAU supports landing on these as shown in fig. 2.9.4. The T-beams are fabricated at the shipyard. The system allows more flexibility in designing PAU structure and supports without having to tie this into local ship's structure. The topside loads are also spread more evenly into the ship's structure and allow local flexing to reduce the hull bending stresses transmitted into the PAU structure.

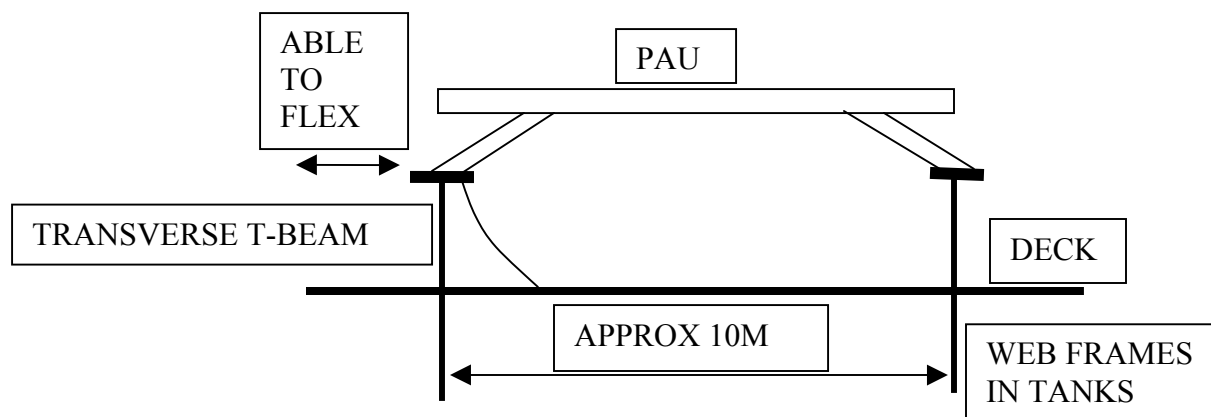


Fig. 2.9.4 - Transverse T-Beam support

### **Bridge bearing proposal**

The use of bridge bearings has been proposed to support topsides while allowing horizontal flexibility to accommodate hull bending. Attention would need to be paid in design to the number of cycles of distortion in the bridge bearing used in this role, compared to the traditional use where the main effect is thermal expansion.

### **Problems with cross-linking of PAUs**

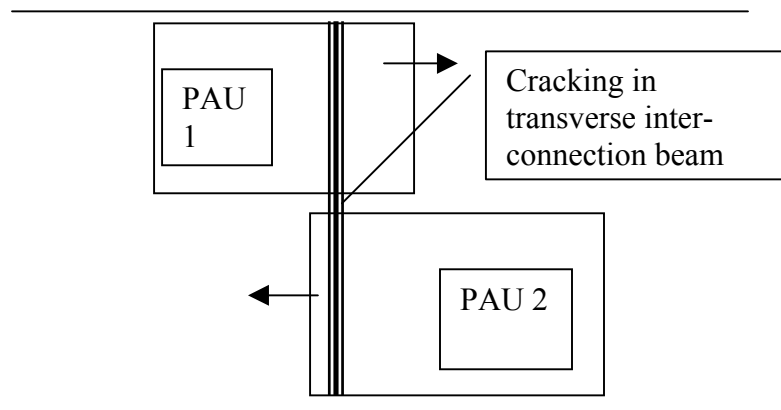
Attention is drawn to additional fatigue problems in transverse beams linking two PAUs where these are sited on different parts of the deck as shown in fig. 2.9.5. The two PAUs experience different deck deflections due to hull bending and the relative horizontal deflection can cause high cyclic stresses in interconnecting structure especially if this is short and stiff.

### **2.9.3 Design loads**

The loads for designing PAUs/modules may be derived from ABS (ref.23) Appendix 2 section 1. The design of local structure in the hull supporting production equipment is also covered by the above reference in Appendix 2, section 7.



PLAN VIEW



ELEVATION

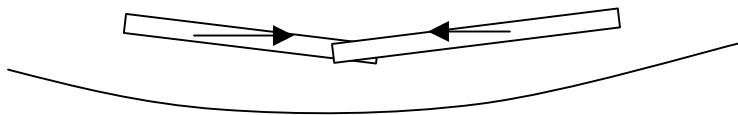


Fig. 2.9.5 - Potential fatigue problem in PAU connections

## 2.10 HULL DEFLECTION PATTERNS

### 2.10.1 Introduction

The FPSO hull acts like a girder and deforms in the vertical plane under the action of 'still water loads' (uneven weight and buoyancy distributions) and wave loading. It is necessary to consider the extreme values of both types of loading to obtain the maximum tensile and compressive stresses/deformations in the deck and bottom. For an FPSO, the extreme 'sagging' condition (fig. 2.10.1A) will be a full load in crude storage tanks coupled with a wave of approximately the ship length with its trough amidships. The extreme 'hogging' condition (fig. 2.10.1B) will be the ballast condition coupled with a wave of approximately the ship length with its crest amidships.



Fig 2.10.1A - Extreme sagging condition

Fig. 2.10.1B - Extreme hogging condition

The FPSO hull also deforms in the horizontal plane under the action of wave loading in oblique seas but this effect can be neglected for practical purposes since (a) horizontal bending loads are smaller than vertical, (b) the FPSO hull is stiffer in horizontal bending (since breadth/depth = 2) and (c) the maximum horizontal loads do not occur simultaneously or in the same conditions as peak vertical loads.

### 2.10.2 Calculation of hull deformation

Hull deformations at deck level should be calculated to give guidance for design of piping for production equipment and structural design of PAUs/modules. Both of these experience a longitudinal strain due to hull bending. This has a static component due to still water bending and a dynamic component due to wave action. The hull deformation pattern is shown in fig. 2.10.2.

The procedure for calculating hull deformation effects in piping and PAUs/modules is:

- 1) Establish a baseline case where the FPSO is at the fit-out stage in dock, with the dry weight of topside equipment on deck, at the point when piping flanges are made up and PAU/module to deck structural connections made.
- 2) Calculate baseline hull deformation for this condition.
- 3) Establish critical sagging and hogging conditions (see above).
- 4) Calculate hull deformations for these conditions (static and dynamic components).
- 5) Deformation in piping and PAU/module structure is the difference between (2) and (4) deformations.

The hull deformations may be obtained from the coarse finite element model of the hull structure. Since this is not usually available early in design, the following simplified procedure can be used for preliminary guidance. The deformations are assumed to increase linearly with distance Y above the neutral axis of the ship (see fig. 2.10.2).

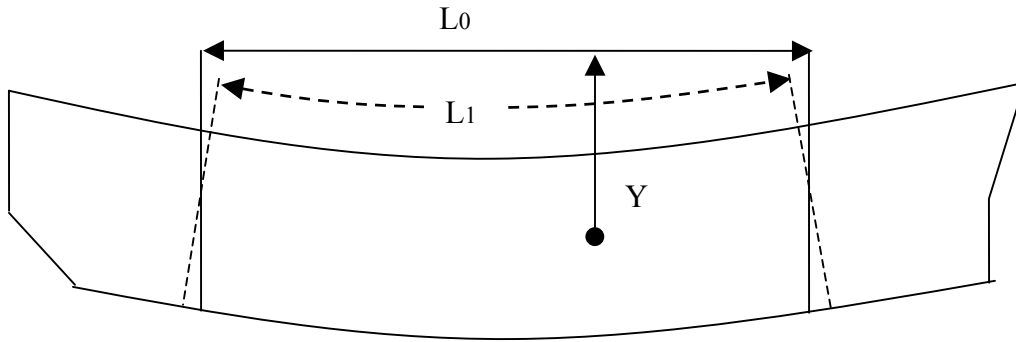


Fig. 2.10.2 - Hull bending deformation pattern

Longitudinal deformation =  $L_1 - L_0 = L_0 \times \text{strain} = L \times \text{stress} / \text{Young's modulus (E)}$

The maximum permissible hull bending stress at deck level due to combined still water bending and wave bending is  $175 \cdot f_1 \text{ N/mm}^2$ , where  $f_1$  is yield strength of high tensile steel in deck / yield strength of mild steel based on classification societies' rules. The strain corresponding to this maximum stress is shown in table 2.10.1.

Strain = deformation (mm) per metre length of ship	Mild steel hull (235 N/mm <sup>2</sup> yield)	High tensile deck hull (340 N/mm <sup>2</sup> yield)
At main deck level	+/- 0.84 mm/m	+/- 1.22 mm/m
At process deck level (+2.5m above main deck) on long process decks	+/- 1.01 mm/m	+/- 1.46 mm/m
At pipe rack level (+5.0m above main deck) on long pipe racks	+/- 1.18 mm/m	+/- 1.71 mm/m
On short process decks or short pipe racks	As for main deck	As for main deck

Table 2.10.1 - Maximum hull strain values at amidships

The above deformation values apply in the central 0.4 of the length of the FPSO and can be tapered outside this area linearly to zero at the bow and stern.

### **2.10.3 Static v dynamic deformations**

The 'static' component of deformation due to still water bending is approximately 40% of the values in table 2.10.1 and the 'dynamic' component due to wave action (for the maximum design wave) is approximately 60%.

## **2.11 MOTION BEHAVIOUR**

### **2.11.1 Introduction**

Good motion behaviour is essential for an FPSO operating in the harsh UKCS environment for safety and efficient operation, especially in the following areas:

- Crew comfort and safety
- Helicopter operation
- Production & utility equipment operability
- FPSO motions ('fishtailing') during offloading to shuttle tanker

In addition, knowledge of extreme hull motions and accelerations is required to establish design criteria for topside structure and systems.

### **2.11.2 Design values**

Design values for motions and accelerations should be derived from model test tank results for the site-specific environment. Preliminary guidance on typical extreme motions is contained in:

LR (ref.28) Table 15.1 gives motions and accelerations for various headings. These values have been derived from LR's database for various FPSO's and environments. The data contained in the above document has been analysed to derive the design curves in figs. 2.11.1 - 3 below. Other useful information is contained in:

ABS (ref.23) Appendix 2, Section 8, 5.7.1 Ship Motions and Accelerations gives formulae for calculating pitch and roll motions and vertical, longitudinal and transverse accelerations.

HSE (ref.44) will carry out a series of systematic tests on a representative FPSO in short and long crested seas to identify maximum motion responses. This work should be available in April 2002.

Degrees or M

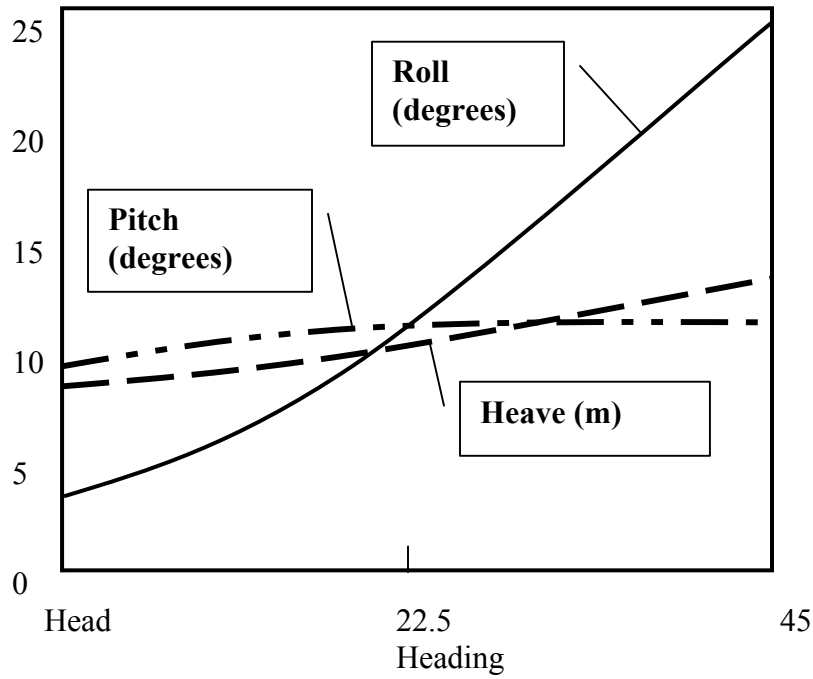


Fig. 2.11.1 - Maximum (100 year) design responses (single amplitude)

M/sec<sup>2</sup>

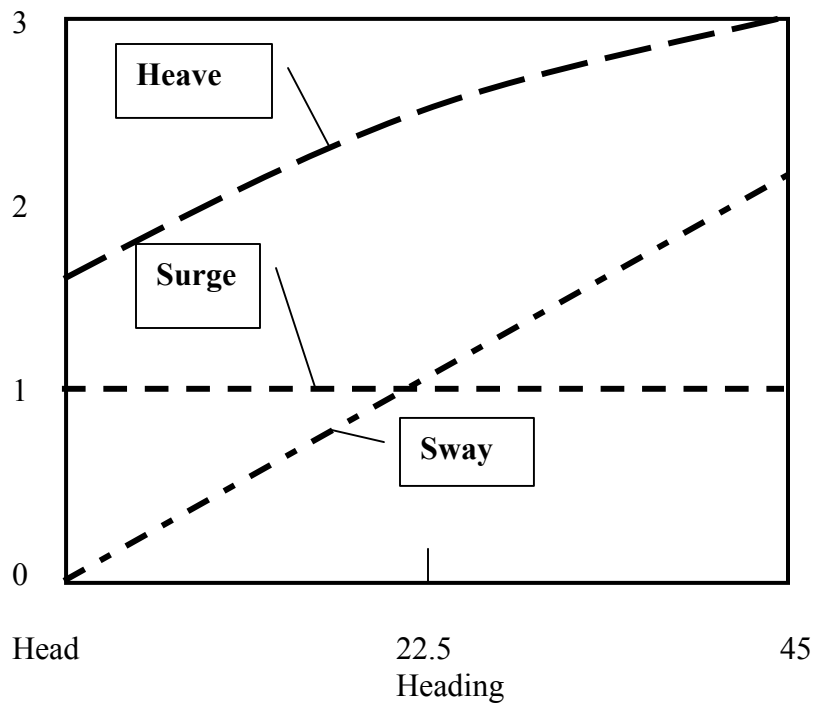


Fig. 2.11.2 - Maximum (100 year) linear accelerations (at vessel CG)

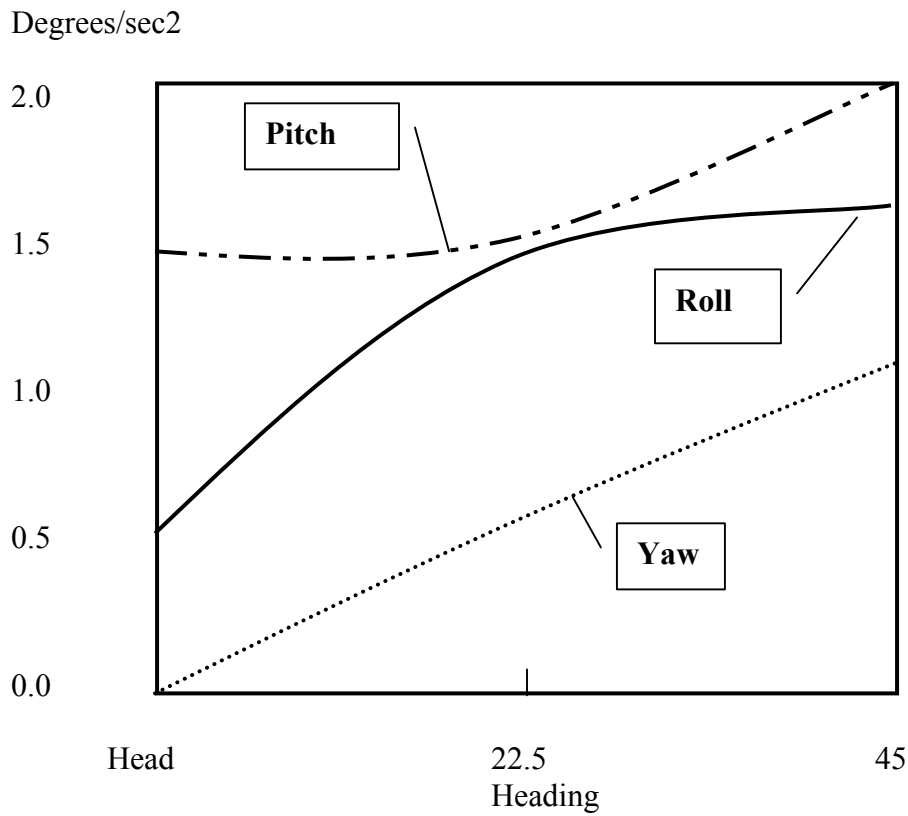


Fig. 2.11.3 - Maximum (100 year) angular accelerations

Large roll motions may also occur due to tide influence turning the FPSO beam on to seas in cases where no active thruster heading control is fitted.

## 2.12 MODEL TANK TESTING

Model tank testing is recommended at an early stage in FPSO design to confirm the numerical analysis results for loads and motions and to pick up any phenomena which the analytical methods do not cover adequately. This is particularly important for vessels of unusual configuration. The results from the model tests should be available in time to feed into detail design of moorings, riser and vessel.

The information to be provided by model tank testing includes the following:

- a) Hull motions and accelerations for all six degrees of freedom to calibrate numerical models and for flexible riser and production equipment design and operational downtime assessment. Maximum responses depend on both wave height and period so a range of  $H_s/T_p$  values should be investigated that are relevant to the site. This should pay particular attention to wave periods close to the vessel natural periods.
- b) Video recording of green water behaviour on deck to confirm freeboard and height of production deck above main deck to avoid green water loads on production equipment.
- c) Pressure sensors on bow, forecastle and other areas susceptible to high wave impact pressures or bottom slamming.
- d) Mooring system loads to design turret and mooring components.
- e) Vessel excursions to feed into riser analysis.
- f) Effectiveness of thrusters in controlling heading.
- g) Any undesirable effects e.g. fish-tailing

The scale of the model should be selected as large as possible, usually constrained by the wave generator's capability to model the maximum wave height or by correctly modelling the water depth in deeper water applications. A typical scale is 1/80. Particular attention needs to be paid to modelling the behaviour of the mooring system which is Reynolds number dependent, compared to the Froude scaling used to determine vessel responses. This will entail modifying the line diameter and surface roughness of mooring lines (and risers, if modelled).

Environmental loads need to be modelled as accurately as possible. Wind loading may be provided by fans and the wind speed profile relative to the reference height should be adjusted as close as possible to the computed site profile. An appropriate wind spectrum should be selected to create accurate long period excursions and mooring loads. If this is not possible, computer-controlled fans on the model can provide the relevant force and moment corresponding to wind speed and vessel heading.

Currents should be modelled to take into account the high loads attracted by risers and moorings particularly in deeper water and the change in wave shape caused by currents. This may be achieved by underwater jets or by towing the model from a carriage. Model basin design should permit testing with non-collinear waves and wind/current.

Further details are contained in HSE Report OTO 2000:123 Review of Model Testing Requirements for FPSOs (ref.50).



## **2.13 TURRET INTERFACES**

### **2.13.1 Introduction**

Turret design requires careful consideration (a) because of its complex nature and being critical to safe operation of the FPSO as a whole and (b) because of the interfaces with the other FPSO systems viz.

- Structural/bearing interface with vessel hull
- Interface with production equipment through high-pressure swivel or wind-on hoses
- Riser interface
- Mooring interface

These interfaces are complicated by the design of each system usually being carried out by different contractors and therefore needing close co-ordination of design basis, design information and construction planning.

### **2.13.2 Structural/bearing interface**

The turret and hull structure in way of turret need to be designed in conjunction to ensure efficient structural paths for turret loads into the hull and compatibility of loads and deformations in hull and turret structural models.

A finite element model is required of the turret and adjacent hull structure. For a fore end turret, the model usually extends from the fore end of the vessel into the cargo tank aft of the tank containing the turret. For an amidships turret, the model usually extends from the tank forward to the tank aft of the tank containing the turret. The loads include:

- a) Turret weight, mooring and riser tensions, including acceleration induced loads.
- b) Overall hull bending and shear forces.
- c) Internal and external pressure loads corresponding to design tank loading conditions and range of operating drafts, with wave action.
- d) Local deck loading due to green seas as applicable.

The acceptance criteria for material yielding, buckling and fatigue are covered in section 2.4.2 of these Guidance Notes.

Fairleads and their supports are to be designed for a load equal to the breaking strength of the vessel's mooring lines.

Further guidance on structural design is given in LR (ref.22), Part 4, chapter 4, 4.2.13-18 and ABS (ref.23), June 2000, chapter 4, section 2.15.1 and chapter 5, section 4.13.

Structural members in turret and adjacent hull should be effectively connected to avoid hot spots, notches and stress concentrations. The loss of hull girder cross sectional area needs to be compensated e.g. by increased deck plate thickness, in way of the turret opening. The increased deck thickness should be tapered smoothly fore and aft of the turret opening to avoid stress concentration.

Particular attention should be paid to access arrangements for inspection and repair of structure and bearings. In this respect, the siting of bearings should be carefully considered. Deck-mounted bearings are easier to inspect but have higher loads than bearings located near turret mid-depth. Bearing arrangements involving pads should have positive securing to avoid pads falling out in service.

ABS requires a corrosion margin of 10% up to a maximum of 1.5mm on turret/hull interface scantlings.

### **2.13.3 Mooring interface**

Mooring arrangements may be either active or passive i.e. locked-off. The active system requires considerable space in the turret to accommodate one winch per mooring line and power/controls for these. Active systems may be employed for several reasons:

- a) Control of vessel position within flexible riser operating watch circle in shallow water.
- b) Evening out line tensions in severe weather or after line breakage.
- c) Facilitating field installation.
- d) Ease of inspection of upper part of mooring chain in service.
- e) Emergency disconnection.

Passive systems are normally employed to reduce first cost and space requirements in the turret. The mooring line length and tension are pre-set during installation using a single winch which acts on each mooring line in turn. This is a time-consuming and weather dependent operation, and highly dependent on the reliability of the single mooring winch. To speed up installation and provide redundancy, two installation mooring winches are recommended from operators' experience.

### **2.13.4 Riser interface**

The layout of the risers and their associated hard piping/manifolding in the turret should consider the following factors:

- a) Riser installation operations.
- b) Access for operations e.g. pigging.
- c) Access (cranes and personnel) for maintenance.

- d) Flexibility for field expansion in terms of spare riser slots, riser installation arrangements, and ease of connecting future lines to manifold with minimum disruption to existing production.
- e) Safety aspects e.g. ventilation, escape means.

#### **2.13.5 Interface with production equipment**

The interface between turret riser systems and production equipment needs to take account of weathervaning of the FPSO around the turret. Fluid transfer is accomplished by either (a) a high pressure swivel system with multiple toroidal paths for different duties/ fluid paths or (b) a 'wind-on/off' system of hoses on a drag chain arrangement.

System (a) permits unlimited rotation of the FPSO around the turret and is therefore suitable for all types of FPSO. System (b) only permits rotation of +/- 270 degrees approximately before the FPSO must be 'unwound'. This limitation restricts system (b) to vessels with substantial thruster power and amidships turrets.

## **2.14 MOORINGS**

### **2.14.1 Design considerations for FPSOs**

In addition to meeting the normal strength requirements for vessel positional moorings, FPSO moorings are also required to contain the vessel excursions within the limitations of the flexible riser system. The flexible riser system represents a sizeable investment itself and operation outside its specified limits would mean delay and loss of production until testing and re-certification takes place. More extreme excursions could result in loss of riser containment and environmental pollution.

FPSO mooring systems have long service lives and frequent inspection of mooring lines is not desirable because of the interference with production and the need to mobilise other vessels to retrieve moorings.

There are therefore strong grounds for high reliability of FPSO mooring components and a design philosophy that accounts for the high economic penalty of mooring failure.

### **2.14.2 Mooring analysis**

Mooring analysis guidance is given in API RP 2SK Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures, 2<sup>nd</sup> Edition, 1996 (ref.51). This covers preliminary design of moorings using quasi-static methods and also final design using dynamic analysis methods. The factors of safety reflect the accuracy of the analysis method. For deepwater applications, it is important to include the contribution of riser loads, stiffness and damping in the mooring analysis.

The calculation of environmental loads and combination of wind, wave and current loads and their relative headings are covered in section 2.3 of these Design Guidance Notes. For mooring analysis, loads to be considered are steady-state (mean wind, current, wave drift), low frequency loads near the natural frequency of the vessel (varying wind and wave drift) and wave frequency motions.

The design conditions to be considered are:

#### **a) Intact design**

The system with all components intact should be checked in the 100year storm environment. Acceptable factors of safety are 1.67 against breaking strength if a dynamic analysis is used or 2.00 if a quasi-static analysis is used.

The fatigue life of the mooring system should be calculated using the site-specific wave scatter diagram. This should equal or exceed the design life which is the service life multiplied by a factor of 3 for inspectable components and 10 for non-inspectable components. The fatigue life of the mooring line is influenced by all components and defined by the weakest element.

b) Damaged case (one line broken)

The system with one mooring line broken should be checked in the 100year storm environment. After reaching equilibrium, the system should exhibit a factor of safety of 1.25 if a dynamic analysis is used and 1.43 if a quasi-static analysis is used.

If thruster assisted moorings are used, then the system should be checked for the above criteria in case of loss of thruster power or mechanical failure on one thruster. This case should be carefully considered where thrusters maintain the heading of the vessel into the environment and thruster loss would result in high environmental loads if the vessel is exposed to a beam environment.

c) Damaged case with transient motion

The dynamic behaviour of the system after one line is broken should be analysed to check the maximum excursion is within flexible riser limitations. The system should have a factor of safety of 1.05 if dynamic analysis is used, or 1.18 if a static analysis is used, in the transient condition.

The limit on FPSO excursion imposed by the flexible riser system should also be observed. This limit is determined by many factors that should all be taken account of during mooring/riser system design. Typical allowable FPSO excursions are in the range of 15%-30% of water depth. This is particularly onerous for shallow water applications. This limit may be constrained by riser clashing (with themselves or with moorings), bend stiffener limitations, pipe overbending, wire stresses, or other factors. The allowable offset can in many cases be increased by configuration design which includes mid-water buoyancy or arches, hold-back tethers near the seabed, large clearance between risers of unequal hydrodynamic characteristics, and large clearances between risers and moorings.

Where steel catenary risers (SCR) are proposed for deepwater applications, a detailed riser analysis is required at an early stage to determine the feasibility and limitations of SCR for the application. The riser design process must be integrated with mooring design in an iterative process. Early analysis of stresses, curvature, fatigue (including vortex induced vibration damage in strong current areas) is recommended in advance of FEED. Because of curvature and fatigue restrictions, SCR use on FPSOs would be restricted to deepwater applications i.e. to West of Shetlands areas.

### **2.14.3 Anchor design**

Different types of anchor have been used for UKCS FPSOs. For shorter field lives where the unit will be required to move to another location, drag anchors are commonly used. For longer term applications, piled anchors e.g. suction piles, may be used. Suitable conservative assumptions on soil behaviour and anchor behaviour should be made to take account of the large economic penalty and environmental consequences of damage to risers from loss of positioning. Guidance on anchor design is contained in ABS (ref.24) chapter 5 section 2, including suggested safety factors in table 1.

## **2.15 CRUDE OIL EXPORT**

### **2.15.1 Introduction**

The decision on oil export route is driven by the availability of a pipeline export system and the available ullage in the pipeline, and by the relative economics of pipeline versus shuttle tanker operation.

Shuttle tanker export is selected in the majority of cases in UKCS since:

- a) The field in question is in a frontier area with no pipeline infrastructure e.g. West of Shetlands.
- b) Pipeline ullage would constrain production.
- c) Shuttle tanker export has very low capex compared to a pipeline system since the shuttle tankers are generally leased on a long-term day rate. With a shuttle tanker export, there are therefore no high committed export costs in case there is poor field performance and early abandonment.
- d) Tanker export opex, although higher than pipeline opex, is proportional to the number of tanker offtakes, and will therefore reduce as production declines.

The disadvantage of tanker export is its vulnerability to weather interruption. However, this is largely mitigated by the large volume of crude oil buffer storage available in the hull of FPSOs. This major advantage is one of the key reasons for selecting FPSOs as opposed to TLPs or semi-submersibles for developments where offshore loading is necessary.

### **2.15.2 Export by shuttle tanker**

The objective of the shuttle tanker export operation is to maximise the production uptime and protect it from downtime from the harsh environment, whilst ensuring a safe operation and minimising the risk of spillage.

Due to the harsh environment, shuttle tanker export in UKCS has standardised on the arrangement where the shuttle tanker is astern of and approximately in line with the FPSO, following it as it weathervanes. Bow manifolds are used on the shuttle tankers to minimize the length of the export hose and enable “dry” storage on the FPSO. Shuttle tanker position relative to the FPSO is normally maintained by dynamic positioning.

Experience in UKCS shows an efficiency of typically >98% for the export system. The main drivers for efficient shuttle tanker export are:

Ability of shuttle tankers to connect and stay connected in high sea states.

Experience of operators in UKCS has shown that DP shuttle tankers can usually connect to the FPSO in the following conditions:

Criteria for	Connection	Disconnection
Significant wave height (m)	4.5	5.5 - 6.0
Maximum wave height (m)	8.0	9.5
Maximum wave period (s)	15	15
Wind speed (knots)	35-40	35-40
Visibility (m)	500-800	-

Table 2.15.1 - Shuttle tanker connection criteria

The percentage time connected can be calculated using the Weather Windows Software (ref.49). This program simulates the offloading operations, and can be programmed with a time series of wind speed and wave height for the field over the field life against which the program tests at 3-hourly intervals for the ability to connect/stay connected at a specified wind/wave threshold.

#### Adequate crude buffer storage

The crude oil storage level should be sufficient to minimise production downtime due to weather preventing shuttle tanker connection. Factors influencing the choice of storage level are discussed in section 1.2.2.

#### Crude export pumping rate

An important factor in maximising the offshore loading efficiency is to reduce the time required for transferring the cargo package from FPSO to shuttle tanker and make maximum use of the short weather windows. This is an economic trade-off between increased capex of larger pumps, lines and metering skids versus increase in operating efficiency. In UKCS, transfer times of between 14-28 hours are achieved.

### **2.15.3 Crude oil pumping and transfer hoses**

The equipment requirements on the FPSO for shuttle tanker loading are described in section 3.7.6.

### **2.15.4 Shuttle tanker operations**

Shuttle tanker dynamic positioning is a key element in ensuring a safe and efficient discharge operation. Shuttle tanker operations require careful consideration of the critical inputs viz. hardware, software and human, to ensure a safe operation. Guidelines have been published by INTERTANKO (Association of Independent Tanker Owners) entitled Risk Minimisation Guidelines for Shuttle Tanker Operations Worldwide at Offshore Locations, March 2000 (ref.52). This contains a risk minimisation process flow chart which focuses on critical elements in shuttle tanker operations and appropriate measures

to reduce risks to acceptable levels. See also OCIMF (Oil Companies International Marine Forum) Offshore Loading Safety Guidelines (ref.53) and UKOOA Tandem Loading Guidelines (ref. 48).

Section 2.8 covers shuttle tanker collision and preventative measures.

#### **2.15.5 Export by pipeline**

Oil export by pipeline is employed on only one UKCS FPSO at present. The requirement for gas export by pipeline is likely to be a priority for FPSOs to avoid flaring and for economic/strategic use of gas onshore or on neighbouring installations. Oil and gas export by pipeline will be dependent on current technology and limitations on high pressure swivel and flexible riser design.



## 2.16 BALLAST SYSTEMS

The capacity and location of ballast tanks should be designed to ensure that with crude oil storage tanks empty or part-full, the FPSO draught and trim meets requirements on stability, maximum trim for production equipment operation and minimum draught forward to prevent bottom slamming.

The capacity of the ballast system should be consistent with the crude oil discharge rate to shuttle tanker to ensure the above requirements are maintained during discharge operations. Ballast system design should take account of the particular demands of FPSO service:

- a) More frequent offloading and ballast operations, 5 - 10 times more than a trading tanker, imposes more wear on pumps.
- b) Offloading and ballasting at sea where ship pitch motions must be considered as well as trim.
- c) Redundancy in pumps to prevent pump breakdown having an adverse impact on production/offloading operations.
- d) Long-term serviceability and accessibility issues for pumps, piping and valves bearing in mind the difficulty of maintenance and repair in the field. This affects for example selection of materials for ballast piping and the design of the ballast sea chest to ensure it can be blanked off easily for maintenance of ship-side valves.

Ballast valves on FPSOs should fail in the closed position to avoid problems with uncontrolled ballasting, de-ballasting or cross transfer of ballast from one tank to another in the event of power failure. See LR (ref.22), Part 5 chapter 12, section 10.1.3.

Attention is drawn to the possibility of rapid flooding of the machinery space in case of failure of the ballast system (or other major piping system). Consideration should be given to the following mitigating measures to reduce this risk:

- Double shut-off isolation valves at the ship's side, with a remote power operated valve in addition to the local manual gate valve.
- CCTV systems to be installed in machinery spaces that are at risk of flooding with a display in the ballast control room.
- Clear and unambiguous bilge and high bilge sensors and alarms.
- Competent marine personnel, manning 24hours per day, in the ballast/ marine control room.
- A means of draining the space at risk of flooding.

Sections 3.6.4 and 3.7.3 also draw the designer's attention to the use of remotely operated main isolation valves on seawater and firewater duties in the lower levels of machinery spaces.

The design of vents to ballast tanks should ensure that there is no risk of vent blockage due to sticking of automatic vent closure devices e.g. WINEL valves, which could create a partial vacuum within the tank resulting in structural damage.

Section 3.7.4 covers ballast piping issues.

## **2.17 THRUSTERS**

### **2.17.1 Applications**

Thrusters may be fitted to FPSOs for several different reasons:

- a) To maintain heading in vessels fitted with an amidships turret that do not have natural weathervaning.
- b) To provide a major part of station-keeping capability in a deeper water application.
- c) To fine-tune heading to minimise roll motions so that the process is settled, for crew comfort and to assist shuttle tanker operations.

Thrusters may also be useful in fire or platform abandonment scenarios where the vessel can be rotated to clear fire or smoke from around production areas and living quarters and to provide a lee side for lifeboat launch.

The configuration of thrusters and power requirement differs for the above applications. In the case of a) and b), they are safety critical items, and so the configuration and the reliability and the availability of the electrical supplies have to be carefully considered.

In type (a), the thrusters are transverse normally tunnel-mounted with sufficient power to 'unwind' the vessel before the limits of the drag chain hose transfer system on the turret are reached.

In type (b), the thrusters are a combination of transverse thrusters to maintain heading and longitudinal thrusters (which could be main propulsion in a converted vessel) to reduce the environmental load transmitted to the mooring system.

In type (c), the thrusters are transverse stern-mounted, either tunnel or azimuthing. The power requirements are relatively small, since the thrusters are used only to fine-tune heading in moderate sea-states, and not to achieve major weathervaning. The normal uses are where the wind and current are not collinear with waves or swell, causing heavy rolling. Thrusters may be used to fine-tune the FPSO heading to reduce rolling. During shuttle tanker connection and loading, the thrusters may be used to reduce fish tailing and slow down changes in FPSO heading following a change in tidal strength or direction.

### **2.17.2 Design considerations**

Thruster sizing and type selection is a function of the duty requirements above, and the environmental loads the thrusters have to overcome. The environmental loading and thrust requirements can be assessed using the methods in section 2.3 of these Design Guidance Notes or more accurately from wind tunnel and model tank testing. Thrust requirements need to be increased for the effects of water inflow speed due to high currents.

The required power rating can be deduced from manufacturers' data or initially as 100 HP to provide 1.3 metric tonne thrust. Power requirements should be increased where necessary to cover continuous ratings.

Thruster redundancy depends on the duty requirement of the thrusters and requires an assessment of the probability and consequences of failure and the reduced capability of the system.

For new-build FPSO hulls of dumb barge configuration, it will be easier to fit an azimuthing thruster(s) in a cut-up stern rather than incorporate a tunnel. For converted vessels, a tunnel-mounted thruster(s) may be more easily fitted in the afterbody skeg.

Thruster type selection should take account of maintenance at sea requirements and allow working parts to be withdrawn into the hull for inspection and repair rather than diver-assisted keel hauling.

## **2.18 OPERATIONAL CONSIDERATIONS**

Design of the FPSO should take account of the demands of long-term service with in-situ inspection and maintenance and the requirements of performing this safely with minimum interruption to production activity.

An integrity management plan should be developed in parallel with the design of hull structure/systems and the mooring system. This document will cover inspection strategy, the frequency of inspection, criteria for acceptance of results and plans for repair or replacement of failed items with a permissible time limit for these to be implemented. Design safety factors, fatigue lives, redundancy and corrosion margins should be compatible with the inspection regime in the integrity management plan.

Hull design should enable safe means of access to all tanks and void areas for inspection and maintenance at sea. Consideration should be given to locating stiffeners in double skin wing tanks and in double bottom where possible to facilitate inspection without entering cargo spaces. Access to pumps and valves for change-out should be provided.

Tank arrangements should provide a sufficient number of tanks to enable production operations to continue at close to optimum efficiency while selected tank(s) are cleaned for inspection and maintenance. Tank venting arrangements should facilitate purging of selected tanks for entry.

The International Chamber of Shipping & Oil Companies International Marine Forum publication International Safety Guide for Oil Tankers & Terminals (ISGOTT) (ref.54) is a reference for many items relevant to tanks operations.

Other useful reference sources are the Tanker Structures Co-operative Forum Condition Evaluation & Maintenance of Tanker Structures (ref.55), which deals mainly with corrosion, and their Guidance Manual for the Inspection and Condition Assessment of Tanker Structures (ref.56) which deals with weld defects and possible repair details.

The mooring integrity plan should include a reliable means of monitoring the integrity of each mooring line and anchor. The permissible delay until a failed line is replaced should also be covered. This will depend on the time of year and the probability of environmental loads exceeding the reduced capacity of the mooring system. Results from DNV DEEPMOOR and ND/MCS Integrated Mooring and Riser Design Study suggested a time limit of 3 months.

# **UKOOA FPSO DESIGN GUIDANCE NOTES FOR UKCS SERVICE**

## **PART 3**

### **PRODUCTION FACILITIES**

#### **CONTENTS LIST**

##### **3.1 INTRODUCTION**

##### **3.2 FRONT END ENGINEERING**

3.2.1 Performance Standards and Specifications

3.2.2 System Sizing

3.2.3. Design Safety Case

##### **3.3 HYDROCARBON AND NON-HYDROCARBON SYSTEMS: CONTINGENT FACTORS**

3.3.1 Introduction

3.3.2 Gas processing including flaring and venting

3.3.3 Water Injection

3.3.4 Produced Water Handling and Disposal

3.3.5 Sub-sea Infrastructure

3.3.6 Export of Oil and Gas via Shuttle Tanker or Pipeline

3.3.7 Potential for Recovery of VOCs

3.3.8 Decommissioning and Abandonment

##### **3.4 DEVELOPMENT OF PHILOSOPHIES**

3.4.1 The Purpose of Design Philosophies

3.4.2 Safety Management

3.4.3 Environmental Strategy and Management

3.4.4 Cargo Management

3.4.5 Area Classification

3.4.6 HVAC

3.4.7 Electrical

3.4.8 Controls

3.4.9 Noise and Vibration

3.4.10 Corrosion Management

3.4.11 Isolation for Maintenance

### **3.5 GLOBAL LAYOUT: DEVELOPMENT FACTORS**

- 3.5.1 Introduction
- 3.5.2 Fires and Explosions including Blast and Firewalls
- 3.5.3 Escape Routes
- 3.5.4 Temporary Refuge (TR) and FPSO Evacuation
- 3.5.5 Containment of Hydrocarbon Spillage
- 3.5.6 Greenwater
- 3.5.7 Environmental Exposure
- 3.5.8 Main Access and Removal Routes
- 3.5.9 Main Cable Routing
- 3.5.10 Mechanical Handling and Lay-down Areas
- 3.5.11 Future Expansion and Upgrading

### **3.6 LOCAL LAYOUT: DEVELOPMENT FACTORS**

- 3.6.1 Living Quarters and Offices
- 3.6.2 Control Rooms
- 3.6.3 Maintenance Access and Removal Routes
- 3.6.4 Operations Access and Operability
- 3.6.5 Workshops and Stores

### **3.7 FPSO MAJOR SYSTEMS INCLUDING SYSTEM INTEGRATION/ SEGREGATION**

- 3.7.1 Introduction
- 3.7.2 Firewater
- 3.7.3 Seawater
- 3.7.4 Bilge and Ballast
- 3.7.5 Inert Gas
- 3.7.6 Product Offloading
- 3.7.7 Vents
- 3.7.8 Drains
- 3.7.9 Main Electrical Power
- 3.7.10 Emergency Electrical Power
- 3.7.11 HVAC
- 3.7.12 Fire Protection
- 3.7.13 Fire and Gas System
- 3.7.14 Production and Marine Controls (including ESD)
- 3.7.15 Telecommunications
- 3.7.16 Cranes
- 3.7.17 Turret and its Support Systems
- 3.7.18 Safety related sub-systems

### **3.8 FPSO SMALL UTILITY AND SUPPORT SYSTEMS**

- 3.8.1 Diesel Fuel
- 3.8.2 Fuel Gas
- 3.8.3 Compressed Air
- 3.8.4 Potable Water
- 3.8.5 Heating Medium
- 3.8.6 Cooling Medium
- 3.8.7 Sewage
- 3.8.8 Helifuel



# **UKOOA FPSO DESIGN GUIDANCE NOTES FOR UKCS SERVICE**

## **PART 3**

### **PRODUCTION FACILITIES**

#### **3.1 INTRODUCTION**

An FPSO is an offshore floating production and storage installation which should be considered as a single unit. The approach to its design must take into account that it is a single unit, even though it is ship-shaped. In the past, the FPSO's production facilities have at times been viewed, somewhat simplistically, as the modules located on the main deck of the hull providing the essential crude oil storage.

The production facilities should be regarded as all the physical systems needed to permit the FPSO to function fully and safely. The marine systems are just as important to the safe performance of the installation as the oil and gas handling systems and should not be considered in isolation. Not all the systems necessarily interact with one another but many are interdependent. It is essential, therefore, that the interdependencies are fully considered and that all the interfaces, both physical and system related, are identified and addressed early in the design phase.

Part 3 reviews a range of significant design related issues which have a bearing on the ability of the FPSO to ultimately function safely and efficiently over the time it is in the field. It covers matters such as the development of design philosophies, layout, and general system design. Although it does not attempt to fully address the design of the oil and gas production systems, it does touch on a number of issues, or contingent factors, connected with hydrocarbon recovery and processing which can have a significant bearing on the FPSOs ability to function as originally envisaged.

It is not intended to provide a commentary on the approach to the management of an FPSO project, but it will at times indicate where certain project management decisions can have a bearing on the engineering outcomes.

## **3.2 FRONT END ENGINEERING**

Whether the project is fast track or is to be run to a more measured timetable, the front end engineering design phase, (FEED), enables the foundations for the success of subsequent phases to be laid down. The project Statement of Requirements, if it has already been drawn up, can be refined and the more detailed Basis of Design can be developed, along with other activities discussed below.

During this phase, it is likely that long lead major equipment items such as turbogenerators, compressors, high pressure pumps, large pressure vessels etc will be ordered. A high level of definition will therefore be needed for these items, at least, to minimise the risk of significant change during their design and manufacture.

### **3.2.1 Performance Standards and Specifications**

These standards, as their name suggests, will set out the performance of the FPSO, its systems and equipment. The standards will indicate the levels of reliability, robustness and durability which will be needed to achieve the safety, environmental and production uptime targets which the field development aspires to. They should not be confused with detailed specifications.

#### **Performance Standards**

A performance standard for a particular item of equipment or system may take the format of a simple data sheet or sheets. The creation of performance standards encourages the owner/ operator and the designer to give careful consideration as to how the item should perform in terms of output, throughput, behaviour etc under the complete range of operating conditions, both normal and abnormal, likely to be encountered in the course of the FPSO's life. Furthermore it enables emphasis to be placed on the need for high standards of reliability and the consequences of low reliability.

#### **Functional Specifications**

Functional Specifications may be employed to set out the requirements which a range of equipment items have to meet to try to ensure a degree of uniformity in layout and peripheral items such as provision of small bore piping, compression fittings, valve types, pressure switches, paint systems, junction and terminal boxes etc. These specifications should go some way to avoid a large number of different item types from a wide range of manufacturers. They should also help to limit the number of vendors likely to be involved for support and maintenance during the operations phase and help to keep the range and levels of the spare parts holding within manageable proportions.

## **Industry Standards and Specifications**

Over recent years, there have been several UK oil industry initiatives to reduce costs of equipment and services. One of these was the CRINE initiative, as part of which model specifications were developed in an attempt to reduce and dispense with the highly prescriptive and costly levels of specifications employed during the 1970's and 1980's. It is also recognised that a wide range of accepted and acceptable national and international standards and specifications exist, e.g. API, BS, ISO, EN, covering the design, manufacture, assembly, installation and operation of the generic types of equipment. It should therefore not be necessary for owners and designers to overly customise these standards and specifications to reflect their preferences.

During the Front End Engineering phase, the preparation of performance standards together with functional specifications and the judicious selection of industry standards and specifications (and any model specifications, if considered to be suitable), should go some way to ensuring that the owner and the operator of the FPSO will not only get the most suitable equipment and systems but the desired efficiency and longevity.

## **Criticality Ratings**

As part of fast track projects, it has not been uncommon for FPSO owners and their major design contractors to let out the designs for small modules or large skids to the supplier of the principal item or items of equipment to be housed in the modules or skids. Two typical examples are gas compression and oil separation packages. As these suppliers and their sub vendors are two or even three steps removed from the design of the FPSO, their appreciation of the particular requirements of the FPSO may be limited.

This can affect the ability of the equipment to perform satisfactorily and so it may become necessary for the owner and the major design contractor to have a closer involvement in the design and build of the particular package. The degree of involvement can be determined by assigning a criticality rating to the equipment. As the name implies, the rating reflects the importance of the equipment to the safety and the uptime of the FPSO: the higher the rating the greater the involvement of engineering and quality assurance staff at vendor and sub-vendor level to secure a satisfactory product. The Front End Engineering phase is the ideal time to assess criticalities and to draw up the ensuing action plans.

### **3.2.2 System Sizing**

The FEED phase will allow the basic design parameters of the FPSO to be firmed up, with the designers liaising with the reservoir engineers to ensure that there is a high degree of confidence in the reservoir profiles and fluid properties. For example, a late increase in the hydrogen sulphide content of the produced fluids can have a serious impact on equipment and system build and on schedule if the relevant material specifications have not been applied.

## **Production Profiles and Flowsheet Development**

System sizing will most likely be carried out using proprietary process engineering simulation packages. The refining of flowsheets or process flow diagrams (PFDs) for the hydrocarbon and principal utilities will be ongoing, and at this stage consideration has to be given to the possibility of future expansions, either within the field or from satellite developments of other accumulations in the vicinity. The production profiles will indicate the duration of the ramp-up to peak oil output, the nature and duration of the peak production phase and the tail off. A sharply spiked profile with a short plateau may not justify sizing the facilities for the peak. On the other hand, the likelihood of in-fill drilling, satellite development or the FPSO acting as host producer may have a major influence on how the facilities are finally sized.

## **Fluids Properties**

At this stage, the properties of the reservoir fluids have to be well defined. During exploration and appraisal drilling, it has often been the case that insufficient attention has been paid to the taking, handling, analysis, storage and retention of fluid samples. Inadequate fluid data can result in a degree of guess-work on the part of the process designers which may create future operational problems. Parameters such as gas-oil ratios, wax content, pour point, specific gravity, viscosity, arrival temperature etc need to be fully defined so that the designer can take in to account fouling, corrosion, chemical injection, heating, cooling etc when sizing the various systems.

## **Production Trains and Equipment Sparing**

Decisions have to be taken on the number and size of oil separation and gas processing trains, the configuration of the water injection system and the sparing of key items of equipment e.g. 2x50% pumps or 2x100% pumps or 3x33%pumps.

System sizing and the development of the layout of the main deck are concurrent, iterative activities. These lead in turn to the sizing and location of production modules and/ or pallets and the development of the construction and installation strategy. In addition, power profiles will be produced, leading to the sizing and selection of the main power system in terms of size and numbers of power generation units, especially spare capacity.

### **3.2.3 Design Safety Case**

The UKCS Safety Case Regulations (ref 9), regulation 4 and guidance note 87, call for the submission of a Design Safety Case to the Offshore Safety Division of the Health and Safety Executive. As the name implies, the document sets out the essential features and provisions to be incorporated in the detailed design of the FPSO to afford the highest

levels of safety on the installation. The project schedule must allow for the development of the Design Safety Case, and its submission to and review by the HSE.

System sizing and layout studies will have a bearing on the assessments of the risks and consequences of explosions, fires, collisions, impacts and other major incidents. The nature, likelihood and possible consequences of such incidents will influence the degree of equipment segregation, the provision and location of firewalls, blastwalls, escape tunnels etc, as well as the provision and extent of passive and active fire protection. A carefully prepared high quality document, submitted in a timely manner, is essential if late and major design changes are to be avoided.

### **3.3 HYDROCARBON AND NON-HYDROCARBON SYSTEMS: CONTINGENT FACTORS**

#### **3.3.1 Introduction**

While the oil separation system is probably the largest system within the production facilities, there are other sizeable hydrocarbon and non-hydrocarbon systems which have an influence on FPSO design. This section does not discuss the design of the oil and gas systems or of these other systems in detail but highlights a number of factors which should be considered and possibly allowed for in the design. Aspects of decommissioning and abandonment are also touched on.

#### **3.3.2 Gas Processing Including Flaring and Venting**

The size of the gas processing system will be dictated largely by the gas-oil ratio, the volume of produced fluids and whether there is a high pressure export or disposal system or a requirement for gas lift.

Given the environmental and economic desirability of minimising the flaring of gas, the owner will have to decide how best to ensure high reliability and uptime of the gas handling system. A single train of gas compression may be adequate where the gas production rate and the fuel demands of FPSO are in balance. Where the gas production rate is high, then environmental considerations may dictate the selection of a twin train of compression. In the past, very low pressure gas in, for example, the third stage separator and coalescer would have been flared or vented. Now, the provision of a very low pressure gas collection and compressor system will serve to further reduce flared and vented emissions.

Gas end-users, such as turbines, injection wells or pipeline, will dictate the specification of the gas, and may necessitate the provision of a gas dehydration system. A decision then has to be made on whether all the gas handling facilities will be mounted in one or more modules, with attendant considerations of global and local layout, operability and maintenance access.

Safe disposal of gas in emergency is normally via the flare system although in some circumstances venting may be used, providing adequate dispersion can be demonstrated. The flare system usually consists of an HP system, and LP system and an atmospheric vent for very low pressure disposals.

The location of the flare stack is determined by the position of the Living Quarters, forward or aft. Elevated flares or ground flares may be considered. In the case of an elevated flare, height will be dictated by flare tip type, radiation and noise levels, proximity of the base to other items of equipment such as the turret structure, and dispersal patterns of the hot gas plume. Where an elevated flare or a ground flare is

located at the stern, the possible effects of the plume on the shuttle tanker have to be considered.

Where cold venting is used, consideration has to be given to the location of the vent outlet, plume dispersal, ignition of the vent plume from external sources including electrostatic discharge and the flare itself, exposure of personnel to radiation from an ignited plume and snuffing of an ignited plume.

The sizing of relief devices and the flare system will usually be in accordance with the API Codes of Practice, API RP 520 Sizing, Selection and Installation of Pressure Relieving Devices in Refineries (ref 57) and API RP 521 Guide for Pressure Relieving and Depressuring Systems (ref 58).

### **3.3.3 Water Injection**

Reservoir pressure support will usually be provided by the injection of high pressure water. The water may be filtered, deaerated seawater, or produced water or a mixture of both. Additional treatment of the injected water may be needed such as the injection of corrosion inhibitors, scale inhibitors and biocides.

Removal of oxygen from seawater may be carried out by vacuum deaeration or by nitrogen stripping. Both methods require a tower and so the position and the height of the tower have to be considered carefully from the point of view of FPSO motions.

Filtration of seawater will be by coarse filters possibly backed up by fine filters. In selecting a filter unit, consideration has to be given to on line cleaning of filter elements using backwash to avoid the need for regular intervention. The filtration system should also take into account “bloom” periods of plankton when the ingestion of large quantities of plankton will lead to rapid increase in pressure drops across the filters and the need for more frequent cleaning cycles.

Injection of the water is via high pressure centrifugal pumps. The pump casing is usually of the barrel design. Depending on the volume of water required and the criticality of water injection for reservoir support, it may in some cases be possible to use only a single high pressure pump. In the design of the high pressure injection pipework consideration has to be given to the possibility of high surge pressures arising from the rapid closure of valves on the subsea injection flow lines and christmas trees.

### **3.3.4 Produced Water Handling and Disposal**

In recent years it has become usual practice to reinject produced water into the reservoir, not only to provide pressure support but to avoid potential environmental problems arising out of the continuous overboard disposal of the fluid. Produced water may be

injected on its own or with treated seawater, provided that the two fluids are compatible and the risk of scale precipitation in the injection string and reservoir is low.

On older fixed installations treatment of produced water to reduce its oil content prior to overboard discharge used to be done using settling tanks, flotation tanks and skimmers. Treatment is now more commonly achieved through the use of batteries of hydrocyclones. Not only are they modular and compact but, more importantly, they are insensitive to FPSO hull motions.

Provision has to be made for the handling, storage and disposal of produced water when the injection pumps are not available. Hull tankage may have to be provided to cover for outages of short duration. In the case of a lengthy outage, the produced water will have to be discharged over board to the oil content specification, currently set at 40 ppm oil in water, laid down by the Department of Trade and Industry, pursuant to the Prevention of Pollution Act 1971, as amended (ref 59).

### **3.3.5 Subsea Infrastructure**

Whether the field is being developed through a single reservoir or a number of reservoirs, a subsea infrastructure will be needed, which will consist of production wells, and injection wells for water and gas. Although the design and provision of subsea facilities are outwith the scope of these Guidance Notes, it is important to make allowances in the FPSO facilities design for elements for the control and monitoring of the subsea equipment and for its chemical injection requirements.

The main interface between the FPSO systems and the subsea equipment is the turret and its support structure. Risers and umbilicals terminate within the turret. Umbilicals will contain both electrical and hydraulic power and control cables which interface with the respective power and control packs. These can be located, to facilitate operations and maintenance, in a dedicated room within the turret structure. The control packs will in turn interface with the main control room usually via dedicated slip rings within the turret swivel or occasionally via a telemetry link.

Chemicals such as methanol and corrosion inhibitors, depending on usage, will pass from the FPSO into the turret via a suitable swivel port.

Where a “wind-on” turret is used, no swivel is required and utility connections etc are direct via flexible hoses.

Once the number of wells required for the field development has been established, close liaison is needed between the subsea infrastructure designer, the turret designer and the FPSO production facilities designer to ensure that the requirements of each party are defined and the interfaces are fully identified. Input is also needed from the operations team on control and monitoring requirements within the main control room.



There may also be a requirement for pigging of the subsea pipelines and risers. Any pigging facilities will be located in the turret and the design will be carried out by the supplier of the turret since the turret, swivel and their facilities are incorporated within a single proprietary design. The design and build of pig launchers/ receivers with their isolation valves, interlocks and vents must ensure that pigging operations can be conducted safely. Where oil is exported via subsea pipeline, the design of the pigging facilities will have to comply with the relevant sections of the Pipelines Safety Regulations 1996 (SI 1996/ 825) (ref 60). Again, good interface management in this area is just as important as sound engineering design.

### **3.3.6 Export of Oil and Gas via Shuttle Tanker or Pipeline**

#### **Export of Oil**

Oil can be exported directly via a shuttle tanker or via a high pressure pipeline into a larger pipeline gathering system. In the UKCS, shuttle tanker is the more common export route. Oil can also be exported indirectly via a lower-pressure pipeline to an FSU in the vicinity of the field.

Direct export into a pipeline system will depend on the availability of riser technology appropriate to the water depth, the flow rates and the system pressure. In theory, on board storage of oil on the FPSO should not be necessary as the situation is similar to export from a fixed platform. However, owners may make provision for on board buffer storage to cover for short outages which could occur in the pipeline system or in the turret and swivel systems.

Direct export into a shuttle tanker from the storage tanks requires high capacity cargo transfer pumps to ensure short turn around times for the tanker. The oil flows from the pumps via a transfer hose which is deployed from the FPSO stern. Flow rates will dictate the diameter of the hose, and FPSO/ shuttle tanker separation during transfer will determine the length. The hose may be stored flat on a “runway” or on a reel.

Where a reel is used, it will be located at the FPSO stern. In that location, it will be necessary to consider its proximity to the living quarters, the temporary refuge, escape ways and the lifeboat embarkation station(s) from the point of view of leakage and spillage, especially in emergency situations. Consideration has to be given to the removal and repair of damaged hose sections and so suitable space and handling provision has to be made.

The cargo pumps will usually be deep well hydraulically powered units. However, in the case of tanker conversions, the owner/operator may choose to use the existing pump units located in the cargo pump room in the machinery space. The removal of deep well pumps for maintenance must be considered in layout and mechanical handling studies, to avoid potential clashes with production equipment located in modules above the cargo deck.

The design of the hydraulic power system must be such as to minimise the effects of noise and vibration both inside the hull machinery spaces and on deck, especially near the living quarters. Care must be taken to minimise the transmission noise into sensitive areas via the structure, pipework and piping supports. The design of the rigid high pressure hydraulic pipework must take into account deck flexure and removal and replacement for maintenance.

Indirect export into a nearby FSU is similar to direct export to a pipeline system, except that the pressures will be lower and the pumping units will be smaller, possibly single stage centrifugal units instead of multistage high pressure barrel units. Again, the FPSO owner has to decide whether FPSO buffer storage is to be provided to cover for short outages of the turret swivel, the export pumps or the FSU

### **Export of Gas**

Gas surplus to fuel requirements can either be reinjected into the reservoir or adjacent suitable geological formations for storage (which may or may not involve subsequent recovery) or it can be exported via a suitable pipeline. It is no longer environmentally acceptable to flare or vent surplus gas on a continuous basis. Either way, high pressure compressors will be needed along with gas dehydration facilities and the provision for the injection of chemicals to prevent, among other things, hydrate formation in the subsea system.

#### **3.3.7 Potential for Recovery of VOCs**

Volatile organic compounds (VOCs) exist in the vapour space above the surface of the oil in the cargo tanks of the FPSO and the shuttle tanker. Filling of the tanks with crude product will displace the VOCs, vapours and inert gas from the inert gas blanket to atmosphere via the tanks' vent system. The drive to improve the environmental performance of FPSO and shuttle tanker operations has prompted consideration in recent years of systems to recover VOCs for reinjection into the FPSO's gas processing system.

During the transfer of crude from the FPSO to the shuttle tanker, it may be possible to lead the displaced gases, via a low pressure hose parallel to the product transfer hose back, into the tanks of the FPSO. In this way the tanker avoids venting the gas to atmosphere. Some tankers may already be provided with vent gas stripping units so that the actual volatile compounds are removed before the inert blanket gas is discharged to atmosphere. If this is so, then no parallel transfer hose may be necessary.

Where a transfer hose is required, it will most likely be stored on and hence deployed from the stern of the FPSO, in which case provision has to be made for a reel (or other payout system) and associated hydraulic (or electric) power as well as facilities for hose handling and repair.

When the cargo tanks on the FPSO are being filled, displaced blanket gas can be transferred into empty tanks. Any surplus gas can be recovered via a very low pressure system using a blower/ compressor into the LP gas system of the FPSO for further compression and after which it may be used as fuel or eventually exported.

### **3.3.8 Decommissioning and Abandonment**

The obvious advantage of the FPSO compared to the fixed jacket installation is that at the end of the field life it can be disconnected from its moorings and its risers and towed away either for subsequent reuse on another field or for breaking up.

Although an FPSO and its facilities will be designed to ensure that it will remain on location throughout its field life and will not have to be taken prematurely to dry dock for repairs, inspection or modification, it is prudent for the designer of the turret to allow for an earlier than planned disconnection. Ideally, mooring and riser disconnection should be the reverse of their installation but provision should be made to ensure that if this not the case, then allowance has been made for an efficient disconnection procedure.

Decommissioning of the FPSO will involve the total purging and cleaning of all hydrocarbon systems, and systems which closely interface with them, before the removal of modules or pallets and the subsequent removal of equipment. The original process engineering design will have allowed for purging and cleaning as part of routine operations leading to planned and unplanned shutdowns etc. It is recommended that at the design stage consideration is also given as to how the systems might be decommissioned. Provision at the design stage for a likely decommissioning scenario can contribute to making decommissioning safer and more environmentally friendly as well as limiting the cost.

The guidance in the DCR guide (ref 8) pertaining to Regulation 10 of the DCR, Decommissioning and Dismantlement, should be noted.

### **3.4 DEVELOPMENT OF PHILOSOPHIES**

#### **3.4.1 The Purpose of Design Philosophies**

Before the detailed engineering of an FPSO gets underway, the project Statement of Requirements and the Basis of Design documents should be in place as a minimum. They provide a high level route map for the project management and engineering teams on the overall objectives for the project.

The next level of the route map will be provided by a series of strategies/ design philosophies. The development of these philosophies will provide a more detailed framework for the design, permitting upfront identification and resolution of a wide range of issues ahead of the detailed design phase when the pressures of the project schedule may not always be conducive to carefully considered decision making.

The strategies/ philosophies discussed below are deemed to be the principal ones which can provide an overall design plan, not just for production systems or marine systems but for the FPSO as a single entity. They serve as a focal point to which all design groups can refer. Provided they are clearly-written, unambiguous documents endorsed by the project and engineering management, they will go a long way to ensure a common understanding of how the major issues of the FPSO design will be handled. They are, therefore, an essential tool for both global design consistency and for effective interface management.

As the design phase progresses, it may be advisable to update the philosophies to assist those developing the operating instructions.

#### **3.4.2 Safety Management**

The safe operation of the FPSO and the safety of its crew over its life is the prime objective of all concerned in its design, build, installation and operation. The safety management philosophy, although prepared by the project safety team, has to be shared with and endorsed by all key project participants. It will provide the foundation for the Design Safety Case and the Operations Safety Case and will outline the steps in the safety decision-making process which will in turn influence the design. The Safety Case regulations (ref 9), the DCR regulations (ref 13) and the PFEER regulations (ref 11) will provide the essential minimum pointers for this philosophy to follow.

It will address the identification of major hazards and the subsequent analysis of these hazards and their frequency. It will give an outline of the approach to the prevention of fires and explosions and other major accidents, and subsequent control and mitigation. (During the detailed design phase further guidance may be obtained from UKOOA Guidelines for Fire and Explosion Hazard Management (ref 61)). Explosion modelling will be discussed. It will cover in outline both active and passive fire protection measures

and the provision of fire and blast walls. Escape, evacuation and rescues will also be covered to enable layouts to be developed and safety equipment provisions to be made.

It will address dropped and swinging object protection and the possibility and consequences of ship collision.

A schedule of safety related studies will be presented to ensure that these are carried out in an optimum sequence to minimise the effects of findings and recommendations on the design programme. Such studies might cover wind tunnel testing, smoke and gas ingress, and smoke clearance. Motion effects and human response will also be included.

The Safety Management philosophy for the design phase will enable the Operations team to form the basis of its safety management system (SMS) which will be a major component of the Operations Safety Case.

### **3.4.3 Environmental Strategy and Management**

All new offshore developments in the UKCS are now required to perform an Environmental Impact Assessment (EIA) for submission to the Department of Trade and Industry Oil and Gas Directorate, in accordance with the Offshore Petroleum Production and Pipelines Act (Assessment of Environmental Effects) Regulations 1999 (SI1999/360) (ref 14). The preparation of the EIA will prompt the field developer to consider his environmental objectives in the light of the potential interactions between the FPSO (along with its export route and its subsea infrastructure) and the ecology of the field, for example fish breeding grounds, cetacean migration routes, seabird activity, and seabed flora and fauna such as corals.

The starting point is a base line survey of the proposed field location and it is against this survey that the impact of the FPSO and the other field systems and hardware can be assessed. Provision has to be made therefore for regular monitoring against the baseline, reporting of changes and implementing improvement measures where these are indicated.

The interactions, which can be short and long term, can arise from a range of activities and operations including:

- drilling in the field and the disposal of drill cuttings
- trenching of buried subsea pipelines
- noise from onboard machinery and associated marine traffic
- overboard discharges from the FPSO such as treated produced water from the reservoir which has not been reinjected
- slops tank water
- ballast water where a more desirable segregated ballast system has not been used
- warm return seawater from the main cooling circuit
- sewage.

Operators should also consider the requirements of the draft Offshore Chemicals Regulations 2001 (ref 62).

However, it is not just the interaction with the local environment which has to be taken into account but also the interaction with the global environment in the form of emissions of flared gas, vent gas, VOCs and exhausts from internal combustion engines. Emissions of carbon dioxide, oxides of nitrogen and of sulphur and methane have all to be considered. Further guidance on these and other emissions are contained in the Offshore Combustion Installations (Prevention and Control of Pollution) Regulations 2001 (SI 2001/1091) (ref 63).

The field developer, along with the FPSO owner and operator, has to set down environmental discharge targets for the short term e.g. during offshore commissioning, field start-up and early operations, as well as for the long term on the basis of using the most appropriate technology and procedures that are available or are likely to become available and proven within a realistic time frame.

Environmental aspirations and targets have to be discussed well in advance with the designers of the FPSO to ensure that these are realistic and achievable. An aspiration towards, say, zero flaring may only be achievable through increased levels of complexity in process system design and control. With the introduction of emissions trading schemes, it may be possible to adopt a strategy of minimum flaring through the use of a conventional flaring system coupled with a strict flare management policy.

A clear, comprehensive environmental strategy at project outset, along with an indication of the operations environmental management system, will guide and assist the designer in providing the systems, hardware, controls and monitoring facilities to meet the desired performance targets.

#### **3.4.4 Cargo Management**

For a purpose built FPSO, it is possible to design the cargo handling system from scratch. The creation of a cargo management philosophy will permit the operations team to work with the design team in addressing not only the interaction with the crude oil production facilities but also the issues associated with:

- Offloading to shuttle tankers
- Reception tanks
- Transfer between tanks and associated valving
- Inerting of tanks
- Venting of tanks
- Tank inspection and isolation for entry
- Tank washing
- Cargo pump types and pump maintenance
- Protection against over- and under-pressuring of tanks

- Prevention of in-tank explosions
- Manifold configuration and isolation
- Product heating and cooling
- Redundancy as cover against equipment breakdown

The cargo management philosophy should be written to ensure that the hull systems designer and the designer of the production facilities work as one to create a system which will provide the highest standards of safe operation and a high degree of operating flexibility. For example consideration may be given to the use of two parallel vent systems, one for tank filling and one for tank discharging, to handle the different rates of tank out-breathing and in-breathing for these two operations.

While Classification Societies' Rules for the classification of ships and tankers can provide useful pointers, adherence to the Rules will not always provide full guidance on the issues above or guarantee the desired outcomes.

In the case of a tanker conversion, the cargo system may have already been designed and built and is therefore likely to require some form of adaptation to meet the needs of the FPSO. Given the imperatives of a fast track project, major modifications to the cargo system may not always be welcome. Nevertheless, a cargo management philosophy can serve to highlight where the existing system may have limitations. If only small modifications are authorised, then provisions can be made to fully describe the limits of safe operation and thus avoid or minimise the risks of incidents such as tank over or under pressuring.

### **3.4.5 Area Classification**

It has not been uncommon on past FPSO projects to have two electrical hazardous area classification systems on the same vessel. On some FPSOs based on converted tankers, equipment on the main deck and in the cargo pump rooms had been designed initially in accordance with tanker area classification codes of practice. In some instances this had resulted in main deck areas classified as non-hazardous.

Production equipment above the main deck was designed in accordance with Institute of Petroleum (IP) code part 15 Area Classification Code for Petroleum Installations (ref 64) or another similar internationally recognised code. The mix of the two codes inevitably resulted in the removal and replacement of many electrical items on the main deck area due to production area zones extending into those areas of the main deck which had been rated as non-hazardous.

Unless they are told otherwise, shipyards will provide tanker hulls in accordance with tanker practice. However, the principal Classification Societies now recognise that a single code of practice should be applied to the FPSO in its entirety reflecting the production duty of the FPSO. The production of a Hazardous Area Classification philosophy document at project outset which gives a single approach based on IP15

and/or the most recent editions of classification society rules, e.g. Part 7, chapter 2 of Lloyds Rules (ref 22), and Section 4 of DNV's Offshore Standard OS-A101, Safety Principles and Arrangements, January 2001 (ref 65), will remove any ambiguity and ensure consistency across the entire FPSO.

### **3.4.6 HVAC**

A tanker, whether second hand or new intercept, will have an HVAC system which has most likely been designed in accordance with marine practices. Although it might be expected that new build FPSOs will have their HVAC systems designed at the outset to reflect their function as a production facility, by following the design approach used on fixed installations, this may not always be the case. On a number of new FPSOs the marine based HVAC systems specified by the shipyard have had to undergo significant upgrading to comply with production installation service.

A comprehensive HVAC design philosophy should ensure that the HVAC system designer will take into account the special requirements of a floating production facility. The philosophy should include not only the living quarters and machinery spaces but also any other hull compartments or superstructures used for control panels, switchgear and storage. In addition any enclosure in the turret has to be included along with the special requirements of the ventilation of the enclosed escape tunnel.

As well as setting temperature, humidity and noise levels and the number of air changes per hour for each room or space, the philosophy will include other major topics such as

- Provision of smoke and gas detection
- Prevention of smoke ingress into accommodation and control areas
- Smoke clearance, especially in accommodation and control areas and in escape routes
- Interaction with the FPSO's main fire and gas system
- Ventilation of the TR and main control areas in emergencies and shutdown of non-essential users
- Provision of minimum life support in upset conditions
- Implications of hazardous area classification
- Dispersion of gas in areas where gas escapes may occur and use of supplementary mechanical devices
- Fire protection and rating of dampers and ductwork
- Controls, control stations and control system configuration (avoiding undue complexity)
- Position of inlets and exhausts relative to hazardous areas (especially where the LQ is downwind of the production facilities)
- Testing of fire and gas and shutdown dampers
- Spareage of fans
- Pressurisation of spaces and airlocks



Classification Societies Rules now generally reflect the need to provide HVAC designs appropriate to an FPSO, not just a tanker. Although now defunct, the Department of Energy Guidance Notes (Fourth Edition) Section 47 (ref 4) still provide a useful guide to designers, with more detailed coverage than that given in the Classification Societies Rules.

### **3.4.7 Electrical**

A preliminary FPSO equipment list and a outline load schedule will enable the electrical designer to develop the key one-line diagram, set generation voltage levels and determine the required generation capacity. Unlike a new build FPSO, where these activities should be straightforward, a tanker conversion will bring the added complexity of existing generation facilities and consumers and the associated distribution and control systems.

A decision will therefore be required on whether or not to integrate the existing tanker system with the new system needed to support production facilities, and the extent of any integration. Furthermore, the existing generators will be liquid fuelled and so their conversion to dual fuel service (for both environmental and operating cost reasons) and the safety implications of introducing fuel gas into the existing machinery space have also to be considered

The electrical design team may have to address a number of options such as

- Retaining the existing systems including the generators, and, providing the equipment and cabling specifications are acceptable, integrating the existing and the new via a central control unit
- Retaining the existing systems but decoupling the tanker's generators and using a single source of power, i.e. gas turbine generation, across the FPSO.
- Mothballing, if space permits, or removing the existing systems and having a single system approach.

The electrical design philosophy will call up the standards and specifications to be used for transformers, switchgear, distribution boards, cabling, lighting etc making it clear that the equipment must be suitable for the arduous conditions under which the FPSO will be expected to operate. Consideration has to be given to the saline atmosphere, possible exposure to hydrocarbons and deluge water. Equipment located in a hazardous area should be suitable for use in a potentially explosive atmosphere and so there should be guidelines on the certification and type testing of electrical equipment for these duties.

Switchgear for general on-shore industrial use is unlikely to perform as well over the life of the FPSO as more robust equipment specified for offshore or marine duty. If large HV transformers are located on the main deck they will probably be exposed to sea spray and possibly green water and will have to be specified accordingly.

General guidelines on earthing should be provided as the existing earthing system on a tanker may not be compatible with production facilities earthing requirements. Where a mix of unearthed and earthed systems may occur, as may be the case with a converted tanker, an assessment should be performed to fully identify equipment on each system, especially essential equipment, and where isolation, monitoring and alarm provision is needed to avoid stray currents between the two systems. The existence and avoidance of induced currents should also be discussed including the physical separation between panels and transformers.

The philosophy should include guidelines on cable routing and segregation. The survivability of cabling and associated equipment on ESD, Fire and Gas and other emergency systems has to be addressed as well as the need for redundancy. Cabling on these systems should be fire resistant. Where existing tanker cabling does not comply, consideration should be given to either new cabling or additional fire protection for high risk areas.

The provision of transits and their sizing should also be addressed. Underestimation of transit capacity can often result in unwelcome and disruptive modifications to structural bulkheads and decks during construction.

The philosophy will also provide guidance to the mechanical package engineers on the minimum electrical standards to be adopted on skid-mounted units to ensure a high degree of electrical uniformity across the FPSO.

The philosophy will contain the high level rationale for the configuration of main power and emergency power generation and the extent of spareage of generation equipment. Emergency supplies for essential systems will include lighting, the Fire and Gas system, the ESD system, HVAC for smoke and gas clearance, ballasting, communications etc. It will also set out the rationale for the sizing of the battery systems and the uninterruptible power supplies (UPS).

It will address “black start” although this topic will probably become the subject of a separate more detailed document developed later in the design.

Heat tracing provision and design approach should also be addressed, with appropriate consideration having been given to process fluid properties and wind chill factors.

A schedule of the main power system studies to be undertaken (e.g. short circuit, stability, load shedding and load acceptance) should be included to ensure that the timing of study outputs will minimise any impact on the design

Further guidance may be obtained from Lloyds Register Rules, Part 6 (ref 22), and from DNV’s Offshore Standard OS-D201 Electrical Installations, March 2001, (ref 66).

### 3.4.8 Controls

Given the nature of an FPSO with equipment in an exposed hostile environment on a moving deck, the use of simple localised control systems, involving greater operator interaction, can be ruled out. Distributed control coordinated via a central control facility will require less intervention involving operators working outside.

The development of a control philosophy allows the design guidelines to be set for the distributed control system (DCS), the emergency shut down system and the fire and gas system. It will also set guidelines for the essential control functions which would be required in the event of a major incident or emergency.

The philosophy will allow the designer and the end user to decide whether to specify a single integrated system encompassing all three elements or a separate system for each of the three elements.

A new build FPSO will have no existing control system(s) unlike a converted tanker. However, it will have production controls and marine controls. The designer and the operator have to decide whether to fully integrate the marine controls with the production controls or have separate systems where there may be a marine monitoring facility within the production system but no executive action.

Where a converted tanker is being used, a judgement has to be made on the suitability and use of the existing marine and utilities control systems in the new FPSO role. Existing local control panels (LCPs) could be retained with alarm functions incorporated into the new central control system. On the other hand, the LCPs could be removed and the control and alarm functions integrated into the new DCS.

The suitability of the tanker's fire and gas detection and control systems and its ESD system have also to be assessed for compatibility with and possible integration into the new systems to be provided for the production facilities. Otherwise, it may be simpler to do away with the existing systems and provide a new system or systems for the new duty.

Again, the philosophy will address the control of mechanical equipment packages and although the package vendors may have controls which are very specific to their packages, the issues of monitoring, shutdown and interfacing with other packages can be highlighted.

The responsibility for the development of the control philosophy does not rest just with the control engineers. A major contribution will come from the process engineers thus ensuring that the FPSO will function and respond as a single entity and not as a disparate assembly of packaged units and other assorted equipment items.

In the development of the philosophy, and later in the design of the control systems' architecture, reference should be made to the International Electrotechnical Commission's (IEC) standard 61508, Functional Safety of Electrical, Electronic,

Programmable Electronic Safety Related Systems, January 2000, (ref 67) and UKOOA Guidelines for Instrument Based Protective Systems, issue No.2, November 1999 (ref 68). Lloyds Rules (ref 22), Part 6, chapter 1 Control Engineering Systems, also provide additional information to assist the author of a controls philosophy.

### **3.4.9 Noise and Vibration**

There are clear occupational health guidelines for the exposure of workers to noise and vibration, for example the Noise at Work Regulations 1989 (SI 1989/ 1790) (ref 69). These guidelines should form an integral part of the project noise and vibration philosophy. In addition the HSE report OTO 99:012 Collection and Analysis of Offshore Noise Data (ref 70) states that “It is noted that the Department of Energy Guidance Notes, Fourth Edition,(ref 4) now have no statutory status but (section 52) may be regarded as recommended guidance on noise levels for design purposes.”

It is recommended that specialist input is used when drawing up the philosophy and in the follow-up of the design and build of the FPSO and its equipment. In this way, it will be possible to demonstrate the extent to which the guideline targets have been met. Where noise and vibration levels for individual items or groups of equipment or areas have not met the targets, realistic and practicable reduction measures can be implemented.

The preliminary layouts for the FPSO will provide an early indication of where the major sources of noise are likely to be located and whether there is likely to be a concentration of high noise generating sources in certain areas of the decks or machinery spaces. Noise can emanate from:

- rotating equipment
- high velocity, turbulent and pulsating flows in piping
- blowdown and relief valves
- control and throttle valves
- orifice plates
- vents, flares etc.

The objective should be to strive for designs which are inherently quiet as opposed to the acceptance of noisy equipment and encasing or shielding it in extensive acoustic cladding. The use of personal hearing protection is not an alternative to effective noise controls. Such protection should only be used where the means of elimination or significant reduction of noise have been clearly shown to be unrealistic or impractical. Restricted areas where hearing protection must be worn can then be designated.

Background noise levels can be estimated which can be taken into account in the design of the public address and general alarm systems. Early indicators can be obtained on the possibility of adverse noise effects on the living quarters and control areas of the FPSO. Steps can then be taken to relocate offending equipment or, if this is not possible, further

action can be made to redesign the equipment or for the provision of acoustic insulation and a range of measures to eliminate or substantially reduce structural borne noise.

Hydraulic power units are often a source of high frequency noise and so closer attention has to be paid to the design of their pumps, valves and pipework to reduce not just the local noise but also the transmission of noise to other sensitive parts of the FPSO.

Vibration and noise frequently go hand in hand and, as stated above, the Fourth Edition Guidance Notes, section 52, (ref 4), also provide useful information on vibration issues. Anti vibration mounts under diesel engines and other types of reciprocating equipment should be specified. Consideration should also be given to the possible effects of shock loading and vibration arising from explosions especially on critical equipment, for example control panels for the ESD and Fire and Gas Systems, emergency electrical power, communications etc and other potentially sensitive items. Cable connections into critical panels and adjacent cable runs should be included.

Early input on target noise levels can be fed into purchase specifications and enquiry documents. Vendors will be expected to state in their bid proposals the anticipated noise levels from their equipment and to demonstrate by shop tests that these have been achieved. Where the anticipated noise levels are exceeded, the vendor should be expected to provide suitable noise attenuation measures which are practicable, robust and durable.

### **3.4.10 Corrosion Management**

The effects of corrosion on any field development can be dramatic, insidious and costly unless there is a clearly defined corrosion management strategy in place from the start of the project phase. The strategy or philosophy has to cover all phases of the development from design, through construction, commissioning and operations and has to encompass all aspects from downhole, through the subsea systems, across the FPSO and the export and disposal routes. There must be active participation of experienced materials and corrosion specialists at all stages

The strategy should address not only the materials selection for the entire range of fluids to be handled or encountered and the monitoring and assessment of their performance but also address preventive and mitigation measures, some of which are indicated below.

The design of equipment and pipework coming into contact with the fluids on the FPSO has to consider not just materials of construction and corrosion allowances but features such as:

- Dead legs
- Areas of low flow and stagnation pockets
- Areas of high fluid velocity, turbulence and erosion
- Complex, high stress piping arrangements

- Low points
- Chemical injection points
- Corrosion under insulation
- Suitability of various types of insulation
- Inspection under insulation
- Areas of inaccessibility

Consideration has also to be given to avoidance of contact between incompatible materials including the use of insulating gaskets and “isolation” spools. Temperature can also influence corrosion rates and higher than anticipated temperatures in service may have a damaging effect.

Corrosion of structural members, pressure vessel saddles and skirts, pipe supports, clamps etc has also to be considered, especially those items under insulation and passive fire protection.

The prevention of corrosion under insulation has to be fully addressed. Pointers should be provided on proper selection of insulation materials and designs, application of insulation systems which, while allowing removal for inspection, preserve their watertight integrity.

Paint and other coating systems have an important part to play in corrosion protection. The selection and application of coatings requires careful consideration, taking into account surface preparation, operating temperatures, fluids to be encountered, susceptibility to damage and methods of repair. Attention should be given to the internal coatings of tanks including crude oil, (especially if the oil has to be kept hot to maintain fluidity), produced water, (if holding tanks are required), and slops.

In the manufacturing and construction phases, there has to be an awareness of the quality of the build to prevent the unwitting introduction of features which can lead to problems later. For example, the attention of engineering and quality control staff should be drawn to the careful selection and handling of welding consumables, the vetting of welding and pre- and post-weld heat treatment procedures, and the monitoring of welding and heat treatments. The fitting (and inadequate sealing) of temporary branches such as high point vents, drains and test points to facilitate the hydrostatic testing of pipework during construction can also introduce corrosion pockets.

During the commissioning phase, the use of inappropriate fluids for flushing or initial circulation of piping circuits can lead to subsequent problems e.g. the use of chlorinated towns water in stainless steel systems without subsequent thorough flushing with demineralised water can lead to chloride cracking while the use of stagnant dock water in cupronickel piping can introduce bacteria which lead to premature holing.

The early involvement of the operations team in the development of the corrosion management strategy is vital to a successful monitoring and inspection programme for the early detection of potentially serious problems and the prevention of their recurrence.

An outline schedule of surveys can be developed for the operations phase to permit a comprehensive assessment of the performance in service of the materials.

HSE report OTO 01:044 Review of Corrosion Management for Oil and Gas Processing (ref 71) provides general guidelines for the creation of a comprehensive life of field corrosion management system.

### **3.4.11 Isolation for Maintenance**

Isolation for maintenance of mechanical equipment, pipework, pressure vessels, tanks, (including cargo tanks) and other confined spaces requires close attention during the development of the process P&I diagrams to ensure a safe and consistent approach across the entire FPSO.

The Isolation for Maintenance philosophy will determine where it is acceptable to use

- Single valve isolations
- Single valve isolations with spades only
- Single valve isolations with vents
- Single valve isolations with vents and spades
- Double blocks
- Double blocks and bleeds
- Double blocks and bleeds and spades
- Physical disconnection i.e. removable spools

It should be a single, unambiguous document for use by both topsides and hull designers.

Input from the operations team and full endorsement by them is essential as it is they who will subsequently have to implement the isolations. The isolation for maintenance policy has also to be understood and correctly implemented by the vendors of skid mounted and modular equipment, as well as their designers and subcontractors.

Early preparation and issue of the isolation for maintenance philosophy will minimise the potential for late design changes involving additional valves, spools, vents and tappings.

## **3.5 GLOBAL LAYOUT: DEVELOPMENT FACTORS**

### **3.5.1 Introduction**

In the development of the layout of an FPSO the prime objective is the creation of a working environment which will be as safe as possible under a wide range of operating conditions, normal and abnormal, and weather related as well as production related. It is a multidiscipline project task, involving many inputs. It is an iterative process which has to take account of the evolving design and has to address potential conflicts and clashes. Above all, it requires good communication between the inputting and interested parties to ensure that the highest standards of safety are achieved.

The following sections address layout issues under a number of headings. All are important and for some FPSOs some of the topics will be more important than others. No attempt has been made, therefore, to list them in any order of importance.

### **3.5.2 Explosions and Fires including Blast and Firewalls**

Loss of containment of hydrocarbon fluids can be minimised by sound design practices and by comprehensive and thorough operations and maintenance practices. Although it is possible to minimise the incidence and size of leaks and spillages, experience has shown that it is impossible to totally prevent them. It is therefore necessary to consider a range of credible circumstances which can give rise to explosions and fires in various locations around the FPSO.

Further guidance is contained in UKOOA's guidelines on Fire and Explosion Hazard Management (ref 61).

#### **Explosion Risk in Production Areas**

The risk of leaks and the possibility of these finding a source of ignition is greatest in the production areas where the operating pressures are higher and the fluid inventories are larger. Consideration has to be given to the likely size and type of leaks, e.g. gas, flashing gas liquids emanating from a flange (e.g. defective gasket) or a hole (e.g. fractured pressure tapping). Preliminary layout studies will have located the main equipment items and so it will be possible to develop explosion scenarios taking into account

- Size of hole
- Initial pressure and pressure decay
- Fluid inventory
- Equipment density
- Weather conditions e.g. still air, or gale force winds



A number of computational models are available to enable the effects of explosions to be estimated in terms of explosion front velocities and overpressures. Among the inputs to these models will be the layout and shape of equipment, the extent of solid decking, the obstructions caused by piping and pipe and cable racks and other structural members.

The development and running of the model for a range of explosion and fire scenarios and layout configurations will enable the designer to adjust the layouts to reduce the velocities and overpressure effects.

The modelling of blast overpressures is a highly specialised activity, sometimes open to a range of interpretations. It is recommended that liaison with the consultants creating and running the model is carried out by individuals who have an appropriate level of experience in this field.

Several joint industry projects have been conducted in recent years in attempts to validate the outputs from the runs of certain models. Further information on the outputs from the JIPs can be obtained by referring to the Research Outputs featured on the HSE's web site [www.hse.gov.uk/research/frameset/offshore.htm](http://www.hse.gov.uk/research/frameset/offshore.htm) (ref 72). However, there is still debate within the industry as to whether any firm conclusions can be drawn.

Regardless of the location of the living quarters, forward or aft, the main blast wall will be along the side of the quarters facing the production facilities to afford the maximum of overpressure protection to the LQ. The blast wall will also serve as the main firewall and is likely to be H120 fire rated. Where other superstructures are provided e.g. at the bow, consideration has to be given to blast wall rating and the fire rating of the bulkhead facing the production area.

Careful consideration has to be given to the use of intermediate blast or firewalls. Their inclusion, while providing, for example, an intermediate line of defence for the main blast wall, could restrict natural ventilation and dispersion of gas accumulations and result in higher overpressures by introducing additional blockage. Higher local over pressures may cause more damage to equipment and piping etc and so produce an incident of greater magnitude than might have been the case if no secondary blast wall had been included in the first instance.

The escape tunnel if provided will present lateral blockage to the explosion front. Being so close to the production modules and therefore exposed to higher blast pressures, it will have to be designed to withstand the full effects of the explosion.

The use of solid decking on the underside of the production modules located above the main or cargo deck may at first glance provide benefits in terms of controlling liquid spillages on to the area below. However, the decking may also reduce natural ventilation effects and lead to higher overpressures.

Single tier modules will allow blast pressures to dissipate more quickly. However, the amount of production equipment required and available deck area limitations may result

in a second level in a module. Where this is the case, open grating between levels should be used if at all possible. Orientation of pressure vessels should also be chosen to reduce overpressure effects. Transverse alignment of their principal axes is likely to provide a greater degree of protection for the LQ by forcing the blast front outwards towards the seaward sides along a shorter path.

The gap between the main (cargo) deck and the underside of the production pallets or modules is usually around 2 to 2.5m, its depth being dictated by a number of factors i.e. the structural framework to support the modules etc above, the need for adequate access to cargo pipework and pump, reduced exposure of production equipment to greenwater and hazardous area classification considerations. Explosions in this area can lead to damage to the crude oil tank roofs and therefore have the potential for event escalation. In the interests of good ventilation and blast overpressure reduction, every effort should be made to keep blockage to a minimum.

### **Explosion Risk in Utilities Areas**

On FPSOs with a forward turret, the utilities equipment will be located towards the aft end of the FPSO and away from the hydrocarbon containing systems. The risk of explosions in this area should therefore be lower. Having the utilities between production areas and the LQ provides a barrier and separation against blast overpressures. Obviously there is still a risk from a dense cloud of gas drifting downwind and finding a source of ignition in the utilities area. Similar attention should therefore be paid to reducing congestion and blockages to promote ventilation and minimise overpressures should an explosion occur.

Furthermore, the main gas turbines for power generation will also be in this area and so it is essential to minimise the possibility of leaks from the high pressure fuel gas supply. Where existing diesel generators have been retained within the machinery spaces and have been converted to dual fuel units, then considerable care has to be taken with the design and routing of the fuel gas supply and the ventilation system within the confined spaces.

### **Fire Risk in Production Areas**

The two main types of fires which can occur are jet fires from ignited jets of high pressure gas and pool fires, as the name implies, on the surface of a pool of hydrocarbon liquid which may have leaked or been spilled. Safety and loss prevention specialists should advise on credible scenarios for both types of fire to assess what can be done to alter layouts to

- minimise jet impingement on critical pressure vessels, cargo tank roofs and support structures
- separate vessels with large inventories of flammable liquids to reduce the chances of several vessels being engulfed simultaneously in a large pool fire.

The main firewall to protect the temporary refuge and the living quarters from a fire on the main or production decks is the face of the LQ facing the production areas. A single appropriately rated wall will serve as both fire and blast wall. While the main firewall will most likely be H120 rated, a lesser rated wall will be provided to protect any additional superstructure on the main deck, such as a forecastle, housing switchgear or local control panels. Intermediate firewalls on the main decks, like intermediate blast walls, only serve to increase congestion and reduce air flow and should only be used where studies indicate a specific need for them.

### **Fire Risk in Utilities Areas**

The farther utilities equipment is from hydrocarbon areas of the FPSO, the lower the fire risk. Fire scenarios should be developed to ensure that the position of gas turbines, for example, will not lead to incidents and escalation from them, such as gas leaks and turbine blade and disc failures. Inside the hull in the machinery spaces, the equipment and the nature of the fluids handled is unlikely to present any significant risk. The segregation of emergency generators and fire pumps in separate rooms, protected by suitably rated firewalls should contain any major fires arising from fuel leaks.

The Classification Societies provide guidelines on machinery space layout and bulkhead and deck fireratings:

- Lloyds Register (ref 22) Part 7, chapter 3
- DNV Offshore Standard OS D301 Fire Protection, January 2001, (ref 73), chapter 1
- ABS (ref 24), chapter 3, section 8, subsection 9

### **3.5.3 Escape Routes**

In the development of the layout of the FPSO the principal consideration is the safety of personnel and their ability to escape safely and swiftly from dangerous incidents and potentially dangerous situations wherever these might occur on the FPSO.

#### **Escape Route Planning**

With the most hazardous areas being in the hydrocarbon processing area, the planning of primary escape routes must consider a range of incident scenarios at an early stage to ensure that the most appropriate provisions are then in place and become a corner stone of the design.

#### **Primary Routes**

The primary routes must ensure that personnel can escape from the remotest parts of the FPSO to the security of the Temporary Refuge in the most direct manner possible with the minimum of detours and obstructions. The overall size of the FPSO and the extent of

the facilities which its carries will dictate whether an enclosed or partially enclosed tunnel or an open escape route is provided for the main and production deck areas. A 50000 bpd facility on a very large tanker may be relatively compact compared with the remaining open deck area and so no enclosed primary escape route may be needed. On the other hand, with a large facility, a tunnel becomes the obvious choice.

Primary escape routes from the machinery spaces must also be considered. Unlike the production areas, there are likely to be several levels within the machinery spaces where escape will have to be via stairways or vertical ladders. Adequate layout provision must be made for stairways and companionways which are wide enough and not excessively steep to allow for rapid escape and for quick access for rescue or fire fighting teams.

Classification Society guidelines on escape can be found in

- Lloyds Register, (ref 22), Part 7, chapter 3
- DNV (ref 65), OS A101, section 6
- ABS reference (ref 24), chapter3, section 8, subsection 13.

### **Tunnels and Alternatives**

Tunnel size and length will have an effect on layout as will the provision of access into the tunnel. Size will be determined by the number of persons using it under emergency conditions and the size of incident response teams. Even though the tunnel may be designed for the worst credible fire or explosion scenario, unforeseen circumstances may render it unusable. In such a situation, an alternative primary escape route to the TR will have to be provided, which may or may not be a second tunnel. Where escape to the TR has become impossible, then direct escape routes to life rafts or other individual forms of escape must be provided.

### **3.5.4 Temporary Refuge (TR) and FPSO Evacuation**

#### **TR Location**

Layout studies together with the outcomes of incident studies will determine the best location for the Temporary Refuge. The most common location for the TR has tended to be in the living quarters on the main deck, having taken into account the proximity of sleeping areas, the main FPSO control room and the exits from the tunnel or other primary escape routes from the main deck and the machinery spaces.

#### **Evacuation to Embarkation Points**

Provision has to be made for the entire FPSO's complement to quickly access the main means of evacuation. In the case of helicopter evacuation, then a secure stair tower to the helideck has to be provided. This will probably be the main stairway in the LQ. Where free fall lifeboats are to be used then the layout has to make provision not only for the

lifeboat support structures but access to them from the TR. Where davit launched lifeboats are being deployed, the route from the TR has to be planned, making allowance for the embarkation stations and whether these will be open, partially open or enclosed.

### **Lifeboat Type**

The choice of lifeboat type, davit launched or freefall, is usually a matter of operator preference, in line with the prevailing corporate policy. The pros and cons of each type are generally well known as are the issues associated with launching from the bow area and the stern in arduous conditions with large motions of the FPSO. Whatever type is selected, layout implications can be considerable and should therefore be addressed early. The maximum anticipated number of persons on board (with allowances having been made for additional personnel, for shutdowns for example) plus the contingency factor will dictate the size and number of the lifeboats, with four intermediate sized TEMPSCs having a greater impact on layout than two 100% craft.

### **3.5.5 Containment of Hydrocarbon Spillage**

Spillages of any liquid on the decks of an FPSO are more difficult to manage than on a fixed installation due to the motions of the FPSO vessel. The risk of run off to the sea is greater with larger amplitudes of pitch and roll coupled with seawater washing over the deck areas. Vessel trim will also affect spillage movement.

The avoidance of spills of any kind, by design and operations procedures, is another cornerstone of any environmental strategy but, nevertheless, provision has to be made for spills occurring. The major dichotomy confronting the operator and the designer when addressing the possibility of a major hydrocarbon spillage is whether to:

- contain as much of the spillage as possible and thus increase the risk, especially under major upset conditions, of a large pool fire or
- allow the spillage to go overboard and face a significant environmental incident.

Adequate provision can be made for small spills under equipment through the provision of strategically placed drip trays, bedplate bunds etc. Where there is the risk of spills from chemicals such as those used for seawater or produced water treatment, the tank inventories are relatively small and containment within the chemical injection skids themselves can be readily achieved.

For larger spills, especially of hydrocarbon liquids, where there is also a large inventory which may not be immediately or readily isolatable, it will be necessary to divide up plated deck areas, but principally the main deck, into zones with longitudinal and transverse upstands or bunds. There will obviously be a limit to the height of any upstands or bunds otherwise access may be compromised and water run off, under normal operation, may be restricted. It is not considered realistic or practical to size the

containment zones for the inventory of a single large pressure vessel such as a third stage separator.

These upstands will help to reduce the migration of spills over the entire deck area due to sloshing. Removable sections will allow the movement of equipment over the deck for maintenance. Depending on operations policy, they may be left in position most of the time or they can be inserted quickly when a large spill occurs. The latter approach does allow better drainage of sea and rainwater off the deck and reduces the potential for corrosion due to free standing water.

The safety and environmental implications should be discussed by the respective specialists at an early stage so that the appropriate provisions can be made during layout development. The management of spills, especially hydrocarbon spills, will feature in both the Operations Safety Case and the Environmental Impact Assessment.

### **3.5.6 Greenwater**

The topic of greenwater has been discussed in Part 2, section 2.5, under the headings of prediction methods and structural avoidance measures, such as bulwarks and breakwaters.

Although the provision of bulwarks and breakwaters may go some way to reducing greenwater effects, it is advisable for naval architects to discuss with layout developers and the other engineering disciplines the susceptibility of a range of equipment and fittings to damage from greenwater, both from the bow and the side. Where there is a high probability of greenwater inundation, attention has to be paid to the orientation of major equipment items to reduce the loadings on shells, foundations, branches and fittings.

On FPSOs where the Living Quarters are stern mounted, the major plant items which are likely to be susceptible to loading from greenwater coming over the bow and the side are:

- Flare knockout drums and flare headers
- Turret
- Slug catcher and separation vessels
- Closed drains drum

For greenwater coming over the bow, the flare stack and flare support structure are also susceptible, while in the case of greenwater from the side, gas compression equipment may also be vulnerable.

Where an escape tunnel is provided, attention has to be paid to possible greenwater loadings.

On FPSOs where the Living Quarters are bow mounted, the quarters themselves will provide a high degree of protection to the equipment in the lee. Much of the equipment will be utilities equipment with a lower profile than that of the hydrocarbon processing equipment located towards the stern. The effects of greenwater loading will be less and adequate side bulwarks may provide sufficient protection without other extensive measures. Where large gas turbine generators are used, care has to be taken with the design of the turbine enclosures to ensure that the large slab sides are not overloaded.

While the gap between the main deck and the production deck above may go some way to protecting equipment on the higher level, the susceptibility of pipework (cargo manifolds, firewater and seawater main headers etc) and equipment in the air gap has also to be considered. Layout designers may be limited in the options for reorientating major piping headers and so the piping designers have to make provision for adequate supports to take any greenwater loading. Provisions may have to be made to protect pipework for overboard dumps for seawater and firewater where these are side mounted.

Major cable racks, if these are positioned at low levels or on the sides of the FPSO, can also be susceptible to greenwater loading and their design must take loadings into account.

Smaller items of equipment such as fire and gas detectors, TV monitoring cameras, light fittings, firewater deluge subheaders, small cable trays, flashing beacons, handrails, signage etc are more difficult to protect but suitable bracketing and support may go some way to minimising impact damage.

### **3.5.7 Environmental Exposure**

The open structure of the FPSO to promote effective natural ventilation inevitably increases the exposure of the crew and equipment to wind, sea spray, rain, snow and to a much lesser extent, ice. The provision of windbreaks to give some protection to those performing plant operations and maintenance may not always be feasible but should nevertheless be considered.

The positioning of equipment with the main axis parallel to the hull centre line can go some way towards reducing bluff body interruptions to air flow and promoting better air movement. It may also reduce heat loss from insulated vessels, especially where heat conservation is essential to good separation and fluidity of product. However, this may provide a more open path for blast pressure fronts travelling towards the TR. It may be necessary, therefore, to choose transverse orientation to provide better protection for the TR. Wind tunnel tests and computer blast modelling will indicate which orientation will afford better overall safety.

The orientation of air intakes for HVAC systems and for turbomachinery should be such as to avoid the ingestion of spray, rain and snow. Where the layout of gas turbines and

their main intakes cannot eliminate or minimise their ingestion, snow hood protection should be provided to avoid air filter blockage.

### **3.5.8 Main Access and Removal Routes**

The more equipment and systems there are on and in an FPSO, the more congested it is likely to become. In the interests of safety and to facilitate operations and maintenance activities, close attention has to be given to how personnel and equipment components can move and be moved around the FPSO with relative ease and speed.

#### **Personnel Access on the Production Decks**

The majority of personnel movements will be between the living quarters and control room areas on the one hand and the main and production decks. Direct access into these areas is desirable when speed of response is needed to deal with plant upsets which require manual intervention. Direct access is also of paramount importance when attending to accidents, evacuating injured personnel and responding to emergency situations such as leaks, spills and fires.

This can be achieved through the provision of a central access way running the length of the production deck with side access ways coming off it at regular intervals. The spacing of these side access ways will most likely correspond to the gaps between modules, pallets or large equipment skids. Some of them will also correspond to intermediate entry points into the escape tunnel.

Where a central access way is not feasible, then consideration has to be given to access ways running down the port or starboard sides of the FPSO. Where an escape tunnel is provided, then this too can serve as a personnel access way. However, it must not be used as an access way for moving equipment as this would compromise the main escape route.

Wherever possible the main access way should be straight, with no ramps, steps or small stairways. The side access ways should also be free of obstructions. The central and side access ways can also serve as primary escape routes, even though the escape tunnel will be the principal primary escape route. The minimum width will be dictated by escape scenarios.

On the main or cargo deck, it may not be as easy to provide straight, flat main access ways due to the complexity of the piping and the header systems. The most direct access will be down the port and / or starboard sides between the side coaming and the main piping areas.



## **Maintenance Access on the Production Decks**

The movement of equipment items and sub assemblies to the laydown areas and to the main workshops in the machinery space or to smaller work areas in a secondary superstructure will have a major influence on the configuration of access ways.

A flat, straight and wide central access way will facilitate the use of trolleys and use of a fork lift truck, suitable for duty in hazardous areas, may also be contemplated. Up-front layout study work may identify the central access way as a “pump alley” providing easier access to pumps and their drivers. Where horizontally mounted shell and tube exchangers are used, the central access way can double up as a tube bundle withdrawal area.

The width of access ways will be dictated by the manoeuvrability of the largest item that could realistically be expected to be moved. During layout development it is often easy to concentrate on aspects of routine maintenance and to overlook the possibility of having to deal with a large single item of equipment or a sub assembly. It may be prudent to conduct a “ what could possibly go wrong” review to identify circumstances which would require better maintenance access, which in turn might lead to quicker turn round and reduced downtime.

## **Personnel Access in Machinery Spaces**

Where the FPSO has large production facilities, it is likely that the machinery spaces will be extensively utilised for utility equipment and systems such as electrical switch rooms, diesel treatment, air compressors, emergency electrical generation, firewater pumps, seawater pumps etc etc. The machinery space will also provide the main workshop.

As these items will be on different levels, access will be via stairs and ladders. Safety considerations will dictate how the stairs and ladders will be configured to ensure that routes are as direct as possible and that steeply angled stairways are avoided. Not all crew members will have come from a marine background and will possibly not be used to ship style companion ways which may permit forward facing or backward facing descent. When rapid personnel response is required, the risk of slips and falls is increased and so normal stairways are recommended wherever possible. They also facilitate the retrieval and removal of casualties, either on foot or on a stretcher.

## **Maintenance Access in Machinery Spaces**

It is likely that the main stores and workshops will be located in the machinery space. A main access route will be required between these locations and the main deck, with the movement of large items taking place through an appropriately sized hatch or hatches. Ideally the hatch will afford direct access into the workshop from the main deck to reduce the requirement for further handling activities once the item is inside.

Wherever possible the main hatch should be located behind the firewall/blast wall. A hatch located on the non-hazardous area of the main deck on the other side of the wall creates problems of potential ingress of gas into the machinery space in the event of a major leak while the hatch is open for access. The hatch design will have to incorporate a reliable gas seal.

The HSE Research Report 3770, Machinery Space Risk Assessment (ref 74) provides useful guidance to the designer on various issues to be addressed in Machinery Space layout development.

### **3.5.9 Main Cable Routing**

Several factors will affect the placement of the main cable routes including

- Cable types and the need for segregation e.g. HV, LV, control, F&G, ESD, telecomms, emergency supplies
- Location of main consumers of power
- Location of control room, termination panel room
- Location of local control rooms
- Module configurations
- Location of main piperack(s)
- Position of power generators and use of new and/ or existing units
- Position of switch rooms

On a large FPSO with substantial production facilities, the main switchgear will probably be located in the machinery space due to limited space on the main deck. Where a bow superstructure is provided, some switchgear may also be located inside it along with control panels for package units such as gas compressors. On FPSOs with much smaller facilities, it may be possible to have switch rooms on the main deck situated in a non-hazardous area.

The use of a central structure running the length of the FPSO can serve both as the main piperack and the main cable rack, giving several tiers and permitting lateral separation. There are obvious advantages in cable pulling operations and greater protection against dropped objects.

Cable rack running down the port and starboard sides are more prone to impact from swinging loads during supply boat offloading. If run at low levels, for example at the edge of the cargo deck and below the production deck within the module support framework, the racks are more susceptible to greenwater damage

### **3.5.10 Mechanical Handling and Laydown Areas**

During layout development, main pedestal crane operations should be addressed to determine the extent of crane coverage, e.g. two cranes or three, port and/or starboard locations, maximum operating radius etc, and the preferred locations of the laydown areas.

#### **Mechanical Handling**

Mechanical handling studies have tended to be carried out during detailed design, by which time compromises will have already been made due to conflicts with equipment modifications, larger modules, additional equipment. It is recommended that at least a high level mechanical handling study is carried out during layout development to ensure that other major issues, and not just those involving main cranes, are addressed.

It may not always be sufficient to reserve space for a central access corridor alone. Consideration has to be given as to how major plant items and sub assemblies such as compressor cartridges, large valves, pump barrels, HV motors, can be moved safely and quickly from their location (which may not necessarily be accessible by pedestal crane) to the central access area and on to a laydown area or a suitable uplift point. Devices such as gantry cranes and main runway beams can be considered.

During FEED, where long lead equipment items are under discussion, involvement of the chosen or potential vendors on maintenance needs will ensure that at least some provision is made at an early stage for the handling of large items whose removal and replacement is critical to the safety or the production uptime of the FPSO e.g. gas generators of gas turbine generation sets.

Inside the machinery spaces, where access between floors will be through hatches involving hoists and possibly an overhead crane, consideration has to be given as to how to get items to the hatches. Again the use of gantry cranes and runway beams has to be considered. Once an item has been moved to main deck level, its route to a suitable pick-up point has to be identified and planned for.

Special provisions have also to be made for items such as the shuttle tanker export hose and any other hoses, mooring hawsers and winches associated with tanker operations.

The turret involves a large amount of high pressure mechanical equipment, such as valves, pig receivers and launchers, and the swivel itself. Early involvement of the turret supplier is essential to ensure that by making adequate allowances at an early stage of the project, turn around times for critical items are minimised in the operations phase. This is particularly important in the event of problems with multi-path swivels.

Depending on the type of turret and the turret vendor, a small jib crane may be supplied with the turret. It is advisable to cross check that the jib crane is suitable for turret duty and that it can reach suitable landing and pick-up points on the main deck area of the

FPSO. It is also to be expected that the turret supplier will have made adequate provision for access to and removal of damaged bearings within the turret housing in the FPSO hull.

### **Laydown Areas**

The provision of sufficient lay down areas is frequently an area of dispute between the FPSO designer and the operator. It is often too easy for laydown zones to be reduced or taken over for additional equipment and late modifications, leaving the operator with inadequate on-deck storage and handling space. It then becomes necessary to provide smaller elevated laydown areas on the roof of a module, for example. The risk of impact from swinging loads and dropped objects becomes greater and so more protective steel work has to be provided.

Laydown areas should always be accessible for the main cranes. Where there are secondary storage areas which are not accessible for the main cranes, then these areas should be in close proximity to minimise the amount of secondary mechanical or manual handling.

Consideration has to be given to the laydown, handling and storage of a wide range of offshore supplies from food to drums of hazardous and toxic injection chemicals. While the great majority of items arrive containerised, it is on the laydown areas that they are unloaded and then moved on. If secondary storage/ laydown areas are created, then potential impact on access for operation and maintenance, means of escape, obstruction of flame and gas detectors has to be considered.

### **3.5.11 Future Expansion and Upgrading**

At the start of a project it is not always possible to predict how the field will perform both in the long and short terms. Making provision for future developments in and around the field can be influenced by a number of factors:

- Well productivity lower or higher than expected
- Opportunities for infill drilling to boost through put or maintain plateau
- Exploitation of other satellites in the vicinity
- Acting as a host FPSO to another unconnected development
- Gas and produced water volumes lower or higher than anticipated

Catering for uncertainty can be achieved by building in a margin into the process engineering design, providing the choice of margin does not result in significant equipment size changes. The initial use of undersized impellers on pumps and compressors (providing there is adequate margin in the drivers) may be acceptable along with the provision of larger nozzles on some pressure vessels as a means of providing flexibility at a low first cost. This approach may also avoid having to make sizeable space provisions.

Small production facilities on a large hull have a smaller footprint and offer scope for the addition of modules, pallets or skids at a later date. Where the production facilities occupy almost the entire main deck, the opportunities for expansion may be quite restricted within the existing facilities. It may be possible to install a module on top of the existing facilities, providing:

- The vessel's centre of gravity and vessel motions are not adversely affected
- The existing modules' structure does not require significant modification
- Structural modifications inside cargo tanks can be avoided

It may be that it is not only the oil processing facilities that have to be expanded and that provisions have to be made in the utilities systems. Placing new large items into the machinery spaces may be impossible or undesirable and so space provisions have to be made on the main deck. One single area may be set aside for hydrocarbon equipment together with utilities equipment, offering the possibility of a single skid or module. Consideration should be given to providing an area on the outside edge of the vessel as this simplifies any lifting operations and reduces the risks from the potential problems of collisions from swinging loads and dropped objects.

### **3.6 LOCAL LAYOUT DEVELOPMENT FACTORS**

During layout development it is often too easy for the designers to concentrate on the larger issues and to devote less time to issues which can in fact have a major influence on the day to day operation of the FPSO, in that the effect on personnel is more tangible. Working in cramped conditions, not having direct access to equipment, having to tolerate sub-ergonomic control room or office layouts are just several of the factors which can affect personnel efficiency and attitudes and can in turn affect safety.

An FPSO has different requirements to a tanker and while these differences may be fully appreciated by those familiar with traditional offshore platforms, they may not be fully understood by ship designers. The following sections are included so that both ship and facilities designers can incorporate appropriate measures to create satisfactory working and living conditions in what is already a harsh external environment.

#### **3.6.1 Living Quarters and Offices**

It is expected that the owner/ operator of the FPSO will have a major influence on the size of the living quarters, its layout and the standards of fabric and fittings. Different companies have different approaches in each of these areas, e.g. single vs two person cabins, but if these requirements are not communicated to the designer, then the end product may not prove satisfactory to those who have to live and work there.

As well as providing facilities for eating and sleeping, the quarters or accommodation block will probably also contain the Temporary Refuge, the main control room(s) and offices. Other facilities may include but may not be limited to:

- Radio room
- Emergency response room
- Helicopter reception area
- Locker rooms and wash rooms
- Recreation areas such as quiet rooms, TV/ video rooms, activities rooms and gym
- Medical room and sick bay
- HVAC plant room(s)
- Switch room
- Stores
- Small workshop e.g. instrumentation
- Fire stations, with safety equipment such as BA sets etc

The input of operations team representatives should be solicited on all aspects along with input from the accommodation or hotel services contractor who will advise on matters of galley, dining room, stores size and layout etc. Care should be taken to avoid routing of pipework for certain services and utilities such as grey sewage through galley and stores areas.

The function of the TR has to be clearly understood by the designer. Input from Safety advisers as to the siting, size and layout is also recommended to ensure that under emergency situations it is possible for the crew to assemble, receive information and instructions and move out to the embarkation points in an orderly manner.

Office layouts should allow for computer terminals, filing and document storage and for small round-the-table meetings. Meeting rooms should allow for larger gatherings and video conferencing and be capable of being temporarily turned into an office or coordination area for, say, commissioning or a major maintenance campaign.

The views of medical and occupational health advisers should be sought for the layout and equipment provisions of the medical room and sickbay.

### **3.6.2 Control Rooms**

The main control room is the permanently manned nerve centre of the FPSO. It is essential that great care is given to its sizing and layout to facilitate verbal communication and movement of personnel and to make sure that decision making is not compromised.

To ensure that the FPSO is operated as a single entity, it is recommended that the controls for the marine systems and the production facilities are co-located in a single control room. Co-location does not imply that there shall be a single combined control system for production and marine systems.

The layout designer must consider among other things

- Size and number of production, marine and emergency control panels
- Back of panel access
- Provision of control desks, including public address facilities
- CCTV monitoring facility
- Administration of the permit to work system and issuing desks
- Production reporting system
- Additional work stations for supervisor and control room operators

Some FPSO owners may have a preference for windows in the control room to allow viewing of the production deck and / or the stern area, especially shuttle tanker operations, even though CCTV facilities have been installed. Where installed the windows shall be rated for fire and explosion conditions.

The control room will have adjacent to it a terminations rooms for the marshalling cabinets for the control systems cabling coming in from the FPSO. The design of the suspended floors in the terminations room and the control room should be deep enough to facilitate the orderly pulling, laying and grouping of cabling as well as access for termination and inspection. There should be sufficient lateral space allowance to avoid

tight radii on cables. Some allowance should be made for the installation of additional cables for possible future expansions.

### **3.6.3 Maintenance Access and Removal Routes**

On a continually moving FPSO with a high level of exposure to the elements, it is essential to personnel safety that there should be, wherever possible, acceptable access for the maintenance and removal of equipment. Those responsible for the overall layout of the FPSO should address the provision of main access routes and the principal features of mechanical handling such as jib and gantry cranes and large runway beams.

However, in the case of mini-modules, palletised and skid-mounted packages, the package designer will be at least one step removed from the main layout designer and may not be as appreciative of the particular difficulties of working on an FPSO. Overall layout considerations will dictate the boundaries of the skid or module and so the designer has to fit everything in as best as he can. Access for maintenance may not be the most important consideration. The early involvement of representatives from the operations team and a mechanical handling specialist and collaboration with the skid vendor should lead to a layout which is more user friendly.

Gas compressor skids in particular can become very congested not just with the main items and valves but also with peripheral valves and piping e.g. lube oil, dry gas seals, casing vents and drains. Flanges are numerous and the integrity of these joints is key to the avoidance of leaks. In such cases, good access is essential. Where there is a single train of compression, any outages have to be dealt with promptly to minimise flaring and associated production cut backs. Having to dismantle half the skid to remove a cartridge is undesirable. Chemical injection skids with multiple pumps and compact, congested pipework can present similar access problems. With up-front attention to maintenance access needs, such a situation can be avoided.

Heat exchanger maintenance can be facilitated by the provision of removable pipe spools around nozzles. These spools can afford better access to plate packs or tube bundles and avoid the need to cut and rejoin welded pipe.

Runway beams above a skid along with optimally positioned padeyes can assist the removal process off the skid. Removal to the workshop or to a laydown area or to a crane pick-up point has also to be allowed for. Trolleys are suitable for working on the flat but where stairs have to be negotiated, manual handling may be unavoidable. In these circumstances the input from the mechanical handling specialist is essential.

The HSE has prepared guidelines for mechanical handling on FPSOs (Research project 3806: Development of Manual Handling Toolkit for FPSO Design and Specification) (ref 75). These should be consulted as part of an approach to ensure greater levels of the safety in mechanical handling and rigging activities.



It is easy to overlook more mundane but nevertheless routine and potentially manpower intensive activities such as

- checking and calibration of level gauges
- routine inspection and cleaning of fire, gas and smoke detectors
- removal of relief valves, bursting discs and flame arresters
- cleaning of inline filters
- change out of light fittings
- checking operation of fire and gas dampers etc etc

In many cases it will be possible to gain access by portable devices, or from nearby walkways, while others may warrant permanent or semi-permanent access from small platforms. Each activity has to be considered on its merits taking in to account the frequency, complexity and duration of the task. The cost of permanent access has to be weighed up against the cost of scaffolding and the potential loss of efficiency.

#### **3.6.4 Operations Access and Operability**

Even with production facilities which are largely controlled and monitored from a remote central control room, it will still be necessary for production technicians to make regular outside tours and inspections and to prepare, isolate and make safe equipment for maintenance.

Although individual items or groups of equipment can be remotely shut down quickly and isolated in normal and emergency conditions, prompt local on-skid intervention may be required. Valves to be operated frequently, if not motorised in the first instance, should be positioned such that levers and hand wheels are readily accessible.

Similarly, sight glasses and local pressure and temperature gauges should also be readily visible. In short, the design of the equipment has to be user friendly in the interests of safety and efficiency.

In the lowest levels of the machinery spaces containing seawater and firewater pumps and headers, there is a risk of flooding in the event of a piping or connection failure. Access may be required to certain motorised as well as non-motorised isolation valves as part of the emergency response. Layouts should take the need for such access into account. Section 2.16 lists several mitigating measures which can be adopted to reduce the risk of flooding in machinery spaces.

The early involvement of experienced operations representatives in the development of the layout of skids and packages should ensure that most of the basic needs, as opposed to individual preferences, are met.

### **3.6.5 Workshops and Stores**

Once an FPSO is on station, it will be expected to remain on station for the field life. It will only be in exceptional circumstances that it will be disconnected to return to port and dry-dock. While certain items of equipment will can be shipped back to shore either as a unit or piece-small for repair, in an emergency it may be necessary to carry out repairs on board. If it is not possible to perform these repairs in-situ, then the work may have to be done in the FPSO's own workshop.

There will probably be two or even three types of workshop

- Mechanical
- Electrical
- Clean instrumentation, including telecomms

The largest will be the mechanical workshop equipped with machining, drilling, grinding and cutting facilities. An oil bath may be provided for removal of lightly shrunk-on components. There will also be a welding bay (with provision made in the HVAC design for fume extract) which can also be used for hand grinding.

Lathes, milling machines and drills should have adequate space around them to allow for manoeuvring items on to the machine. Overhead lifting facilities will include runway beams and possibly a small gantry crane. The location of the main workshop should be selected to avoid excessive handling of equipment and, if possible, located on the main deck or first level of the machinery space. Access for equipment coming from above or below will be via hatches. These should be positioned vertically above one another to facilitate single direct lifts from the lowest level to the main deck. Hatch openings will be provided with removable barriers.

Main walkways in the workshop should be straight to facilitate movement of bulky items as well as for escape purposes.

It is likely that the mechanical superintendent will have an office in or adjacent to the workshop and this should be equipped appropriately to enable any computerised maintenance planning and recording system to be run. Provision should be made for document storage such as vendor maintenance manuals where these are not computerised.

Where other smaller workshops are provided they too must cater for the routine needs of the particular discipline which they serve.

#### **Stores**

The storage space requirements of an FPSO differ from those of a tanker. The larger inventory of equipment alone will call for more storage volume, and the larger crew will also have a bearing on stores and storage.

It is unlikely that any major capital spares or bulky items will be stored offshore but given the range of equipment on a typical FPSO, the range of consumable items can be substantial. At the start of a project no one can say with certainty what the final offshore stores inventory will be. However the combined experience of marine and production representatives should provide early reliable indicators as to the general requirements.

On larger FPSOs with larger production facilities, the amount of equipment, especially in machinery spaces, bow compartments and forecastles (where these are used) will reduce the free space available. Instead of having a large single store to serve the maintenance needs, the maintenance crew may have to operate between two or more storage areas. Providing the needs have been addressed in advance this situation may be quite acceptable. However, when dedicated space is inadequate, use will inevitably be made of other free areas as ad hoc storage, leading to double handling, risk of obstruction of access ways and possibly a slightly increased fire risk as well.

If possible, main stores, like the main workshop, should be close to the main entrance of the space or superstructure in which they are located. This will reduce the amount of handling needed to get from the main drop off point, which in turn should be accessible to the main crane(s). From the standpoint of personal safety, manhandling of stores and other supplies is not desirable and may not even be possible in adverse weather.

Stores will have computer facilities to help control the issue and usage of components.

Racking should be designed for ease of access but should take account of possible movement of items with movements of the hull.

In addition to the main stores, there will be galley stores (dry and cold), paint stores, chemical stores (these may be on open deck areas properly dedicated to their storage), and rigging and lifting gear stores. All have special requirements, including ventilation etc for humidity control and fume removal, which the designer will have to address.

### **3.7 FPSO MAJOR SYSTEMS INCLUDING SYSTEM INTEGRATION/ SEGREGATION.**

#### **3.7 1 Introduction**

In this section, design aspects of the major non-hydrocarbon systems on an FPSO are discussed. Where appropriate, issues of integration and segregation are touched on as this is an area which requires careful consideration when a conversion of an existing tanker or modifications to an intercept tanker in an advanced state of build are being contemplated.

The design of systems which handle production fluids are not discussed, with the exception of product offloading, vents and drains. The design of topsides processing facilities is almost always undertaken by contractors who generally have an established track record in the design of similar facilities on fixed platforms. These contractors are familiar with the main design issues and use international and national codes and standards for hydrocarbon system design and equipment specification and build.

However, this section and section 3.8 cover several systems, which although not hydrocarbon systems themselves, are an integral part of the production facilities, e.g. seawater, heating medium, inert gas etc. In the past, because some of these systems have had their origins in the hull of the FPSO, their design has been handled by the hull contractor. In such cases, it might have been more appropriate for the production facilities designer, with his greater appreciation of the requirements of production facilities, to have had overall design responsibility. In this way many of the interface problems and conflicts between design codes could have been avoided, or at least minimised.

Feedback from FPSO owners, operators and designers suggests that there are still areas where the facilities designers, on the one hand, do not appreciate that the FPSO is not a fixed facility, while on the other hand, the vessel designers do not understand the characteristics of production facilities. This has led to problems in the design of piping systems in the production facilities which, while designed to recognised API and ANSI standards, have not got sufficient flexibility to accommodate hull bending and flexing. Similarly, some “ship” systems have been designed to traditional marine standards when piping codes more suited to continuous production operations might have been more suitable.

For each of the following systems, therefore, it is recommended that the designers’ teams are made aware of the special characteristics of an FPSO to ensure that a single facility is provided. This will go some way towards avoiding a repetition of the problems which have affected projects in the past and to creating consistency and continuity for projects in the future.

### **3.7.2 Firewater**

The firewater system, if not the largest system on an FPSO, is certainly the most extensive. As it is one of the key safety and loss prevention systems it naturally receives wide coverage in the Classification Societies Rules, in SOLAS and in other recognised national and international codes and standards. In spite of designers adhering to the general guidelines given in these various documents, design shortcomings have arisen which have lead to major and minor disruptions in the operation of many FPSO's.

#### **Segregation/ Integration**

On a new build FPSO there will be a single firewater system throughout the installation. In the case of a conversion, the size of the production facilities will dictate the extent of firewater coverage and so the existing ship's system will have to be checked both for capacity and design pressure. Design pressure will usually be determined by the height of the monitors serving the helideck.

In the case of a small production facility, only minor uprating of the existing system may be necessary in terms of pump head and capacity, providing the general condition of the pumps and piping is satisfactory for the field life. Where there is a substantially greater water requirement than the ship's system can deliver, checks have to be carried out to establish whether the existing system can operate in conjunction with the new, in terms of pump curve compatibility. It may then become necessary to dispense with the existing pumps and use the existing firewater network (again subject to its condition) as an extension of the new system for the production facilities.

#### **Pumps, Drivers and Hydraulics**

On a new build FPSO the designer has several choices for pump configuration:

- Diesel direct drive centre-line mounted pumps located in the machinery space
- Diesel direct drive caisson pumps located on the main deck
- Diesel/ hydraulic drive caisson pumps, with deck mounted pumps and remote drivers

Electric drives may be considered for firepumps provided it can be demonstrated that the security, reliability, protection and integrity of the electrical supply is as high as that offered by conventional diesel driven units.

Deck mounted firepumps will each be located in a suitably rated enclosure to protect them against fire and explosion. Firepumps in hull machinery spaces will also be protected against fire and each will be housed in a suitably fire rated enclosure.

The designer can refer, for example, to

- Lloyds Register, (ref 22), part 7, chapter 3
- ABS, (ref 24), chapter 3, section 8, subsection 5
- DNV, (ref 73), chapter 2

where guidance can be found on driver requirements, batteries, hydraulic starting, aspiration air, exhausts including insulation and silencers, enclosure ventilation, lube-oil heaters, cold starting, fuel supply and storage, remote isolation of fuel supply, sizing of fuel tanks, remote starting etc.

Caisson pumps are used on fixed installations but have recently been used on some FPSOs because they are easier to install and remove for maintenance than pumps in the bottom level of the machinery space. They also avoid the need for a firewater seachest and the attendant problems of seachest blanking to permit inspection of the seachest isolation valves. Where pumps are located in the lowest level, the issues of seachest inspection have to be fully considered at an early stage in the hull design. It should not be assumed by the hull designer that divers will be used for this activity on a fully operational FPSO. Good designer/ operations team dialogue is needed to ensure that a workable inspection system and a practicable closure scheme are adopted.

For a conversion, issues surrounding segregation and integration, as referred to above in the preceding section, must be addressed. Where additional capacity is needed, the pump types listed above have to be considered.

Whatever the outcome, it will be necessary to fully examine the pressure distribution within the system to ensure that the correct quantities of water are delivered when and where required. Various software packages are available to assist the designer in achieving optimum distribution.

A surge analysis of the firewater system should be carried out to avoid overpressuring the piping on the start up of large capacity high-head pumps, especially where cupronickel is used (current design pressure limit is 20 bar). Hydraulic analysis consultants can usually undertake this work, which will include making recommendations about minimum flow and dump line sizing, the use of surge accumulators, and valve sequencing and opening and closure times.

A small jockey pump or auxiliary seawater pump should be provided to maintain main header pressure and prevent premature activation of the deluge system in case of valve leakage and the inadvertent opening of drain or flushing valves at header ends.

### **Metallurgy and Piping**

In the majority of FPSOs the firewater system will be built out of cupronickel alloy. Practical alternatives are superduplex alloys, which are stronger and more robust than cupronickel but are generally more expensive, and glass reinforced plastic (GRP) which

may be used with some limitations in those areas where the size and intensity of the fires is deemed to be less.

The HSE has carried out a Review of the Degradation of Firewater Piping and Nozzle Performance due to Blockage OTO 00:035 (ref 76). The review allows the designer to consider the advantages and disadvantages of the various material options which may be appropriate for the specific installation. UKOOA has produced a Recommended Practice for the Use of GRP Piping Offshore (ref 77) and ABS in reference 24, Appendix 1, gives guidance on the use of Plastic Pipe Installations.

This section deals with cupronickel systems and the following points should be noted

- Velocities should not exceed 3m/sec to avoid erosion
- Avoid stagnation pockets which can result in anaerobic bacterial attack of the oxide layer and lead to pitting and holing
- At the extremities of headers and subheaders consider bleed points to avoid dead legs
- Where dock water is used for initial flushing and commissioning, thoroughly flush the entire system with clean water immediately thereafter to avoid the risk of rapid corrosion.
- Guard against mixing incompatible materials and fittings including deluge nozzles, compression fittings, and carbon steel temporary construction aids, as this can lead to premature galvanic corrosion.
- Carbon steel pipe supports and hangers should employ neoprene or similar sleeve material to prevent galvanic corrosion
- Small-bore pipework should be adequately supported to avoid vibration failures. Avoid large valve assemblies on small branches.
- While larger bore branches will use swept tees, small branches should have weldolets to provide reinforcing. Set-in branches must not be used, even for pressure gauge tapings.
- All fittings must be strong enough to withstand the higher pressures on firepump start-up. In the living quarters, domestic quality copper piping, joints and fittings must not be used for firewater duty.

The main firewater headers will be run in a ring main designed so that sections can be isolated for maintenance and inspection without affecting the availability of the ring main. The headers should also be protected from the effects of blast and from missiles from explosions by locating them behind deep structural members, for example. Care should be taken when locating the first supports for branch lines off the ring main to take account of the linear movement of the ring main and prevent overstressing of the branch connections.

### **3.7.3 Seawater**

#### **Direct or Indirect Cooling**

The seawater system is probably the largest system on the FPSO, providing water for cooling and for injection into the reservoir to maintain pressure support. Seawater cooling may be direct or indirect. In direct cooling the seawater acts as the heat transfer medium in an open loop system and is returned overboard. Where indirect cooling is used, the heat transfer medium is a fresh water/ glycol mixture in a closed loop, exchanging heat with seawater which is then discharged overboard.

Indirect cooling is usually the preferred method in that the materials of construction of the piping and heat exchanger shells and tubes in the cooling circuit will for the most part be carbon steel. The main seawater/ cooling medium exchanger will probably be of titanium or superduplex alloy. Where direct cooling is used, there will more cupronickel or superduplex piping and the heat exchangers will require more exotic materials either for the tubes where there is tubeside cooling or for the tubes and the shells where there is shellside cooling.

Return seawater may be discharged over board from an overside pipe or its may be returned via a through deck caisson. Where caisson discharge is used, then the position of the exit should be remote from seachest or seawater lift caissons to avoid warm water being recirculated.

Where direct cooling is used, pressure drop considerations may rule out the use of cupronickel whose maximum design pressure is 20 bar. If this is the case, then superduplex or similar alloys will have to be used.

The seawater system will be cross connected to the firewater system to provide a degree of flexibility during commissioning and pre-start up activities. While relatively small volumes of firewater may be used for short periods to provide seawater, seawater cannot be used as the main source of firewater unless it can be demonstrated that the reliability and integrity of the seawater system, including the electrical supply, is as good as that of the firewater system.

#### **Segregation/ Integration**

It is unlikely, in the case of a tanker conversion, that the existing seawater system will have the capacity to serve the substantially larger demands of the production facilities. The three options open to the designer are:

- to provide new pumps to serve the new and the existing system with a cross over between the two sets of piping
- to provide new pumps for the production facilities demands and run the two systems in parallel (pump characteristics being compatible) again with a cross over



- replace or mothball the existing system and provide a single new piping and pumping system for the entire FPSO.

Factors affecting the decision will include the relative costs for each option and the general condition of the tanker's seawater pumps and piping for longer service.

In the case of a new build the obvious choice is a single system for the entire FPSO unless there are special considerations specific to the FPSO which dictate otherwise.

## **Pumps**

For a new build FPSO the designer may locate the seawater pumps in the machinery space, using conventional centre line mounted casings, or on the main deck, subject to space availability, using caisson pumps of the type used on fixed jacket installations.

Compared with pumps in the lowest level of the machinery space, caisson pumps take up less volume. The length of the header runs is shorter as they are closer to the main end users. They are also more accessible for operations and maintenance, and as they do not require a seachest, they avoid the problems associated with seachests and seachest inspections. They reduce piping congestion in the machinery space and reduce the risks of seawater flooding in the lower levels because of the significantly reduced numbers of valves and flanges.

Although more accessible for maintenance, they do involve more mechanical fitting and handling which may be affected by rough weather conditions on a more exposed deck.

It is worth repeating here that where in-hull pumps are selected, the inspection of seachests and valves must be addressed early in the design phase. The use of divers and /or ROVs to fit blanking plates should not be assumed and so the design of seachests, the positioning of main isolation valves, the specification and selection of valves should be regarded as significant activity in its own right. Involvement of corrosion and inspection engineers is recommended to determine what non-invasive methods can be used in service to monitor seachest, main valve and piping integrity while in service.

## **Metallurgy and Piping**

Where cupronickel is used, then the guidance given above in section 3.7.2 on Firewater also applies.

Superduplex or duplex alloys used on seawater duty ensure more robust piping systems than cupronickel, which is more vulnerable to impact from dropped objects or swinging loads. However, cupronickel is already widely used offshore and crews are generally aware of its limitations in this respect.

Attention should be paid to the metallurgy of bulkhead transition pieces to avoid the use of incompatible materials, either through the use of insulating gaskets or special spools with good corrosion properties.

GRP piping may be considered for use on seawater duty as an alternative to metallic piping. Earlier concerns over its vulnerability to fire or thermal radiation are now less and as mentioned in section 3.7.2, there are codes of practice for the design and construction of GRP systems which can be applied with greater confidence.

Chemical dosing will be needed to prevent the build up of marine growth in the pumping and piping systems and in seawater cooled heat exchangers. Dosing of the firewater system is also required to avoid marine growth. Sodium hypochlorite is usually injected into pump suctions and into caissons (where these are used). This chemical can be generated on board from raw seawater in a hypochlorite generator. Due to its corrosive nature it has to be piped in GRP or PVC or titanium. Titanium tubing is used down caissons to deliver the hypochlorite into the pump suctions as it is less prone to mechanical damage during pump stack removal and replacement.

Care has to be taken with the injection of hypochlorite to ensure that it is well mixed downstream of the injection point and thus avoid high local concentrations which can be aggressively corrosive in cupronickel systems. Regular in-service monitoring of the effectiveness of the dosing is recommended to detect the early build up of marine growth. The use of injection quills will reduce the likelihood of corrosion, but the quills must also be designed to avoid fatigue failures.

Consideration should be given to the provision in the lower levels of the machinery spaces of remotely operated main isolation valves for both seawater and firewater as a means of reducing the risk of flooding of these spaces in the event of a flange or branch failure (refer also to section 2.16).

#### **3.7.4 Bilge and Ballast**

Coverage of these two systems in the Classification Societies Rules is extensive and comprehensive, e.g. LR (ref 22), part 5, chapter 12. System design issues are also discussed in section 2.16 of these Design Guidance Notes. Consideration may be given to alternate means of bilge disposal/ storage to give operating flexibility for slops tank inspection, taking due cognisance of the need to avoid communication between hazardous and non-hazardous drains systems, as discussed in section 3.7.8.

Attention should also be given to the material of construction of both systems. In the case of the bilge system, the bilge water will be predominantly stagnant seawater with diesel and lube oil from small leaks and spillages. The ballast system also is prone to exposure from stagnant seawater, although the displacement of this and system replenishment will be dictated by crude oil production rates and the frequency of cargo transfers to shuttle tankers.

As dosing of these systems with chemicals is not practicable due to the intermittent nature of their operation, the choice of materials of construction becomes important. Where GRP has been specified for the larger ballast system, then care must be given to the configuration of the main headers. Sufficient flexibility has to be built in to allow for the flexing experienced by the hull during regular filling and discharge of the cargo tanks. Where the FPSO exports continuously to a pipeline or an FSU and sits at constant draft, then the problem is less.

The design of GRP ballast piping systems should be done in conjunction with the manufacturer of the pipe and the fittings to ensure that these components will operate within their design stress limits. Pipe supports should support but not restrain excessively. The interface between ballast pumps and main ballast pipework should be examined to ensure that nozzle loads in service are within the acceptable limits.

### **3.7.5 Inert Gas**

There are two inert gas systems on an FPSO, one for the blanketing and purging of production equipment where the inert gas is nitrogen and one for the blanketing of the main cargo tanks, where the inert gas is carbon dioxide.

By comparison with CO<sub>2</sub>, nitrogen usage is small and is usually generated from compressed air in a membrane exchange unit. The compressed air comes from the FPSO instrument and plant air system. Pressure swing absorption units may be used as an alternative source of nitrogen. Back-up is provided from large bottles of high pressure nitrogen called “quads”. Cryogenic nitrogen can be used but has to be transported from shore in special flasks. Careful handling is required to prevent leakage and spills as the very low temperature of the escaping nitrogen impinging on a surface may result in brittle fracture of carbon steel components, deck plate etc

The carbon dioxide is produced from the combustion of diesel oil in an inert gas generator. The two systems are not cross-connected. Inert gas generators for tanker use are familiar equipment items. (LR (ref 22), part 5, chapter 14, section 6).

On a seagoing tanker the inert gas header system is relatively uncomplicated. Tank inspections or maintenance can be more readily done in port or in dock and tank entry can be done while all the tanks are empty. By contrast, the header system on an FPSO is more complex due to the need to fully isolate individual tanks for inspection or repairs while other tanks are still in service.

The creation of a cargo management philosophy or strategy document, along with an isolation for maintenance philosophy, at an early stage in the project should greatly assist the designer of the inert gas header(s). Whether the FPSO is a conversion or a new build, the designer should be able to develop a header system which provides full flexibility for operations and inspections and at the same time confers the highest level of safety for

personnel entry into tanks and protection against mal-operation and possible overpressure.

While safety of operation is of paramount importance to avoid tank overpressure or under pressure, care should be taken to ensure that the system of isolation does not become overly complex and difficult to implement in practice. A risk assessment should be carried out during design to ensure that the system of isolation is both safe and workable. Cargo tank overpressure and vacuum sensors with alarms should be considered.

### **3.7.6 Product Offloading**

This section deals mainly with the engineering issues associated with product offloading to a shuttle tanker. Operational matters, including the use of global and line of sight positioning systems, controls - both automated and manual, emergency procedures etc, associated with shuttle tanker offloading are covered in publications by shipping interest groups such as INTERTANKO (ref 52) and OCIMF (ref 53).

Offloading via a pipeline to an FSU or into a high pressure gathering system is likely to be a continuous operation, similar to that for a fixed jacket installation. Crude oil from the separators/ coalescer will be pumped through booster and barrel pumps into the high pressure system while conventional cargo pumps will be used to export to an FSU. Flexible or steel catenary risers (depending on water depth) connect the FPSO to a subsea riser base. Where high pressure pumping is involved, checks should be performed to establish surge pressure levels on the rapid closure of subsea isolation valves.

The two principal components of the product offloading system to a shuttle tanker are the cargo pumps and the hose reel. Cargo pumps can be conventional centrifugal units located in a cargo pump room (more likely to be found on a tanker conversion where the existing pumping facility is retained) or deep well pumps in each cargo tank.

In the case of pumps in a pump room, the main design issues centre around

- possible loss of containment
- the early detection of leaks and prompt shutdown
- fire detection and protection
- hazardous area classification
- ventilation
- acceptable access for operations and maintenance.

For deep well pumps the design issues relate to isolation for maintenance and removal. It should be possible to isolate a pump set without having to take more than one tank out of service. When designing the production facilities located in modules above the main deck, sufficient overhead clearance should be provided for pump withdrawal. In the design of pipework, allowance should be made for removable spools and for the insertion

and removal of line blinds/ spectacle plates to avoid unacceptable loads on pump nozzles and to reduce the possibility of flange leakage from poorly made joints.

At this point, it is appropriate to draw the designer's attention to a significant difference in the way the crude oil piping system on an FPSO is operated compared with that on a tanker.

When a tanker takes on a cargo in port, the deck piping runs warm. While at sea the piping cools down and, some days or weeks later in port, warms up again during cargo discharge. Provision for thermal expansion is through the use of proprietary flexible piping components. Should there be any leakage from these components while the tanker is in port, it is likely to be noticed quickly and easily contained.

On an FPSO, the cargo manifolds may be running warm almost continuously, expanding and contracting depending on which tanks are filling at any one time. Under these conditions, the flexible piping components are subjected to continuous movement. The chances of leakages of oil on to the main deck are greatly increased, as are the risks of an uncontained or poorly contained oil spillage flowing overboard and into the sea. There is also a greater risk of fire should there be a large loss of containment. In the interests of safety and environmental protection, the main cargo pipework should be designed with no flexible couplings or bellows units. Provision for expansion should be made using expansion loops. Consideration should also be given to expansion loop provision on the inert gas and vent headers although the risks to safety and the environment are less

Where a hose reel is used, the reel size will be determined by the export rate and the separation distance between FPSO and shuttle tanker. The hose reel can be a sizeable structure, located at the stern of the FPSO, possibly close to lifeboat stations and living quarters. For these reasons and the prevention of leaks, the hose reel and hose design should ensure smooth payout and rewinding of the hose to avoid snagging, kinks and overstressing of the hose sections and joints. The swivel joint / goose neck should be of a proven design. The hose will also be provided with a weak link connector also of proven design, to minimise any spillage to the sea of crude oil in the event of a sudden disconnect, controlled or otherwise, between FPSO and shuttle tanker.

Adequate provision has to be made for maintenance of the reel and change out of hose sections, with sufficient handling and storage capacity for several hose sections in the event of a failure close to the centre of the reel.

It is likely that cargo pumps and hose reel will be hydraulically powered. Power packs and motors can be noisy unless sufficient attention is paid to the design of these components and the valves. Whether the power packs are positioned on deck or in the hull, every attempt should be made to minimise structure borne noise. System cleanliness is essential for smooth operation and so the configuration of the high pressure hydraulic piping should allow for cleaning and ease of dismantling and reassembly.

Winch systems will also be required for handling of pick-up buoys, messenger lines and any hoses associated with the recovery of VOCs from the shuttle tanker. Located at the stern, they will also require provision for power and maintenance.

### **3.7.7 Vents**

There are essentially two venting duties on an FPSO. The larger venting requirement is for the cargo handling system while the smaller is for the hydrocarbon production facilities. On a new build FPSO it is possible to integrate both duties into a single system. On tanker conversion, while integration into a single system is also possible, the owner may choose to keep the two systems segregated.

#### **Cargo Vent System**

On a tanker, the rates of cargo loading can be several times higher than on a producing FPSO. A tanker vent system, based on the use of vent posts or a single vent header, may not be appropriate for the new FPSO duty. A vent header originally designed for tanker operations will have a low pressure drop and low velocities such that at vent exit, the dispersion velocities will be also be low and there may not be adequate plume momentum to give satisfactory dispersion in low wind or still air conditions.

Vent posts located on the main deck may clash with the rest of the production facilities on a congested topsides and will have to be led away to suitable locations for safe dispersal or else manifolded into a header collection system.

The vent system and the inert gas blanketing system interface with each other at the cargo tanks. During unloading, high discharge rates demand high inerting rates and so the designs of both systems have to take account of the differences between the filling and discharge modes of operation. A dual header system may therefore be considered as a means of providing flexibility of operation.

The configuration of the tank isolation valves on these headers, if correctly chosen, can provide a high degree of operational flexibility as well as reducing the risks of tank overpressure. The tank pressure/vacuum valve discharges have to take account of the production modules located above and must be led away to a suitable point to ensure adequate and safe dispersion or else manifolded and incorporated into the vent header or atmospheric vent system.

If the owner's environmental strategy demands it, recovery of VOCs from the cargo tank vents may be achieved through the use of a blower/ low pressure compressor and recycling the vent gas into the process. Alternatively some form of VOC stripping system may be incorporated.

## **Production Venting**

Depending on the pressure level of equipment to be vented, vent gas may discharge in to the HP flare header, the LP flare header or the atmospheric vent header. In the case of the very low pressure discharges, consideration may be given to the use of a low pressure compressor, linked to the cargo vent system to recover gas which might have been flared or vented direct to atmosphere.

## **HP/ LP Interfaces**

Venting from production systems may be intermittent or regular, controlled or manual, routine or emergency. The venting or blowdown may be via blowdown valves, pressure relief valves, bursting discs or orifice plates and through the use of manual valves. In many venting, relief or blowdown situations, there is the possibility for a high pressure /low pressure interface to exist where the low pressure side may not be capable of withstanding the design or operating pressure of the more highly rated system. It should be the responsibility of the process engineering designers to identify all potential HP/ LP interfaces to ensure that overpressurisation of the lower rated system is not possible. An HP/ LP interface register should be created and maintained throughout the whole life of the unit.

## **Acoustically Induced Vibration in Flare/ Vent headers**

In the case of high pressure venting into the closed HP flare header system, the designer should be aware of the phenomenon of acoustically induced fatigue in thin walled stainless steel pipework.

Fatigue failures can occur rapidly where there is a regular blowdown or venting cycle, for example in a gas dehydration regeneration sequence. Where there is a discontinuity in the flare header wall, such as a small vent line or a pressure tapping, fatigue failures can occur in the parent pipe at the junction between the branch and the header. The discontinuity may also be a construction aid such as test or vent point for hydrostatic or low pressure pneumatic testing, where such form of testing has previously been fully authorised. The use of these construction aids must be monitored and where used, design checks must be carried out ensure there is no susceptibility to acoustically induced fatigue failure, either in the short or long terms.

### **3.7.8 Drains**

There are three types of drains system on an FPSO which are associated with production, namely the closed drains, the hazardous open drains and the non hazardous open drains. Drains serving the enclosed machinery and other spaces within the FPSO are, as in a tanker, channelled into the slops tank collection system.

## **Closed Drains**

The closed drains systems is slightly overpressurised and gathers the drains from all piped hydrocarbon drain points into a collection vessel where the drained liquids are allowed to gas off before being pumped back into the oil production train. There should be no cross connection with any of the other drains systems. The collection vessel will be located at main deck level below the production deck to permit drainage under gravity.

In the main production area where the deck area is open grated, drip trays positioned under pressure vessels collect minor leaks etc from flanges, sight glasses etc. Pump bedplate bunds with valved drains intercept small leaks from seals and flanges. These and the oily contents of drip trays are in turn drained off locally into the hazardous open drains and then to the slops tank, possibly via an intermediate holding tank.

## **Hazardous Open Drains**

On an operational tanker, the main drains are only likely to have to deal with leaks and spills while loading and discharging in port. Scuppers have bungs inserted to prevent spills going overboard and larger spills may be contained within main deck bunds. While at sea, the main deck drains have mostly to handle rain water, wash down water and seawater washing over the decks, with discharges all going to sea.

On an FPSO, the cargo piping system on the main deck will be running full for a high percentage of the time. The main deck is open to the production deck above through the open grated flooring. Consequently, the deck drainage system has to deal with all types of spillages and leaks plus rainwater, washdown water, firewater deluge and seawater.

The hazardous open drains will utilise a trap system to intercept small spillages. These can flow into a hazardous drains collection tank, where oil/ water separation takes place. Recovered oil is returned to the process and oily water can be transferred to the slops tank for further separation and final discharge over board, to comply with the permissible oil in water levels determined by law or by company policy, whichever is the more stringent.

The problems of containment of large spills and leaks while minimising the risk of a main deck pool fire have been discussed earlier in Part 3, section 3.5.5. Bunding around the main deck with removable sections can provide a workable compromise

It is impossible to design a hazardous open drains system to deal with such a wide range of flow rates and so it has to be accepted that under certain circumstances, e.g. under deluge conditions or during storms, the drains system will be overloaded, the back-up bunding will overflow and some coincident hydrocarbon spillage may be washed overboard.

The hazardous and non-hazardous drains should not be interconnected directly or indirectly, even via a common reception tank. By maintaining segregation, any gases from the hazardous drains cannot migrate back into the non-hazardous system. On a



tanker, the slops tank and the cargo tanks share a common inert gas system and are therefore cross-connected. On an FPSO, the inerting of the slops and cargo tanks should be fully segregated. Traps should be inspected and cleaned on a regular basis to ensure that there is still a seal and that the trap is not blocked with debris. Throughout the system, there should be adequate provision for rodding points for cleaning out drain headers.

In the past there have been a number of serious incidents on fixed platforms where gas has migrated, via cross-connected drains and dry seal traps, into a non-hazardous area causing explosions and serious injury.

### **Non-Hazardous Open Drains**

As the name implies, this system serves the non-hazardous area of the main deck. Traps are provided and will take away seawater, rainwater, washdown water and deluge into the slops tank collection system. Large volumes of water overflowing the traps go overboard.

The comments on hazardous drains in the preceding section and on the avoidance of possible interconnections also apply here.

## **3.7.9 Main Electrical Power**

### **Options for a new-build FPSO**

On a new build FPSO, the power requirements will be largely determined by the demands of the production systems. The demands of marine systems e.g. bilge and ballast, thrusters (where fitted to assist shuttle tanker operations) and any propulsion system (should the owner require this either for future use of the FPSO in another location or for the voyage from yard to field), will be much smaller by comparison. Unless the owner has very good reasons for choosing two power systems, then the entire FPSO can be powered from a single main power supply.

### **Generator Type and Location**

The main generators are likely to be dual-fuel gas turbines, which may be aero-derivatives or industrial units. Whichever type is selected, they should be of proven design with a clearly demonstrable track record of reliability on offshore duty. Where the turbine is not packaged by the original equipment manufacturer, the packager should also be able to demonstrate a sound track record of packaging this type of unit for offshore use.

The layout of the area around the generation sets and the layout of the enclosure should afford ease of change out of main components such as gas generators. The risks to the generation unit itself and to surrounding equipment from the failure of turbine blades, discs and rotor should also be considered when locating the package.

In view of their size and the complexity of the turbine package e.g. inlets and exhausts, enclosure ventilation etc, they will be positioned on the main deck to avoid any clash with the build of the hull.

The number of generation sets to be selected will have to take account of:

- Fit with the maximum continuous load
- Operating flexibility
- Operating strategy i.e. machines on full load, part load, hot stand-by etc
- Start up of the largest drive/ drives
- The machines' proven performance and perceived reliability
- Running costs
- Weight and space impact
- First cost, cost of spares holdings and maintenance costs

### **Transformers and Switchgear**

Where deck space permits, it may be possible to locate the main transformers on the main deck while the main switchgear is housed in a purpose built switch room or in a suitable superstructure. As most of the large power consumers will be on the main deck, this arrangement reduces cable runs. If deck space is at a premium, then the specifying, selection and procurement of transformers and switchgear to be positioned inside the hull must be done in good time to minimise the potential for interface problems during hull construction.

Transformers located on the open deck must be suitable for the exposed marine environment. Switchgear specification should take account of the offshore duty.

### **Options for converted tankers: Integration or Segregation**

In the case of a conversion, the tanker will already have power systems for propulsion (most likely direct drive diesel units) and for electrical power (also diesel driven). It is likely that the owner will retain the propulsion units for the voyage to the field and for possible use later if the FPSO is to be deployed on another field.

Depending on the power demands of the production facilities, (much of which will be placed on the deck), compared with those for any of the "ships systems" which may have been retained, the options open to the owner could be:

1. Retain the existing generators in the hull and if hull space permits add new diesel units to make up the shortfall for the production facilities
2. Retain the existing generators in the hull and add new units on the main deck
3. Mothball the existing generator units and add on deck generation capacity for the entire FPSO

Option 1 can result in an integrated, more flexible main power system or the two sectors can remain segregated. Consideration must be given to converting the existing generator units to dual-fuel firing to maximise the utilisation of produced gas. Where the conversion takes place, the safety issues of fuel gas supplies in a confined space must be fully addressed.

Option 2 offers both integrated and segregated systems with the choice of the additional gas turbine units or dual fuel reciprocating engines on the main deck.

Option 3 is the fully integrated option

Whichever option is chosen, and depending on the amount of deck space available, new switchgear and transformers can be placed on the main deck. For integrated options, checks should be carried out on retained electrical switchgear, cabling etc to for compatibility with the new system. Where systems are segregated, the existing system should be checked for condition and to confirm its electrical suitability for the new FPSO application. The use of a single electrical control system will improve operability, especially in emergency situations.

### **3.7.10 Emergency Electrical Power**

The emergency load schedule (including critical loads such as thrusters), will determine the size of the emergency generation capacity. The load schedule for an FPSO will be considerably larger and different from a tanker. The designer, who may be more familiar with ships than with offshore production platforms, may require additional guidance from the owner and the production facilities designer to ensure full emergency power coverage.

On loss of main power, it is essential that the production facilities can be shut down safely and that the rest of the FPSO, with all its essential and emergency control and management systems and life support systems (including TR) can continue to function normally and safely.

In the event of a major emergency, the battery back up systems must ensure that minimum control room functions are maintained along with emergency lighting, radio and communications facilities, navigation aids etc. Battery systems design must take account of access for inspection and maintenance, heat removal and ventilation of the battery room.

Consideration has to be given to starting up the entire FPSO from what is commonly known as “black start conditions”. The preparation of a black start philosophy at an early stage in the electrical design will highlight the basic power supply needs to establish and maintain life support and emergency systems.

Larger systems requiring power from emergency generators will include auxiliary seawater, instrument air, potable water, HVAC, diesel fuel etc in sufficient quantities to get at least one main generator on line. It should also be possible to operate at least one pedestal crane, especially if it is an electro-hydraulic unit, to permit essential fuel and supplies to be transferred from supply boats. As design progresses, it is prudent to check that the actual loads on the emergency and critical load schedule do not exceed the capacity of the emergency generator. Eventually it may be necessary to carry out a full connected load test of the generators to ensure that they are capable of supplying the total connected power for the required period of time.

The size of the emergency generator will in general be dictated by the size of the FPSO, ranging from 500 to 800 KW for smaller production units to over 1MW for an FPSO with a throughput of over 100,00bpd. There are well-established guidelines for the design of the emergency generator and its support systems including fuel supply, starting facilities, inlet air and exhausts, the enclosure and its protection and ventilation. (For example, reference can be made to Lloyds Register, (ref 22), Part 6, chapter 2, section 3). There are also guidelines for the design and protection of the emergency switch room and the distribution system.

It is usual to have two 100% rated emergency generators. It is possible to justify the need for a single emergency generator on the basis of the risk of losing main power and emergency power at the same time and for an extended period being low. Making the case for a single or a second emergency generator will also have to take into account the potential loss of production should the FPSO be unable to return to normal operation within a realistic time interval.

The location of the emergency generator(s) and the emergency switch rooms should take account of their accessibility relative to the main control room or switch rooms should manual intervention be needed quickly in an emergency situation.

### **3.7.11 HVAC**

As stated earlier in Part 1, the development of an HVAC Design Philosophy or Basis of Design document will highlight the fundamental requirements for an offshore oil and gas installation operating as an FPSO. Furthermore, the document should clarify the differences between an FPSO and a tanker to ensure that designers, due to a lack of familiarity or understanding, do not initially design and specify marine type systems.

Although the Classification Societies now generally recognise that floating production installations have particular requirements, their guidance on HVAC is still contained in their rules for the classification of ships or mobile offshore drilling units. An alternative source of guidance can be found in the Department of Energy Fourth Edition Guidance Notes (ref 4), section 47.

Although a large proportion of the HVAC design is for the Living Quarters, the overall design should reflect the requirements of the FPSO as a unit. Should a specialist HVAC design contractor be engaged, the contractor should demonstrate a proven track record in the design of offshore systems. Experience of hotel systems alone is not sufficient.

The main outputs from the HVAC systems design will be the flow diagrams, the schematics and the D&ID's (ducting and instrumentation diagrams). Good quality documents will greatly assist those commissioning and operating the systems and can prove beneficial if and when modifications are needed at a later date.

In the specification and selection of HVAC equipment and in the development of layouts, three main requirements have to be addressed:

#### **Suitability of equipment for offshore use (robustness, materials of construction)**

The range of equipment and components is considerable e.g., fans (supply, extract and recirculation), air handling units, dampers (fire and gas, pressure control, shut-off, volume control), silencers, heater units, louvres, mixing boxes, humidifiers, ductwork, bellows units etc etc. The specifications have to ensure that all items (not just the high value items) are suitable for duty offshore with its high saline atmosphere, high relative humidity levels and the risk of condensation. Incorrect materials can lead to premature corrosion and the inconvenience and cost of replacement. Special attention should be given to battery rooms and laboratories

#### **Accessibility for operation and testing**

Once the system(s) have been commissioned and satisfactorily balanced, there will still be a need to perform regular tests and checks on certain components, principally those connected with the Fire and Gas system. These include the fire and gas dampers and the smoke and gas detectors in the inlet and exhaust ducts. These must be readily accessible as they are essential parts of the safety system.

#### **Maintainability**

During layout development of the FPSO, HVAC maintenance needs can often be overlooked with equipment and ducting being shoehorned in after the main piping runs and cable rack routings have been determined.

Where there are large spaces to be ventilated, the size of fans, filters, and air handling units will be commensurate. Adequate provision should be made for access to these items and for removal of components. In-duct fans units are a good example of items where handling difficulties can arise due to inadequate provision.

### **3.7.12 Fire Protection**

Fire protection on an FPSO will be a mixture of active and passive protection. Active protection is provided by fire water (deluge, sprinklers, monitors, hose reels), foam, CO<sub>2</sub> blanketing and portable extinguishers.

Passive protection is provided by the use of fire rated partitions and by fire resistant coatings applied to primary structural members, bulkheads, decks, framing, equipment foundations, and pressure vessel shells, saddles and skirts. Protection may also be required on structures, e.g., the flare tower and turbine exhaust supports, whose premature collapse on to other structures and equipment may result in escalation of an event

The type and extent of each method of protection will be determined by the outcome of fire and other safety related studies. While estimates of fire-water coverage developed at the start of FEED can give a reasonable guide to the sizing of the firewater pumps for the early placement of purchase orders, the extent of passive protection takes much longer to assess. The timing of these studies is therefore important to enable realistic workscopes for the supply and application of passive protection to be developed.

Close liaison between safety and loss prevention engineers and process engineers is desirable for the development of fire scenarios, the outcome of which may indicate that in some areas of the FPSO, blanket deluge or extensive passive protection is not always necessary in the control of fires and the preservation of structural integrity. In certain areas, which in the past might have been provided with sprinkler coverage, it may be possible to provide adequate protection against the size and types of fires anticipated using strategically placed hose reels and hand held extinguishers appropriate to the type of fire.

Once the number and extent of fire zones have been established, then it becomes possible to determine the full extent of water coverage and passive protection for each zone.

#### **Active Protection**

Various aspects of the design of the main firewater system such as pumps and metallurgy have been discussed above in section 3.7.2. The following section deals briefly with peripheral equipment.

In areas which are deluge protected and /or hoses and monitors are used, it is essential that insulation, (thermal, acoustic, passive fire protection) on equipment, piping and structural members or panels, is designed and installed to withstand the deluge water forces. Insulation should also be impermeable to firewater and seawater to prevent corrosion under it.

The numbers and size of deluge valve sets will be determined by the water demands of individual fire zones. (Large sets frequently require more space than had been initially

allocated for them in preliminary layout studies). They also have to be positioned away from the area which they serve and suitably shielded to ensure that they are not rendered unserviceable by the event they were intended to be used against.

Although deluge valve sets have been features of active systems offshore for many years, it is still possible to encounter problems of metallurgy and the design of small bore piping (see section 3.7.2 above). The choice of materials for valves and valve components exposed to seawater should be agreed with the project corrosion adviser to avoid mixes of materials which can give rise to early corrosion. Rubber lining of seats, discs and gates as a means of protecting somewhat inferior, cheaper materials may break down resulting in high rates of localised corrosion.

Flushing of subheaders with fresh water after in service testing will help to prevent pitting of cupro-nickel pipework. Deluge nozzles orifices should be sized not only to provide the required coverage and spray pattern but to avoid blockage by foreign bodies or by salt deposits. The choice of metallurgy is also important to prevent corrosion which could render the nozzle(s) ineffective.

The choice of metallurgy is also important for the monitors, hydrants and hose reels to be used on seawater duty. Hose reels will be found mostly inside in the living quarters and machinery spaces. The standards for the supply pipework for the reels and for the valves and fittings should be the same as those for the rest of the firewater system.

Foam for rapid knock-down of fires will be aqueous film forming foam (AFFF). There is still discussion within the industry about the merits of 1% and 3% foam concentration and so the choice will depend on the preference of the operator's fire and safety engineers.

The selection and location of hand held extinguishers will be determined by the size and nature of the fire which might be expected in a given area.

The use of inert gas for extinguishing fires is now confined to carbon dioxide. The use of halon gas and other similar chlorofluorocarbon (CFC) extinguishants has been banned by international convention, i.e. the Montreal Protocol.

Carbon dioxide is used mainly in the enclosures of gas turbines. Special precautions have to be taken during entry to turbine enclosures to prevent the exposure of personnel to CO<sub>2</sub> in the event of spurious activation of the system.

Where halon flood was once used in switch rooms to extinguish electrical fires, it is now possible to have simpler active protection using hand held extinguishers only. A combination of panel design and strategically placed smoke and heat detection providing early warning can contain a fire and permit early intervention through electrical isolation and follow-up use of hand held units.

## Passive Protection

In the event of an explosion, the deluge system for the affected area may be damaged to the extent that it cannot offer any protection. Passive protection therefore becomes the only protection against progressive collapse of structure and equipment until such time as:

- the source of fuel has been isolated
- the fire brought under control by depressuring of the production facilities
- disposal of inventory, where that is possible
- the use of water or foam from other source

Passive protection can be provided by partitions, suitably rated for the anticipated type of fire, and by coatings. The use and ratings of partitions e.g. H120, A60, B15 etc, are covered in the Classification Society Rules as follows:

- Lloyds Register (ref 22) , Part 7, chapter 3, section 2.
- ABS (ref 24), chapter 4, section 8, subsection 9.
- DNV (ref 73) OS D301, chapter 1.

Where coatings are used to protect critical equipment and structures, the coating system must be

- Able to withstand the impact of firewater deluge and fire hose jets
- Able to remain intact following an explosion
- Able to withstand jet fires
- Non-combustible
- Flexible to accommodate movement of structural members and equipment due to flexing of the FPSO hull.
- Impervious to seawater, firewater, hydrocarbons and corrosive chemicals
- Chemically inert to prevent degradation over time
- Able to absorb impacts from tools etc without spalling

Consideration has also to be given to the method of application as some passive coatings systems are more labour intensive than others e.g. trowelled on vs spray application. Some may also require a supporting mesh structure to hold them in place.

The use of cementitious materials is not recommended due to unsatisfactory flex characteristics and a tendency to spall on impact.

Additional short term “passive protection” against thermal radiation for personnel escaping from a fire can be provided by the use of strategically placed mesh screens of proprietary design. These screens also provide a degree of weather protection in exposed places such as the turret structure.



### **3.7.13 Fire and Gas System**

The fire and gas system on an FPSO will be much larger than on a tanker by virtue of the coverage of the production facilities. In the case of a conversion, therefore, where there is already a fire and gas system in place, the system will not be capable of extension and upgrading to meet the new duty.

A review of the tanker system will be needed to determine if it is compatible with the proposed system for the production facilities and if the existing coverage is adequate in the spaces which it already serves. Depending on the outcome of the review, the designer and owner may decide to a) retain the existing system and extend it in the areas already served and then interface it with the new or b) scrap it and have a single system for the FPSO.

In view of the size and complexity of the F&G system it is recommended that the overall responsibility for the design of the system is given to the designer of the production facilities. The involvement of shipyard design personnel will be confined to any supporting role, if that is considered necessary.

The system will have many detection devices for gas, flame, smoke and where reservoir fluid properties demand it, detection for hydrogen sulphide H<sub>2</sub>S. Where there are large production modules, line of sight gas detectors looking along a module may be affected by the flexing of the hull and so any twist has to be compensated for. Fire detectors may be supplemented by thermal imaging cameras or CCTV for similar reasons.

Fusible plugs may be used to initiate the response of the deluge system, and pneumatic loops constructed from a low melting point material may be used where the shape and layout of equipment make the positioning of conventional detectors complicated or impractical. Care should be taken when positioning these loops to ensure that they are not exposed to warm equipment, thermal radiation from the flare, flaming liquid carry over from the flare or to unnecessary mechanical damage.

The design of the system and the monitoring and control hardware should be carried out by a system design house which has a proven track record in the design, manufacture, testing, delivery, installation and commissioning of large scale offshore fire and gas systems. The system may be stand alone or may be part of the overall production control and ESD system. Where a combined system is selected, then the system designer/supplier must also have a proven track record in the supply of combined systems as well as the individual component systems.

### **3.7.14 Production and Marine Controls (including ESD)**

In the case of a conversion, it is unlikely that the integration of production and marine control systems will be a viable option. Unless the conversion involves an intercept tanker at an early stage in its build, the marine control system will already be in place and

proven. Much of the control system will centre around the propulsion system. It is very likely that the owner will wish to retain the main engines and their auxiliary systems for a variety of reasons, such as station keeping, possible future uses, movements between yards and fields, etc.

The tanker bridge will be the marine control room, giving clear views ahead and astern during offloading operations. Locating the production control room adjacent to the bridge may not be possible due to structural and space constraints and the complexity of control cabling, termination cabinets etc. A production control room some distance away would appear to be the only option necessitating good communications between the two, especially during transfers to shuttle tankers. It may be possible to control the existing marine system from the production control room via mimics, status panels and a remote command panel.

In the case of a new build, the possible options for control rooms and systems are:

- A single control room with a combined marine and control system
- A single control room with separate control systems
- Separate control rooms and hence separate systems.

The production facilities control systems consist of the process and utilities controls, the ESD system and the fire and gas system. These three may be combined into a single control system or they may be separate but in communication with each other. Whichever configuration is chosen, the vendor of the single combined system or the vendors of the individual systems should have a proven track record for these type of systems, especially the supplier of the single system with its three main constituents. Proven experience is essential to ensure, among other things, that data highways and other related systems are not prone to overload, which may result in failure at critical times.

Where individual systems are selected from separate vendors, then one should be appointed as the lead to ensure that the interfacing and interaction is properly coordinated and managed. Active involvement on the part of process engineers and control engineers from the production facilities design contractor is recommended to assist the vendor in developing a clear understanding of the design intent. The involvement of the owner's operations representatives from an early stage is also essential in ensuring that screen displays are clear, easily understandable and unambiguous and that control desk layouts are user friendly.

The presentation of on-screen information must be such that in the event of alarms, trips and other abnormal events, the control room supervisory teams are not subjected to information overload. While the preservation of plant status data is needed to understand why certain events have occurred, the data actually presented should be selective and the scanning frequency set so that control room staff can quickly interpret what is happening and can intervene in the most appropriate manner.

Whatever choice is made for a new build FPSO, i.e. combined or separate marine and production control systems, the above comments on vendor experience apply. Where a combined system is selected, it is a project engineering decision on how the production and marine elements should interface and be managed. The lessons learned from past projects suggest that coordinating responsibility should be given to the production facilities design contractor and not to ship yard design staff.

### **3.7.15 Telecommunications**

The design and supply of telecommunications is often undertaken by a specialist contractor, working to a basis of design set by the FPSO owner and taking cognisance of the differences between ship requirements and those of offshore production facilities.

The basis of design will reflect the statutory requirements for marine communications between the FPSO and shore base, supply boat, shuttle tanker, stand by vessel, rescue vessel, passing traffic etc. Aeronautical band provision will also be required for communication with helicopter traffic. Radar will be included to monitor passing traffic and alert the FPSO crew to possible collision events. Ship to shore communication will also be via satellite link, where in addition to voice and fax communications, provision has to be made for production data transfer, email and intranet and internet traffic, television channels, video conferencing etc.

Care has to be taken with the positioning of radome support structures and aerials on top of the living quarters to avoid possible interference with helicopter traffic and crane operations.

Internal communications on the FPSO will consist of the General Alarm and Public Address system, the telephone system, the intercom system with call points, hand-held radios and pagers. Provision has to be made for communication between crane operators, deck supervisors and banksmen and supply boat crews. Work-stations and computers in offices around the FPSO will be linked via a local area network tied back via satellite into the operator's own computer network. In addition, there will be an entertainment system for radio, television and video.

The general alarm signals both audible and visual must comply with the guidelines laid down by the HSE in the PFEER Regulations (ref 11) Regulation 11. The numbers and siting of the flashing lights and the loudspeakers has to ensure complete coverage of the FPSO and must take account of obstructions and areas of high background noise, including wind and inclement weather. At the end of the construction phase and during commissioning the locations should be checked and repositioned if necessary. Cable lengths should allow for possible repositioning of fittings.

UKOOA has provided guidelines for the design of Safety Related Telecommunications Systems on Normally Attended Installations (ref 78) covering internal, external and emergency communications.

### **3.7.16 Cranes**

The location and number of main cranes on an FPSO will be determined by the size of the FPSO's deck i.e. length and breadth, and by the layout of the facilities on the deck.

#### **Mechanical Handling Studies**

Once the broad principles of layout have been established, the location of the main items of equipment has been agreed and laydown areas identified, it is advisable to perform outline mechanical handling studies. These studies should aim to determine first of all the sizes and shapes of the largest components of equipment items which might have to be removed for routine maintenance or in the event of a major breakdown or failure e.g. compressor bundles, gas generators from gas turbines, HV motors, heat exchanger bundles etc. The features of any unusual equipment items such as turrets, cargo loading reels and hoses, should also taken into account, as well as any need to access the helideck area.

The method of removal and potential removal routes are then identified and this information will help to determine the operating envelop of the cranes. (It is assumed that the FPSO will have a minimum of two main cranes as insurance against breakdown or prolonged outage). It is also possible that one crane may be needed to assist with the maintenance or overhaul of the other.

#### **Crane Type**

Operating envelopes and load tables will determine the crane ratings. It is at this point that the crane type will be chosen and it is essential that the owner/ operator/designer select a type that is suitable for offshore duty on a moving FPSO, subject to a wide range of vessel motions. Basic ship cranes, which are primarily used for loading to and from a vessel at a quayside, are not suitable for the rigours of a North Sea or West of Shetlands operating environment, unless considerable expense is devoted to upgrading the basic model before it leaves the manufacturer's works.

#### **Offshore Specification and Safety Features**

Cranes incorporating the more demanding specifications used for cranes on fixed offshore structures should be specified. At least one classification society refers to a European standard for general purpose offshore cranes, EN 13852, (ref 79). The manufacturers should be made aware of the special characteristics of an FPSO, including vessel motions and associated accelerations, and the potential difficulties of supply boat loading/ unloading operations when the FPSO and the supply boat will both be moving but with different motions. The design of the boom rest should also take into account the accelerations likely to be experienced in severe weather conditions with the boom parked and secured.

Safety features incorporated in the crane would include gross overload protection (to protect against hook snagging), load monitoring and alarms, emergency brakes to permit controlled load lowering on loss of power, and fire and gas detection. The cab location and design should afford the crane driver all round visibility and the controls layout and seat design should afford ease of operation. Communications will include GA/PA features. Means of escape provision should take FPSO vessel movement into account.

### **Availability**

Once a basic offshore crane type has been chosen, the method of powering the crane has to be selected i.e. electric-hydraulic or diesel hydraulic. Whatever method is selected, the crane should be capable of parking its load safely in the event of a loss of main and auxiliary power on the FPSO. Consideration should be given to crane availability, and any adverse impact on FPSO operation, in the event of a protracted outage of main and auxiliary/ emergency power.

### **Major Maintenance**

The inspection and change out of a slew ring are major activities on a pedestal crane as is an engine change out. The designer, in conjunction with the crane manufacturer and the operator's maintenance team, should make suitable provisions for these activities. Booms should be provided with an adequate walkway or other suitable access to facilitate inspection of the boom and ropes and other maintenance activities.

### **3.7.17 Turret and Support Systems**

Although the turret and its swivel are proprietary items, where the overall design responsibility rests with the supplier, the FPSO owner must be able to provide input on matters of operability and access for operation and maintenance. The safety standards which apply to the rest of the FPSO shall apply to the turret also e.g. width of walkways, stairways, ladders, handrails, lighting etc.

The complexity of the turret layout is determined by the number of risers which it is designed for, including spare riser slots. A large field development with several subsea satellites will require large manifolds for production from the groups of well clusters, for water injection, for possible gas lift and gas injection, chemicals, etc. Additional complexity can come from gas export, crude oil export to an FSU or a pipeline gathering system and from pigging requirements for subsea flowlines. Pigging operations require a system of interlocked valves, launchers and receivers to ensure the highest standards of safety. Design guidance may be found in the Pipelines Safety Regulations 1996 (SI1996/825) (ref 60). Good layout around the launcher/ receiver and valve stations is a prerequisite.

Swivel fluid paths carry produced fluids, injection water, gas, chemicals such as methanol and utilities for the turret area, such as air, nitrogen and water. Slip rings are also required for electrical power, control-including ESD and F&G, and telecomms.

The turret will also contain the subsea control panels either in the open or in an enclosure. The enclosure, where provided, is located in a hazardous area and so the design of the ventilation system will have to take this into account i.e. air intakes and exhausts located in a non hazardous area, smoke and gas detection in intakes and exhausts, overpressured relative to outside, pressurised air lock.

### **3.7.18 Safety Related Sub-Systems**

In addition to active and passive fire protection systems, fire and gas and emergency shutdown systems, escape routes and means of evacuation, there is a range of other safety related sub systems or units which have to be taken into account. This section does not go into any technical discussion about these but merely provides a list of items which have to be addressed in the course of the design phase. The list is not exhaustive and a final list should be drawn up by the project safety and loss control team in conjunction with the owner's/ operator's safety advisors. Where an FPSO vessel was previously a tanker, the original provisions should be reviewed to ensure that the design and numbers of any retained items are appropriate for the new application.

- Emergency lighting (taking account of obstructions and high density areas)
- Marking of escape routes for visibility in smoke conditions
- Manual call points (MACs) and their location
- Breathing apparatus and charging compressor
- Firemen's equipment (overalls, helmets, gloves, axes etc)
- Personnel protection equipment, including survival suits, life jackets, smoke hoods, torches, gloves etc (see PFEER Regulations (ref 11) Regulation 18)
- Lifeboats (TEMPSCs) and Liferrafts
- Lifebelts
- Secondary means of escape to sea including proprietary harness devices, chutes, ropes, nets etc
- Portable fire extinguishers
- Signage and safety plans
- Safety showers and eyebaths (and heat tracing of these)
- First aid equipment including stretchers

### **3.8 FPSO SMALL UTILITY AND SUPPORT SYSTEMS**

This section covers the common small utility systems, which are technically uncomplicated but are nevertheless vital to the smooth, reliable operation of the FPSO. It is possible that some of these systems will be designed by the hull contractor who may be less familiar with the specific needs of the production support systems. By paying attention to relatively minor details, the designer can help to prevent outages and avoidable downtime

#### **3.8.1 Diesel Fuel**

The consumers of diesel on the FPSO are the main power generation units (turbines or reciprocating engines), gas turbine drivers for large compressors and pumps, the emergency generators, the fire pumps and the inert gas generator for cargo tank blanketing. Marine quality diesel, filtered and centrifuged to remove water and particulates, is unlikely to present problems for the fuel systems of the reciprocating engines on propulsion and main power generation (where these have been retained), and on emergency generator and fire pump duties.

#### **Filtration and System Cleanliness**

Where aero-derivative gas turbine drives are used, the quality of the diesel is of major importance to prevent the build-up of soot and other deposits on the turbine HP and LP section blades which can lead to premature blade failure. The engine manufacturer's specification for liquid fuel must be communicated to the designer of the diesel system so that the target particulate levels can be achieved by both coarse and fine filtration.

For some engines the maximum particle size can be as low as 5 microns, a level which will require coarse filtration followed by fine filtration. Duplex filters should be specified as a minimum for each duty so that cartridges can be changed on line and quickly. All fuel supply pipework downstream of the fine filter should be of stainless steel to avoid scale pick-up. Chemical cleaning of pipework is recommended before commissioning. Compatible gaskets for the stainless steel pipework should also be specified.

Even though the diesel fuel specification for the gas turbines may be stringent in terms of water content, particulate and metals such as vanadium, the quality received from a supply boat cannot always be guaranteed. Coalescers or centrifuges can be used to remove water to acceptable levels. The internal coatings of the main diesel tanks and any day tanks should be chosen with care and applied in accordance with the manufacturer's instructions to prevent premature breakdown of the coating and the onset of corrosion, leading to a larger particulates burden from rust and scale.

The draw off from the tank base should be via a stand pipe to avoid contamination from water and particulates. The outlet from the supply line and the recirculation line should be submerged to avoid splashing and the risk of static build up.

## **System Monitoring**

Where crew size has been kept to a minimum, it is likely that attendance in the machinery spaces will be low and hence regular routine system monitoring is also likely to be low. Rapid increase in filter pressure drop may result in cartridge collapse and the break through of debris in to the combustion chambers with consequential damage. The amount of instrumentation and alarms alarming in the control room may therefore need to be higher than might be expected on a conventional diesel engined tanker and operations input should be sought in advance to agree what is required.

### **3.8.2 Fuel Gas**

The main consumers of fuel gas will be the main generators, gas turbines or dual fuel engines, and gas turbine drivers for large compressor trains or pumps, where these are required.

#### **Gas specification and system cleanliness**

The fuel gas specification will be dictated by the turbine manufacturer with very stringent limits in terms of moisture, sulphur content and particulates.

As with diesel fuel, fuel gas system cleanliness is very important and so duplex fuel gas filters will be required to ensure uninterrupted supply during filter cartridge change out. Stainless steel piping should be specified and chemical cleaning is recommended to achieve as high a cleanliness standard as possible.

#### **Avoidance of Leaks**

The supply piping from the dehydration unit in the gas processing area should be all welded to minimise the risk of leaks within the utilities area where the main power generation turbines are likely to be located. The number of valves in the supply should also be minimised. The only flanged joint should ideally be at the edge of the turbine skid. Inside the turbine enclosure, flanged joints should be kept to a minimum if at all possible, although access for maintenance on the turbine skid will necessitate flanged joints to permit easier piping removal.

#### **Fuel Gas in the Hull**

Where the existing ships generators are retained and where the FPSO fuel gas balance and flaring policy demands it, fuel gas may have to be supplied to the machinery space. The design of the supply system must involve safety engineers as well as piping designers to ensure that risks of leaks of high pressure fuel gas are minimised. An all welded “pipe in pipe” supply will eliminate flanges and provide a second means of containment in the event of leakage from the inner pipe.



The numbers and the location of gas detectors around the generators and within the generator room(s) have to be given careful consideration. The design of the ventilation system should provide high rates of air changes to dilute leaks, and its controls and power supply must ensure as high a degree of reliability and availability as possible.

### **3.8.3 Compressed Air**

The compressed air system supplies plant air and instrument quality air for pneumatic instrumentation systems. Instrument quality air is also used for the inert gas unit supplying nitrogen to the production facilities for blanketing and purging.

#### **Air Quality**

For general plant air duty, i.e. hand tools, pneumatic hoists etc, air quality is generally not critical. Instrument air quality means the air has to be oil free and has a dew point of minus 20 to minus 40 degC. Apart from causing obstructions in pneumatic controls, the presence of oil can also damage the membranes of the inert gas generator and the desiccant of air dryers. Where reciprocating air compressors or injected oil screw compressors are used for general air duty, oil knock out facilities will be needed to achieve oil free quality. Where dry screw compressors are used, the design of the shaft seals should be checked to ensure that inward leakage of lube oil does not contaminate the air.

#### **Air Receivers**

Sizing of the instrument air receiver has to take account of the demands of the air system to allow the FPSO facilities to be shut down safely and restarted quickly in the event of a power outage.

Some FPSO owners have used single air receivers to provide both plant air and instrument air, a single receiver being less costly than two. Whether one or two air receivers are used, non essential air consumers will be shut down in ascending order of importance to maintain satisfactory pressure levels in the system. Sometimes a small charge compressor, powered from the emergency switchboard, can be employed to maintain pressure and can also be used for black start purposes.

The instrument air receiver sizing does not need to allow for the demands of the inert gas (N<sub>2</sub>) generator. During upset conditions, nitrogen demand can be met from the high pressure bottled supply (quads).

### **3.8.4 Potable Water**

On fixed production platforms with limited bulk liquid storage, potable water maker packages have been installed, especially where re-supply times have been less predictable in periods of bad weather.

On FPSOs, where there is ample storage tank capacity, there is no need to provide on board treatment capacity, unless the vessel already has a water maker installed for its former tanker role.

Whether potable water is shipped in or is made on board, water purity and system cleanliness are essential in preventing health related problems. Water storage tanks must have internal coatings which apart from being non toxic must also have long term durability and sufficient flexibility to adapt to the twisting and bending of the hull without cracking and spalling.

Potable water circulation pumps and main pipework shall be of non-corrosive, non toxic materials. In the living quarters domestic copper piping is acceptable in cabins, galley, wash rooms etc. A sterilisation unit will provide final purification to supplement manual dosing of bulk liquids.

### **3.8.5 Heating Medium**

The heating medium system, if correctly designed, should help in optimising the energy balance of the FPSO by capturing waste heat primarily from the exhaust gases of the power generation turbines. As the turbines are on line for most of the time, they can provide a steady source of waste energy.

#### **Waste Heat Recovery Units (WHRU)**

Waste heat recovery units are usually provided by the package vendor of the gas turbines as part of his scope of supply, fully integrated with the rest of the turbine packages. The WHRUs should be robust, totally suitable for exposed outdoor offshore use and have adequate access to damper controls and main duct joints.

If at some later date in the field life, the heating medium load increases, the WHRUs may need to cater for turbine exhaust reheat.

#### **Heat Exchangers**

The system is a relatively low pressure water/glycol mixture circulation system where carbon steel is the main material of construction. It may be used with shell and tube and plate exchangers. Where “compact” designs of exchangers are used, such as the “printed circuit” type of design, provision has to be made for in-line duplex filters to avoid scale and rust clogging up the small passages of this type of exchanger. As it is a platform-

wide source of heat, attention should be paid to pressure differentials across heat exchangers to minimise the risk of contamination of non hazardous users and of the heating medium itself. Heating medium fluid should not be introduced into the living quarters.

### **3.8.6 Cooling Medium**

The cooling medium system is an FPSO wide closed loop cooling system. The fluid is a water-glycol mixture which is in turn cooled by seawater. There are various cooling duties and a variety of heat exchangers can be used in the cooling circuit- shell and tube, plate and proprietary “compact” units such as printed circuit heat exchangers.

#### **Pressure Differentials**

The system design pressure is relatively low and on duties such as gas compressor intercoolers the gas pressure can be many times higher than that of the cooling medium system. The process designer has to ensure that the possibility of leakage of high pressure fluids into the low pressure cooling side is minimal to prevent the migration of the high pressure fluids in to non hazardous areas of the FPSO. The design measures to be taken include:

- Careful choice of materials of construction of the exchanger
- Avoidance of thermal cycling
- Avoidance of pressure cycling including pulsating flows
- Design to prevent tube or plate vibration and fatigue failure
- Provision of pressure alarms and trips
- Provision of bursting discs and pressure relief valves for sudden tube failure
- Motorised isolation valves in supply and discharge lines for quick shut-off.

Operations in-service checks will include pressure trend monitoring and cooling medium fluid analysis.

Some cooling duties in the utilities and non-hazardous areas of the FPSO will be by direct auxiliary seawater cooling or a separate, small cooling medium system to eliminate the possibility of cross contamination of these systems by hydrocarbons or other harmful fluids.

#### **System Cleanliness**

Printed circuit and compact heat exchangers are often chosen in preference to heavier and bulkier shell and tube exchangers because of the perceived weight and space savings they provide. Their narrow flow paths require then to be used on clean duties so that the risk of flow path blockage is minimised. System cleanliness is therefore essential and the first line of defence is appropriate levels of fine filtration on both the coolant and the cooled sides of the exchanger.

Carbon steel is usually the material of first choice for the water/ glycol mixture. In order to meet the standards of cleanliness to prevent flow path plugging, the piping design should avoid dead legs and minimise low points. The construction and commissioning phases of a project have to include power jetting of pipework to remove scale and extensive flushing followed by chemical cleaning and passivation.

### **3.8.7 Sewage**

The design of the sewage system , including treatment plant, will most likely comply with classification societies' rules for the classification of ships or steel vessels and the discharge specification will be in accordance with MARPOL regulations (ref 17) or company standard whichever is the more stringent, depending on the company's emissions and discharges policy. (Note that although the UK has ratified MARPOL Annex IV, it has still to introduce appropriate legislation).

In the case of a seagoing vessel moving ahead of the discharge point, the risk of cross contamination of seawater intakes is negligible. On an FPSO on a fixed location, the risk of sewage entering the seachests or seawater caissons should be low due to effects of heading, wind and current, except when current prevails over wind. Nevertheless, attention should be paid to the relative positions of intakes and outfalls to avoid contamination

Materials of construction in the main are PVC, with adequate provision for rodding points throughout the system. Care should be taken with the routing of sewage carrying pipework to avoid galley and dining and recreational areas.

### **3.8.8 Helifuel**

Helicopter refuelling facilities are generally supplied by specialist packagers of this type of equipment, conversant with industry requirements. Individual owners and operators have specific requirements and so it is advisable to obtain the early input of their logistics groups to ensure that the package meets their particular needs. LR (ref 22) part 5, chapter 13, section 6, provides general guidelines.

Firewater deluge and foam arrangements for the main skid and for the skid for the portable helifuel containers should be discussed with safety and loss prevention engineers to ensure adequate coverage. Initiation will most likely be by fusible links or by proprietary pneumatic tubing. These devices are prone to mechanical damage which can lead to premature water and foam release. Care should therefore be taken with the positioning of links and the routing of tubing to minimise damage from handling, maintenance and operations activities on and around the skids.

## REFERENCES

The references in this section are believed to be correct at the time of publication. It is the responsibility of those designing an FPSO installation in the UKCS to ensure that all complete and up to date references are applied.

Useful web site addresses covering some of the following references are:

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Health and Safety Executive:	<a href="http://www.hse.gov.uk">www.hse.gov.uk</a>
UKOOA:	<a href="http://www.ukooa.co.uk">www.ukooa.co.uk</a>
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