

### 3.1 INTRODUCTION

This chapter provides a description of the Jubilee Field Phase 1 Development project. It starts with an overview of the main project offshore infrastructure and schedule. The alternative options considered during the project design, along with the reasons for the final choices made, and details of the project facilities and equipment are described. Details are given of the main project activities, from installation to decommissioning, and the likely personnel and shore support requirements. Finally information on the various emissions, discharges and wastes likely to arise from the proposed project activities is provided.

Permits for the well drilling activities have already been issued and the Phase 1 project activities addressed in this EIS commence from what is known as the well completion stage. Well completions are undertaken by the drilling vessels in preparation for the installation of the subsea infrastructure, therefore, relevant details of the drilling vessels are also included in this project description. Where necessary links with the previous EISs from the drilling activities are made and a summary of the EISs for the drilling activities is included in *Annex B*. *Annex B* also includes a discussion on drilling fluids and drill cuttings discharges.

### 3.2 PROJECT OVERVIEW

#### 3.2.1 Offshore Infrastructure

The Jubilee oil field was discovered in 2007 and is located in deep water (1,100-1,700 m) approximately 60 km from the nearest coast in western Ghana. The field underlies portions of the West Cape Three Points and Deepwater Tano licence blocks (see *Chapter 1: Figure 1.1* and *Figure 1.2*).

The field is planned to be developed in a number of phases with the information on the size and nature of the oil and gas reserves obtained during Phase 1, as well as the results of further exploration and appraisal drilling within the Jubilee Unit Area and other parts of the licence blocks, informing any future developments. The initial estimated production capacity for the Phase 1 development is 160,000 bbls<sup>(1)</sup> gross liquid per day including 120,000 barrels of oil per day (bopd).

The Phase 1 development will involve a planned 17 wells drilled from up to eight drill centres. These wells will be a combination of nine hydrocarbon production wells to bring oil and gas from the underground reservoirs to the surface, and six water and two gas injection wells used to re-inject water and

(1) 1 US standard barrel of oil (bbl) = 159 litres or 0.159 m<sup>3</sup>

gas back into the reservoirs, respectively, to maintain pressure and increase reserve recovery. The initial target for five of the production wells and the three water injection wells is the Lower Mahogany reservoir. The remaining four production wells and three water injection wells, plus the two gas injection wells target the Upper Mahogany reservoir. Early drilling results have refined the original well locations and the current well positions are shown in *Figure 3.1* below. These targets will be further refined as more data is obtained during the drilling programme.

The wells will be connected on the seabed through a series of sub-sea wellheads, manifolds and pipelines to a Floating Production, Storage and Offloading (FPSO) vessel located on the surface at the northern edge of the Jubilee field in approximately 1,100 m of water. The FPSO will be used to process and store crude oil and gas. Crude oil will be exported to markets using export tankers (some may be transported direct to the Tema refinery in Ghana). Gas will not be routinely flared to permit oil production and will either be used for energy needs on the FPSO for electrical power generation or be re-injected into the wells. A potential future project would allow the gas to be exported to shore for processing and power generation (see *Section 3.3.5*) and this project would be subject to a separate permitting process and EIA.

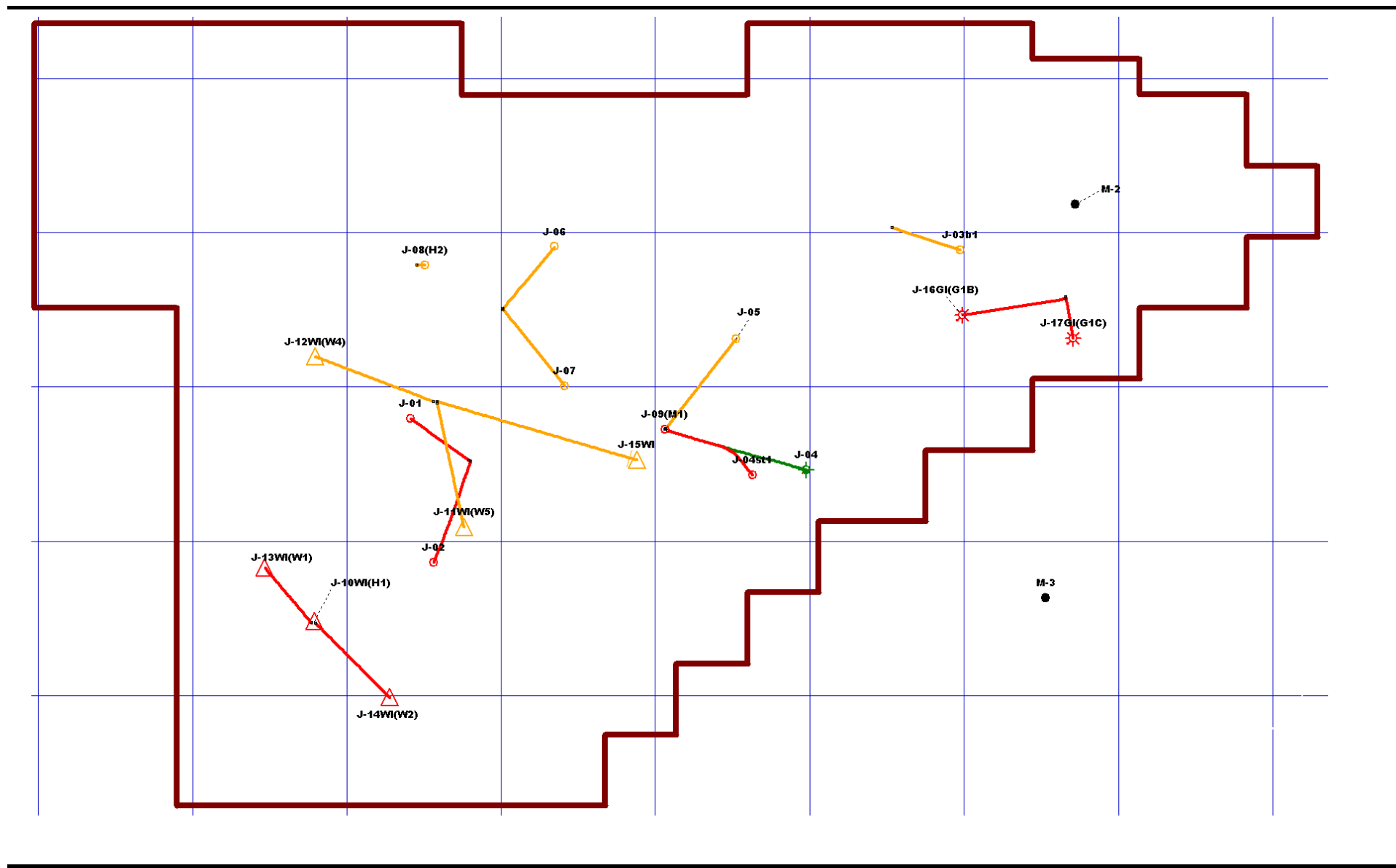
The subsea equipment to be installed will have the capacity to accommodate 32 wells (through additional well slots and manifold connections) which will allow infill drilling during the operational phase of the project to maintain or restore production levels depending on the observed production response from the Phase 1 wells. The design will also allow subsea connections to potential future wells in outlying parts of the field. The FPSO is also designed to accommodate additional wells with extra riser space/slots in the FPSO turret. Potential future phases could maintain production within the 120,000 bopd oil processing limit of the FPSO for an extended period, although future phases may not be required or may be deferred if the actual performance of the initial 17 Phase 1 wells is better than forecasted. In necessary, a second FPSO vessel could be installed as part of a future phase of development. As discussed in *Chapter 1* any future phases would be subject to separate permitting processes by the EPA, which could include a requirement to undertake further EIAs.

### **3.2.2 Phase 1 Project Schedule**

Two of the wells drilled as part of the exploration phase (Mahogany 1 and Hyedua 1) will be used in Phase 1 along with new 15 additional wells drilled and completed progressively from late 2008 to early 2011. Installation of subsea equipment is planned to start in the first quarter of 2010 and continue for about six months.

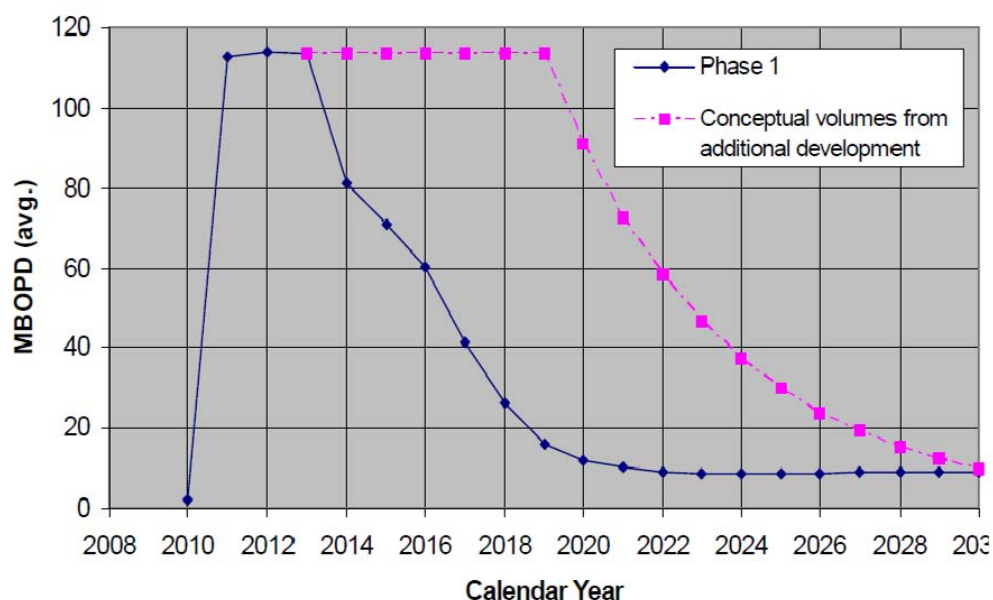
The FPSO vessel is being converted from an existing tanker in Singapore and is due for completion at the end of the first quarter of 2010. On completion it will transit under its own power from Singapore to Ghana and is scheduled to arrive in second quarter of 2010 for mooring and installation.

Figure 3.1 Current Well Locations (Source Tullow Ghana Ltd June 2009)



First oil production is planned for fourth quarter 2010 and the field is expected to produce oil for at least 20 years based on current estimates of the reserves. Figure 3.2 shows the production forecast for the Phase 1 development from the Plan of Development (PoD) with an average production volume of 114,000 bopd (after process downtime) in the first full year. Potential oil volumes from future phases are also indicated based on conceptual modelling undertaken by the Jubilee JV partners.

**Figure 3.2** *Oil Production Forecast*



Source: Tullow Ghana Ltd

### 3.3 PROJECT ALTERNATIVES

During the design concept phase of the project, the project team evaluated a number of alternatives before defining the final project design. This section summarises the main alternatives considered and presents the reasons for the choice of the final field development concept. The evaluation of alternatives took into account safety, engineering, technical, financial and environmental considerations with the final choice being based on the option that provided the best overall performance against these criteria.

This section describes the overall Safety Case approach taken to the project design followed by a discussion on the following main project alternatives considered.

- Development Approach.
- FPSO Design.
- Mooring System.
- Gas Utilisation.
- Shore Base.

### 3.3.1

#### *Project Safety Case*

It is a requirement of the Tullow Environmental, Health and Safety Management System (EHS MS) that a hazard and risk assessment is integrated into all stages of the project lifecycle, including project definition, selection, implementation and operation. The Phase 1 Jubilee project has been subject to hazard and risk assessment through both internal and external processes and this will continue throughout the life of the project. As part of this process the Jubilee JV partners have implemented a Safety Case which identifies major hazards, assesses their significance and implements mitigation measures to reduce their potential to acceptable levels.

The Safety Case includes various Formal Safety Assessments (FSAs) and Hazard Identification/Hazardous Operations (HAZID/HAZOP) studies of risks such as explosion, fire, dropped objects, ship collision and gas release. Outcomes of these studies are integrated into the design through mitigation measures or Safety Critical Elements (SCEs) which are monitored against Performance Standards during field life. The Safety Case is updated as the control measures are tested and verified and during the field life as the risk profile changes or modifications are made to the facilities. The Safety Case will be submitted to a third party for verification.

For the Jubilee Phase 1 project a key mitigation measure for the project selection and design phases has been to use proven technology, systems and implementation methods which have been successfully used in other parts of the world.

### 3.3.2

#### *Development Approach*

During the Phase 1 project feasibility studies undertaken between late 2007 and early 2008, a number of field development concepts were identified. The options were screened against various factors including requirements for no continuous gas flaring and avoidance of an oil export pipeline to shore due to time, cost and environmental considerations. Cost, revenue and schedule models were developed for each option, based on the subsurface and surface data available at the time of the screening studies. In the assessment of the different development options, the following factors were taken into consideration.

- Comparisons with development options used in other similar fields worldwide (benchmarking).
- Flexibility to respond to the reservoir production information obtained during the project operations.
- Environmental, health and safety considerations.

Five main options were developed and compared at a development options workshop, held by the project design team in January 2008. The five main options are listed below, followed by a summary of the main option components.

1. Extended well test and later major field development using an FPSO or Tension Leg Platform (TLP).
2. Continued field appraisal with phases of development commenced by utilising an FPSO.
3. Continued field appraisal with phases of development by TLP with Floating Storage Unit (FSU) or export line to shore with terminal.
4. Full field appraisal, then followed by full field development with FPSOs.
5. Full field appraisal, then followed by full field development with TLPs/FSUs.

An alternative to the FPSO or FSU oil storage-export approach would be to consider an oil pipeline to shore along with an oil terminal including subsequent buoy or jetty tanker export facilities. This approach requires a long lead time and was not justifiable for the first phase of the Jubilee development given the schedule for delivering first oil.

*Extended Well Test FPSO and Later Major Field Development using an FPSO or TLP*

This concept comprised extended well testing with four production wells connected to a small (approximately 40,000 bopd) FPSO to gather early production data from the field prior to a larger scale development. At the same time appraisal drilling would continue to obtain information on the extent of the field. The oil processing would necessitate gas flaring during production and there would be no water injection to maintain reservoir pressure. Later development would be optimised by the data gathered.

First production would be achieved in approximately 18 months from development permit approval.

*Continued Field Appraisal with Phases of Development by FPSO*

This concept comprised continued field appraisal well drilling and phased development of the field with initial installation of an FPSO (80 to 120,000 bopd). The FPSO would have full oil processing and water and gas injection capabilities across a core area of the field. Phase 1 development would be based on data from the first exploration well results (Mahogany 1 and Hyedua 1). Dynamic production data from the field would be gathered and there would be no gas flaring. Water and gas would be injected for reservoir management. The Phase 1 scheme would have the ability to expand with further subsea well connections as appraisal well results were obtained.

This approach would allow first production to be achieved in 24 to 30 months from development permit approval, and is the present approach being pursued by the Jubilee JV partners.

*Continued Field Appraisal with Phases of Development by Tension Leg Platform (TLP) with Floating Storage Unit (FSU)*

This approach would involve continued field appraisal well drilling outlined above but use of TLP technology and surface wellheads rather than an FPSO and subsea wellheads. The TLP would be capable of both drilling and supporting the full oil, water and gas processing facilities, with oil export via a Floating Storage Unit (FSU). The FSU would be a separate installation similar to an FPSO but without the processing topsides and the oil taken to market by export tankers. Gas would be re-injected at the TLP to the producing reservoir formations for improved recovery with an option for later export of gas. The TLP would also provide sea water injection for reservoir pressure support.

The advantage of a TLP with surface wellheads compared to a subsea well only development is the ability to carry out cost effective and detailed reservoir surveillance and well maintenance. However, given the areal extent of the field and the relatively shallow depth of the reservoir it would not be possible to drill all the wells from even a single TLP production centre, therefore, additional drilling rigs would be required and some subsea wells would still be connected (tied-back) to the TLP from the periphery of the field.

This approach would allow first production to be achieved in 30 to 40 months from development permit approval.

*Full Field Appraisal followed by Full Field Development with FPSOs*

This non-phased development approach requires full field project development to be deferred until appraisal drilling of an estimated four to eight further wells has been completed. Given the fields potential extent it is expected that two or three production centres could be required; most likely separate FPSOs with their own subsea well networks. This development approach results in the highest initial capital spend without having production data to understand reservoir performance to optimise any potential later development work and mitigate risk of a lower reservoir performance outcome.

This full field appraisal approach was estimated to require an appraisal period of between 24 to 30 months and then following permit approval a construction period of 24 to 30 months before first oil. In total, 48 to 60 months would be required to first oil production.

*Full Field Appraisal followed by Full Field Development with TLPs/FSUs*

This approach is similar to the previous approach but using TLPs and FSUs rather than FPSOs. This approach would have a likely longer schedule to the FPSO approach given the more extensive facility build requirements.

The screening work undertaken at the January 2008 workshop concluded that the second option outlined above was the preferred option, ie a continued field appraisal drilling programme to delineate field size and with phases of development initiated by a large (120,000 bopd) Phase 1 FPSO linked to a subsea well layout. This option met the requirements of no continuous gas flaring, satisfactory reservoir management to protect and maximise oil reserves (gas and water injection at field start-up) whilst providing a relatively rapid first production schedule. The phased approach allows a development plan to be put in place for the first phase with later phases of development being optimised using the reservoir data from the first phase, including the actual production response of the field to extraction and injection. This phased approach to major investments mitigates financial risks and is common practice in major oilfield developments.

### 3.3.3 FPSO Design

Various types of production facilities are used worldwide and, depending on the situation, the facility may be fixed to the ocean floor (eg tension leg or jack-up platforms) or may float (eg floating production systems).

A turret-moored FPSO was selected as the development concept for the receipt, processing and storage of the Jubilee Phase 1 reservoir fluids. The primary factors influencing this choice were:

- water depth;
- remote location of the field (remote also to any other infrastructure such as any oil pipelines) leading to a relatively high storage capacity to limit the number of export tanker visits;
- areal extent of the field not permitting a centralised drilling platform;
- safety and environmental performance (ie a turret moored FPSO weather vanes in alignment with current and wind conditions reducing collision and oil spill risks during export tanker offloading operations); and
- is a proven method in similar fields worldwide.

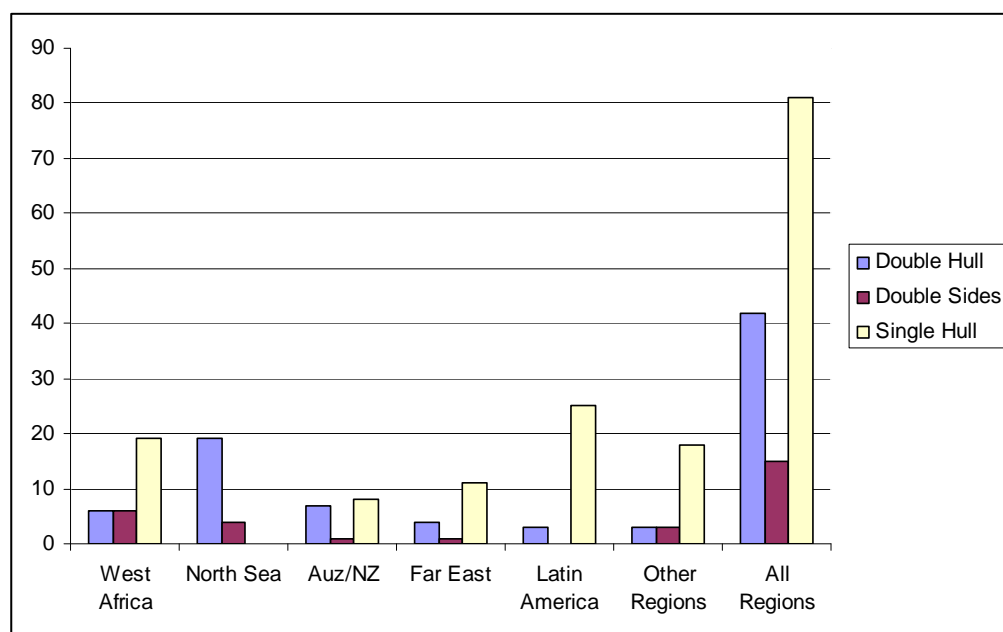
The FPSO size would meet the anticipated field productivity from the initial well count with a frequency of offloading set at approximately every five to seven days, which is considered to be practically achievable in West Africa given available offload tanker traffic in the area.

The use of FPSOs is a well established development concept deployed in numerous areas of the world and extensively in Atlantic Africa. There are now 138 FPSO vessels operating worldwide. FPSOs are either newly built hulls or converted from existing trading tankers with new topside facilities added on to the main deck. For the Jubilee field a tanker conversion of a single hulled Very Large Crude Carrier (VLCC), originally built in 1991, was selected. Tanker conversions into FPSOs are more prominent than new build facilities due to their reduced procurement schedule, reduced cost and the



large selection of vessels available. *Figure 3.3* presents regional variation in the selected hull configurations.

**Figure 3.3** *Percentage of Current World Fleet by Geographical Location and Hull Type*



Data Source: CEC FPSO Database

Double-sided hull configurations (usually new build FPSOs) are normally used where conditions demand a purpose built vessel, generally with increased or specialised storage capacity. This configuration is also used where harsh environmental conditions exist such as the North Sea or Australasia (ie occurrence of cyclones and hurricanes) or in areas of heavy shipping traffic such as the Niger delta. In these circumstances, extensive steel replacement is required to fulfil fatigue life requirements, thus making conversion of an existing vessel uneconomical. In West Africa, where the environmental conditions are relatively benign, there are 31 FPSOs; 19 single hull, six double hulled and six double sided (see *Figure 3.3*).

In most cases, the requirement for new builds was for the very large storage hulls required where the extra rigidity and strength was required due to their dimensions and need for extended fatigue life against long expected production/field life.

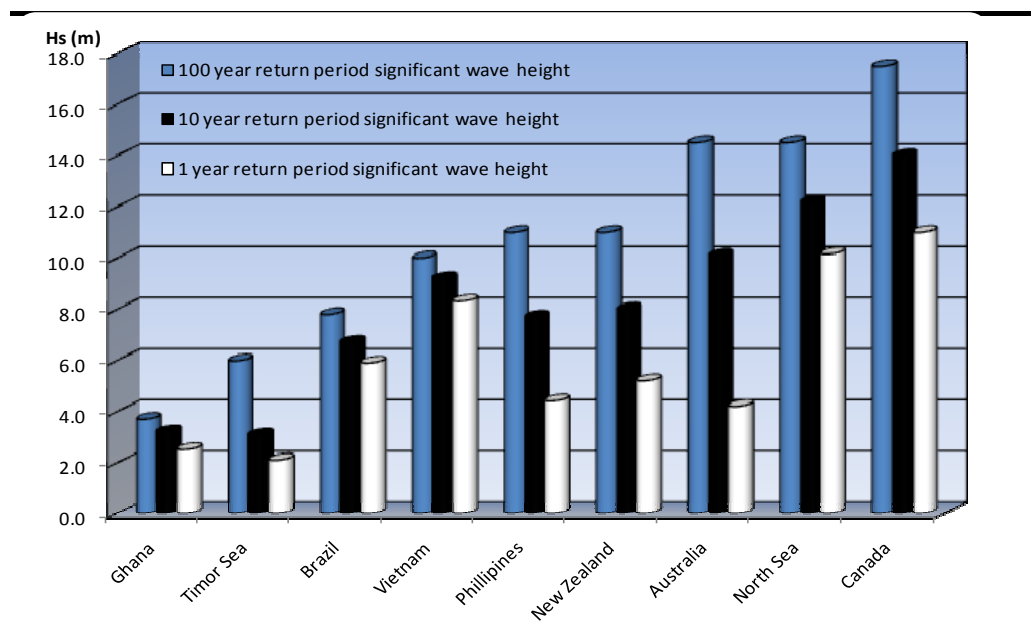
Details on the considerations that apply to the management of double hulls and the type of hull best suited to a particular location and project are provided in OGP (2001), EMSA (2005) and IMO 2009. These include:

- double hulls can be more prone to thermally accelerated tank bottom corrosion without regular inspection;
- double hulls may operate to higher stress levels causing future fatigue problems;
- double hulls are more difficult to conduct inspections;

- there is a higher potential for explosion in double hull ballast tank due to leaks between hulls where there is more tank spaces and more complex confined geometry.

Single sided hull configurations (usually tanker conversion) are the most common, particularly for low energy metocean environments (ie low wind speed and wave height). *Figure 3.4* shows the typical metocean conditions (in terms of significant wave height) in the Jubilee project area, which are seen as relatively benign compared to other regions around the world, therefore the hydrodynamic loading on the FPSO hull and turret swivel will also be relatively low. Site specific metocean data has also been obtained from specialist buoys deployed in the Jubilee field. The data from these buoys have been incorporated into the design of the FPSO, its mooring system and subsea connected flowlines and controls.

**Figure 3.4** *Regional Significant Wave Height (Hs)*



Source: Tullow Ghana Ltd

A third party quantitative risk assessment was undertaken of collision hazards and risks from vessel traffic around the FPSO such as supply ships, incoming offloading tankers, MODUs and from the nearest major shipping lane located approximately 8 nautical miles to the south of the FPSO location. The study considered the metocean conditions in the Jubilee field (see *Table 3.1*), the shipping traffic density and type in the region and scenarios of powered or drifting craft/vessels. The ship collision studies found that unmitigated collision risks (ie without the protection measures designed in to the operations) with the potential to breach the selected single hull were very low (once in 5,300 years) with negligible risk reduction benefit gained from having a double hull or double sided FPSO with respect to these likely collision risks (once in 6,300 years).

**Table 3.1**      *Summary Metocean Field Conditions Adopted in FPSO Design*

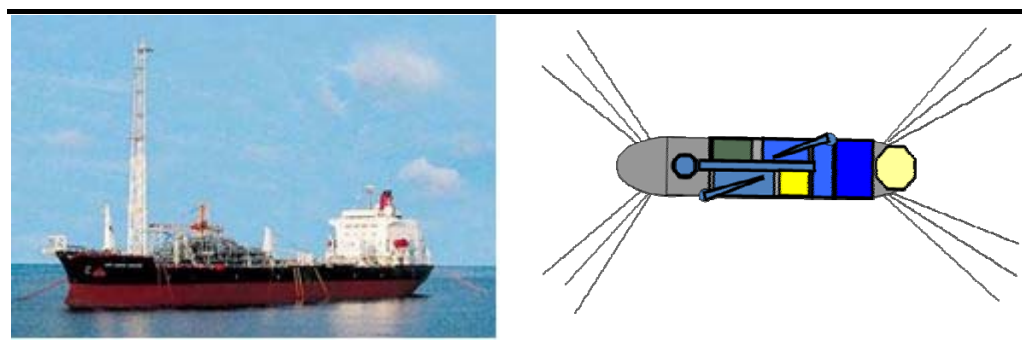
Return Period	Swell		Sea		Wind
-	Hs (m)	Tp (s)	Hs (m)	Tp (s)	W3sec (m/s)
1 year	2.5	14.5	1.3	5.1	19.8
5 years	3.0	15.8	1.7	5.6	22.8
10 years	3.2	16.2	1.8	5.8	24.1
100 years	3.7	17.2	2.3	6.2	28.4

### 3.3.4      *Mooring System*

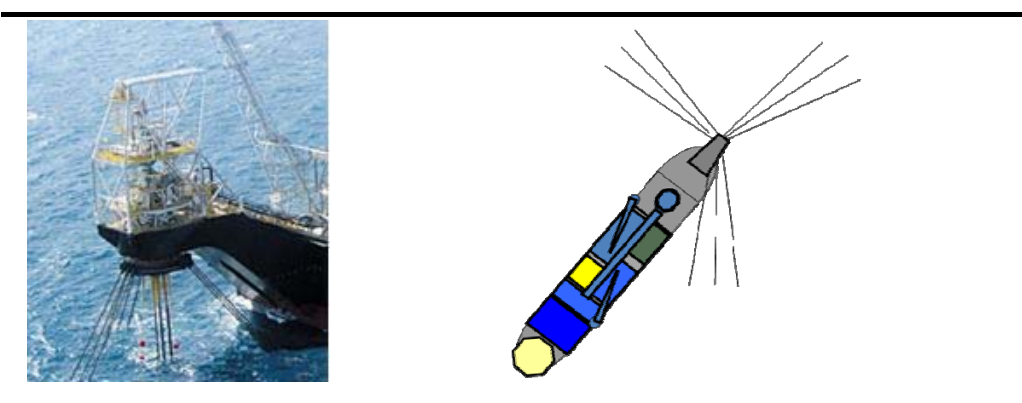
Two types of mooring configuration have been considered for Jubilee FPSO. These consisted of spread mooring or a forward mounted turret Single Point Mooring (SPM). Spread mooring typically consists of mooring lines from the extremities of the vessel spreading outwards to their anchored locations (*Figure 3.5*). These mooring lines are normally made of chain and fibre rope which keeps the vessel in a fixed position.

Turret mooring is defined as a system where a number of mooring legs are connected to a turret which is essentially part of the vessel to be moored (*Figure 3.6*). The moorings are connected to the turret by means of a chain table. Similar to the spread mooring system, the mooring lines are typically made up of chain and fibre rope. The turret system has a universal joint which allows the vessel to freely turn 360° around the SPM vertical axis to align itself with the prevailing wind, wave and current conditions (ie the FPSO weather vanes).

**Figure 3.5**      *FPSO with a Spread Mooring System*



**Figure 3.6**      *FPSO with an External Turret Single Point Mooring System*



A forward mounted external turret SPM was chosen for the Jubilee FPSO for the following reasons:

- Potential reduced vessel motion from sea-states as the weather vaning reduces the period of time the vessel is side on (beam-on) to the weather.
- Reduced risk exposure to direct side vessel collision.
- Less restriction of mooring lines on infield support vessels and export  
Reduced exposure of risers and umbilicals during support vessel operations alongside the FPSO.
- Lower mooring and hawser loads during oil transfer operations.
- tankers.

### 3.3.5

#### *Gas Utilisation*

During Phase 1, an estimated 120 million standard cubic feet per day (MMscfd) of natural gas will be produced when producing the forecasted 120,000 bbl of oil per day. The natural gas produced will need to be handled and there are a number of options available:

- gas utilisation for on-site energy needs;
- venting or flaring to atmosphere;
- gas injection for reservoir pressure maintenance and enhanced recovery;  
and
- export of the gas to a neighbouring facility or to market.

Approximately 20 MMscfd of gas will be used on the FPSO for electrical power generation, steam generation and to supply the processing and utility facilities. This leaves up to 100 MMscfd of gas for disposal or potential export to local energy markets.

No continuous flaring or venting of hydrocarbon gases is planned during normal operations for the Phase 1 development. There will be intermittent flaring of gas during plant commissioning, start-ups and operational upsets and to purge the flare header to reduce explosion risk from oxygen ingress. The flare will have a pilot light on all the time but flaring will be kept to the minimum required for safe operations. The remaining gas not used for power generation (up to 100 MMscfd) will be injected back into the reservoir from the FPSO for pressure maintenance and improved oil recovery. The volumes flared will be metered to aid continuous improvement and monitor performance against goals for high gas utilisation.

The Ghana National Petroleum Corporation (GNPC) is considering a separate Gas Export Project comprising a gas export pipeline from the Jubilee field to shore and a new receiving terminal. It is expected that this would take 70 percent of the net (after fuel) gas (ie 70 MMscfd) from the Jubilee Field when in steady-state operation. The remainder (30 MMscfd) would be injected into the field by the FPSO for pressure maintenance and improved oil recovery. The FPSO would maintain the ability to inject 100 percent of the gas in the event that the receiving terminal is unavailable to receive all the gas due to unplanned events or planned maintenance.

The gas export project will be subject to its own project design and construction schedule managed by GNPC and is separate from the Jubilee Phase 1 development project and therefore not addressed in this report. At this stage it is anticipated that the gas export project could be operational within 12 to 24 months of the 2010 first oil date of the Jubilee Phase 1 FPSO project ie 2011 or 2012.

### 3.3.6 *Shore Base Locations*

A shore support base will be needed for the offshore service vessels. The port of Takoradi was selected as the location for the support base as it is the nearest Ghanaian port that can meet the capacity requirements, is currently being used by the offshore oil industry and has recently been expanded. It has the following key facilities:

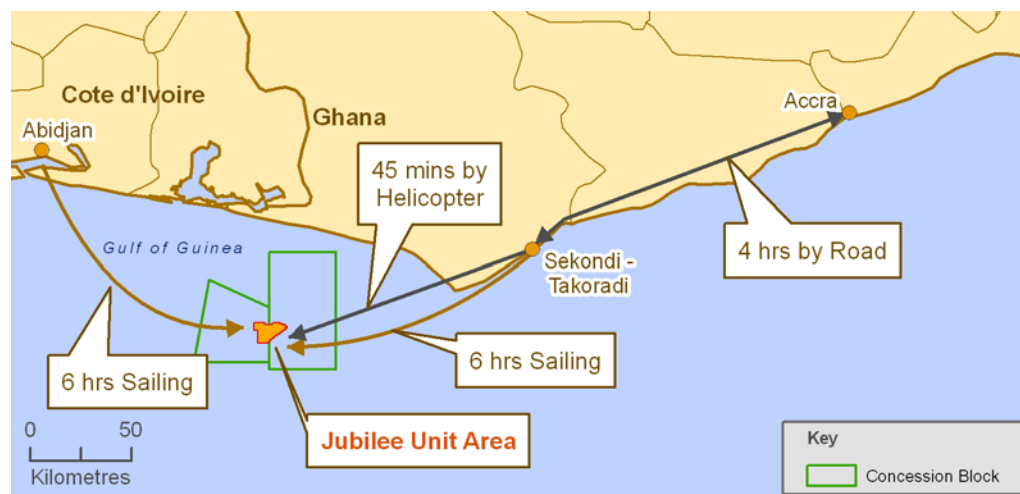
- dock space to serve as a loading/offloading point for equipment and machinery supporting offshore operations;
- facilities for dispatching personnel and equipment;
- temporary storage for materials and equipment; and
- availability of a 24-hour dispatcher.

If the port of Takoradi is full, overflow vessel traffic can be diverted to the Naval port at Sekondi. The other main port in Ghana is Tema, however, this port was not considered for a support base as it is much farther from the development area (about 350 km compared with 132 km for Takoradi) (see *Figure 3.7*).

The port of Abidjan also has suitable facilities and is a similar distance to the field as Takoradi. Historically the port of Abidjan was used for logistical support for Ghanaian offshore exploration drilling operations; however, its role is fast receding as facilities are developed in Takoradi. Consequently, it is not expected to play any significant role related to the Phase 1 FPSO development and operations.

Landing and handling facilities for fixed wing aircraft from Accra and Helicopter support to and from the Jubilee field will be provided from the Ghanaian Air Force Base at Takoradi. The Air Force base also provides office, warehousing and material storage facilities for the project. As the project develops Tullow will also lease other office space, warehousing and personnel accommodation in Takoradi.

**Figure 3.7**     *Alternative Shore Base Locations and Logistics Routes*



### **3.4**     *OFFSHORE FACILITIES AND EQUIPMENT*

#### **3.4.1**     *Overview*

This section describes the various surface and subsea facilities and equipment to be installed in the Jubilee field. It starts with a description of the FPSO vessel including its design, top-side facilities, mooring system, exclusion zone and offloading system and then describes the subsea elements of the infrastructure including production and injection wells and associated connection manifolds and pipe work.

#### **3.4.2**     *Floating Production Storage and Offloading Vessel*

The FPSO will be designed and operated by MODEC Inc and will be leased from MODEC under a long term contract. Tullow will have a Company representative onboard the FPSO responsible for ensuring production and safety targets are met and for the specific operation of the subsea system and wells connected to the FPSO. The MODEC operations crew will report daily to the MODEC Offshore Installation Manger. Tullow will set targets for production and safety with MODEC, administer the contract, provide supporting logistics, own the integrated operations plan and schedule production and oil tanker offloading operations.

The FPSO vessel will be converted from an existing single hulled, 330 m long and 60 m wide VLCC, named *Tohdoh*, which was built in 1991. The VLCC *Tohdoh* and a similarly sized FPSO are shown in Figure 3.8. The *Todoh* was a single hulled trading tanker and therefore the resultant FPSO is also classified as a single hull vessel.

The regulatory regime for FPSOs is different to that applied to normal trading tankers because of the different risks that FPSOs and tankers are exposed to.



The 2005 IMO Resolution MEPC 139 (53): *Guidelines for the Application of the Revised MARPOL Annex I Requirements to Floating Production, Storage and Offloading Facilities (FPSOs) and Floating Storage Units (FSUs)* state that FPSOs and FSUs are a form of floating platform and not a sea-going tanker. The guidelines state that for FPSOs based on a conversion of a single hull tanker may then be utilised provided that 'appropriate measures' are taken to mitigate the risk of low energy collisions between the FPSOs and other vessels, such as supply ships.

**Figure 3.8** VLCC Tohdoh (top) Prior to Conversion to an FPSO Vessel (bottom)



Source: Modec, 2008

The engineering, construction and operational design of the project has taken into account good industry practice measures to reduce the risk of failure of the hull cargo containment system. Failure can result from low energy collision (ie from vessels or MODUs) or structural failure due to fatigue cracking or corrosion. The design of the FPSO was assessed by the project team to ensure that it meets relevant regulatory requirements of the Coastal State (Ghana), the FPSO Flag State (Bahamas Maritime Authority) and international conventions such as those of the International Marine Organisation (IMO) which includes MARPOL. The Ghana Maritime Authority (GMA) has the responsibility of monitoring, regulating and coordinating activities in the maritime industry. The GMA does not currently have any specific requirements for FPSOs and refers to the regulations of the nominated Flag State (see *Section 2.4.2*).

### *Classification*

The FPSO design, construction and operation will comply with the requirements of the American Bureau of Shipping (ABS) Classification Society Rules. ABS is an international and independent verification body.

The ABS Class notation for the FPSO indicates that the vessel will have been built/converted such that it complies with the Classification Societies Rules for a Floating Production and Offloading System, with a remaining structure fatigue life of not less than 20 years before any dry-docking for inspection would be required, and is designed for the site specific environmental conditions at the Jubilee Field in Ghana and that it satisfies all collision and impact criteria to which it could be reasonably exposed. In the unlikely event that dry docking was required within the filed lifetime then the FPSO is designed so that the production can be temporarily shut down, the risers isolated and detached, and the FPSO towed away to dry dock. Fatigue and impact assessments also include the requirement for the FPSO design to withstand 100 year environmental metocean criteria and storm events for the project area. Class approval of the FPSO will be evidenced by the issue by of certificates to show that the requirements of the ABS have been complied with.

The following ABS Rules and Guidelines will apply.

- Guide for Building and Classing Floating Production Installations.
- Rules for Building and Classing Steel Vessels.
- Rules for Building and Classing Single Point Moorings.
- Rules for Non-destructive Inspection of Welds.
- Guide for Building and Classing Facilities on Offshore Installations.
- Guide for Underwater Inspection in lieu of Dry Docking Survey.
- Guide for Crew Habitability on Offshore Installations.



Classification will cover the following areas.

- Vessel, including structure, equipment and marine systems (inclusive of helideck and cranes).
- Turret mooring, including structure, riser systems, mooring systems.
- Production and production support systems, including all items supported above the support stools on the main deck of the hull.
- Offloading system.

For Classification, the FPSO design will need to demonstrate adequate structural strength and metal fatigue life to cover transit, installation and operation in the field. Structural enhancements have been implemented by the MODEC in the shipyard including hull plate replacement, where needed, and re-enforcement of deck members to take the load of the later installed processing facilities.

The Jubilee project team also subjected the FPSO design approach to a third party review by a verification agency, Det Norsk Veritas (DNV) in 2009. This review concluded that a Best Practice approach for a single hull conversion was being taken by Tullow and its Contractors.

A number of measures were identified during the design to address collision risk issues for the Jubilee FPSO (see *Section 3.3.2* and *Box 3.1*). Pneumatic rubber fenders known as 'Yokohama fenders' (see *Figure 3.9*) and water ballast and slop tanks will be installed where alongside supply vessel operations will be conducted to provide double sided protection for some parts of the oil cargo holding tanks, as shown in *Figure 3.10*. The FPSO hull design was assessed by ABS to meet the 'appropriate measures' criteria of MARPOL for single hull use against low energy collision risk (defined as a 11 MJoule impact from 5000 T vessel traveling at 2 m/s (3.7 knots)).

**Figure 3.9** *Yokohama Pneumatic Fender (2m x 3.5m)*



Source: Modec, 2009

*Planning:*

Risk identification has been adequately carried out through an in-situ HAZID, Quantitative Risk Assessment, Collision Risk Assessment and other project documents.

*Design:*

Design measures that are of common industry practice have been put in place to mitigate the identified risks. These include:

- weather-vaning mooring system to reduce the chance of collision;
- fenders to absorb supply boat impact (*Figure 3.9*);
- wing tanks will be used for ballast water and slop tanks in the areas where supply boat operations will be conducted;
- collision radar;
- structural design of the hull will be checked to meet side impacts as per class requirements; and
- global structural model showing the FPSO is of adequate strength and has a remaining fatigue life that takes into account hull condition, repairs and predicted corrosion rates for a minimum life of 20 years. The FPSO is designed for 1 in 100 year storm events.

*Construction:*

Construction conversion measures will also be put in place subject to class and the required infield life of the FPSO, including:

- steel renewals taking into account current corrosion and estimated future corrosion rates;
- coating protection from corrosion which will last 20 years;
- cathodic protection from corrosion which will last 20 years; and
- quality control checks and inspections from class.

*Operation:*

Operational measures that are of common industry practice have been put in place to mitigate the residual risks, including:

- Two vessels in field during tanker transfer operations including a hold back tug and a multipurpose vessel to divert a drifting tanker.
- Criteria for monitoring of hawser line loads for emergency disconnection.
- Training and competency verification of transfer crews and offloading crews. Offloading operations are controlled by Tullow Master/pilot.
- Regular emergency exercises and drills.
- Established Safety Zone around FPSO.
- Collision avoidance radar system fitted to FPSO

*Contingency:*

Contingencies that are of common industry practice have been put in place to reduce the consequences of an emergency event such as oil spill response from in-field support vessels and the wider resources available through the Oil Spill Contingency Plan. These measures then respond to an oil spill if it has occurred to ensure timely control and clean-up.

*Tank and Hull Corrosion Protection*

The FPSO will have sacrificial anodes in all cargo and ballast tanks to protect against corrosion. Additionally an impressed current cathodic protection system will be used to protect the external surfaces of the hull for the entire design life of the vessel. The level of protection afforded by these systems means that periodic visits to a dry-dock is not required. The inside of the cargo tanks will be coated to provide internal corrosion protection to meet

minimum field life expectations of 20 years. The tanks will also be fitted with cleaning systems to remove potential sludge under which accelerated corrosion can occur if the coating is damaged or reduced. Corrosion protection will be verified during field life by non-invasive hull thickness survey assessment techniques by submerged Remotely Operated Vehicles (ROVs) as part of a regular inspection program.

### *Capacities*

The FPSO will be modified to allow for the storage of approximately 1.6 million barrels of oil. In addition there will be slop tanks for oily water from drainage areas and off-spec tanks for out-of-specification crude and produced water which is required to undergo further treatment to reduce oil content. The FPSO will have capacity to process up to 160,000 bbls gross liquids per day, including 120,000 bopd and up to 80,000 barrels of produced water per day (bpwpd). The FPSO will have the capacity to provide 232,000 barrels of water injection per day (bwpd) and 160 MMscfd of gas for on-site energy use and reservoir re-injection or future export. Methanol storage capacity on the FPSO will be approximately 800 bbls.

The FPSO turret will be designed to accommodate 14 flexible risers and three umbilicals from the seabed. For Phase 1, there will be four production risers, two gas injection risers, two water injection risers and one gas export riser. There will be two remaining riser slots for future use (one spare umbilical slot and one spare for water injection or gas export). Electrical power and hydraulic control to the field will be provided through the umbilicals.

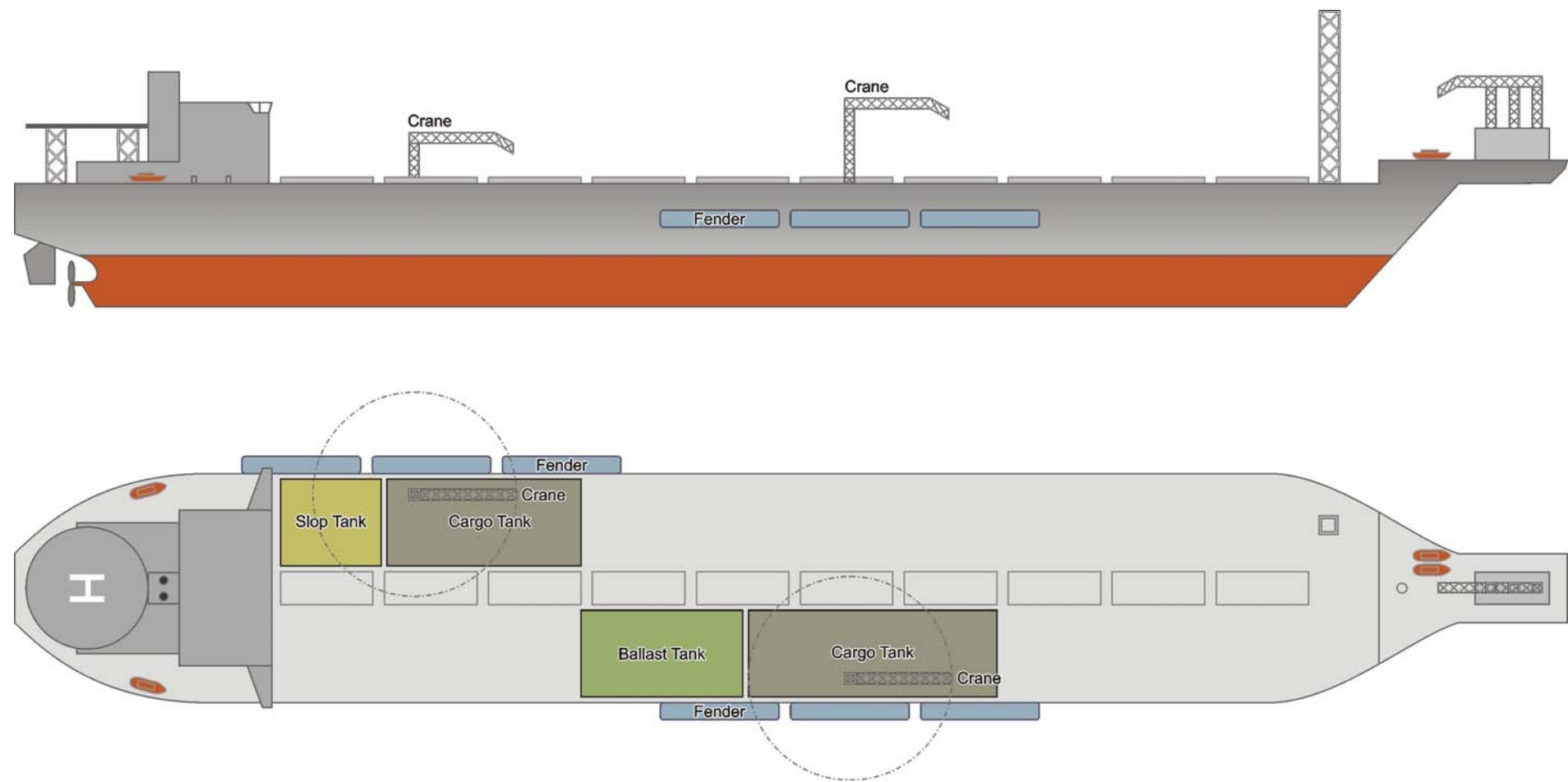
### *Accommodation*

The accommodation will be converted for a maximum of 120 persons (permanent and temporary personnel). Existing facilities will be refurbished and extended to accommodate the expected level of people. All materials and equipment used will be in accordance with relevant requirements<sup>(1)</sup>. Included in the accommodation are the following facilities:

- cabins for 120 persons and utilities;
- galley, catering and messing facilities;
- recreation facilities;
- central control room (including Emergency Command Centre);
- radio room;
- offices (including Permit Control and Emergency Command Centre);
- uninterrupted power supply or battery room; and
- helicopter waiting room.

(1) International Labour Organisation (ILO) 92/133, the MODU Code 1989 and ABS Class Structural Fire Protection

Figure 3.10   *Cranes, Fenders and Associated Tank Locations for Support Vessel alongside Operations*



Source: ERM 2009

## *Topside Facilities*

A description of the main FPSO facilities is presented in *Table 3.2*, a general layout plan of the topside facilities is shown in *Figure 3.11* and a flow diagram is shown in *Figure 3.12*.

**Table 3.2**      ***Topside Facilities***

<b>Facilities</b>	<b>Description</b>	<b>Function</b>
Subsea controls and support systems	Subsea Master Control system including hydraulic and electrical supplies, riser manifolds and associated facilities to run cleaning or inspection equipment (pigs)	System provides controls and chemicals for the subsea equipment (wells, manifolds etc)
Subsea flowline circulation system	Subsea flowline circulation system including two pumps and a flowline circulation fluid heater	Provides ability to circulate fluids to prevent hydrate formation within the subsea production pipelines.
Crude separation/stabilisation train	Four stages of stabilisation provide enhanced oil recovery, with two high pressure (HP) separators for increased flexibility/availability	Separation of crude from emulsified water, brine and solids (primarily sand) and removal of dissolved natural gas.
2 low pressure gas compression trains	Three-stage low pressure (LP) gas compression trains and associated equipment	
2 medium pressure gas compression trains	Single-stage medium pressure (MP) gas compression trains upstream of dehydration	
Gas dehydration and regeneration system	Gas dehydration and Tri-Ethylene Glycol (TEG) regeneration system	To avoid hydrates in the submarine pipelines, all of the gas will be dehydrated.
2 high pressure gas compression trains	Single-stage HP gas compression trains downstream of dehydration	The gas compression system is required to re-inject associated gas from the separation system into the producing reservoirs and for riser gas-lift.
2 gas injection compression trains	Single-stage gas injection compression trains downstream of HP gas compression	
Fuel gas conditioning system	Fuel gas conditioning system with 2 filters	Conditioning of fuel gas to remove rich heavy hydrocarbons before use in gas turbines.
3 Power Generation Units	Gas turbine driven electrical generators	An electrically driven centralised power generation scheme will be employed to drive main rotating equipment and power consumers. Electricity would be produced by three gas turbine generators.

Facilities	Description	Function
Produced water treating system	Produced water treating system including hydro-cyclones	Produced water is treated to remove particulates, oil and water from the produced water.
Chemical injection system	Chemical injection tanks with pumps	Facilities for chemical injection are required in order to efficiently treat the hydrocarbons before export, maintain flow assurance, maintain corrosion inhibition and enable treatment of seawater.
Service water system.	Utilised for cooling and water injection, includes lift pumps, suction caissons, coarse strainers and distribution system	Desalination system of seawater to produce fresh water for domestic use on the FPSO.
Process cooling medium system	Closed-loop (service water to cooling water) process cooling medium system, with two circulation pumps and one expansion tank	For cooling the production prior to going to storage
Sea Water Injection System	Multi-media and cartridge filters, vacuum de-aerator with associated vacuum pumps and three high pressure injection pumps	Sea water is filtered and the oxygen removed to minimise corrosion in the downstream water injection facilities
Sulphate reduction unit (SRU) seawater injection treatment system	SRU seawater treatment package including feed pumps and Membrane Units	Sulphates are removed from seawater by use of a SRU on the FPSO prior to injection to reduce built up of sulphate scale, which in high concentrations will reduce or block oil production.
Flare/vent system	Flare/vent system with HP and LP flare knockout drums	The flare/vent system will collect and safely dispose of high pressure hydrocarbons in the event of an emergency or other shutdown.
Heating medium system	Closed-loop heating medium system, with two circulation pumps and one expansion tank	Circulation system to allow heating of the gross production downstream of the HP separators
Drainage systems	Closed drainage system and oily water treatment	Drainage system for oily water that does not drain directly to sea but is required to be contained for treatment and clean up.

### *Communications and Navigation*

Electronic communications equipment will allow the FPSO operators to communicate with other vessels in the vicinity and acquire up to date information from offsite administration and weather forecasts. The

communication equipment on the FPSO will meet SOLAS (Safety of Life at Sea) requirements and include the following equipment (MODEC, 2009).

- Marine fixed VHF marine radio telephone.
- Aeronautical fixed VHF marine radio telephone.
- INMARSAT telephone.
- E-mail facilities.
- UHF hand held radios and repeater stations.
- Backup communications in the form of lights, fog horn and flares as per regulatory requirements.

The following navigation aids will be provided and will meet SOLAS requirements:

- navigational lights and flashing lights (in accordance with International Association of Light House Authorities);
- fog horn (in accordance with International Association of Light House Authorities);
- aeronautical beacon for easy location of the FPSO in bad visibility;
- X and S band marine RADAR with more than 20 nautical miles range;
- RACON (Radar transponder commonly used to mark navigational hazards); and
- collision RADAR system.

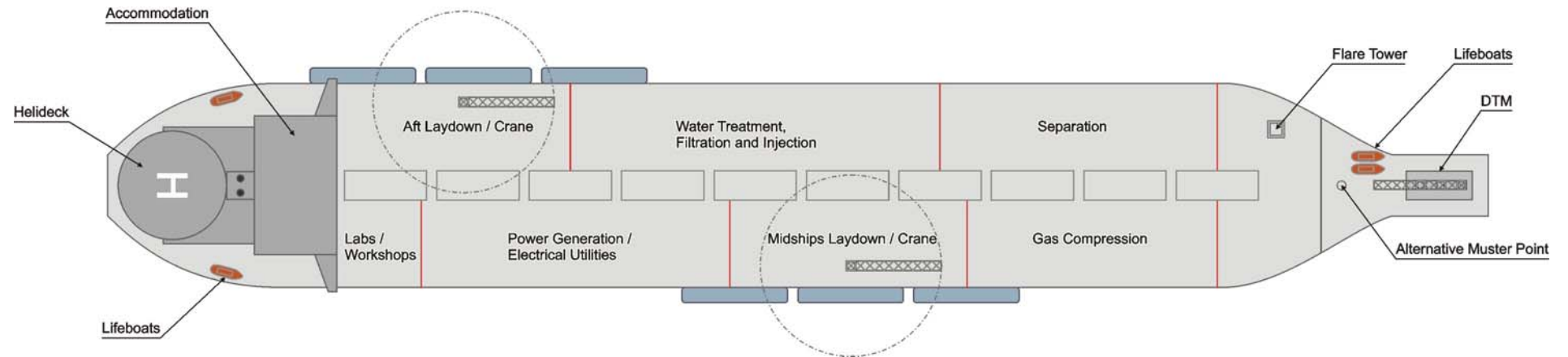
Backup power supplies will be provided for all communication and navigation equipment.

#### *Drainage System*

There will be two separate drainage systems, an open and a closed drain system (*Figure 3.13*). The FPSO drainage system and operations procedures are designed to meet the following objectives:

- comply with MARPOL requirements on discharges;
- prevent the build-up of rainwater or wash-down water in the plant area and the immediate surroundings;
- allow safe and operationally efficient maintenance of the process facilities;
- limit environmentally damaging emissions to air or water as a result of drainage operations or normal rainfall, to within agreed specifications;
- maintain hazardous area segregation, to prevent liquids or vapours from hazardous areas migrating to other hazardous or non-hazardous areas;
- manage run-off from a 100 mm in one hour rain event; and
- prevent spread of fire via the drain system between process areas.

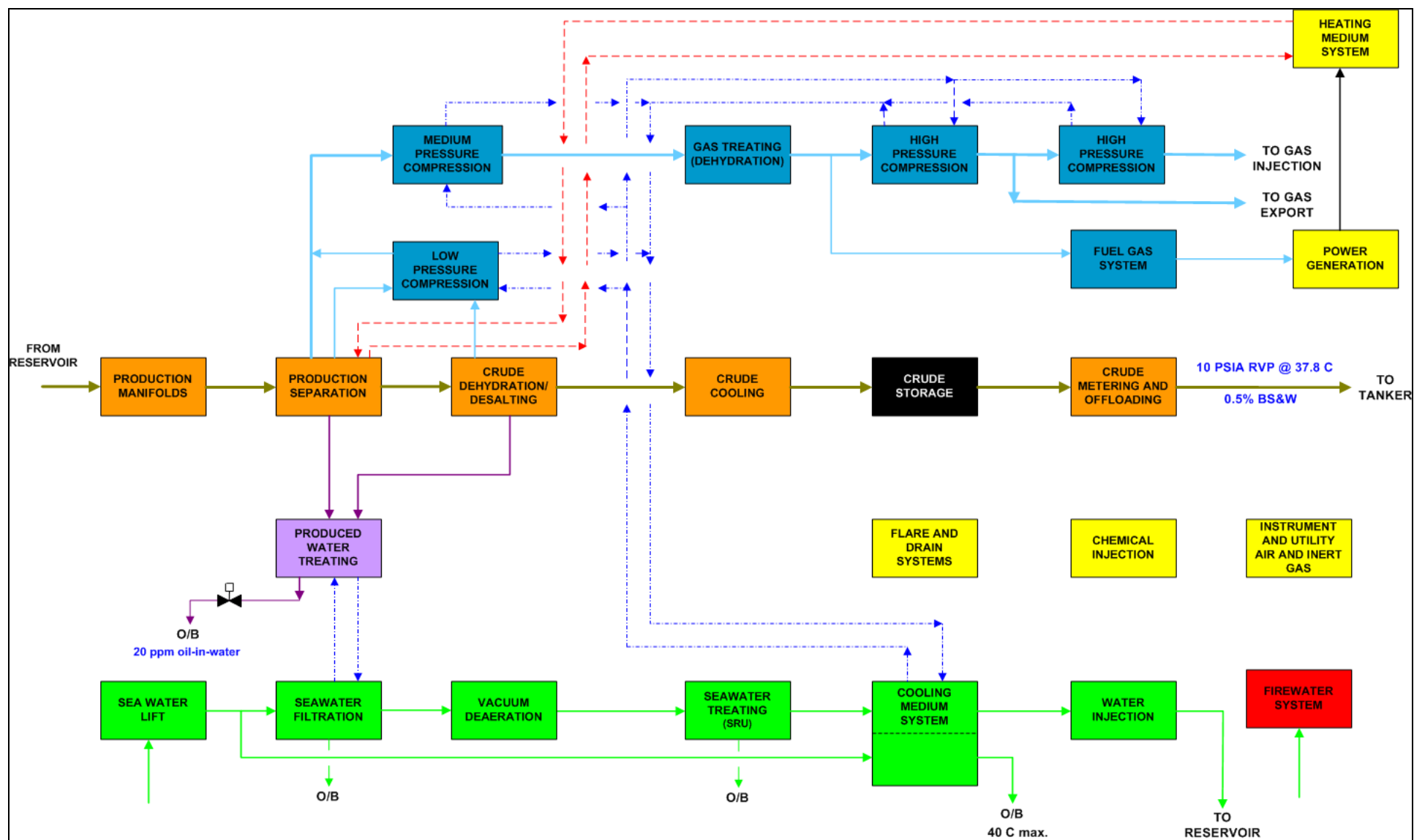
Figure 3.11 General Layout and Arrangement of Jubilee FPSO



Source: ERM 2009

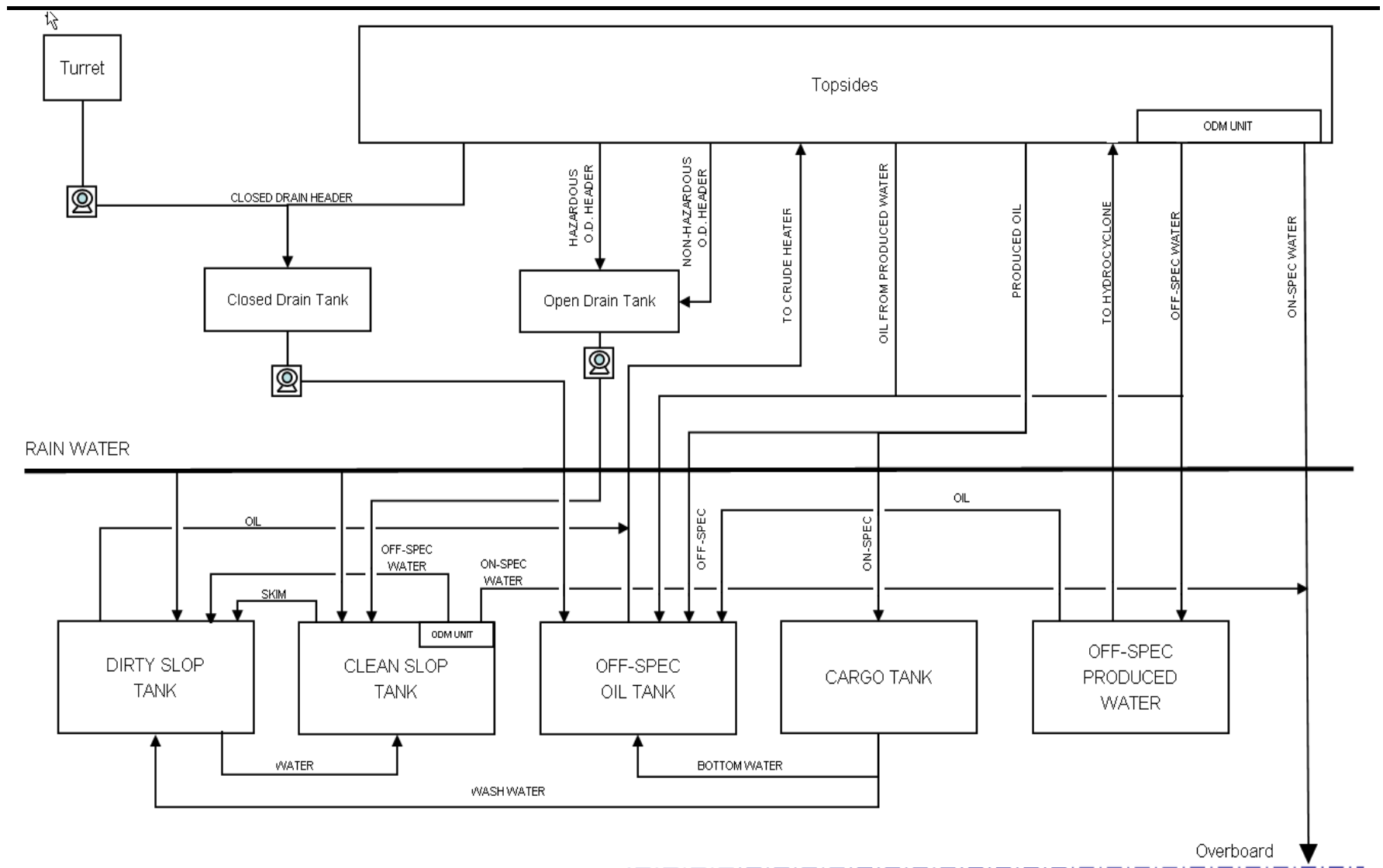


Figure 3.12 Topsides Facilities Flow Diagram



Source: Modec, 2009

Figure 3.13 Open and Closed Drainage System Schematic



Source: Modec, 2009

The slop tanks (dirty and clean) will accept rainwater, oxygenated seawater, hazardous and non-hazardous open drain fluids. Waters collected from the slop tanks will be processed within a separate system before it will be discharged overboard. Settled water in the clean slop tank will be discharged through the oily water separator and oil discharge monitor. The water will either be discharged overboard if the oil content in water is measured on-spec (15 ppm<sup>(1)</sup> instantaneous reading) or diverted back to the dirty slop tank.

The off-spec oil and off-spec produced water tanks will accept:

- off-specification crude from the process;
- off-specification produced water from the process;
- closed drain fluids; and
- separated oil from the produced water system.

These will be further processed through a common system and pass through an oil discharge monitor before it will be discharged overboard if the oil content in the water is measured on-spec (15 ppm).

#### *Chemical and Fuel Storage*

Chemical and fuel storage tanks will be located on the FPSO. It is envisaged that diesel bunkering of the FPSO will be frequent in the commissioning period (eg twice a week) and when in steady state it will be approximately monthly. Diesel will be stored in the FPSO hull and distributed to the topsides. Bulk storage for chemicals will be provided in a multi compartment tank on the FPSO topside. Chemicals and fuel will be delivered by the supply vessel using bunker (direct supply by hose), drums (2.5 m<sup>3</sup>) and tote tanks (4.4 m<sup>3</sup>).

FPSO diesel usage is estimated at 170 m<sup>3</sup> per day during the three month start-up period while diesel usage will be approximately 8 m<sup>3</sup> per day during steady state operations. Approximately 20 MMscf per day of gas will be used as fuel in main generators, deck boiler and for the flare pilot flame onboard the FPSO.

A helicopter refuelling package will be installed on the main deck. Two portable 500 gallon tote tanks will feed two 14m<sup>3</sup>/hr pumps.

#### *Flaring System*

The FPSO is designed to minimise routine flaring. Periodically, short term flaring will be required such as during commissioning, maintenance, and for upset/safety purposes. The flare and vent systems on the FPSO include a separate high pressure flare, atmospheric (low pressure) flare and atmospheric vents (eg from cargo tanks) which feed into the low pressure flare. The volumes of gas in the flare headers will be continuously metered and during

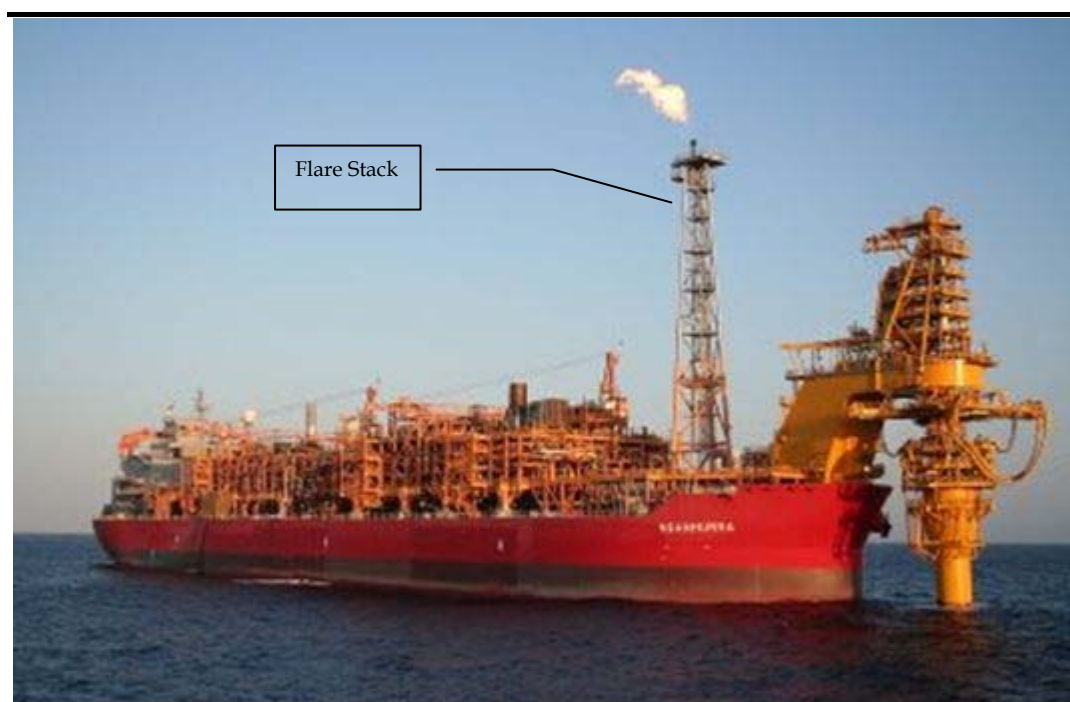
(1) ppm - parts per million

normal operations only the pilot flare will be burning. The clean-burn flare header system on the FPSO is designed to collect and safely dispose of high pressure hydrocarbons in the event of an emergency or operational maintenance/shutdown and facility start-up. A flare system is a safety prerequisite for FPSOs and other oil and gas producing facilities so that the pressurised hydrocarbon gas inventory can be safely disposed of in the event of an emergency to reduce risks to personnel and the facility itself. *Figure 3.14* shows the flare stack on a typical FPSO.

### 3.4.3 Mooring System

An external turret Single Point Mooring (SPM) system designed for the load associated with tandem offloading will be used to connect the riser system to the FPSO. The SPM system will be designed to allow the FPSO to freely turn 360° around the SPM vertical axis to align with the prevailing wind, wave and current conditions (*Figure 3.15*). The SPM system will be comprised of an external box-mounted turret (also known as a riser porch) mooring system for connecting the seabed mooring lines to the FPSO. The subsea production pipes (risers) will be supported in the FPSO by the turret. The FPSO will use a taught-leg mooring system to keep the vessel on location while permanently moored. The system will consist of nine 1,900 m long chain and polyester rope anchor 'legs' in three groups of three with the groups 120° apart. Each leg will be anchored to the seabed using 4 m diameter suction piles. The anchor leg system is designed to have adequate wear and corrosion allowance and fatigue life for 20 years and will require minimal maintenance. FPSO and mooring anchor locations are provided in *Table 3.3*.

**Figure 3.14** *Illustrative FPSO Flare Stack*



Source: Modec, 2009

**Figure 3.15** *Typical External Turret Single Point Mooring System (on a FSU)*



Source: Modec, 2009

**Table 3.3** *FPSO and Suction Pile Locations*

Facility or Component	Easting (m)	Northing (m)	Water Depth (m)	Slope (degrees)	Position
FPSO	512800	508000	1,100		-
Pile 1	512767	509477	974	3.0	East
Pile 2	512692	509516	974	3.5	West
Pile 3	512617	509550	972	3.5	Middle
Pile 4	510288	508053	1,054	4.0	North
Pile 5	510291	507965	1,060	4.0	Middle
Pile 6	510300	507877	1,067	4.0	South
Pile 7	512911	506534	947	5.5	West
Pile 8	512990	506585	937	5.5	Middle
Pile 9	513066	506639	929	5.0	East

#### **3.4.4** *Advisory and Exclusion Zones*

Restricted access areas, such as advisory and exclusion zones, will be enforced around offshore facilities in the Jubilee Unit Area for the safety of all users of the sea (*Figure 3.16*). These areas will be mapped on international nautical charts and formally gazetted and communicated to stakeholders, including local fishermen. Tullow proposes to establish the following restricted areas in consultation with the Government of Ghana.

- An advisory zone of 10 km radius centred on the middle of the Jubilee Unit Area (Well J09) that would cover the entire Jubilee Unit Area, indicating the presence of an oil production area where non-essential users are recommended to stay outside. Entry will not be excluded but the area will be marked on nautical charts as cautionary advice to all sea-users and

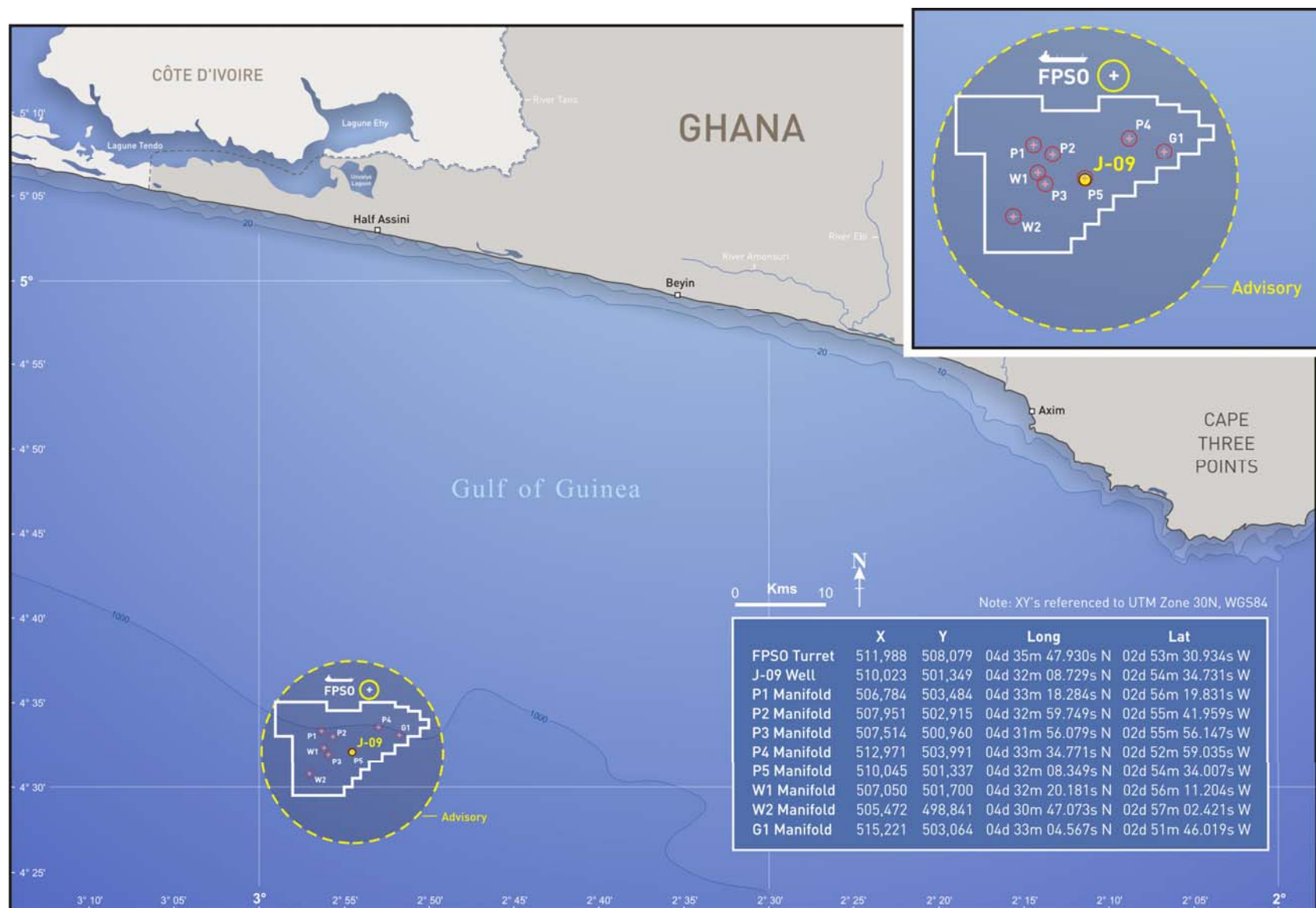
specifically to the sea lane to the south.

- 1 km radius exclusion zone surrounding the FPSO facility and centred on the FPSO turret which will be legally enforceable. A 1 km radius circle provides sufficient coverage for the FPSO and an offloading tanker when astern for oil export load-up; a total length including the off loading hose and hawser of some 750m.
- 500 m radius exclusion zones to be applied at each of the subsea drilling manifolds when a MODU (drilling rig) is present.

Exclusion zones are an international standard for oil industry zoning. They would be legally enforced with the assistance of the agencies of the Government of Ghana, for the safety of the facility and other users of the area (eg fishermen) when potentially close to the FPSO or MODUs (when present). The enforcement would also be applied by project standby and guard vessels.

Measures will be implemented to ensure that all those engaged in maintaining the exclusion zones have received adequate training on the correct code of conduct and rules of engagement which will be based on the UN Voluntary Principles of Security and Human Rights.

Figure 3.16 Proposed Advisory and Statutory Exclusion Zones



Source: Tullow, 2009



*Production Drill Centres*

A total of nine production wells are planned for Phase 1. These will be drilled from up to five drill centres (P1 - P5). Drill centres are locations where the Mobile Offshore Drilling Units (MODUs) will be placed (see *Figure 3.17*). Each drill centre will have a four-well slot production manifold and therefore capacity for four wells, although not all of these well slots will be used in each of the drill centres during Phase 1 of the development.

**Figure 3.17** *Modular Offshore Drilling Unit (MODU) - Eirik Raude*



Source: RigZone, 2009

Production drill centres identified as P1, P2 and P3 will be located on the western side of a deeper central subsea channel running through the field and five production wells will be drilled. Two production drill centres (P4 and P5) will be located on the east side of the central channel. Drill centre P5 will be located adjacent to the Mahogany 1 wellsite and will accommodate up to four production wells. No drilling at drill centre P4 is currently planned under Phase 1, unless one of the wells from drill centre P5 is not drilled.

The drill centre locations and the development wells are provided in *Table 3.4*. A schematic showing the subsea system is provided in *Figure 3.18* and the drill centre locations are shown in *Figure 3.19*.



### Production Wells

The nine production wells that are planned under Phase 1 will be connected to the subsea production manifolds from the production trees with rigid, insulated pipes (known as well jumpers). Crude oil and gas will be carried from the production manifolds through intermediate manifolds and then to the riser base via dual insulated pipes (known as flowlines). Finally crude oil and gas will be carried from the riser base through flexible risers to the FPSO. All production risers have an internal diameter of 254 mm.

**Table 3.4** *Coordinates of Drill Centres and Associated Phase 1 Wells*

Well Type	Drill Centre	Well Number	Drill Centre Location	
			Easting (m)	Northing (m)
Oil Production	P 1	J 8 (Hyedua 2)	506808	503474
	P 2	J 7	508350	502665
	P 3	J 6	507539	500951
		J 2		
	P 4	J 1	512112	504279
	P 5	Unused		
		J 3		
		J 4		
		J 9 (Mahogany 1)		
		J 5		
Water Injection (WINJ)	WI 1	J-11WI	507539	500951
		J-12WI	505480	498864
	WI 2	J-15WI		
		J-14WO		
Gas Injection (GINJ)	GI 1	J-10WI(Hyedua 1)	513691	502991
		J-13WI		
		J-17GI		
		J-16GI		

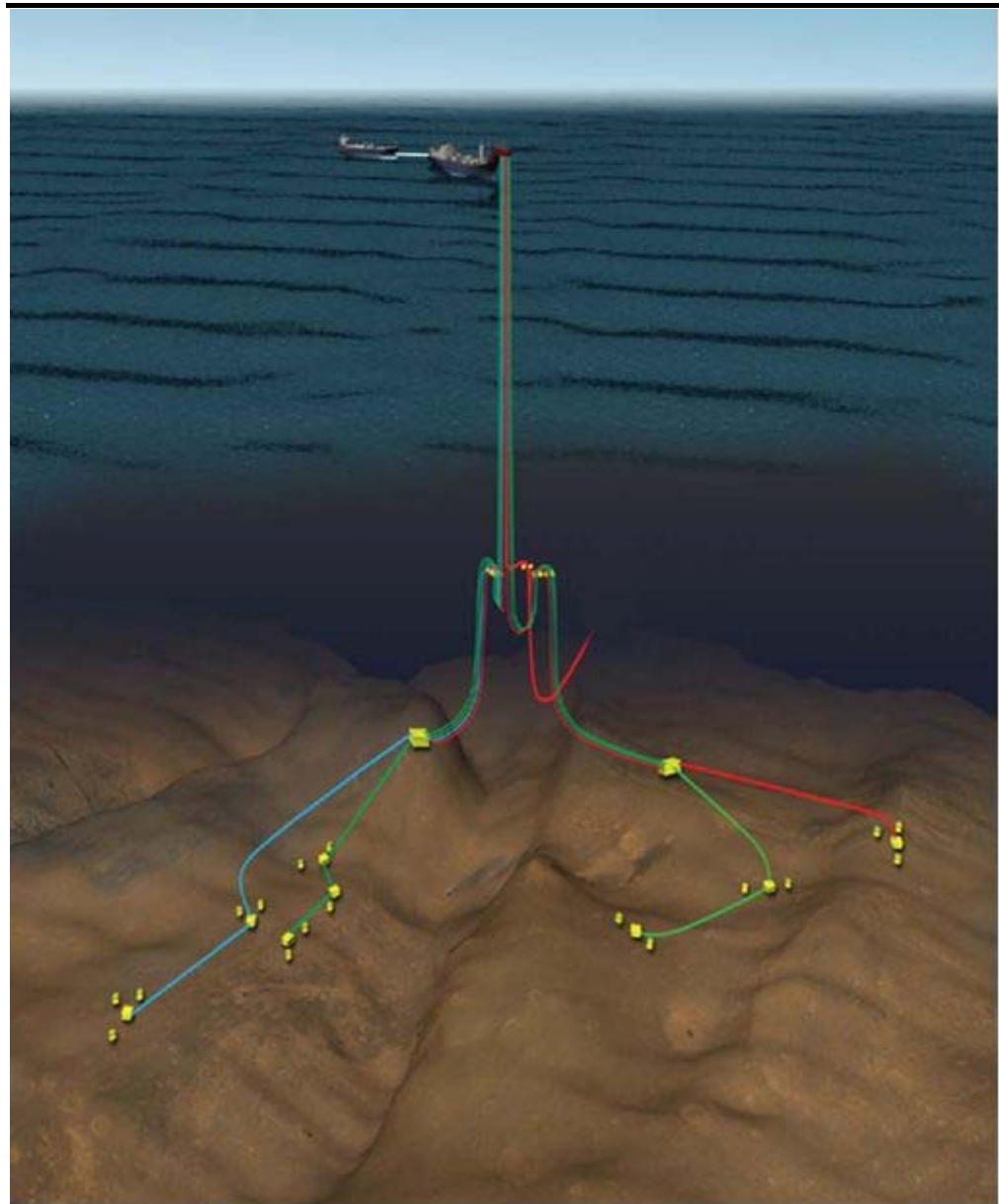
Datum: WGS84

### Production Manifolds

Production manifolds will be installed on the seafloor as a gathering point for the produced fluids (oil, gas and water) from individual production wells. The production manifolds have dual headers to allow for pigging<sup>(1)</sup> of the production lines allowing for inspection and maintenance during the life of the field operations. Manifolds will be mounted on suction piles measuring 4.6 to 5.2 m in diameter. The dimensions of each manifold are 6.1 by 9.1 m, with a weight of 100 tonnes. Production manifolds and suction piles, exclusive of production lines, will occupy an area of 56 m<sup>2</sup> each.

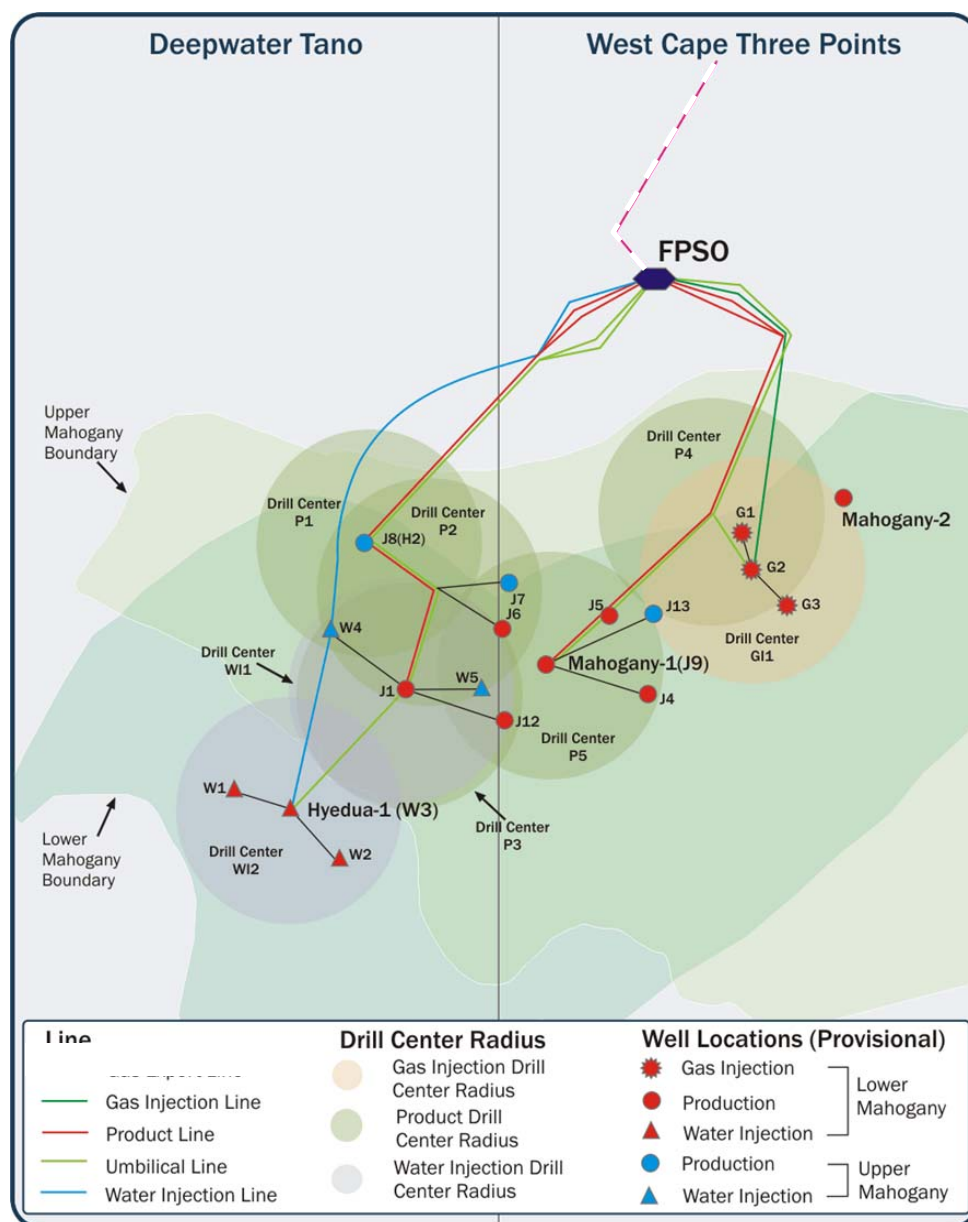
(1) Pigging in the maintenance of pipelines refers to the practice of using pipeline inspection gauges or 'pigs' to perform various operations on a pipeline without stopping the flow of the product in the pipeline.

*Figure 3.18 Schematic of FPSO and Subsea System*



Key: production (green), water injection (blue), gas injection (red). Source: Tullow, 2008

**Figure 3.19** *Drill Centre Locations and Associated Flowlines, Injector Lines and Umbilicals*



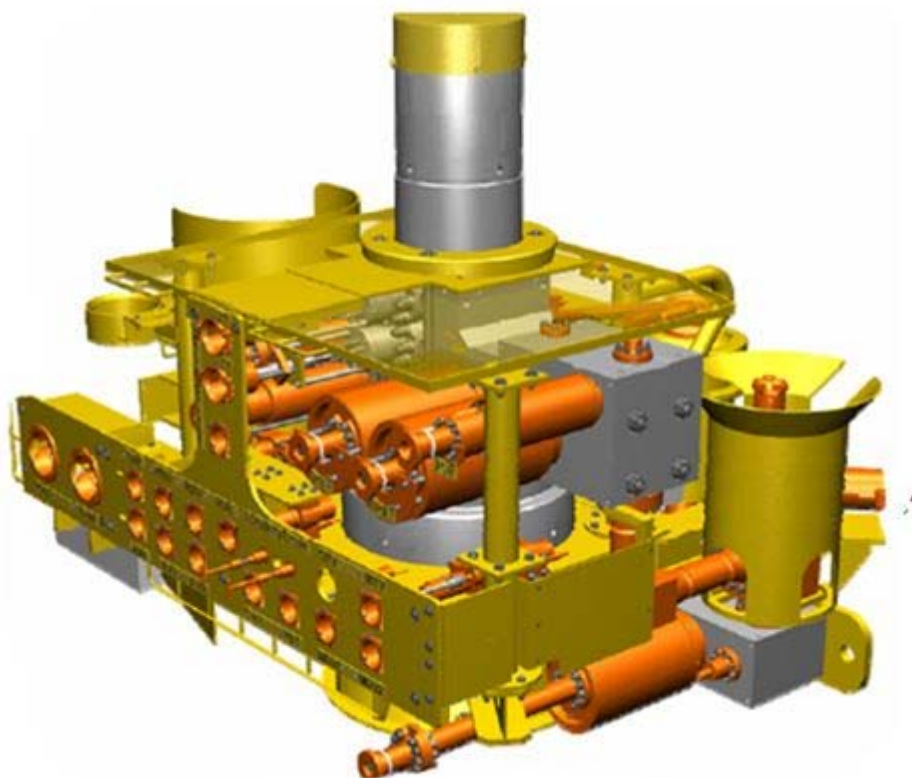
Source: Tullow, 2008

### Production Trees

Production from individual wells will be controlled by subsea control valves (within a Subsea Production Tree) connected to the wellhead. The type of production tree to be used is an 'enhanced horizontal subsea' tree (Figure 3.20). With an estimated weight of 48 tonnes, the seafloor footprint dimensions for each production tree are approximately 4.4 by 4.4 m, or approximately 20 m<sup>2</sup>.

**Figure 3.20**     *Production Tree Schematic*

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Source: Tullow,2008

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#### *Production Flowlines and Risers*

Phase 1 development flowlines will carry multi-phase and commingled well streams from individual wells and manifolds. Dual, insulated 25.4 cm (10 inch) steel production flowlines will extend to all production manifolds in series and convey the well streams to riser bases located in proximity to the FPSO. A total of 29,669 m of production line will be installed in the Jubilee Field under Phase 1, comprising four paired lines running each from the east and west drill centres (manifolds) to the risers and FPSO. Riser gas-lift gas will be taken at the riser base through control valves. The riser gas will be used to facilitate the liquid flow of production fluids to the FPSO. Typically 5 to 30 MMscf per day will be used for riser gas. Flexible risers will connect the individual lines at the riser base to the FPSO connection through the turret. Risers will be installed in the field after FPSO installation.

### **3.4.6**     *Water and Gas Injection System*

#### *Water Injection Drill Centres*

Water injection is planned for the west side of the field. There are two water injection drill centres planned, each of which can accommodate up to four water injection wells. In Phase 1, each of the water injection drill centres (W1/W2) will accommodate three injection wells each.

### *Water Injection Manifolds*

Water will be distributed to the individual injection wells via water injection manifolds that will be installed on the seafloor. The water injection manifold has a single header and is externally inspected during the life of the field. Suction piles will be installed for additional support. Single flexible risers will be installed from the FPSO turret to each riser base. From the riser base, a single flowline will carry water to an intermediate water injection manifold and then to the outlying water injection manifolds. A vertical connection system will be used on the rigid jumpers to connect injection wells to the manifold. Each injection manifold will measure 6.1 by 6.1 m, with a weight of 80 tonnes. Injection manifolds and suction piles, exclusive of injection lines, will occupy an area of 37 m<sup>2</sup>. The two water injection risers have an internal diameter of 24.5 cm.

### *Water Injection Trees*

All injection well trees will be enhanced horizontal subsea trees, mounted on top of subsea wellheads in a similar manner to that employed for the production trees (*Figure 3.21*). The injection trees will weigh approximately 38 tonnes each and with a seafloor footprint dimension of approximately 4.4 by 4.4 m, or approximately 20 m<sup>2</sup>.

### *Gas Injection Drill Centres*

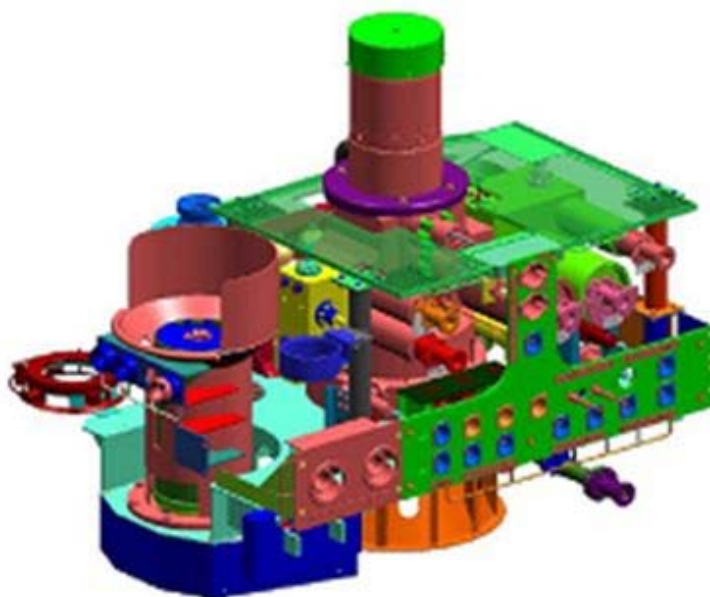
Gas injection will occur at the east side drill centre (G1), which will accommodate two gas injection wells during Phase 1. On the west side of the field the riser base will be equipped for future gas injection expansion. Gas injection will leave the FPSO through a single flexible riser to a riser base. A single steel flowline will then transport the gas to a gas injection manifold.

### *Gas Injection Manifolds*

One gas injection manifold will be installed on the seafloor as a distribution point for injected gas to the individual injection wells. Similar to the water injection manifold, it will have a single header with branches from this header to allow for up to four injection wells. The manifold will rest on a flat mats (known as mud mats) placed on the seabed in proximity to the manifolds to distribute the weight of infrastructure to prevent it from sinking into the seabed. The gas injection manifold will be similar in dimensions to the water injection manifold and will measure 6.1 by 6.1 m, with a weight of 80 tonnes. The injection manifold will occupy an area of 37 m<sup>2</sup>. The gas injection riser has an internal diameter of 20 cm.

**Figure 3.21**     *Injection Tree Schematic*

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Source: Tullow, 2008

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### *Gas Injection Trees*

Gas injection trees will be similar to the water injection trees and will weigh approximately 38 tonnes with a seafloor footprint dimension of approximately 4.4 by 4.4 m, or approximately 20 m<sup>2</sup> each. A total of 10,724 m of water injection lines, 3,024 m of gas injection lines and 19,843 m of umbilicals are to be installed in the field.

### *Injection Flowlines, Risers and Umbilicals*

Injection flowlines will carry treated seawater from the water injection plant on the FPSO and dehydrated gas from the HP compression train to the individual subsea water and gas injection manifolds. Water injection will be through single 25.4 cm (10 inch), steel flowlines from the FPSO to an intermediate water injection manifold and then to the outlying manifolds. Single 20 cm (8 inch), steel flowlines will carry gas to the gas injection manifold.

Flexible risers will connect the individual lines at the riser base to the FPSO connection through the riser turret. Risers will have buoyancy modules installed to optimise positioning. Risers will be installed in the field after FPSO installation.

Umbilicals will be used to convey chemicals, data (control system information, pressure and temperature) electrical power and high/low pressure hydraulic fluid supply to allow manipulation of infrastructure valves and tree safety valves and flow chokes.

### **3.4.7      *Gas Export Flange***

The gas export riser will terminate on the seabed to allow for future connection to a gas export pipeline to shore. A pipeline termination unit will be installed with a manual valve that would be operated by ROV.

### **3.4.8      *Subsea Control Systems***

All subsea hydraulically operated valves will be actuated using a multiplexed electro-hydraulic subsea control system. Hydraulic power, electrical power, communication signals and production chemicals will be supplied and distributed from the FPSO Subsea Control System through Subsea Control Modules (SCMs) mounted on the riser bases, manifolds and trees. The umbilical will be routed from the riser Umbilical Termination Assembly (UTA) via intermediate UTAs mounted on mud mats. Electric and hydraulic leads will connect the SCMs to the subsea trees and manifolds. Each UTA measures 4.6 by 9.1 m. Mud mats will measure 7.6 by 12.2 m, occupying an area of 93 m<sup>2</sup> each. Dynamic umbilical sections will connect at the FPSO turret and riser bases, and static umbilical sections will connect the riser bases to the UTAs and SCMs.

### **3.4.9      *Downhole Safety Devices***

The project will install downhole safety devices - surface-controlled subsurface safety valves (SCSSVs) - at each well, which will be controlled by subsea and FPSO safety control systems. These systems will shut the valve in the event of an emergency or operational upset in the well. These devices are typical to the oil industry and isolate the well contents and oil reservoir from the environment in emergency conditions.

### **3.4.10     *Chemical Injection System***

A number of production and water treatment chemicals will be injected into the FPSO topsides facilities, the subsea flow lines and directly into the wells (both at the subsea trees and within the wells closer to the reservoir). Injection in the topsides is through purpose built injection lines, while subsea and well chemicals are deployed down the subsea umbilical lines to their point of injection. Chemical injection is required to:

- prevent gas hydrates within subsea wells, flowlines and facilities to maintain flow paths;
- aid the oil-water hydrocarbon separation process to achieve export specification crude;
- aid conditioning of gas (water dew point reduction) prior to injection or export;
- provide corrosion inhibition for the subsea and surface facilities;
- prevent scale deposition within the subsea and surface facilities; and
- condition seawater prior to injection into the reservoir.

A series of chemical injection tanks, pumps and associated pipework will be located on the FPSO for injection of chemicals into various operational locations. Chemicals will be restocked via supply vessel, mainly using large transfer tanks (tote tanks) rather than drums. A specialist production chemicals supply company will be used with experience in chemical selection, storage, use and optimisation. The purpose, injection points, typical concentrations and frequency of use of the various chemicals to be used are listed in *Table 3.5*.

**Table 3.5**      ***Injection Chemicals used in the Jubilee Field Phase 1 Development Project***

Chemical	Purpose	Injection Point	Concentrations and Frequency of use
Hydrate Inhibitor (Methanol)	To prevent hydrate generation from well fluids during initial production/start-up until a fluid temperature outside the hydrate zone is achieved.  Gas facilities to disperse hydrates that may be generated within process facilities.	Subsea wellheads and surface	Long-term unplanned shut downs (>8 hours): batch injection of 5 bbls per well on well closure  Planned shutdowns: 200-400 barrels may be injected into the total system for safeguard for an extended period
Demulsifier	To assist with oil/water separation.	Surface	Continuous injection at between 20 – 100 ppm depending upon proportion of water present.
Scale Inhibitors	Calcium carbonate inhibition.	Subsea - downhole or wellhead. Surface – Crude Heat exchanger, heating/cooling medium tanks  Note: location depends on type and location of scale problems and would be upstream of the scaling area.	Injection rates between 5 – 50 ppm are normal. Injection frequency is continuous.
Corrosion Inhibitors	Injection to control corrosion of facilities/flowlines	Subsea and surface (separation and heating or cooling medium tanks).	Treatment rates would depend upon corrosion conditions.



Chemical	Purpose	Injection Point	Concentrations and Frequency of use
Paraffin (Wax) Inhibitors	May be injected subsea if the arrival temperatures are persistently below the wax appearance temperature.	Subsea flow lines: Subject to crude waxing properties.	If required continuous injection at between 50 – 200 ppm.
Defoamers (antifoam)	Foaming depressant	Surface – Process separators, foaming depressant.	If required continuous injection at 10 – 50 ppm.
Water Clarifiers	To de emulsify water to allow for better separation of contaminants	Surface Injection points on produced water draw off from separators prior to inlet to the Flotation Cell to enhance final clean up of the produced water	Continuous injection at 5 – 10 ppm.
Bacteria Treatment/Biocides	To control bacterial growth.	a) Process separation equipment and storage tanks where produced water accumulates. b) Water Injection process facilities. c) Diesel storage tanks.	Periodic batch treatments to keep bacteria under control. Injection rates would be 200 – 400 ppm over 2-4 hour period. Laboratory samples routinely taken to determine effectiveness of treatment programme.
Triethylene glycol (TEG)	Continuous circulation. To provide gas dehydration for downstream plant.	Surface facilities – TEG Contactor. Gas dehydration process to lower water content.	Continuous circulation within TEG process to provide gas dehydration (water dew point control).
Oxygen Scavengers	Water injection. To remove residual oxygen to reduce corrosion	Surface - Single injection point into Water Injection De-aerator tower.	Injection rates are 8 -10 ppm for oxygen scavenger
Chlorine Scavenger	Reduces chloride levels in water	Surface – Sulphate Reduction Unit	Injection rates approx 4 ppm.

(Note: This is an indicative list only: (a) Additional chemicals may be required if process or other problems are encountered and (b) Chemical Injection rates will be finalised by chemical supplier/support.)

### 3.4.11 *Radioactive Sources*

Limited radioactive sources will be used during the construction and production phases of the project. During the construction phase, X-ray techniques will be used for non-destructive testing of welding seams as part of the quality control process required prior to installation of subsea infrastructure.

During the operational phase, nine multi-phase flow meters will be installed on each of the production well jumpers to monitor the production rates of the wells. These flow meters contain a gamma emitting source (Barium 133), which are shielded and of low activity. Each flow meter will be tested by a certified authority prior to shipment from Europe to ensure compliance with article 3 of the EU Euratom Directive that stipulates maximum exposure levels <sup>(1)</sup>. All radioactive sources will require certification by the Ghana Radiation Protection Institute, including both an Import permit and Utilisation permit. Tullow will comply with the requirements of the Ghana Radiation Protection Institute.

### 3.4.12 *Seafloor Footprint*

Within the 110km<sup>2</sup> Jubilee Unit Area, subsea infrastructure for the Phase 1 Development will be installed over an area of approximately 34 km<sup>2</sup>. The area of seafloor directly disturbed by the installation of the subsea infrastructure will be approximately 0.023 km<sup>2</sup> (2.3 hectares). Seafloor disturbance will be caused by the FPSO moorings and the installation of subsea production facilities, such as manifolds, trees, umbilicals, flowlines, injector lines, and riser bases. A summary of Phase 1 facilities and its expected footprint on the seafloor is provided in *Table 3.6*.

No seafloor disturbance is expected during well completions as the MODU (Eirik Raude) will be dynamically positioned and therefore not require anchoring.

(1) (1 micro Sievert (μSv)/h (100 μRem/h).

**Table 3.6**      *Seafloor Footprint for Phase 1*

Facility	Dimensions (m)	Total Seafloor Affected (ha)
<b>FPSO Facility</b>		
Suction piles (9)	9 x 0.0018 ha (3 x 6 m)	0.0162
<b>Production Wells (5)</b>		
Manifolds (5)	6.1 m x 9.1 m, with suction piles measuring 4.6-5.2 in diameter	0.028
Trees (9)	4.4 m x 4.4 m	0.017
<b>Water Injection Wells (5)</b>		
Manifolds (2)	6.1 m x 6.1 m	0.0074
Trees (6)	4.4 m x 4.4 m	0.0010
<b>Gas Injection Wells (3)</b>		
Manifolds (1)	6.1 m x 6.1 m	0.0040
Trees (2)	4.4 m x 4.4 m	0.0060
<b>Flowlines, Injector Lines, Umbilicals and Risers/Riser bases</b>		
Production	29,669 m of 25.4 cm flowlines	0.75
Water Injection	10,724 m of 25.4 cm water injection lines	0.27
Gas Injection	3,024 m of 20.32 cm gas injection lines	0.06
Umbilicals	19,843 m of 20.32 cm	0.40
Riser bases (3)	100 m x 24 m	0.72
SDUs	10 m x 10 m; 3 units	0.03
<b>TOTAL</b>		<b>2.3096</b>

### 3.4.13      *Support Vessels and Helicopters*

A number of vessels and helicopters will be required to support and supply the Phase 1 installation, production and decommissioning operations. These are outlined in *Table 3.7*.

**Table 3.7**      *Summary of Vessel and Helicopter Support Requirements for Jubilee Field (through Field Life)*

Phase	Number Required	Candidate Vessel or Aircraft Characteristics	Frequency (Round trip per day)
<b>FPSO and Infrastructure installation</b>			
AHV/ AHTS	1	60 to 75 m length, 10,000 hp	N/ A
Tow-in vessel	3-5	Length variable; 4,200 to 7,000 hp	N/ A
Supply vessel	2	56 m workboat; 8,500 hp	1
Pipelay vessel	1	Length 200 m, 20,000 hp	N/ A
Pipelay-Umbilical vessel	1	Length 160 m, 16,000 hp	N/ A
Light Construction Vessel	1	Length 110 m	N/ A
Heavy Lift Vessel	4	Length 140 m	N/ A

Phase	Number Required	Candidate Vessel or Aircraft Characteristics	Frequency (Round trip per day)
Pre-commissioning vessel	1	Length 90 m	N/A
Crew Boat	1	Length 30 m	1
Fixed wing flights	1	15-20 passenger maximum turbo-prop from Accra-Takoradi	2-3
Helicopter	2	Dauphin AS365N3	4
<b>Well completions</b>			
MODU	1	Dynamically positioned or moored semi submersible drilling unit	N/A; moored or positioned on site. Moves between well sites will average once per month.
AHV/AHTS	1/2	60 to 75 m length, 10,000 hp. Likely share with production requirements (see below)	N/A
Helicopter	1	Dauphin AS365N3	1
Shared with installation phase (see above) and later with production phase (see below)			
<b>Production</b>			
FPSO	1	Single hull, VLCC 330 m length, 59 m beam	N/A; moored
Supply / Contingency vessel	1	100 Tonne Bollard pull – specification subject to tender. Delivering basic supplies (chemicals, spares, food provisions, etc), able to provide diesel fuel to FPSO and drilling rigs. Contingency vessel for MSV/ Hold back Vessel outages.	1- 2 per week
Multi Service Vessel (MSV) with daughter vessel	1	100 Tonne Bollard pull – specification subject to tender. Safeguard vessel for export tanker operations. Daughter craft (line handler) host, hose handler, security (ISPS) during terminal operations, provide general field support (eg pollution, fire fighting) and subsea ROV inspection and minor intervention works.	N/A
Hold Back Vessel	1	100 Tonne bollard pull – specification subject to tender. Hold back vessel for export tanker operations.	N/A
Export tanker	1	1 Mbbbl Suezmax or part filled VLCC vessel assumed	N/A
Helicopter	1	Dauphin AS365N3	1 – average

AHV = Anchor Handling Vessel; AHTS = Anchor Handling Tug Supply; MPV = Multi Purpose vessel

### *Construction and Operation Support Vessels*

All construction and support vessels used by the project will operate in compliance with their classification standards, including SOLAS Convention requirements. All the vessels that are to be used for the project are either relatively new or have had a recent refit. Specialist vessels with experienced crews will be required for the installation of the infrastructure.

To enable the operational support vessels to cut engines and avoid engine idling time, two deepwater buoys will be installed in the field for the production phase. This will have the benefit of reducing greenhouse gas emissions.

### *Export Tankers*

All export tankers that will receive oil from the Jubilee FPSO will be vetted prior to arriving in the territorial waters of Ghana. Tullow will require a copy of the tankers' assessment report (called a Q88 report) at least 10 days before its arrival. These reports are to ensure that the tanker meets all maritime regulations and standards (ie SOLAS, IMO). The Q88 report will help to ensure that the export tanker:

- is fit for purpose;
- complies with recommendations contained in OCIMF/ICS Ship To Ship Transfer Guide;
- has pollution liability coverage;
- has an appropriate emergency towing system;
- is doubled hulled;
- has sufficient power and manoeuvrability (ie bow thrusters) to handle prevailing sea conditions;
- has a valid inspection of compliance report;
- crew has appropriate training and competence;
- has a valid Safety Equipment Certificate;
- has a valid Oil Pollution Prevention Certificate;
- has a valid Safety Management Certificate; and
- has a ballast management plan.

Tullow's Offtake Coordinator will assess the Q88 report and ensure it is valid and that the vessel complies with all requirements. This will include confirmation of ballast water management. Upon arrival at the FPSO 'port limit', the vessel will be boarded by the Jubilee FPSO Mooring Master and inspected. This inspection is intended to ensure that the vessel is properly equipped and operational, has the required certification and that no defects can be seen.

Onshore logistics support bases will be located in tSekondi-Takoradi, which lies approximately 130 km to the north-east of the Jubilee Field. Sekondi-Takoradi will provide warehousing, accommodation, office and supply support to the FPSO as well as provide the centre for community liaison activities. The majority of onshore logistics support infrastructure in Sekondi-Takoradi has already been put in place for the drilling programme and only minor expansions are planned.

The main facilities to be used by the Jubilee Project are located at the Takoradi Commercial Port, Takoradi Air Base and Sekondi Naval Base (*Figure 3.22*). A description of the Sekondi-Takoradi facilities, current and planned, is presented below.

The Tullow head office is located in Accra and currently provide logistics, engineering, administration, legal, Information Technology, procurement, finance and management oversight. From 2011 onwards the sub-surface (ie reservoir engineering) and project management team will move to Accra.

Approximately 120 people will be located in Accra during operations, a further 50 in Takoradi, with the remainder based offshore. Personnel numbers will peak during construction, when over 200 people will be based in Accra. An office complex has been leased to accommodate these personnel. Tullow will provide accommodation by leasing houses or apartments in both Accra and Takoradi.

### 3.5.1 *Sekondi Naval Base*

Technip, a subsea contractor on the Jubilee project, plans to undertake small scale fabrication works (including welding of line pipe, cleaning, sand blasting and painting) at an existing site inside the Ghana Navy base at Sekondi. They will also supply their installation vessels from the Navy base (*Figure 3.22*).

### 3.5.2 *Takoradi Commercial Port*

Takoradi is one of Ghana's main ports and between 1997 and 2006, the port handled an average of 524 vessels per year (*Figure 3.23*), which comprises 37 percent of Ghana's seaborne traffic. Berthing facilities at the port include eight berths with lengths ranging between 120 and 225 m (*Figure 3.24*). The maximum draft at the wharf is 10 m.

The Ghana Ports and Harbours Authority (GPHA) is undertaking a port feasibility and development master plan study for the Port of Takoradi. A draft 20 year master plan has been prepared and was being reviewed by GPHA at the time of writing. This plan takes into account the broad context of port infrastructure, estimated traffic flows, the impact of port development on the national economy and covers various concession and franchise arrangements for attracting private sector participation. The Jubilee partners have provided input on the re-development to support upstream oilfield

operations. There is likely to be port upgrade works in the future to provide improved facilities to support the oil and gas industry.

Tullow currently lease a number of areas for offices, storage and berths within the Takoradi port area from GPHA (see *Figure 3.25*). Any upgrades of the leased areas will require prior approval by the GPHA and the areas will be handed back to GPHA once the areas are no longer required.

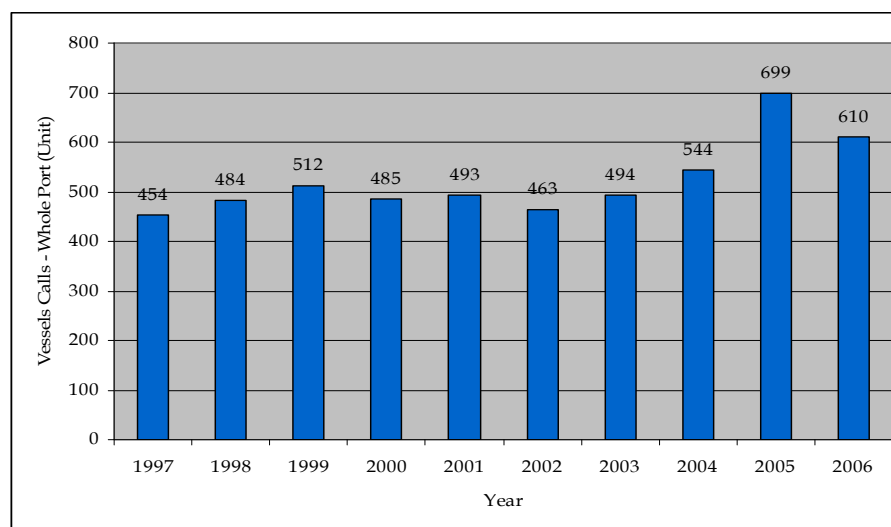
Takoradi's port will be used by the Jubilee Project for:

- the importation of materials with some dock space to serve as a loading/offloading point for equipment and machinery;
- dispatching equipment and allow for temporary storage of materials and equipment;
- bulk chemical and materials storage; and
- pre-deployment checks (eg hydrotesting) and assembly of equipment (eg production trees).



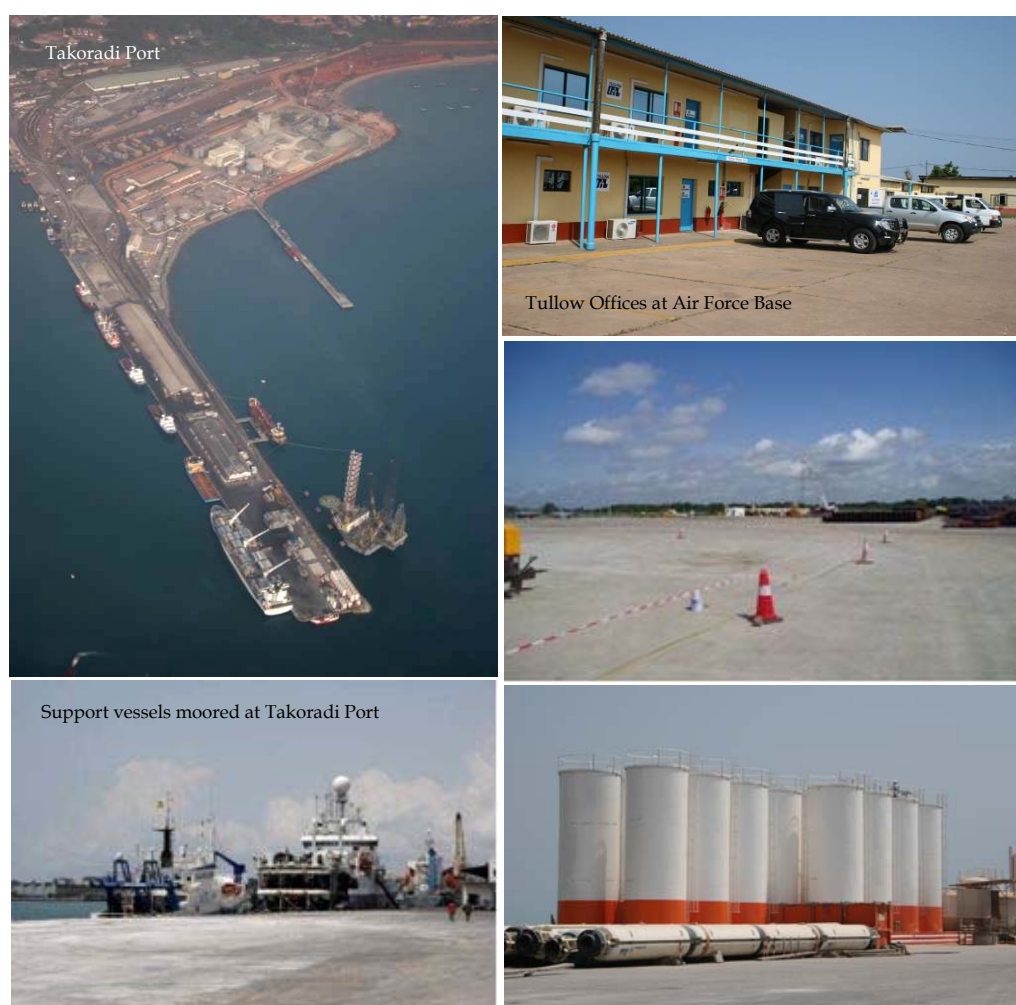


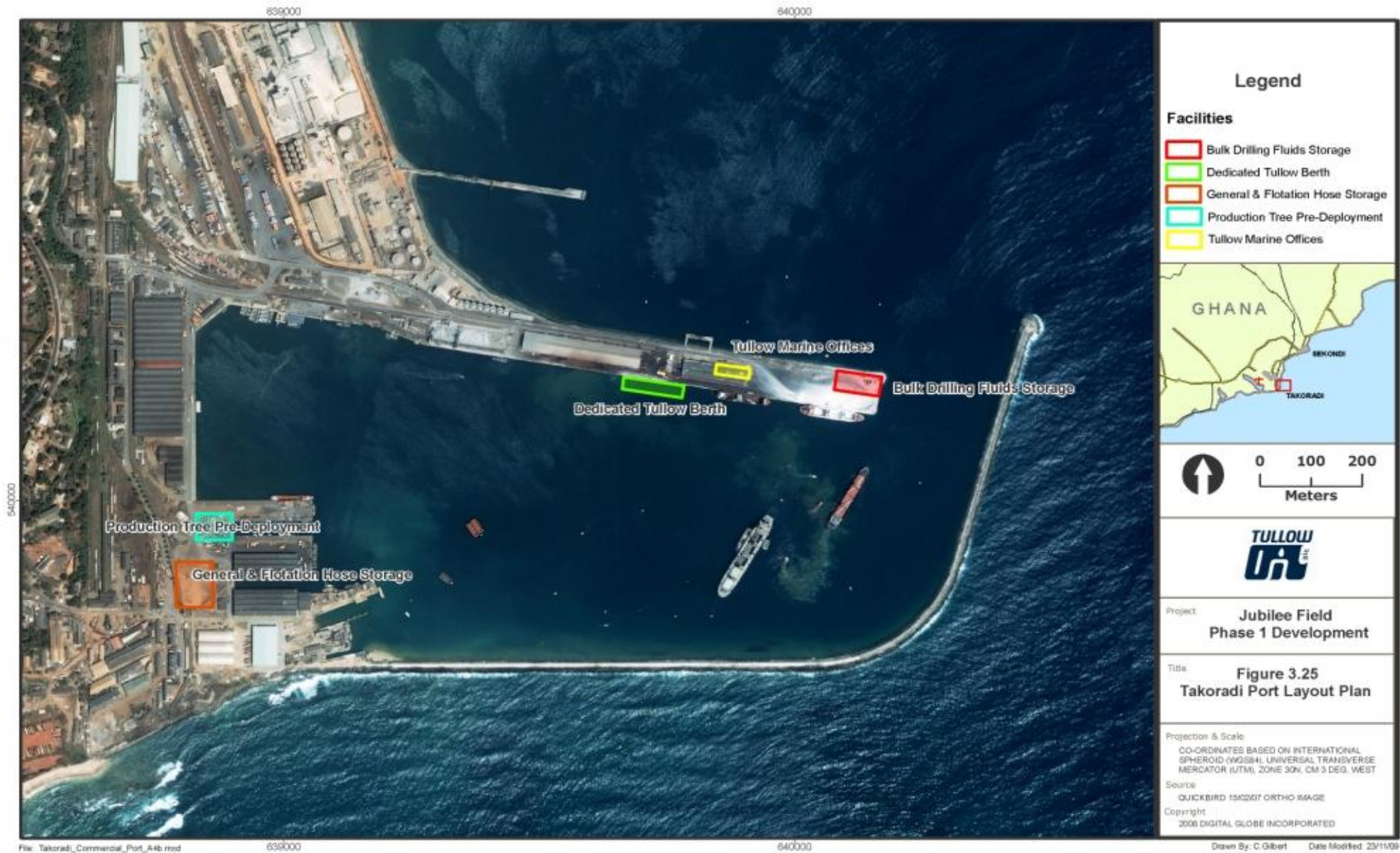
**Figure 3.23** *Total Port Takoradi Traffic (Vessel Calls) 1997 - 2006*



Source, Adapter from GPHA, 2006

**Figure 3.24** *Onshore Base at Takoradi Port and Ghana Air Force Base at Takoradi*









### *Berths*

Dedicated berths have been leased by Tullow to service the Jubilee Project and exploration activities (*Figure 3.25*). These will be required for the remainder of the project life. Support vessels for offshore oil exploration activities are serviced at berths 5 and 6. If there is insufficient space at Takoradi port on occasion, support ships may use Sekondi Naval base.

During exploration activities, one support vessel called at the port each day on average, with a maximum of four support vessel calls per day. Once the FPSO has been installed and begins operations, a supply boat will visit the FPSO once or twice a week, depending on the requirements for supplies. Additional calls will be required during the construction activities.

Specific activities at the port that occur include bunkering, transfer of waste to waste contractor, loading supplies for the MODU, FPSO and support ships, and during construction the loading/unloading of seabed infrastructure.

### *Laydown and Storage Areas*

A pre-deployment area will store and carry out pressure-test work of the production trees. This work will be carried out by subsea equipment specialists FMC in close conjunction with the Tullow well engineering team. This will involve small quantities of potable water being used in an enclosed isolated area for safety reasons given the high pressures that will be used. This work is being undertaken at the port to avoid the need to transport oversize loads (ie the production trees) through the city of Takoradi to Tullow's Air Base facilities. This area is 300 m<sup>2</sup> and leased directly by Tullow.

A fully-bunded 500 m<sup>2</sup> bulk drilling fluids facility has been constructed on the main port quay and is operated MI Swaco and BJ cement. The maximum storage capacity of the largest tank in the plant is 950 bbls and the bund capacity is 2,000 bbls. These suppliers also lease two warehouses (3,850 m<sup>2</sup> and 1,350 m<sup>2</sup>) from the GPHA for dry bulk goods such as cement and caustic soda. Both warehouses are covered and well ventilated. There are spill containment kits, including chemical retrieval tools, and absorbent material in the warehouse. It should be noted that these are pre-existing facilities that supply exploration and development phase drilling and are included for completeness.

In the first quarter of 2010, it is planned that a larger development of approximately 2,000 m<sup>2</sup> will take place inside the existing commercial perimeter of Takoradi port. This will be a storage area for further subsea equipment and well trees, FPSO spare offloading hoses and other materials and spare parts and will be directly leased by Tullow.

In 2010 subsea equipment specialists FMC plan to directly lease an area of land approximately 5,000 m<sup>2</sup> immediately adjacent to the area described above to build a workshop facility to support future operations. This is a longer

term project to support the oil industry in Ghana, where equipment can be stored and various fabrication tasks may also be carried out such as welding, pressure testing etc.

Tullow will build a secure chemical store inside the existing commercial perimeter of Takoradi port to supply the operational phase. The store will be a covered and fully bunded 50 m by 30 m building to be constructed on land to be leased by Tullow from GHPA. Production chemicals to be stored include oxygen scavengers (eg sodium bisulphite), biocides, scale inhibitors (eg Phosphanate), corrosion inhibitors (eg Amine), acids and methanol.

#### *Water Supply*

Tullow has installed a new 600m<sup>3</sup> potable water tank on the main quay near to the drilling fluids storage area. This water is primarily used for the drilling programme, which uses approximately 2,500 m<sup>3</sup> of freshwater per month and 42,500m<sup>3</sup> in total during the drilling programme. The total amount of freshwater to be used during the well completion programme is estimated to be between 400 m<sup>3</sup> to and 800 m<sup>3</sup>. This will be used over a six month period. Some additional water may be required (ie 50m<sup>3</sup> per month for 6 months) to supply the smaller construction vessels that do not have desalination plants.

The MODUs, FPSO and the major construction vessels will produce their own potable water using onboard desalination plants. Pressure testing of pipelines and vessels during construction will use inhibited seawater.

### **3.5.3 Takoradi Air Force Base**

Tullow leases part of the Air force base and currently uses it to support existing exploration and production drilling activities. Tullow will use these (or similar) facilities for life of the project. Tullow has upgraded infrastructure at the Takoradi Air Force base to develop efficient onshore storage and support facilities for the Phase 1 drilling programme and the Phase 1 Jubilee development and operation (*Figure 3.26*).

A disused aircraft hanger on the base has been converted into a warehouse, with adjacent office space and meeting facilities for approximately 30 persons dedicated to the running of Tullow's facilities. A canteen and toilet block has also been built.

A 40,000m<sup>2</sup> area that will be used primarily as a pipeyard has been fenced and lit for access control. The area will be used to store steel pipe/casing and well construction and testing equipment.

To minimise Tullow heavy vehicle traffic affecting access to the air base by other vehicles and pedestrians, a small access road to the Takoradi Air Force base has been upgraded to segregate pedestrians from traffic.



The base will also be used by Tullow to locate its helicopter operations to transport personnel to the FPSO as well as using a fixed wing aircraft to fly to/from Accra. Flights will be on a daily basis and will use the Dauphin AS365N3 helicopter for flights to/from the FPSO/MODU and a Beech Craft B1900D fixed wing for flights to/from Accra. FPSO requirements will be integrated and optimised with MODU requirements.

Aviation fuel will be sourced from a new fuel farm located at the base that will be commissioned by early 2010 and shared by the Ghana Air Force with oil companies located at the base. NHV Aviation has been contracted to provide service and operation of these machines.

#### *Bay Court*

Office and warehouse facilities have been leased by Tullow at the Bay Court complex near the airport in Takoradi (*Figure 3.26*). High quality chrome tubing and other delicate parts (eg electronics) will be stored at this location. This will also form the main Takoradi regional office for Tullow.

A number of service companies such as Baker Oil Tools, i-Tech-7 and Schlumberger will also directly lease sections of the Bay Court complex. These specialists companies will provide direct support to the Jubilee Project and the oil industry in general. Operations include assembly of specialist equipment for later installation in the wells, pressure testing, support for subsea remote operated vehicle operations and well logging.

### **3.6 MAIN PROJECT ACTIVITIES**

#### **3.6.1 Overview**

This section describes the main project activities from the well completion stage, through installation, commissioning, operations and decommissioning after the predicted 20 year project lifetime.

#### **3.6.2 Well Completions**

After wells have been drilled a process known as well completions is undertaken to prepare the well for its operational function (ie producing well or injector well) and to install a number of safety and operational controls, such as produced sand filters. Completions will be undertaken from the mobile drilling units and for each well this process will take approximately 25 days.

For each well, subsurface safety valves will be installed to provide pressure isolation and prevent pollution in the event of damage to the wellhead, surface (mudline) isolation valves and flow control valve (subsea tree). For producing wells downhole pressure and temperature gauges will be installed to provide continuous data during the life of the wells. In addition, pressure and temperature will be recorded at the subsea tree and throughout the

subsea facilities. The data will be transmitted back to the FPSO via umbilicals and will be used in the ongoing reservoir and system management of the Jubilee field.

To prevent sand from the well face from entering the well completion, sand control will be installed by hydraulically fracturing the reservoir rock and placing a known size of synthetic gravel (sand) in the fractures. The gravel prevents migration of sand into the well bore and a screen within the well casing prevents the gravel from being transported back into the well with the flow of hydrocarbons.

During well testing crude oil and gas are released to the surface and require to be sent to the MODU flare for combustion. Typical well tests are likely to consist of two combustion periods, each lasting approximately 24 hours, however the amount of hydrocarbons combusted will depend on flow rates. All emissions associated with the well test operations will be recorded as part of the well reporting procedures.

Completion fluids (see *Section 3.7.3*) such as weighted brines or acids, methanol and glycols will be injected into the wells to clean the wellbore, stimulate the flow of hydrocarbons, and/or to maintain downhole pressure. Upper completion and well flowback fluids will be flared off after use (see *Section 3.9.1*).

### **3.6.3 Moorings and FPSO**

#### *Acoustic Array*

Prior to installation work at the site, an acoustic-positioning array will be established on the seafloor to provide accurate navigational control for positioning objects on the seafloor. The positioning array will be made up of battery-powered transponders which are mounted on small support frames that sit on the seafloor. Transponders send and receive low-level acoustic signals. After installation the transponders will be remotely released for recovery while the small support frames are left on the seafloor.

#### *Moorings*

The initial activity will be to install three mooring clusters using the positioning array. Each of the three mooring clusters will consist of three 3 m by 6 m fabricated steel suction piles (one for each mooring line; a total of nine), approximately 305 m of 13.7 cm chain, a length of spiral wire strand (approximately 14 cm in diameter) and a temporary support buoy to support the lines prior to the FPSO hook-up.

The work will be undertaken using a pair of large (60 to 75m ) 20,000 hp anchor handling vessels (AHVs) or anchor handling tug supply (AHTS) vessels and will last approximately two to four weeks. It is assumed that the vessels will make two round trips to the shorebase for re-supply therefore the

vessels will spend approximately half of this time working in the vicinity of the FPSO site and half in transit or at the shorebase.

#### *FPSO Installation*

The FPSO will retain the original marine engine and propulsion systems for the transit from the conversion and pre-commissioning site in Singapore to the installation site in Ghana. Hook-up of the FPSO to the mooring spread will be performed by a Dynamically Positioned (DP) construction vessel with the assistance of three AHVs mentioned above. The vessel will pick up the upper end of the preinstalled mooring lines, move toward the FPSO and connect the mooring wire to the FPSO turret. On completion of mooring the marine engine/propulsion systems will be decommissioned in line with class requirements.

### **3.6.4**

#### ***Subsea Infrastructure***

##### *Subsea Manifolds*

Each of the eight subsea manifolds (five production, two water injection and one gas injection) will be installed on the seafloor at various locations in the Jubilee Field. The manifolds will be installed using a DP construction vessel using the acoustic positioning system to control location and orientation. Production manifolds will be mounted on suction piles equipped with short steel extensions that will penetrate the sediments to approximately 30 m (depending on the strength of the seabed sediments) and provide horizontal resistance to movement and stability.

##### *Flowlines and Umbilicals*

Installation of the flowlines (production, water injection and gas injection) will be performed by a DP lay vessel (*Figure 3.27*) which will lower the flowlines between the FPSO location and the manifolds or riser bases. Wells and flowlines will both be connected to the manifolds or riser bases via jumpers to link the sequenced manifolds and associated riser bases. The riser bases will be connected via flexible risers up to the FPSO, which will be installed after the FPSO is moored in place. The lay vessel will be re-supplied (with pipe, material and fuel) either by supply vessel or cargo barges towed by tugs.

Installation of the control umbilicals, one to each subsea manifold, will proceed in a manner similar to installation of flowlines and by the same lay vessels that installs the flowlines. Installation will likely begin by lowering the umbilicals on the seafloor within 15 to 30 m of the subsea manifold, interconnecting one to the other and eventually laying them in the direction of the FPSO location.



**Figure 3.27**     *Typical DP Subsea Installation Vessel*



Source: Tullow, 2008

### *Risers*

Installation of umbilical risers, production risers, and the gas and water injection risers are required to complete the FPSO installation. All risers will be suspended underneath the turret of the FPSO. A DP construction vessel will perform the installation of the risers. The bottom end of the riser will first be connected to the flowlines or riser base. The vessel will then move toward the FPSO and will pass the top termination of the riser to the FPSO and terminate on the turret deck.

### **3.6.5**     *Pre-commissioning, Commissioning and Start-up*

Extensive pre-commission and commissioning tests will be undertaken on the FPSO at the conversion yard in Singapore, and where possible, all prefabricated elements of the sub sea system (eg manifolds, flexible jumpers, umbilicals, vales) will be hydro-tested (pressure tested) onshore prior to transportation and installation offshore.

Once the subsea system has been installed, pre-commissioning will commence. This will involve pressure testing the all the flowlines and control umbilicals to ensure there has been no damage during installation, testing the integrity of the systems and verifying that the control systems are fully functional. The pressure tests will be undertaken of the entire flowline network using treated water containing chemicals such as dye, oxygen scavenger, corrosion inhibitor and biocide. The purpose of the dye is to find any leaks during the hydro-testing and leak testing operations. The purpose of the oxygen scavenger, corrosion inhibitor and biocide is to protect the

pipelines and associated subsea structure piping and valves prior to start up after introducing raw seawater into the system for pressure testing purposes.

Following leak testing, production flowlines and gas injection pipelines will be flushed repeatedly with clean-filtered sea water to the sea through open valves at each end. This is to clean out any remaining debris after the installation works. The production and water injection flowlines will also be flushed and left with inhibited sea water composed of biocide and corrosion inhibitor. Dewatering or flushing operations will involve discharging the treated water used for hydro-testing and circulating several equivalent flowline volumes to sea. Production flowline contents will be discharged at the surface while water injection and gas injection flowline contents will be discharged subsea. Further information on the use and discharge of commissioning fluids is provided in *Section 3.7.3*.

Once the FPSO is connected to the subsea infrastructure final commissioning of all systems will take place including all fire and gas, safety and process control systems. Commissioning and start-up is likely to take up to six months, although this period may be extended if any pre-commissioning or commissioning work originally intended to be completed onshore needs to be undertaken offshore.

### **3.6.6 FPSO Processing and Production**

#### *Oil Processing and Production*

The well stream fluid will be stabilised and separated on board the FPSO and the produced crude oil stored on board for subsequent export via export tankers. Produced gas will be processed or compressed and used for fuel, with surplus sent into the gas injection flowline. Produced water will be treated to meet discharge emission limits and discharged overboard.

#### *Gas Injection, Compression and Riser Gas-lift*

Primary gas injection equipment (compression and dehydration equipment) will be located on the FPSO in support of gas injection and production riser gas-lift. Surplus gas from the FPSO will be injection at high-pressure into the reservoir to enhance hydrocarbon recovery. Gas for the production riser gas-lift will be supplied by taking a side-stream off of the high pressure gas injection riser in the riser base.

#### *Water Injection*

Water injection will be required from the commencement of production to maintain reservoir pressure for oil recovery. The water injection facility located on the FPSO will pump seawater from the FPSO service water system, de-aerate the water and then filter it through coarse and fine filters. This will then be treated to remove bacteria and oxygen to reduce the potential formation of hydrogen sulphide in the reservoir. In addition, the sulphate content in the seawater will be reduced to eliminate the possibility of barium

sulphate and strontium sulphate scale formation in the subsea network and wells in the longer term. The injection water will be pumped at high pressure to the water injection wells in the field. Injection volumes into each well are metered on each well jumper and controlled via chokes on the subsea trees.

#### *Electrical Power Generation*

The electrical power generation system aboard the FPSO will consist of three dual fuel turbine generator sets that can provide sufficient electrical power to serve the entire facility. The gas turbine generators will typically have electrical specifications of 11.0 kV, 3 phase, 60 Hz. Precise specifications will be determined later during detailed engineering. Diesel engine power emergency or back-up/black-start generators will have an output of 450 Vac, 3 phase, 60 Hz.

#### *Export Tanker Operations*

Crude oil stored on the FPSO will be transferred to an export tanker approximately every five to seven days when producing at plateau rate of 120,000 bopd, with offloading volumes typically being approximately one million barrels of oil with offloading requiring 20 hours, not including marine operations time.

Within the Jubilee field all crude oil transfers and vessel movements will be controlled via marine terminal procedures. The export tankers will not be owned or operated by Tullow and will only be accepted to enter the exclusion zone and offload oil following a structured tanker vetting process (see *Section 3.4.13*). Following approval, the export tanker will be boarded by the Tullow Mooring Master before proceeding to the loading position with the FPSO.

Offloading of crude oil from the FPSO to the export tankers will be undertaken using a tandem mooring system where the export tanker connects to the FPSO bow to stern using a 100 m hawser and the oil is transferred via a floating hose (see *Figure 3.28*). The floating hose will be 180 m long from the stern offloading station, starting with a 0.5 m (20 inch) diameter section that will split via a Y piece into two 0.4 m diameter (16 inch) hoses for connection to the tanker inlet. A Marine Break Away Coupling is fitted in the 20" hose close to the 16" branches (see *Figure 3.29*). The hawser system includes a tension meter, recorder and alarm system which will display the mooring system load in the main control room of the FPSO. If the tension limits are reached, the export tanker will be alerted for hose disconnection and unmooring. When not in use, the cargo transfer hose will be looped back to a storage point on the starboard side of the FPSO.

During the approach and cargo transfer operation a 100 tonne bollard holdback tug will assist the export tanker maintaining its position in relation to the FPSO. The holdback tug will be operated by an experienced master on long term contract to Tullow and reporting to the Tullow Mooring Master during the entire operation.

The entire tanker offload operation will be under the direct supervision of a Tullow Superintendent. The hose and hawser transfer will be conducted by MODEC crew, under the Tullow Mooring Master's supervision. A MODEC/Tullow crew will board the tanker to connect the hose and undertake the offload operation. All MODEC crew are trained and experienced in this type of operation, as are the Tullow Superintendent and Mooring Master. The export tanker crews will follow similar procedures to loading at a shore facility and are fully trained and certified in the requirements of tanker operations.

After connecting the FPSO oil export hose to the export tanker loading manifold, the pressure is slowly raised by the FPSO shipping pumps to the operating pressure of approximately 7 atmospheres (bar) as a leak test. During this time, all connections are visually inspected. At any point in the operation should a leak be detected (ie visually, drop in pressure), the system can be shut down. Drip plans are in place to catch any leak should it occur and also to catch residue oil once the hoses are disconnected.

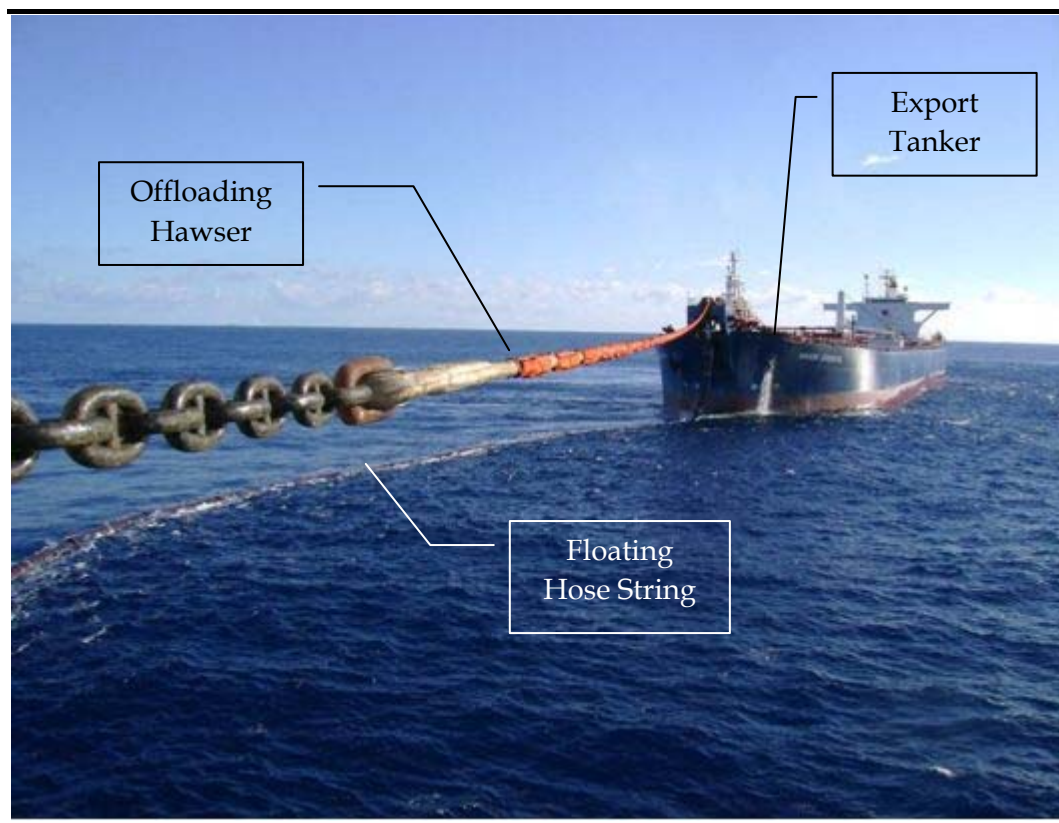
The export hose assembly undertakes a formal pressure test every two years or after a component change out (eg hose section change). The formal pressure test is completed with water taken to a test pressure aligned with the hose rating of 12 bar. The hose is also inspected prior to each transfer.

**Figure 3.28** *Typical Export Tanker Operations*



Source: Modec, 2009

**Figure 3.29**     *Illustration of Offloading System in Operation*



An FPSO support multi service vessel (MSV - see *Figure 3.30*) will also be the primary means of transporting the lifting crew from the FPSO to the export tanker and will assist in berthing and un-berthing of the shuttle tanker. The FPSO MSV support vessel will be in position during export tanker berthing, ready to intervene by pushing the nose of the tanker out of the direction of the FPSO in the event of an export tanker engine, or hold back vessel, failure. In addition the support vessel will have fire-fighting and spill response capabilities.

The hawser will be handed over to the export tanker by a separate 500 hp daughter vessel that will reside on the FPSO MSV support vessel. The daughter vessel will carry out the hawser handling duties as well as floating cargo hose inspections. The hawser will be equipped with an emergency release system that will be manned during mooring and transfer.

**Figure 3.30** *Typical MSV (80m length, 3160 gross tonnage and 180 tonnes bollard pull)*



The following measures will be put in place by Tullow to reduce the risk of export tanker collisions during offloading operations.

- Good communications: operational discussions to be initiated with the export tanker 72 hours prior to offloading.
- Qualified and competent FPSO lifting crews, export tanker crews and mooring master to be onboard. Training and competency verification of crews and regular exercises and drills.
- Approved procedures and checklists, including weather restrictions for infield vessels and export tankers to approach and depart the FPSO and good illumination at night.
- Adequate infield vessels for off loading operations. There will be at least two dedicated oilfield service vessels (OSVs): one anchor handling tug supply (AHTS) and one multipurpose vessel (MPV). One OSV will act as a hold back tug for the tanker and the other will be on standby to divert a drifting tanker. In addition there will be one AHTS used for supply runs to and from Takoradi.
- Adequate inspection, maintenance, surveys and classification for FPSO, infield vessels and shuttle tankers.
- Qualified export tankers of suitable specification for tandem offloading.



### *Ballast Water*

Export tankers in the Jubilee field for cargo transfers may only discharge clean ballast water meeting MARPOL standards. This will form part of the tanker vetting procedure. The Jubilee FPSO and visiting export tankers will undertake ballast water management measures in accordance with the *International Convention for the Control and Management of Ships Ballast Water and Sediments*. This includes ballast exchange at sea, to minimise the transfer of organisms. The FPSO has permanent, separate ballast tanks and there will be routine discharge of clean ballast water from the FPSO to maintain the proper draft during production and cargo loading cycles.

### *Tank Venting*

All FPSO cargo tanks are maintained in a pressurised state and the vapour space created in the storage tanks of the FPSO is filled with an inert gas. The purpose of maintaining the inert condition of the void spaces in the storage tanks is to avoid the potential for oxygen ingress and thus a fire or explosion. All excess inert gas is vented during cargo tank filling operations. The inert gas emissions from the FPSO are dispersed via a cold vent line located on the LP gas flare tower. A Vapour Recovery Unit (VRU) will be installed to collect the vapours from the gas treatment system's TEG dehydration reboiler unit to mitigate the venting of aromatic hydrocarbon compounds that can be released by these units.

### *Flaring*

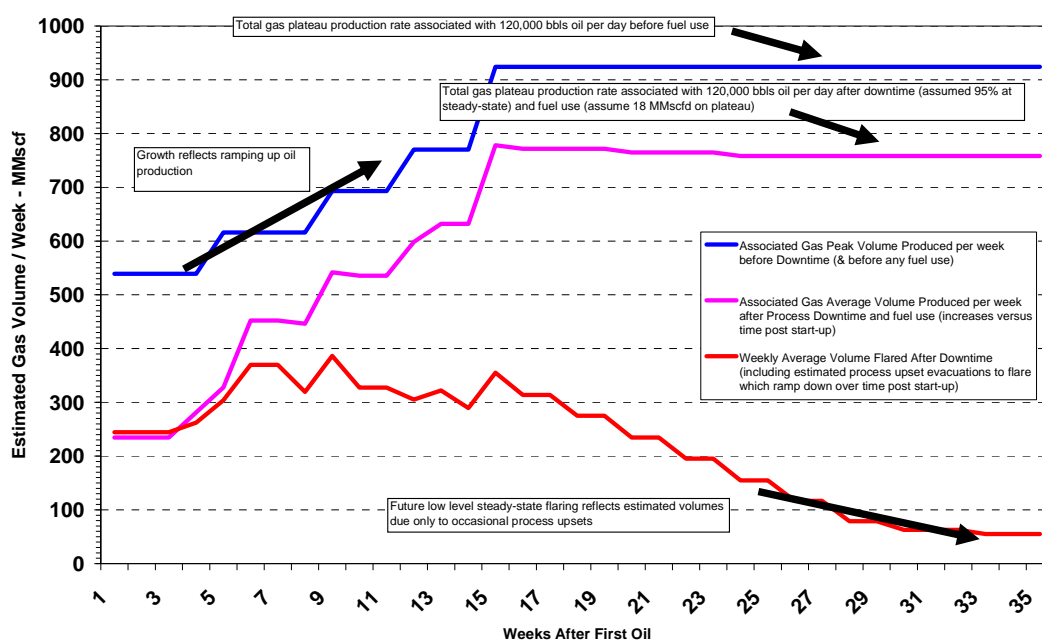
No continuous flaring of excess hydrocarbon gases during normal operations is planned. Flaring will be avoided other than to maintain safe conditions such as flaring purge gas, facility depressurisation, operational upset conditions or during limited duration activities such as process start-up, re-start and maintenance activities.

As part of the well completion operations, short-term flaring will be required during well testing and well flowback to the MODUs for well cleanup purposes (see *Section 3.7.1* for further details). Well clean up maximises the production rate for the wells by ensuring reservoir fluids enter the wellbore thereby removing previous drilling fluids. Well testing and cleanup is estimated to last for a maximum of 24 to 48 hours per well.

Short-term flaring is also likely at the Jubilee FPSO during the initial commissioning period of three to six months where the gas compression is brought to steady state. Pre-commissioning of gas handling and compression systems in the Singapore dockyard prior to vessel sailing to Ghana will reduce the offshore time required to complete later commissioning and will therefore reduce the volumes of gas that may have to be flared in the Jubilee field.

Figure 3.31 shows estimated gas flaring levels forecast for the FPSO from start-up to reaching steady-state operation in approximately 24 weeks. This is a conservative estimate with respect to commissioning flare volumes, duration required and gas volumes produced. The estimate assumes a gradual ramp-up of oil production and associated gas volumes up to system capacity. The operator of the FPSO will apply for relevant permits to the Ghanaian authorities with respect to expected gas flaring volumes.

**Figure 3.31** *Estimated Weekly Flaring Levels Forecast During Commissioning*



Source: Tullow, 2009

### 3.6.7 *Monitoring of Fluid Migration*

It is possible that additional seismic data will be required over the Jubilee field, either to improve on the existing datasets with newer technology or as a component of an ongoing monitoring of fluid migration within the reservoir due to production. If this is required, the acquisition would most likely occur three to five years after first oil and would be the subject of a separate permit submission to the EPA. Tullow will implement specific environmental mitigation measures that will be developed in a management plan, with a focus on marine mammal protection.

### 3.6.8 *Interventions and Workovers*

Intervention and workover involves the repair or stimulation of an existing well for the purpose of restoring, prolonging or enhancing the production of oil or gas, or the injection of water or gas. All of the 17 planned wells have been designed with a 20 year life with no planned interventions or workovers.



Unplanned interventions or workovers may be required, however, for the following reasons.

- Mechanical integrity – tubing/completion failure due to stress, corrosion or installation failure.
- Sand control failure – screen failure, build-up of fines in water injectors due to back-surge, plugging of screens.
- Premature water breakthrough – cement failure behind casing.
- Permanent down-hole gauge failure.
- Loss of productivity requiring acid stimulation of formation.

Unplanned workover operations would be expected to take approximately 30 days based on previous experience. The workover operations would require an appropriate intervention vessel or MODU.

### **3.6.9      *Emergency Response Plan***

An Emergency Response Plan (ERP) has been developed for Phase 1 to provide a means to coordinate response efforts in the event of an emergency to protect life, the environment and property. The ERP will cover medical evacuation operations, search and rescue operations, fire prevention and protection, and other incident responses. One part of the Emergency Response Plan will be an Oil Spill Contingency Plan (also see *Chapter 9*) which will describe actions to be taken to prevent spills as well as the resources and procedures for responding to a spill. The Oil Spill Contingency Plan will address the following items:

- operating procedures that prevent oil spills;
- control measures installed to prevent a spill from spreading; and
- counter-measures to contain, clean up and mitigate the effects of an oil spill.

### **3.6.10     *Decommissioning***

The decommissioning of offshore facilities occurs when the reservoir is depleted or the production of hydrocarbons from that reservoir becomes uneconomic. At the end of the economic field life of the Jubilee Field, the facilities will be decommissioned in accordance with prevailing legislation and guidelines. An outline decommissioning plan is included in *Chapter 8*.

## **3.7          *PERSONNEL REQUIREMENTS***

Tullow's head office in Accra will provide the overall business management for the project. There are currently over 80 staff based in Accra and 35 staff based at the logistics and operations support base in Takoradi. Staff numbers in both areas will grow as the project develops.

During the Phase 1 drilling and well completion operations, which are expected to continue until mid 2011, engineers, technical and support personnel will be required by the MODU contractors and the support services companies. The main project installation activities will occur in 2010 with a fleet of installation vessels offshore, followed by the start of production at the FPSO. During installation and production, the FPSO and support vessels will be manned by trained operators, technicians, engineers and vessel crew.

The estimated manning levels across the various phases of the project are indicated in *Table 3.8*. This includes the current status with drilling activity, followed by installation and operation of the FPSO and export tanker and support vessel operations. It should be noted that these figures are estimates and will vary with activity levels.

The projected number of job opportunities for Ghanaians at the start of the project is also noted and this will increase over the project life. Tullow and its contractors are committed to the development of national staff and capacity for the oil industry in Ghana. Tullow has set a local content target of 90 percent Ghanaian staff and direct contract personnel across all disciplines within four to eight years from the end of 2008.

**Table 3.8** *Summary of Personnel Requirements by Stage*

Stage of Phase 1 Activity	Duration	Total Manning Level	Approximate Local Content
<b>FPSO and Project Construction and Installation Phase</b>			
Tullow Accra Headquarters	To first oil 4Q 2010	80 growing to 120	80 growing to 110
Tullow Takoradi shore base	To first oil 4Q 2010	35 growing to 50	20 growing to 45
FPSO field installation, commissioning and start-up	9 months	200	40
Port Support – marine	9 months	60	35
Aviation Support – helicopter and fixed wing	9 months	40	20
Onshore construction	9-18 months	30 - 150	25 – 140
<b>Drilling</b>			
MODUs (x2 if 2 MODUs in field)	To mid 2011	120	30 – 40
Supply vessels (x2 assumed)	To mid 2011	20	10
<b>Total Drilling, Construction and Installation</b>		<b>585 - 760</b>	<b>260 – 440</b>
<b>FPSO Operation (Production, Oil Transfer)</b>			
Tullow Accra Headquarters	20 years	120	110
Tullow Takoradi shore base	20 years	50	45
FPSO Production phase	20 years	80	10 later 65
FPSO Hold Back Vessel	20 years	10	4 later 10
FPSO Multi Service Vessel	20 years	17	5 later 15
FPSO Supply Vessel	20 years	10	4 later 10
<b>Onshore Support</b>			
Aviation Support	20 years	20	16
<b>Total Operations and Support</b>		<b>307</b>	<b>196 later 271</b>

Notes: Duration denotes the need for designated manning levels for the entire stage of the project.  
Local content target – indicates a target level for local employment; actual levels will be dependant on available personnel and training results.

This section presents a listing, discussion and estimation of the magnitude of the main sources of emission to air, discharges to water and waste generated for shore disposal that will result from the proposed project and operations. The data have been obtained from engineering estimates and by benchmarking to other FPSO projects, as well as from the project design team.

## 3.8.1

*Air Emissions*

Phase 1 activities, including well completion operations, the subsea equipment and FPSO facility installation, commissioning and operation, export tanker operation, flowline and umbilical installation and support vessel and helicopter operations will emit greenhouse gases and varying amounts of other pollutants such as carbon monoxide (CO), oxides of nitrogen (NOx) and sulphur (SOx), volatile organic compounds (VOCs) and particulate matter (PM). As discussed under *Section 3.6.6*, VOCs will be reduced through maintaining FPSO cargo tanks in a pressurised state with an inert gas.

*Table 3.9* outlines projected emissions of these pollutants from the main project activities. Estimated Greenhouse Gas (GHG) emissions are provided in *Table 3.10*. Detailed calculations, assumptions and emissions factors used are included in *Annex E*.

**Table 3.9** *Estimated Air Pollutant Emissions for the Jubilee Field, Phase 1 Development*

Project Stage	Approximate Duration	Estimated Emissions (tonnes)				
		PM	SOx*	NOx	VOC	CO
Well Completion (Erik Raude)	425d	185	5,269	7,417	214	1,502
Flowline/injector/umbilical installation	190 d	113	3,275	4,650	113	621
FPSO installation	120 d	36	930	1,235	36	196
Commissioning (flare)	180d	0	0	93	1	8
Abnormal Event flaring**	Monthly	0	0	367	3	31
Inert gas system***	Maximum	-	-	-	18,204	-
	Average	-	-	-	15,170	-
Production	Annual	67	1,887	2,319	72	444

\*Assumes 2% Sulphur in fuel \*\*Assuming abnormal flaring will not exceed 2.5 percent of the monthly average total gas produced. \*\*\* Maximum emissions assumes production rate of 120,000 bbl/d and most likely is based an average annual crude throughput of 36,500,000 bbls per year.

**Table 3.10** *Estimated Greenhouse Gas Emissions for the Jubilee Phase 1 Development*

Activity	Duration	Estimated Emissions (tonnes)		
		CO <sub>2</sub>	CH <sub>4</sub>	CO <sub>2</sub> equivalent
Completion (Erik Raude) including well cleanup flaring	425 d	400,248	78.8	402,060
Well flowback flaring (17 wells)	24-48 hrs	3,304	0.9	3,325
Flowline/injector/umbilical installation	190 d	263,970	2.3	264,022
FPSO installation	120 d	74,669	0.7	74,685
Commissioning (flare)	180 d	670,374*	988.6	693,1111
Abnormal Event flaring	Monthly	92,821*	136.9	95,969
Production	Annual	148,252	17	148,648

\*CH<sub>4</sub> was assumed to have a CO<sub>2</sub> equivalence of 23. \*\* Includes amount of CO<sub>2</sub> that will be contained in the pre-combustion gas that will also be released unchanged into the atmosphere

### *Flaring Emissions*

Routine flaring will be avoided, however, there will be non-routine flaring to maintain safe conditions or during short-duration activities such as start-up, re-start and maintenance activities. The flaring system is discussed in *Section 3.4.2*. A design and operational target will be established such that abnormal flaring will not exceed 2.5 percent of the monthly average total gas produced. High- and low pressure flares will be purged with hydrocarbon gas to ensure an oxygen free environment is maintained within the systems. A total of 50,000 scf of hydrocarbon gas is estimated to be purged per day.

### *Well Flowback*

During well completions upper completion and well flowback fluids will be flared off after use. *Table 3.11* provides a provisional list of fluids and volumes to be flared during well completions.

**Table 3.11**      **Well Flowback Fluids**

Chemical	Function	Potential usage (per well)
HW443	Control Fluid	1,500 litres
FR3	Dielectric Fluid	30 litres
Diesel	Underbalance fluid that will allow the well to flow without artificial means.	68 tonnes
ESCAID 120 (Base Oil)	Underbalance fluid	81 tonnes
DFO82306 Defoamer	Coalesces gas bubbles and allows more efficient separation	182 litres
DMO86338 Demulsifier	Aids the separation of emulsions (water in oil)	182 litres
Methanol	Prevent hydrate formation	13,075 litres

### **3.8.2**      ***Routine Water Discharges***

The FPSO facility and associated support vessels and export tankers will produce a series of discharges including black water, grey water, produced water and miscellaneous discharges (ie bilge water, deck drainage and cooling water). FPSO discharges will continue for the life of the Phase 1 development. The discharges and treatment systems are summarised in *Table 3.15* at the end of this section. Water discharges will comply with Ghanaian standards or industry standards in the absence of appropriate Ghanaian standards.

### *Produced Water*

Produced water is a by-product of the processing of hydrocarbons from underground reservoirs. Water is naturally present in these reservoirs and water is produced as a liquid with the oil or as a vapour in gas. Produced water will be discharged to the sea following treatment to reduce the concentration of dissolved oil to at or below 29 mg/l maximum monthly average and 42 mg/l maximum daily average oil content and no visible sheen.

These limits are in accordance with the IFC's guidance for offshore oil and gas development<sup>(1)</sup> and comply with recommended practice from OSPAR<sup>(2)</sup> and the USEPA<sup>(3)</sup>.

A three stage water treatment process for produced water has been specified which has the ability to direct all water to tanks and re-process the water, if the water specification to sea does not meet the specified requirements.

- Stage 1: All of the produced water removed from the FPSO process trains is collected in the water collection or skim vessel. Skimmed hydrocarbons are removed and directed to the off-spec tank in the hull.
- Stage 2: The separated produced water is then pumped out of the skim vessel to the de-oiling hydrocyclone units.
- Stage 3: The partially treated produced water from the hydrocyclone units is pumped into gas flotation cells. Gas is induced into the produced water inlet stream. The hydrocarbon layer formed at the top of the vessel is periodically skimmed off and directed to the off-spec tank in the hull. The treated water is pumped out of the flotation cell and directed through the produced water cooler prior to overboard discharge.

A small amount of hydrocarbons will remain dissolved in the produced water. An on-line analyser will continuously measure the oil in water levels and an alarm will sound at 35 mg/l to alert operations staff and allow for intervention. There will be an automatic trip limit of 42 mg/l that will divert the produced water to the off-spec tank in the hull for recycling. Storage for produced water in the FPSO hull will be able to hold 24 hours of storage at the maximum system throughput of 80,000 bwpd. The discharge into the sea will be monitored such that 30 day average should not exceed 29 mg/l. Effluent concentrations will be verified by taking manual samples every twelve hours for analysis in the on board laboratory.

Volumes of discharged produced water can be extremely variable. Low volumes of produced water are expected in the early stages of Jubilee field production. The graph in *Figure 3.32* shows a forecast for low, mid and high scenarios of produced water discharged volumes. The FPSO has been designed with water handling capacity of 80,000 barrels of water per day. This is to manage large volumes of produced water in the event that there is rapid water breakthrough in the reservoir between water injector wells and producer wells. It also allows for further field expansion projects, if infill drilling was undertaken and additional producing wells brought on-line.

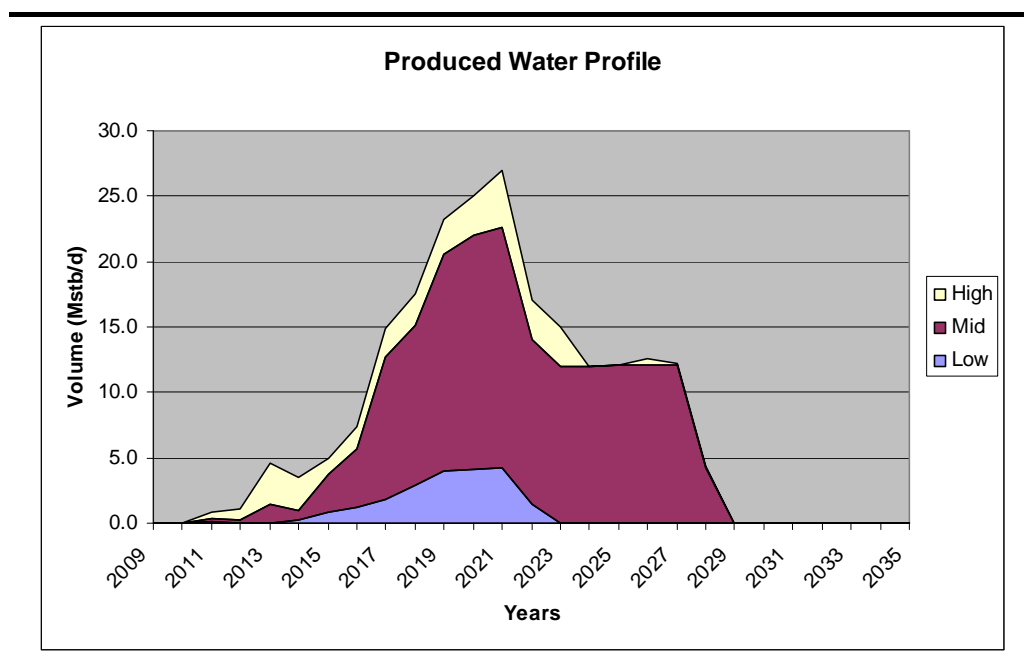
(1) World Bank IFC "Offshore EHS Guidelines for Offshore Oil and Gas Development": 29 ppm monthly average; 42 ppm daily average oil content and no visible sheen.

(2) Oslo-Paris Commission (OSPAR): 30 ppm maximum oil content

(3) US Environmental Protection Agency (EPA) Gulf of Mexico NPDES general permit (permit #GMC290000): 29 ppm monthly average; 42 ppm daily maximum oil content and no visible sheen

In the Jubilee field PoD, seawater will be injected into the wells for reservoir pressure management reasons and to sweep oil towards the production wells. Re-injection of produced water into the reservoir is not considered feasible during the early stages of the project due to the risk of scale formation in the reservoir and subsea equipment as a potential consequence of mixing treated produced water and seawater. However, once produced water composition and quality (eg solids content levels and bacteria concentrations) are more fully understood, then the potential for re-injection of produced water will be investigated. This is typically carried out by conducting pilot mixing trials and injection periods. The produced water process on the FPSO has been designed to permit future configuration of the process pipework to retro-fit produced water re-injection. It is planned to undertake investigations into produced water re injection at the start of the operations with a decision on the feasibility taken within two years of the start of substantial production of water from the field.

**Figure 3.32** *Produced Water Profile – Plan of Development Ranges*



#### *Black and Grey Water*

Black water (ie sewage or sanitary effluent), consisting of human body wastes from toilets and urinals, will be treated using a marine sanitation device that treats the waste and produces an effluent with a minimum residual chlorine concentration of 1.0 mg/l and no visible floating solids or oil and grease. Grey water (ie domestic waste) includes water from showers, sinks, laundries, galleys, safety showers and eye-wash stations. According to MARPOL, grey water does not require treatment before discharge.

It is assumed that one person generates 100 l/d of black water and 220 l/d of grey water. It is predicted that sanitary wastes have an associated biological oxygen demand (BOD) of 240 mg/l. BOD estimates for domestic waste are

variable and significantly lower than that measured for sanitary waste. Assuming a crew complement of 80 persons on the FPSO, 50 person on the export tanker and 26 persons on support vessels, Phase 1 facilities can be expected to generate an average of approximately 15,600 l of black water (resulting in 3.7 kg of BOD) and 34,320 l of grey water on a daily basis during the operational phase.

#### *Deck Drainage*

Deck drainage consists of liquid waste resulting from rainfall, rig washing, deck washings, tank cleaning operations, and runoff from curbs and gutters, including drip pans and work areas. The FPSO has been designed to contain runoff and prevent oily drainage from being discharged directly to the ocean. Deck drainage that may contain oil is diverted to separation systems depending on the area collected. There will be no discharge of free oil in deck drainage that would cause a film, sheen or discoloration of the surface of the water or a sludge or emulsion to be deposited beneath the surface of the water.

Only non-oily water (ie 15 ppm oil and grease, maximum instantaneous oil discharge monitor reading) will be discharged overboard. If the deck becomes contaminated, oily deck drainage will be contained by absorbents or collected by a pollution pan for recycling and/or disposal. Assuming a surface area of 20,000 m<sup>2</sup> for the FPSO and a maximum monthly rainfall amount of 170 mm, the monthly average deck drainage would be 3,400 m<sup>3</sup> (3.4 x 10<sup>6</sup> l). Deck washes may account for an additional 200 m<sup>3</sup> (approximately) per month.

#### *Cooling Water*

On the FPSO cooling water is a closed loop system with a top-up from the Reverse Osmosis (RO) unit. Cooling water discharges are expected to be minimal given the closed loop system. In the event that cooling water is required to be discharged via service valves the temperature of the cooling water discharges is expected to be 55°C (mean) with a range of 32 to 60 °C. This will be infrequent, probably required no more than twice a year during maintenance periods, given the closed loop nature of the systems.

Most modern diesel propulsion and auxiliary engines installed on support vessels are fresh water cooled. Water coolant is circulated in a closed-loop piping system around the engine block and cylinder heads and then cooled by a heat exchanger. There is no thermal discharge into the marine environment.

Older vessels may operate with a 'once-through' cooling water arrangement, typical on larger deep-draft vessels. Once-through cooling utilises the intake of raw seawater through a sea chest. Water is then circulated around the engine before it is discharged back into the environment. It should be noted that cooling water normally does not contain any contaminants; however, water quality could be affected by returning heated water to the environment. Vessels outfitted with once-through water cooling arrangements would have

varying rates of discharge depending on the engine make/size and cooling water piping arrangement.

A typical marine diesel propulsion engine can use 1.2 l per minute (lpm) of cooling water. Using the heat transfer/cooling water requirements for this engine as the basis for extrapolation to other diesel engines, the approximate discharge rates of once-through engine-cooling water for diesel engines would be:

- idle: 0.28 lpm per bhp;
- 50 percent load: 0.43 lpm per bhp; and
- 90 percent load: 0.6 lpm per bhp.

For example, a 3,000 bhp vessel idling would discharge approximately 841 lpm of engine-cooling seawater; at 50 percent load and at 90 percent load this volume would increase to 1,277 and 1,787 lpm respectively.

#### *Bilge Water*

Support vessels will occasionally discharge treated bilge water. These vessels will comply with the applicable sections of MARPOL. Under these regulations, water must be retained onboard until it could be discharged to an approved reception facility, unless it is treated by approved oily water separators and monitoring equipment before being discharged to the sea. Vessels must employ approved equipment, examined and tested in accordance with the specifications and requirements of the IMO Guidelines and Specifications for Pollution Prevention Equipment for Machinery Space Bilges of Ships.

#### *Ballast Water*

Ballast water that is discharged will be subject to MARPOL 73/78 requirements. MARPOL 73/78, Annex I, requires that discharges into seawater outside of special areas contain no more than 15 mg/l oil and grease. In addition, requirements of the *International Convention for the Control and Management of Ships' Ballast Water and Sediments* will be adhered to. Ships are required to have onboard and implement a Ballast Water Management Plan. All ships using ballast water exchange will do so at least 200 nautical miles from nearest land in water at least 200 m deep. All vessels that operate in the field will comply with MARPOL 73/78 with respect to any ballast water discharge impacts and their potential oil-in-water levels.

On the FPSO the primary means of maintaining an even keel, stability and trim will be through management of the distribution of crude oil within the storage tanks, therefore the requirement for ballast water intake and discharge will be minimal. In the event that ballasting is required the ballast pump is capable of pumping at a rate of 5,000 m<sup>3</sup>/hr. Ballast water will be segregated into dedicated ballast tanks.



### *Brine Discharge*

Brine generated from reverse osmosis during freshwater generation will be discharged overboard. Brine discharges are estimated at 35 to 50 m<sup>3</sup>/d.

### *Desulphation System*

To maintain pressure in the oil reservoirs to aid oil production, water injection is required. The water will be sourced from seawater which can produce barium sulphate and strontium sulphate scale when mixed with the reservoir water, which in high concentrations will reduce or even block oil production from the wells and accumulate throughout the flowlines, piping and vessels. Therefore, as part of the design of the sea water injection system on the FPSO sulphate ions must be reduced to a level to mitigate this risk later in field life. A Sulphate Removal Unit (SRU) on the FPSO will be installed to treat the sea water once it has been filtered and de-aerated.

The SRU will also produce a discharge stream of sulphate rich seawater at an estimated maximum rate of 100,000 bwpd. The discharge will contain several chemicals used in the system, the most significant of which being an intermittent discharge of biocide (approximately 200 ppm) to control organism growth which would cause bio-fouling in the topside facilities. A biocide will be selected with the lowest possible risk of environmental harm, capable of achieving operational objectives.

In addition, both the filters and membranes must be cleaned on a relatively regular basis to prevent clogging and will result in an intermittent discharge to sea of approximately 10,000 bwpd. In addition, the reject stream will contain approximately 11,778 mg/l of sulphate ions, ie approximately three times the natural background level in seawater. The anticipated composition of the reject stream, based on a 15°C water intake, is provided in *Table 3.12*.

**Table 3.12**      ***SRU Reject Stream Chemical Composition***

Component	Amount Discharged (mg/l)	Amount Feed (mg/l)
Sodium	14,743	10,890
Potassium	644	460
Magnesium	5,339	1,368
Calcium	1,550	428
Strontium	31	8
Chloride	32,750	19,700
Sulphate	11,779	2,960
Bicarbonate	279	124
Total Dissolved Solids	67,153	35,938

Note: Concentrations are conservative estimates as membranes usually operate better than predicted

This section provides details on non-routine discharges to water.

### *Completion Fluids*

During well completions, various chemicals will be used on the MODUs. Completion fluids can typically include weighted brines or acids, methanol and glycols and other chemical systems. Once used these fluids may contain contaminants including solid material, oil and chemical additives. Most of the chemicals used during completions will remain downhole or will be injected into the formation. Some completion chemicals such as upper completion chemicals and flowback fluid chemical will be flared off after use. Returned fluids, such as wellbore cleanup fluids, will be discharged overboard (Table 3.13). This will include completion brine (calcium chloride: CaCl<sub>2</sub>), CELITE 545 (diatomaceous earth filter aid), Tetraclean-105 (surfactant) and Tetraclean-106 (surfactant booster).

**Table 3.13** *Well Workover Chemicals to be Discharged to Sea*

Chemical	Function	Potential usage (estimated per well)	Disposal	CHARM Rating	OCNS Category
CaCl <sub>2</sub>	Completion brine	845 T	Re-use as much as possible or overboard discharge	N/A	E (PLONOR)
CELITE 545	Diatomaceous Earth Filter Aid	5.3 T	Overboard discharge once tested	N/A	E (PLONOR)
Tetraclean-105	Surfactant	5.9 T	Overboard discharge once tested	Gold	N/A
Tetraclean-106	Surfactant Booster	3.3 T	Overboard discharge once tested	N/A	E (PLONOR)

Three of these chemicals are essentially non-toxic and are rated as ‘pose little or no risk’ (PLONOR) according to the OSPAR Offshore Chemical Notification Scheme (OCNS) (Category E)<sup>(1)</sup>. The OCNS provides hazard assessments on chemical products that are used offshore using a dispersion model (known as the CHARM model<sup>(2)</sup>) to calculate the ratio of Predicted Effect Concentration against No Effect Concentration (PEC: NEC) and is

(1) OCNS – developed by the Oslo/Paris Commission, groups chemicals according to their environmental effect. Groupings are from A to E and indicate the potential environmental effect of chemical discharge to the marine environment with grouping E being those with least potential for adverse environmental effect.

(2) CHARM - requires offshore chemicals to be ranked according to their calculated Hazard Quotients (HQ). Chemicals on the OSPAR List of Substances / Preparations Used and Discharged Offshore which are Considered to Pose Little or No Risk to the Environment (PLONOR) do not need to undergo CHARM. The ratio of the Predicted Environmental Concentration (PEC) (ie concentration of chemical to which environment is exposed) to the predicted No Effect Concentration (NEC) (ie estimate of concentration level that no adverse effects are to be expected) is calculated and is called the Risk Quotient (RQ). If the RQ is >1 then there is predicted to be an effect on the environment; if the RQ is 1 then predicted effects/no effects are the same; if the RQ is <1 then there is no predicted effect upon the environment. If the RQ value exceeds 1 then the operator must either substitute another chemical OR justify the discharge.

expressed as a hazard quotient (HQ), which is then used to rank the product in the form of a colour banding. Data used in the OCNS assessment include chemical toxicity, biodegradation and bioaccumulation as well as volumes used. According to the CHARM model the surfactant is categorised as Gold (see Table 3.14).

**Table 3.14**      *Key to Hazard Quotient and Colour Bands*

Minimum Value	Maximum Value	Category
> 0	< 1	Gold
>= 1	< 30	Silver
>= 30	< 100	White
>= 100	< 300	Blue
>= 300	< 1,000	Orange
>= 1,000		Purple

Before any fluids are discharged overboard they will be tested for oil content as follows: maximum one day oil and grease discharge should not exceed 42 mg/l; 30 day average should not exceed 29 mg/l as per IFC (2007a) EHS Guidelines discharge levels. If the oil content is greater than the specification above then the relevant returned fluids will be retained on the vessel in closed systems (such as tote tanks) and shipped for onshore disposal. If the oil content is below the specification then the fluids will be discharged to sea.

If any acid is used during well completions or workovers for breakdown of the rock formations, the spent acid will be injected into the rock formation. In the unlikely event that acidic completion/workover fluids are returned back to the MODU, they will be neutralised to attain a pH of 5 to 7 using lime or similar prior to discharge, as per IFC (2007a) EHS Guidelines.

#### *Pre-Commissioning and Line Flushing Fluids*

A typical fluid that will be used to pre-commissioning the subsea flowlines is the seawater soluble Clariant TROS 655. This fluid contains dye, oxygen scavenger, corrosion inhibitor and biocide. The total volume of pre-commissioning fluid that may be discharged to sea is 5.0 m<sup>3</sup> combined at 1,000 ppm in approximately 5,000 m<sup>3</sup> of raw sea water. The discharge will be subsea, except for the production flowline volumes which will be produced back to the FPSO and discharged from surface. This is a conservative estimate for all flowlines and subsea lines that will be installed.

Prior to injecting into the water injection wells the water treatment facilities will be commissioned. During this process approximately 30,000 m<sup>3</sup> of deoxygenated sea water will be discharged overboard. In addition, deoxygenated and filtered sea water will be pumped through the subsea flowlines and manifolds to flush the subsea system. Four line flushes are planned with an overall volume of 5,000 m<sup>3</sup> of deoxygenated and filtered sea water.

When the gas injection flowlines and risers are dewatered (ie the water is pumped out) Monoethylene Glycol (MEG) will be pumped through the pipelines to remove any remaining water. Typically 50-100 m<sup>3</sup> of MEG will be discharged to sea.

For the long term storage of the umbilical tubing including transportation, installation and post installation testing, SST5007 umbilical storage fluid (40% MEG) is used. The volume (approximately 15.0 m<sup>3</sup>) within the umbilicals will be discharged at the seafloor once the umbilicals are commissioned. Approximately 4.0 m<sup>3</sup> of methanol will also be displaced in this umbilical flushing process.

#### *Workover Fluids*

When wells require repair for mechanical reasons or restoration of their production or injection levels due to blockage or other reasons such as severe injection water breakthrough, they are worked over by bringing a MODU into the field for a workover operation of approximately 30 days. In general, workover fluids are similar to completion fluids (described above) and will be re-used, re-injected into the formation or remain downhole. Some chemicals will be returned to the surface for disposal to sea after testing, or taken to shore and returned to the supplier for disposal.

#### *Hydrate Inhibitor*

Gas hydrates form at low temperature and elevated pressure at certain conditions with natural gas and water present. Hydrates are a form of 'hard ice' which is difficult to remove if they form subsea. Methanol is used worldwide in the oil and gas industry as the hydrate control chemical of choice for production systems. Alternative chemicals may be used in the future, however, they are generally limited in their application and specific field testing would be required before these can be used.

Methanol will be used for the following purposes;

- Intermittent use for hydrate inhibition during well start-up.
- Displacement of subsea trees, well jumpers/flowlines and wellbores across sub-surface safety valves for hydrate inhibition during shutdowns.
- To equalise the differential pressure across subsea valves prior to opening then where cooling due to pressure drop upon opening could otherwise cause hydrate formation.

Methanol will be injected in batches of approximately 5 bbls per well during long term (>8 hrs) systems shutdowns (either planned or unplanned) to prevent hydrate formation. Following shutdown the methanol will be discharged to sea. Methanol will also be used when water is produced or present in the wells, for example in the early commissioning phase of the subsea

system and wells. With increasing produced water later in the Jubilee field life, larger volumes of methanol will be used during extended system shutdowns and following well start up the methanol will be discharge to sea in volumes of up to 200 to 400 barrels in one day.

#### *Hydraulic Fluid*

Subsea hydraulically operated manifold and tree valves will be actuated using an electro-hydraulic subsea control system. The subsea control system will use Oceanic HW443 control fluid which is a water based glycol and has an OCNS Group D rating. Small volumes of hydraulic fluid will be vented from the control system equipment when given a command to close. This will result in the discharge of approximately 45 l of hydraulic fluid per year (based on 14 valves releases every three months each discharging an average of 0.8 l), although the exact quantities discharged depend on the frequency of operation of the subsea valves. Valves on water and gas injection manifolds are ROV actuated, so they will not release any fluid.

#### *Naturally-Occurring Radioactive Material*

Produced water, having been in contact with various rock strata at elevated pressure and temperature, contains many soluble components including barium and the radioactive intermediates of the uranium and thorium decay series. As the water is produced from the wells the temperature and pressure decreases creating conditions in which the barium and radionuclides can co-precipitate inside separators, valves and pipework, forming an insoluble naturally-occurring radioactive material (NORM) scale. Some of the soluble radionuclides and particles of NORM scale can pass through the system and be discharged with the produced water. Similarly, some particulate scale and soluble radionuclides can be entrained with the exported oil.

No NORM scales or sludges are expected for the Phase 1 Jubilee development project. From recent well Pressure Volume Temperature (PVT) samples, only very low traces of barium (max 25 ppm) were detected. Therefore, no significant barium sulphate scale is expected. However, as a contingency, a water injection sulphate removal unit will be installed on the FPSO for removal of the sulphates from injection water. In addition, to prevent scale formation, there will also be capability to inject scale inhibitor into the well and process facilities.

**Table 3.15**     *Summary of Discharges and Treatment*

Discharge and Source	Treatment	Discharge Point (s) and Location	Volume	Limit	Standard
Black Water	Treat with approved sanitation unit. Maceration and Chlorination	Single; holding tank storage; discharge overboard	Variable depending on number of personnel. Estimated 100 l per person per day. <u>Well completions</u> : MODU: 100 personnel, 10,000 l/d; Support vessels: 52 personnel, 5,200 l/d <u>FPSO installation</u> : FPSO and Support vessels: 200 personnel, 20,000 l/d <u>Subsea equipment installation</u> : 3 vessels, 60 personnel, 6,000 l/d <u>FPSO Operations</u> : 80 personnel, 8,000 l/d <u>Support vessels</u> : 26 personnel, 2,600 l/d <u>Export Tanker</u> : 50 personnel, 5,000 l/d	<ul style="list-style-type: none"> <li>• Achieves no visible floating solid</li> <li>• No discolouration of surrounding water</li> <li>• &lt; 1.0 mg/l chlorine concentration</li> </ul>	Annex IV MARPOL
Grey water	Remove floating solids	Single; holding tank storage; discharge overboard	Total volumes variable, depending upon number of personnel. Gray water discharges estimated at 220 l per person per day. <u>Support Vessels (AHTS and work boat)</u> : 52 personnel, 11,440 l/d <u>FPSO Installation</u> : FPSO and support vessels: 200 personnel, 44,000 l/d <u>Subsea equipment installation</u> : 3 vessels, est. 60 personnel, 13,200 l/d <u>FPSO Operations</u> : 80 personnel (maximum), 17,600 l/d; <u>Support Vessels, installation</u> : 26 personnel, 5,720 l/d; <u>Export Tanker</u> : est. 50 personnel, 11,000 l/d	<ul style="list-style-type: none"> <li>• No visible floating solids or discoloration of surrounding water</li> </ul>	Annex IV MARPOL

Discharge and Source	Treatment	Discharge Point (s) and Location	Volume	Limit	Standard
Produced Water	Oil-water separation	Single; holding tank storage; discharge overboard	<u>FPSO</u> : Low levels during initial production; discharge rate of 6 Mbbbl/d is expected over project lifetime with a peak discharge rate of 18.4 Mbbbl/d. Maximum level for Phase 1 facility installed is 80 Mbbbl/d.	<ul style="list-style-type: none"> <li>Oil and grease not to exceed 42 mg/l daily maximum or 29 mg/l monthly average.</li> </ul>	IFC and USEPA 2007; Also complies with OSPAR 2001 (OSPAR 01/18/1, Annex 5) 30 ppm monthly average oil content and North Sea UK 30 ppm monthly average and 100 ppm daily average oil content
Deck Drainage	Oil-water separation	Single, discharge overboard	Deck drainage water generation variable, depending upon facility and vessel characteristics, rainfall amounts; discharge volumes variable. <u>FPSO</u> : 11,000 l/d 3.4 x 10 <sup>6</sup> l	<ul style="list-style-type: none"> <li>No free oil;</li> <li>15 mg/l instantaneous reading oil water threshold</li> <li>20 mg/l (monthly weighted average) oil water threshold.</li> </ul>	Annex 1 MARPOL
Bilge Water	Oil-water separation	Single, discharge overboard	Bilge water generation variable, depending upon facility and vessel characteristics; discharge volumes variable <u>FPSO</u> : 110 bbl/d (est.) <u>Support Vessels</u> : 110 bbl/d (est.) <u>Export Tanker</u> : 100 bbl/d (est.)	<ul style="list-style-type: none"> <li>No free oil;</li> <li>15 mg/l instantaneous reading oil water threshold</li> <li>20 mg/l (monthly weighted average) oil water threshold.</li> </ul>	Annex I MARPOL



Discharge and Source	Treatment	Discharge Point (s) and Location	Volume	Limit	Standard
Ballast Water	Oil-water separation	Single; Discharge overboard	<u>FPSO</u> : 5 x 10 <sup>6</sup> l per hour	<ul style="list-style-type: none"> <li>No free oil;</li> <li>15 mg/l instantaneous reading oil water threshold</li> <li>20 mg/l (monthly weighted average) oil water threshold.</li> <li>Ballast water exchange at least 200 nautical miles from nearest land in water at least 200 metres deep. The absolute minimum being 50 nautical miles.</li> </ul>	Annex I MARPOL International Convention for the Control and Management of Ships' Ballast Water and Sediments
Cooling Water	Oil-water separation	Single, discharge overboard	Pass through cooling water for internal combustion engines; volumes variable.	-	-
Completion and Well Workover Fluids	<ul style="list-style-type: none"> <li>Oil-water separation</li> <li>Any acids used will be neutralised to pH 5-7 by addition of soda ash prior to any discharge</li> </ul>	Single, discharge overboard	Estimated volumes per well: <ul style="list-style-type: none"> <li>Calcium chloride (CaCl<sub>2</sub>) (Completion brine) 845 tonnes</li> <li>CELITE 545 (Diatomaceous Earth Filter Aid) 5.3 tonnes</li> <li>Tetraclean-105 (Surfactant) 5.9 tonnes</li> <li>Tetraclean-106 (Surfactant Booster) 3.3 tonnes</li> </ul>	<ul style="list-style-type: none"> <li>Maximum one day oil and grease discharge should not exceed 42 mg/l; 30 day average should not exceed 29 mg/l.</li> <li>Any spent acids will be neutralised (to attain a pH of 5 to 7) before testing and disposal.</li> </ul>	IFC (2007) and USEPA (2007)
Riser, umbilical and pipeline commissioning	None	Primarily subsea discharge with some near surface discharge	<ul style="list-style-type: none"> <li>Clariant TROS 55 solution: 5,000 m<sup>3</sup></li> <li>Deoxygenated seawater : 35,000 m<sup>3</sup></li> <li>Monoethylene glycol: 50-100 m<sup>3</sup></li> <li>SST5007: 15 m<sup>3</sup></li> <li>MeOH : 4 m<sup>3</sup></li> </ul>	<ul style="list-style-type: none"> <li>Treatment chemicals: maximum manufacturers recommended dose or 500 mg/l</li> <li>No Free Oil</li> </ul>	USEPA 2007

Discharge and Source	Treatment	Discharge Point (s) and Location	Volume	Limit	Standard
Hydrate Inhibitor	None	Single, discharge overboard	Discharge in batch mode only during unplanned and planned system shutdowns.  Volumes of up to 200 – 400 barrels per day.	-	
Hydraulic Fluids	None	Multiple subsurface discharge	<u>Subsea trees</u> : 45 l/yr assuming normal valve operations	-	-
Brine	None	Single, discharge overboard	Brine generated during freshwater generation; volumes variable. <u>FPSO</u> : 35 to 50 m <sup>3</sup> /d; <u>Support Vessels</u> : NA; <u>Export Tanker</u> : 30 to 100 bbl/d	• No Free Oil	USEPA 2007
Desulphation Reject Stream	None	Single discharge overboard	FPSO reject stream: 100,000 bwpd FPSO Filter backwash: 10,000 bwpd	-	-

The main project activities associated with noise are discussed in *Section 3.5*. For the Phase 1 Jubilee Project, activities can be grouped under the following phases:

- well completions;
- FPSO and infrastructure installation; and
- production.

Information on the key types of activity which are expected to be responsible for much of the underwater sound likely to be generated as part of the various phases of the project has been gathered through a high level desktop study using relevant literature. The main sources of underwater sound associated with the project phases identified above can be categorised into the following.

- *Propeller and Thrusters (where fitted)*. Noise from propellers and thrusters is predominately caused by cavitation around the blades whilst transiting at speed or operating thrusters under load in order to maintain a vessel's position. Noise produced is typically broadband noise, with some low tonal peaks.
- *Machinery Noise*. Machinery noise is often of low frequency, and often becomes dominant for vessels when stationary or moving at low speeds. The source of this type of noise is from large machinery, such as large power generation units (diesel engines or gas turbines), compressors and fluid pumps. Sound is transmitted through different paths, ie structural (machine to hull to water) and airborne (machine to air to hull to water), or a mixture of both. The nature of sound is dependant on a number of variables, eg number and size of machinery operating, coupling between machinery and deck. Noise is typically tonal in nature.
- *Equipment in Water*. Noise is produced from equipment such as flow lines, valves and caissons. Noise produced will tend to be relatively low for drill casing, but possibly more significant for sub-sea valves.

Indicative sound levels and frequency ranges for vessels and subsea equipment are presented in *Chapter 5*.

Some wastes generated during the project may be appropriate for disposal offshore such as sewage and grey water, food, and other organic wastes (see *Section 3.7.2*). This section describes those wastes that will be required to be transferred onshore for treatment, recycling, and/or disposal at appropriate facilities. A Waste Management Plan was developed for the drilling phase and this will be updated to include the requirements of the FPSO installation and long term operations.

### *Sources of Wastes*

The volumes, and to a lesser degree types, of waste produced will vary according to the stage of the project development. During initial installation and commissioning, operational and decommissioning phases, the nature and quantities of the materials generated will vary. The majority of waste will result from the following sources.

- FPSO (and associated supply vessels) that form the centre of operations during commissioning and production phases.
- MODU which will be located in the Jubilee Field during well commissioning and maintenance phases of the project.
- Onshore base activities in support of construction and commissioning activities (where utilised) and operational activities offshore. These may be Tullow or third party operated.

### *Categorisation of Wastes*

Wastes generated offshore and onshore will be categorised as either hazardous or non-hazardous following a risk assessment. If any unidentified waste should occur, it will be treated as hazardous until a full risk assessment is carried out and a final disposal option is identified. The definitions of hazardous and non-hazardous waste are as follows.

- Hazardous Wastes exhibit one or more characteristics which mean that the wastes are potentially harmful to health and/or cause damage to the environment (land, water contamination, air pollution). For example, the waste may be corrosive, reactive, toxic, mutagenic, teratogenic, infectious, carcinogenic, ecotoxic, flammable, or explosive.
- Non-Hazardous Wastes are wastes that do not exhibit any of the characteristics of hazardous waste such as those listed above. They are biodegradable or inert and do not cause any harm to people and environment. This category will include a range of materials that may be recycled or can safely be disposed in a landfill.

The approach to predicting the waste arising from the FPSO and related activities has been informed by actual waste generated from similar FPSO projects that are now operational.

### *FPSO Waste*

Certain types of non-hazardous waste (generally solid waste) will be separated and sorted on the FPSO and shipped to shore for onshore treatment, recycling, or disposal.

The types of non-hazardous solid waste that would be expected to be generated from the FPSO include:

- cabin domestic waste, such as mixed waste from living quarters or galley;
- scrap metal, eg off-cuts and turnings;
- wood, eg pallets, cartons;
- paper and cardboard;
- metal cans (aluminium and steel) from food;
- plastics, eg crushed plastic drinks bottles;
- maintenance cables; and
- glass.

The estimated upper and lower volumes of non-hazardous waste that will be produced by the construction and operation of the Jubilee Field FPSO is presented in *Table 3.16*.

The Jubilee Field FPSO is also expected to produce a range of hazardous wastes; estimates of quantities generated are provided in *Table 3.16*. These wastes will be transported to shore for disposal, except waste oils such as lubricating oils from machinery maintenance and servicing which will normally be disposed of by mixing with the production crude stream. If this is not possible then it will be transported ashore in secure containers for disposal to the waste oil process as per the Waste Management Plan. Other hazardous wastes will be segregated offshore prior to transfer to the onshore base. The types of hazardous waste that would be expected to be generated from the FPSO include the following.

- Hydrocarbon residues from vessel clean out activities and un-pumpable sludge from oil processing and production equipment, crude oil storage and other storage tanks, and from bilge/machinery space that cannot be pumped/mixed into the production stream.
- Miscellaneous hazardous waste such as:
  - benzene, toluene, ethylbenzene and xylene in cartridge filters from glycol package;
  - spent ion exchange resin from fresh/potable water system;
  - fluorescent tubes, bulbs;
  - batteries (eg lead-acid);
  - solvent/oily rags etc.; and
  - tri ethylene glycol in lean/rich glycol filter.
- Drum containers with hydrocarbon, chemical and/or paint residues.
- Dry hydrocarbon deposits from rotating machinery cartridge oil filters, pump strainers or fuel gas system filter cartridges.
- Gas pressurised cans from maintenance or domestic sources.
- Produced sand (if >1% oil by dry weight) from the formation transported to the FPSO with the crude oil.
- Clinical waste such as syringes, medicine bottles and dressings.

Table 3.16 presents both upper and lower limits for volumes of waste generated by the FPSO and support vessels. The upper limits apply to the construction and commissioning phase whilst the lower limits apply to a typical year of operation. It should be noted that some waste type, such as scrap metal and paint will be significantly lower in the initial years of operation as there will be less maintenance requirements compared to later in the project life.

**Table 3.16** *Estimated FPSO Non-hazardous and Hazardous Waste Inventory*

Category	Type	State	Source/Description	Quantity (t/yr)
<b>Non-hazardous</b>	Glass	Solid	Bottles and jars etc	2-4
	Grease	Sludge	Galley grease from oil separators	3-6
	Metals	Solid	Ferrous and non-ferrous, including drinks cans (steel and aluminium)	25-200
	Paper and card	Solid	Papers, magazines, office paper etc.	20-100
	Plastic	Solid	Bottles and mixed plastics	12-30
	Residual mixed waste	Solid	Domestic types, food from galley, packaging, bin waste etc	96-150
<b>Hazardous</b>	Wood	Solid	Pallets, crates, furniture	18-100
	Batteries	Solid	Lead acid, alkaline, lithium ion, etc	0.25-0.5
	Chemicals, various	Liquid	Solvents or contaminated chemicals	1.5-2.0
	Medical/clinical	Solid	Swabs, dressings, old medicine etc	0.05-0.1
	Oil contaminated materials	Solid	Filters, oily rags	20-40
	Oil, used	Liquid	If cannot be mixed with crude export stream	12-35
	Tank bottom sludge	Sludge	Tank clean out and un-pumpable sludges	5-10
	Various types	Solid	Fluorescent tubes & bulbs, Glycol filters, paints, solvents, cleaners	5-7
	Water, slops	Liquid	Oil contaminated etc	20-50

Note: estimates based on typical operations, arisings will vary depending on project phase

#### *MODU Wastes*

The MODU and support vessels will produce mostly general and scrap metal wastes and relatively small amounts of hazardous wastes. However, the scale and nature of waste will vary as the duties change from drilling to well development.

Records from the first 10 months of 2009 show that the MODU and support vessels generated 1,032.8m<sup>3</sup> of general waste, 389.5m<sup>3</sup> of wood waste, 145.2m<sup>3</sup> of scrap metal, 513.1m<sup>3</sup> of oily waste and 25.3m<sup>3</sup> of other hazardous wastes. The quantities of waste generated in 2010 should be similar in total for MODU activities as these will not vary greatly, although this will depend on the total scope of the drilling program undertaken.

Wastes from offshore are received by the GPHA approved waste contractor in accordance with MARPOL regulations. The management of these wastes are as follows.

- General waste comprises paper and cardboard, plastic packaging, glass and domestic cabin waste. This is currently sent to the Sofokrom landfill.
- Wood comprises dunnage, pallets and packaging and is either reused or sent to landfill, depending on its condition.
- Scrap metal is sent to Western Castings Limited for recycling.
- Oily waste including pure oil, water/waste oil, oily sludge and slops are treated at Takoradi thermal power stations' oily waste water treatment plant.

Other Hazardous wastes comprise the following.

- Used batteries: stockpiled at waste contractors facilities pending recycling via Pagrik Ghana.
- Paint cans: all empty paint cans are crushed and stored pending development of appropriate management solution.
- Oily rags, contaminated Personal Protective Equipment (PEE), oil filters, process filters: stored pending development of appropriate management solution.
- Steel drums: are first drained and then crushed/punctured before adding to other metal waste for recycling at Western Castings Limited. Oily slops are added to waste stream treated at the Takoradi thermal power station.

It is noted that during well completions there will be no drilling operations and therefore no drill cuttings produced requiring disposal (see *Annex B* for discussion on drill cuttings disposal).

#### *Shore Base Waste*

The supply base in Takoradi will produce mostly general and scrap metal wastes and relatively small amounts of hazardous wastes. However, the scale and nature of waste will vary as the duties of such bases change from support of drilling and installation and construction to operation of the FPSO. Records from the first 10 months of 2009 show that the Takoradi base facilities generated 65.0m<sup>3</sup> of general waste, 6.5m<sup>3</sup> of wood waste and 1.0m<sup>3</sup> of oily waste. The quantities of waste generated in 2010 will increase by approximately 100% over 2009 levels (ie during FPSO and subsea installation) but the waste streams will remain primarily general waste, scrap steel (recycled) and wood used for packaging and dunnage. Some waste oil will also be generated. Post-construction, the quantities will revert to lower levels.



Wastes generated are consolidated with those brought to shore from the offshore activities and are treated or disposed of at appropriate facilities in-country or stored at appropriate facilities.

Office and accommodation areas have waste facilities for general office waste such as paper and plastic. Contracts are held with waste contractors registered with the Sekondi-Takoradi Metropolitan Assembly.

### **3.9 PERSONNEL HEALTH AND SAFETY**

#### **3.9.1 Introduction**

The basis of good maritime safety is compliance with all applicable conventions and codes that cover the type of operations being conducted. These cover all aspects of the project, from FPSO design and construction through to operation and training of personnel. The FPSO and support vessels must comply with the following IMO conventions that are concerned with safety at sea.

- International Convention for Safety of Life at Sea (SOLAS) 1974 and associated Protocols and Amendments.
- International Convention on Load Lines (LL) 1966.
- Convention on the International Regulations for the Prevention of Collisions at Sea (COLREG) 1972.
- International Standards of Training, Certification and Watchkeeping Convention (STCW) 1978 and 1995 Amendments.
- International Convention for Safe Containers (CSC) 1972.
- International Convention on Maritime Search and Rescue (SAR) 1979.
- Convention on the International Maritime Satellite Organisation (INMARSAT) 1976.

The project will also comply with safety requirements outlined in Ghanaian legislation and regulations that cover shore based operations. These include the following.

- Labour Act 2003 (Act 651).
- Explosives Regulations 1970 (LI 666).
- Road Traffic Act, 2004 (Act 683)
- Electricity Corporation of Ghana (electrical power) regulations, 1988 (LI 1366)
- Radiation Protection Instrument, 1993 (LI 1559)

#### **3.9.2 FPSO Design**

The FPSO design must satisfy requirements set out by the IMO (see above) and, for the Jubilee Project, the ship classification society American Bureau of Shipping (ABS). The purpose of a classification society is to evaluate floating vessels, including FPSOs, against the structural and mechanical standards

developed for the particular class of vessel. These standards (see *Section 3.4.2*) are used to guide construction and ensure that the vessel is fit for purpose.

The ABS has certified that the design for the Jubilee FPSO hull and topside processing facilities complies with the Classification Societies rules for a Floating Production and Offloading System. An independent technical authority will constantly review construction of the Jubilee FPSO to verify compliance with the certified design. The final stage in the process to attain classification is a survey of the FPSO by ABS once construction is completed.

In addition to the ABS and IMO requirements listed above, various industry standards (eg RP 2SK Recommended Practice for Design and Analysis of Station Keeping Systems for Floating Structures) will apply to the FPSO.

To maintain its classification, the FPSO will undergo regular inspection throughout its operational life by an authorised certifying body. Loss of classification will result in a stand down of the FPSO. The Classification process is discussed in more detail in *Section 3.4.2*.

It should be noted that whilst the discussion above has focused on the FPSO, class specific standards also apply to other ships involved in the project. Regular maintenance will be undertaken to verify ongoing compliance with stipulated IMO standards and class requirements.

#### *Safety Case*

In addition to the requirements of ABS, the Jubilee joint venture partners have agreed to undertake a Safety Case on the project design, which will be based upon the protocol used for North Sea operations (see *Section 3.3.1*). The Safety Case will be used to help develop the safety management system for the FPSO as well as to make sure that the design is modified accordingly; eg provisions for evacuation and rescue, safe refuge for personnel in the event of an emergency and fire systems are fit for purpose.

#### *Hierarchy of Control*

Tullow will apply the following hierarchy of control principles to reduce risks identified in the design and operation of the FPSO (and other operations) to as low as practicably possible.

- **Elimination** - remove the hazardous substance, machine or task completely from the work place.
- **Substitution** - replace the hazardous substance, machine or task with a safe one.
- **Engineering** - modify tools or equipment, enclose equipment, or put guards in place.

- **Administration** - develop and implement safe procedures for hazardous jobs.
- **Personal Protective Equipment** - equipment such as safety glasses, footwear and hearing protection can be important, but are a last resort.

#### *Design Environmental Conditions*

The FPSO must have adequate structural strength and remaining fatigue life to cover transit, installation and operation in the field. The Jubilee FPSO has an expected minimum remaining fatigue life of 20 years and has been designed for the site specific environmental operating conditions at the Jubilee Field in Ghana, without the need to access dry docking facilities.

The FPSO has also been designed to withstand the “design environmental conditions”, which are the extreme weather conditions of wind, waves, and current. ABS requires that 100-year storm data be used (see *Figure 3.4* and *Table 3.1*).

#### *Mooring System*

As described in Section 3.3.1, the FPSO will employ a turret system with a universal joint that allows the vessel to freely turn freely 360° around the vertical axis to align itself with the prevailing wind, wave and current conditions (ie the FPSO weather vanes). This provides added safety to the offloading process as both vessels (ie FPSO and export tanker) will be aligned one behind the other, reducing risk of collision. Allowing the FPSO to weather vane will reduce fatigue to personnel as well as reducing metal fatigue on the hull.

#### *Fire and Gas Protection Systems*

The fire and gas protection system will be monitored from the central control room on the FPSO and is designed to provide early detection of any hazards, initiate appropriate mitigations (operational shutdowns and active fire suppression and protection) and to facilitate the safe evacuation of personnel. The system is also designed to provide rapid automatic emergency shutdown and blow-down of gas inventories. The active fire protection system and equipment will be designed in accordance with ABS Class requirements to contain local fires to prevent escalation, to protect escape and evacuation routes and provide cooling for equipment and structure. The active fire protection system and equipment will include the following:

- firewater system;
- foam system;
- gaseous (CO<sub>2</sub>) fire extinguishing system;
- water mist system; and
- portable fire extinguishers.

The Safety Case (*Section 3.3.1*) will identify all the Safety Critical Elements (SCEs) such as fire and gas detectors, fire pumps, emergency shutdown valves, which comprise the major safety detecting and mitigating equipment on the FPSO. Performance standards will be developed for all these SCEs and will be integrated into the FPSO Maintenance Management System to ensure that they continue to meet the required performance over time. Topsides process equipment certification will be carried out annually.

To reduce the risk of fire, the FPSO will have intrinsically safe systems in hazardous process areas, following the requirements of ABS Class Rules and in particular API-RP505 for classification of Hazardous Areas. The design will follow International Electrotechnical Commission (IEC) equipment selection and installation methods plus the following:

- Field/instrumentation shall, as a minimum, attain the standards required for deployment in Zone 2 (defined as hazardous only in an abnormal operating condition and therefore for a short period of time) Hazardous Areas.
- Hazardous Area equipment shall be in compliance with IEC 60079 (standard for electrical equipment for explosive gas atmospheres).
- Electrical equipment shall be suitable for 'Electrical Apparatus for Explosive Gas Atmosphere, Electrical Installations in Hazardous Areas', suitable for gas group IIA with a temperature class of T3 (ie 200°C).

#### *Emergency Evacuation*

Shutdown procedures in case of emergency will be developed as per ABS requirements, in which a general alarm will sound and the emergency lights, public address system, and radio communication will be functional.

Emergency evacuation is primarily by helicopter from a helideck situated directly above the accommodation block, or by support vessels.

Sufficient lifeboats/rafts will be installed to accommodate twice the total maximum number of people on board the vessel. These will be located both fore and aft of the work deck in safe zones that are designed to provide safe access to lifeboats under a range of emergency situations (see *Figure 3.11*).

There will be at least one SOLAS life jacket per person in readily accessible locations adjacent to each lifeboat station.

The FPSO also has a safe refuge for personnel in the event of an emergency.

### *Other Safety Design Features*

Other design features that improve safety on the FPSO include the following.

- Crude oil stage tanks are blanketed with nitrogen, an inert gas, to maintain a safe environment for loading and discharging crude oil.
- The accommodation block is mechanically ventilated and pressurised, taking fresh air from a safe location remote from the process equipment.
- Oil and gas processing is controlled and monitored remotely.
- Shutdown systems are built in to close off the flow and contain hydrocarbons under pressure in an emergency and allowing depressurisation via the flare stack.
- Suitable ventilation is built into the vessel to prevent gases building up in a confined space.
- The flare tower design is compliant with ABS provisions. Allowance is made in the design for prevailing winds to limit the exposure of personnel, equipment, and helicopter traffic to vented gas, flare exhaust or flame radiation.

### *Offshore Safety*

Robust safety standards and rules will be implemented by Tullow as the Jubilee Unit Operator and will be rigorously enforced. Tullow will implement a Safety Case for the facility which will demonstrate its case for safety, risk mitigation and on-going operation of the facilities in a safe manner. This is a live process built into the total operation of both facility and personnel, and will be independently verified by an experienced Third Party body. The Safety Case for offshore oil and gas installations is the standard for safety management in UK and Norway North Sea facilities and also in other countries such as Australia, Vietnam and Malaysia. Ghana does not currently have a statutory requirement for implementation of a Safety Case but the Jubilee partners have adopted this approach as good industry practice.

In addition to the previously mentioned IMO Conventions, the following International Codes apply to the safe conduct of Tullow's marine activities and shall be observed accordingly.

- International Labour Organisation (ILO).
- Prevention of Accidents (Seafarers) Convention 1970.
- ILO Maritime Labour Convention 2006 (not yet in force).
- International Management Code for the Safe Operation of Ships and for Pollution Prevention (ISM Code).
- The International Ship and Port Facility Security (ISPS) Code.
- International Maritime Dangerous Goods (IMDG) Code.

- IMO Code of Safe Practice for Cargo Stowage and Securing (CSS Code).
- International Life Saving Appliance (LSA) Code.
- International Code for Fire Safety Systems (FSS Code).
- The Code of Safety for Dynamically Supported Craft.
- International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk (IBC Code).
- Code of Safe Working Practices for Merchant Seamen (COSWP).

Procedures for the FPSO are currently under development by Tullow and MODEC. These will be completed during the first half of 2010 and will be used to train personnel before commissioning.

Tullow currently have a number of procedures in place covering offshore work on the MODUs. Hazardous areas require boots/hard hat/eye protection and fire retardant long sleeved overalls. Hearing protection is required as per noise zone requirements. Hand protection per task requirements. Other PPE per task requirements eg harnesses and lines for working at height. Examples of safety procedures are provided in the CD accompanying this EIS.

*Section 3.4.13* outlines the vetting process that Tullow will undertake to confirm that the export tankers are fit for purpose and are safe for the task.

### 3.9.3

#### *Flight Safety*

Aviation support operations are managed by the aviation team based in Accra and Takoradi. Procedures are included within the Takoradi Supply base operating guidelines manual and cover the following.

- General aviation.
- Planning of personnel movements / offshore passenger handling.
- Requirements for personnel travelling offshore.
- Takoradi Heliport facilities and check in process.
- Airfreight and hazardous substances.
- Monthly reporting.
- Medivac by helicopter.

Aircraft will be operated and managed in accordance with the standards laid down in the OGP Aircraft Management Guidelines Report No. 390 (July 2008). Flight operations will be conducted under the aircraft manufacturers Flight Manual and NHV Operations Manual which is approved in accordance with JAR OPS 3. Maintenance will be conducted under EASA Part 145 approvals.

Only passengers who have completed the offshore survival training course will be allowed offshore to work unless in possession of a dispensation. All passengers will receive a briefing before departure which will include safety information and actions to be taken in case of emergency. Hearing protection will be provided in the helicopters.

The heli-deck on the FPSO is approved to International Civil Aviation Organisation Annex 14 Vol. 2/Heliports and UK Civil Aviation Authority Publication CAP 437 which includes standards for fire fighting and crash rescue.

### 3.9.4

#### *Shore Safety*

Safety for onshore activities will follow Ghanaian laws and international practices for similar operations. The key areas are described below.

#### *Vehicle Safety*

All Jubilee Project vehicles and drivers will comply with the Road Traffic Act, 2004 (Act 683). Procedures will be put in place to cover the following.

- To ensure all vehicles are roadworthy and in good condition. Vehicles will be maintained on a regular basis, with safety checks of essential parts completed. In addition, heavy vehicles will have a pre-shift check by the operators to ensure the vehicle is in good running order.
- Drivers will not be allowed to drive under the influence of alcohol or drugs.
- Hazardous goods transported by road will be in accordance with Dangerous Goods transportation guidelines, including methods of packaging, quantity of goods, labelling, and the training and certification of drivers. Dangerous Goods training covers land, sea and air aspects of the project.
- Load weights and dimensions on heavy vehicles will comply with national requirements and local conditions. Vehicles with loads are checked prior to leaving the site.

It should be noted that the need to transport oversize loads through the city of Takoradi has been eliminated by the lease of facilities at the Takoradi commercial port where the oversize loads will be temporarily stored prior to shipment to the field. Heavy vehicles used for transporting pipes, casing or materials will follow the main Axim Road from the Shore Base facilities (ie Air Force base and Bay Court) to the port, which is the approved route for heavy vehicles.

#### *Materials Storage and Handling*

A number of regulations are in place to manage the safe handling and storage of materials. These include the following.

- Explosives Regulations 1970 (LI 666) regulate the transport, use, handling and storage of explosives. A small amount of explosives are intermittently



used on the MODUs drill rigs and full compliance with safety requirements is enforced whenever they are used.

- Radiation Protection Instrument 1993 (L I 1559) for the use of radioactive devices. It should be noted that the majority of devices are to be installed on the subsea infrastructure with no exposure during operations. However non-destructive testing equipment will be used during construction and radiation officers will supervise their use.
- Labour Act requires the safety and absence of risks to health in connection with use, handling, storage and transport of articles and substances.

Tullow will design chemical storage areas to comply with the HAZCHEM system of storing and segregating dangerous goods, which is based on the United Nations system. Segregation means keeping incompatible goods apart from one another, using either a physical barrier or intervening space, depending on requirements. Chemicals must be segregated when either stored or shipped to ensure they do not mix in case of spillage. The HAZCHEM system also aids emergency responders to quickly recognise dangerous goods, their properties and dangers, thereby enabling them to respond in the most appropriate manner. HAZCHEM signs shall be placed wherever chemicals are stored.

The risks posed by the usage of chemicals shall be addressed through engineering solutions to reduce exposure, and through training of personnel (ie awareness and standard work procedures). Ongoing access to information on chemical handling and storage shall be facilitated through the distribution of Material Safety Data Sheets and standard procedures at appropriate locations. Appropriate spill cleanup equipment shall be located at each site where chemicals are stored.

Working with chemicals demands a culture of cleanliness. Workers will be required to wash their hands before eating, drinking or smoking. Safety shower/eye wash stations shall also be located strategically, which will be readily available in the immediate work area of all areas where exposure is a risk. Appropriate PPE will also be used by all personnel.

### *Buildings*

Buildings used by Tullow must be fit for purpose and comply with Ghana regulations. The main aspects include the following.

- National Building Regulations 1996 (LI 1630) stipulate standards for buildings in Ghana, including structural fire precautions.
- Fire Precautions (Premises) Regulations 2003 (LI 1724) requires fire compliance certificate for buildings.

- Electricity Corporation of Ghana (electrical power) regulations, 1988 (LI 1366) stipulates electrical standards for buildings. No person shall undertake the wiring maintenance alteration or repair of any electrical circuit apparatus or equipment unless licensed and registered as an electrical contractor.
- Labour Act requires Tullow to provide and maintain at the workplace, or plant, a system of work that is safe and without risk to health.

### 3.9.5

#### *Procedures and Training*

To prevent occupational illness or injury, Tullow will develop a strong safety culture through ongoing employee training and education. Hand in hand with this safety culture is the development of a safety management system that identifies the hazards, assigns risks and develops controls to effectively manage safety in all operations. Controls for onshore and offshore will cover:

- Duty of care – responsibilities of Tullow towards employees and responsibility of employees at work
- PPE
- Working over water
- Hot work permits for welding near fuel or other hazardous areas– onshore and offshore
- Fire prevention and response – includes training for initial response and evacuation– onshore and offshore.
- Working at height– onshore and offshore
- Accident/Incident investigation
- Emergency shut down of the FPSO
- Evacuation procedures and drills– onshore and offshore
- Training and certification of crews– onshore and offshore
- Fatigue management
- Chemical storage handling
- Confined space entry– onshore and offshore
- Diving
- Boat operations
- Bunkering
- Cargo transfer
- Cranes and lifting – onshore and offshore

Tullow will provide the necessary information, instructions and training having regard to the age, literacy level and other circumstances of the worker to safeguard, so far as is reasonably practicable, the health and safety at work of those other workers engaged on the particular work. This process shall start with structured inductions during the first days of employment and continue throughout the term of employment.

Tullow Ghana has developed an Emergency Response Plan to address potential emergencies, designate roles and responsibilities of personnel and identify the requirement to interface with Government and external parties.

The crisis management and emergency response plans are communicated to the workforce through regular drills and training exercises carried out and recorded in the Emergency Response Training Record. Significant findings from drills are communicated to the workforce and used to further develop the crisis management and emergency response plans.

Personnel receive initial and refresher training to ensure they are competent to carry out their designated roles and responsibilities in a crisis or emergency. Equipment, facilities and trained personnel for crisis management and emergency response are identified and readily available. An assessment of emergency equipment needs will take place every six months and / or post exercise.

Scenarios are developed for each phase of the project including:

- drilling;
- subsea construction;
- transfer of FPSO;
- hook-up and commissioning; and
- production.

#### *Ghana Offshore Emergency Leadership Forum*

Tullow is involved in the Ghana Offshore Emergency Leadership Forum (GOELF). The objectives of this forum are as follows.

- To share learning and understanding of Tullow Ghana operations in respect of emergency response.
- To table top oil and gas scenarios through government to ensure accurate involvement, contacts and reporting.
- To facilitate links between Accra and Aberdeen Emergency Response. The experience and lessons learned by Aberdeen emergency responders following development of first oil in the 1970s can be passed on to their counterparts in Ghana; eg National Disasters Management Organisation to Scottish Government Emergency Planning Group or Ghana Maritime Authority to HM Coastguard.

The GOELF participants include:

- Ghana Maritime Authority
- Energy Ministry
- Ghana Airports Authority
- Senior Military Medical Officer
- Police
- Navy
- Fire Service
- Air Force
- National Disasters Management Organisation (NDMO) which also represents Ministry of the Interior
- WARA
- GNPC
- NSA
- Environmental Protection Authority

As each phase of the project approaches, potential scenarios associated with that phase are discussed with Government Agencies and bodies to identify key departments and communication channels. The forum was started in mid-2009 and has concentrated on mass casualty scenarios to date (eg helicopter crashes and fire) but will include oil spill scenarios in future.

#### *Resources*

For offshore emergency response, the FPSO will always be accompanied by Multi Service Vessel (MSV) with daughter vessel and Hold Back Vessel. The Supply / Contingency vessel will either be on station or no more than 6 hours cruise time from the field and a helicopter will always be within 1 hours flight time of the FPSO. Search and rescue operations will be conducted in partnership with Ghana Navy, GMA and Air Force assets.