OTC 23456

Jubilee Development Installation, Hookup and Commissioning and Ready for Startup
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Abstract

The world-class Jubilee Field Development located 60 km offshore Ghana began Phase 1 production in November 2010, just 3.5 years from its discovery. This paper highlights the challenging but successful execution of the in-country Installation, Hookup and Commissioning (IHUC) Phase of the project in conjunction with Operations Readiness and Assurance (OR&A) activities to safely bring the production system to an on-time Ready for Startup (RFSU) condition to meet the aggressive schedule. This paper highlights the keys to success during the IHUC Phase including the use of an Integrated Project Team (IPT), close Contractor relationships, proven technologies, exceptional communication, and the design-for-safety concept. Some of the execution challenges faced by the IPT during this phase are also discussed along with the strategies implemented such as organization structures, interface planning, tools, systems, and specific results.

Although fast-tracking major oil and gas development projects is often a stated objective for many projects, few achieve the performance achieved on Jubilee. This work illustrates the successful integration of a multi-partner project team, the management of critical interfaces, and the technical and logistics challenges with major Contractors during the IHUC Phase. Despite the engineering and planning effort put in place to meet the aggressive schedule, the project team did encounter several unexpected events during the IHUC Phase which required quick response to keep the project on schedule. The key to successfully resolving these challenges was linked with the overall execution strategy of empowering the team to quickly develop and implement response plans with the proper assurances that allowed the project to move ahead.

Introduction

The Jubilee Field was discovered in June 2007 in the Gulf of Guinea, approximately 60 km offshore Western Ghana. It is a very large, light, sweet oil accumulation in 1200-1500m of water. The Jubilee Partners, along with Ghana National Petroleum Corporation (GNPC) decided in January 2008 to develop the field using a phased approach, after just one appraisal well. Kosmos Energy was appointed Technical Operator to lead an Integrated Project Team (IPT) in executing the development project and Tullow Oil (Ghana) was appointed Unit Operator to execute in-country activities, deliver wells, and operate and manage the field in the future. A third major partner, Anadarko, provided numerous key project personnel to the IPT. The IPT developed a plan to target just under 300 million barrels in Phase 1 with a 17-well subsea well system and 120,000 bopd FPSO as illustrated in Figure 1. Phase 1 was approved by Partners in August 2008, and First Oil was achieved in November 2010, within the aggressive goal set by GNPC and the Jubilee Partners.
The overall project schedule in Figure 2 shows the aggressive schedule with critical path activities occurring primarily within the Installation, Hookup and Commissioning (IHUC) Phase of the project including:

• FPSO transit, delivery and mooring,
• Riser installation/pull-in; and
• Subsea and Topsides mechanical completion, pre-commissioning and commissioning.
By the fourth quarter of 2009 as construction and conversion on the FPSO was progressing at the Jurong Shipyard in Singapore, the Jubilee Leadership Team (JLT) began focusing on preparations for the upcoming fabrication and installation activities in Ghana that would begin in January 2010 concurrently with the remainder of the FPSO conversion. This work started the transition into the IHUC Phase of the project which would bring the facilities to a “Ready for Startup” (RFSU) condition.

Despite effort put in place to plan and meet an aggressive schedule, the IPT still encountered some significant challenges onshore and offshore Ghana during the IHUC Phase. The key to successfully resolving these issues was linked with the execution strategy as well as the experienced team’s ability to develop a response plan and implement it successfully. The success of this work highlights the importance of building a multi-discipline team driven by well-defined goals, development of an effective execution plan, creating a structure suited for the in-country execution, and of selecting the right Contractors for the project and building strong relationships with them.

This paper gives an overview of the organization and strategies used by the IPT and Unit Operator during IHUC and RFSU activities to manage the challenges within the aggressive schedule and in a country in the early development stages of its Oil and Gas industry. Specifically, it addresses the execution challenges and strategies used to overcome them regarding:

- Selecting and managing Contractors
- Working with the local oil and gas infrastructure
- Managing logistics of equipment and people
- Managing simultaneous operations (SIMOPs) in the field
- Safely and efficiently conducting IHUC activities and assurances for RFSU conditions
- Dealing with unexpected events
IHUC Planning, Organization, and Execution Strategy

The Jubilee Leadership Team (JLT) recognized that the IPT organization and interfaces with the Unit Operator needed to evolve with the progression of the project. As such, the Development activities were divided into the following four phases with governance models designed for each:

- **Phase 1:** FPSO Construction and Subsea Procurement *(Led by the IPT and supported by the Unit Operator)*
- **Phase 2:** IHUC *(Led by the IPT with the addition of the IHUC Team with continued support by the Unit Operator)*
- **Phase 3:** Start-up *(Led by the Unit Operator and supported by the IPT’s IHUC Team)*
- **Phase 4:** Steady State *(Led by the Unit Operator)*

Figure 3 shows the major activities and timelines of each Phase. It also illustrates how the IHUC Phase 2 activities (shown in blue) overlapped with Phases 1 and 3 activities which necessitated the clear governance distinction between each phase.

**Figure 3: Jubilee Activity Phases and Timeline**
In September 2009, the IHUC Team was formed by the Jubilee Leadership Team (JLT) to begin planning for the transition into Phase 2 activities in Ghana. Two IHUC Managers, rotating in-country, were added to the JLT and reported directly to the Project Director. One of the two transitioned to this position from his role as the Subsea Equipment Delivery Manager and so was already familiar with the project and could readily continue his responsibilities for subsea technical support. The Subsea Installation Manager transitioned directly to the IHUC team. The Facilities Manager focused on delivery of the FPSO, which overlapped the offshore installation phase for the first five months, but continued to coordinate the major contracts for commercial continuity. An HSE Coordinator was added to the in-country IHUC Team to coordinate six (6) rotating HSE Advisors on the installation vessels and two (2) on the FPSO. One of the HSE Advisors for the FPSO transitioned from his similar role at the Jurong Shipyards which helped support continuity in HSE oversight.

The organization and governance roles of the offshore activities during the IHUC phase was carefully considered and agreed as shown in Figure 4 to ensure accountability for coordinating safety, logistics, and particularly simultaneous operations. This accountability was transitioned from the IHUC Manager/Project Director to the UO’s Operations Manager (and JLT member) at Startup (Phase 3).

**Figure 4: Phase 2 IHUC Organization and Roles**

![Diagram showing the organization and roles of the Phase 2 IHUC Team](image-url)
The IHUC Team developed an IHUC Execution Plan consistent with the overall strategy of using “fit-for-purpose” management processes as well as the use of field proven technology wherever possible. This strategy created efficiencies in numerous areas, thus allowing the project to maintain its fast pace. The success of this strategy relied on the experience of the IPT members as well as leveraging of world class Contractors and Suppliers providing field proven solutions.

This strategy also provided for a cost vs. schedule arbitrage to take place with a bias towards a fit-for-purpose solution which would meet project delivery and safety requirements. That is, another possibly cheaper technology may have been used but would have required additional studies, engineering or qualifications or could have resulted in additional complexity and/or fabrication/installation risks which could have negatively impacted the project. For these types of decisions, team member experience and quantity of field applications of the technology played a major role in recommendations of the technical solutions selected. This required the empowerment for IPT members to make decisions within their authorities with minimal management intervention. Similarly, senior IPT managers were able to provide feedback and/or sanction recommendations relatively quickly without overbearing processes.

**Contracting Strategy and Resources**

A contracting strategy was put in place to favor IPT control over the schedule imperatives utilizing the following elements:

- Selecting world class Contractors to perform the work with recognized track records of delivering on-time projects with excellent engineering.
- Incentives and penalties for meeting critical milestones.
- Separating the scope of Umbilical, Riser, and Flowline (URF) activities that could be performed off the critical path from those that had to be done on the critical path and negotiating different incentives/penalties for each.
- Establishing a construction site in Ghana to fabricate the forty-one (41) jumpers locally as subsea trees and flowlines were installed.
- Chartering vessels which could be used for multiple operations throughout the offshore construction period and put under the control of the Contractor who needed the particular vessel at the time. This in turn minimized the number of vessels in the field, the overall mobilization costs, the auditing requirements and the necessary onshore support.
- Recognizing the contractual gaps associated with incomplete data gathering / engineering and/or interfaces yet to be resolved and providing sufficient allowances within the budget to cater for these in an expedient process.
- Use of Letters of Intent (LOIs) to keep the work progressing on track.
- Maintaining a good relationship with the Contractor in an upfront manner at different levels of the organizations to foster an atmosphere favorable to problem resolution in an expedient manner.

**Key Contractors selected included:**

- FMC – supplier of major subsea production systems,
- Technip – Umbilical, Riser, and Flowline (URF) and jumper engineering, procurement, construction, installation (EPCI) and pre-commissioning,
- MODEC – FPSO EPCI, and final commissioning/startup of the facilities with the Unit Operator
- Aker – Suction pile and FPSO installation, pre-commissioning and installation of trees and rigid jumpers.

The primary Contractor vessels used for the IHUC activities are shown in Figure 5. In addition to these, numerous supply vessels, crew boats, Anchor Handling Tugs and Heavy Lift Vessels to support activities and/or transport equipment into Ghana.

The IPT therefore took an active part in the negotiations leading to the selection of the Construction vessel used to transport and install the piles and the mooring lines which the IPT would then use as an attendant vessel (described later) and the selection of the anchor handlers which would then be transferred under management of the URF Contractor for his use to position the FPSO during the riser pull-in operations.
**Figure 5: Primary Vessels Used for IHUC Activities**

<table>
<thead>
<tr>
<th>Vessel</th>
<th>Work Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technip Deep Blue</td>
<td>Rigid pipe, PLETs, suction piles, manifolds and riser base installation</td>
</tr>
<tr>
<td>Technip Deep Pioneer</td>
<td>Dynamic umbilicals and flexible riser installation</td>
</tr>
<tr>
<td>Olympic Triton</td>
<td>Static umbilicals, rigid jumpers, trees, flying leads and SDUs installation and surveys</td>
</tr>
<tr>
<td>Skandi Aker</td>
<td>Multi-purpose Attendant Vessel FPSO, piles, trees and rigid jumper installation; Pre-commissioning; Additional accommodations</td>
</tr>
<tr>
<td>Normand Installer</td>
<td>Tie-back system installation</td>
</tr>
</tbody>
</table>

**Local Oil and Gas (O&G) Infrastructure Strategies**

As Jubilee was the first major discovery for Ghana, the country had very little existing O&G business infrastructure available to support the needs of a major project. This resulted in many challenges in the following areas:

- Support of the offshore operations (drilling and offshore installation)
- Locating and using qualified local labor
- Logistics (discussed in the next section)

Through cooperation with the Ghanaian government and GNPC, agreements were reached to enable the use and upgrade of dedicated space at the Ghana Air Force Base and Commercial Port (both located in Takoradi) and the Ghana Naval Base located in nearby Sekondi since the availability of other commercial facilities was insufficient.
The Takoradi Air Force Base was used also as the arrival point for the fixed wing flights to and from the capital city of Accra as well as for all helicopter operations to and from the FPSO, the IHUC vessels, and drilling rigs in the field. A major pipeyard was also established for major drilling equipment. The Navy base was used in conjunction with the Takoradi Commercial Port to support offshore activities for the following operations:

- Supply Vessels
- Crew Transfers
- Equipment loadouts from base and from Heavy Lift Vessels (HLVs)
- Quayside
- Fabrication yard used by Technip as major URF Contractor for the final assembly and fabrication of the Jumpers and Flowline Expansion and Walking (FLEW) remediation system.

### Logistics Strategies

#### General

A key element to the success of the Jubilee project was the effort in planning and coordinating the vast logistical needs during the IHUC Phase. A very large number of equipment, vessels and personnel were involved during the operations phase of the IHUC. The equipment, including rigid pipes, flexible risers, umbilicals and subsea structures were delivered continuously from January 2010 to the end of December 2010 from many parts of the world. More than 30 vessels were involved during the IHUC operations, including 5 large construction vessels and 10 HLVs.

#### Equipment Transportation

The use of a large number of HLVs to support transportation and installation activities was a key contributor to the success of the IHUC activities. **Figure 6** shows the multiple international locations from where subsea equipment had to be transported.

![Figure 6: Transpiration of IHUC Equipment](image)

While the main driver for using HLVs was the requirement of loading out or offloading a vast quantity of heavy materials at a location where no appropriate shore-based lifting facilities were available, the HLVs brought a significant number of benefits to the IHUC operations including:
• Intercontinental transportation at high transit speeds (in excess of 15 knots) that was fully appropriate on a project involving fast track procurement and fabrication,
• Very high flexibility in accommodating changes of sequence of installation operation due to easy rearrangement of equipment on deck or easy transfer of equipment between HLVs,
• Safe and controlled temporary storage area for various equipment,
• Safe transportation of project-specific material onboard a dedicated platform ensuring the integrity of the product at all times,
• High versatility in berthing arrangements enabling lifting operations to take place alongside any vessel inside the Naval base and in Takoradi harbor when needed and on short notice if required.

Onshore Equipment Staging and Support Base

A key in-country challenge faced for the vessel logistics involved the already very congested port of Takoradi which was busy with local activities (including manganese and cocoa exports and deliveries into Western Ghana) as well as ongoing drilling support in Ghana. As a result, another logistics base, together with a dedicated jumper fabrication facility had to be identified and developed.

Several sites were assessed, but while most of them would require extensive quayside development, the Naval Base Port in Sekondi shown in Figure 7 located only a few kilometers away from Takoradi, was offering readily available quayside access and a suitable area that could be developed for the fabrication of the 41 jumpers that were planned to be fabricated in-country. In addition, several large areas were available nearby the Naval Port for storage of equipment during the year of IHUC operations. The security and controlled aspect of the Naval Base was a real benefit to the operations that involved thousands of personnel movement and a very large quantity of equipment to be transferred between transportation, heavy lift and construction vessels. As a result, early negotiations with the Navy took place in Sekondi and Accra to progress and formalize the hire of the dedicated areas for vessel mobilization and jumper construction.

A 5000 m² storage area located outside the Naval Base was also hired, grounded and fenced for the entire duration of the operations. This was used for temporary storage of equipment during the operations. In addition, the deepwater quay of the Sekondi harbor was hired in order to perform the transfer of equipment to the supply or construction vessels working in the field. This included the transfer of flexible pipes from the HLVs as shown in Figure 8, all the control system load outs, together with subsea structures weighing up to 230 tons each. More than a hundred vessel movements were safely executed throughout the IHUC offshore campaign on the Naval Base confirming the appropriate selection of the site.

Figure 7: Naval Base Port in Sekondi
In-country Jumper Fabrication Yard

A dedicated fabrication area as shown in Figure 9 was allocated to Technip for jumper fabrication inside the Naval Base. The area had to be leveled, grounded and covered by concrete slabs. The fabrication area had to be fenced and access-controlled to ensure appropriate safety of the site. Offices with all services, phone, internet, lavatories, and sick bay were set-up in the fabrication yard for the onshore support team coordinating the night and day load-out operations and personnel crew boat transfers.

Establishing this site locally was challenging but provided the following key advantages:

- Jumpers could be fabricated in real time as trees, manifolds, and flowlines were installed, providing a significant schedule advantage by saving the time it would have taken to transport the forty-one jumpers from outside the country,
- Minimized the impact of schedule delays should a jumper have to be refabricated or repaired due to misalignment or damage; and
- Provided a local content opportunity to use in-country Contractor equipment and labor

Figure 9: Jumper Fabrication Yard at the Sekondi Port
Multi-Purpose Attendant Vessel

Personnel on Board (POB) and deck space on the FPSO proved to be challenging issues during the IHUC Phase. While the solution of employing an Attendant Vessel on Jubilee is not unique, there were further considerations taken into account when selecting the vessel either for schedule optimization, operability in certain sea states or contingency operations. To prepare for the shortage of storage and working area on the FPSO for IHUC activities, early discussions and alignment forums between FPSO and URF contractors were organized to understand all constraints and to explore every opportunity for the mobilization of the IHUC equipment.

Considering the congested layout of the FPSO turret and bow, it was quickly identified that most of the pre-commissioning equipment, in particular the dewatering spread, could not fit on the FPSO as more than 1000m² were needed for that purpose. It was then decided at an early stage that a pre-commissioning DP2 support vessel would be required throughout the pre-commissioning campaign of the IHUC.

The Attendant Vessel selection criteria included:

- Providing accommodations for up to 60 additional POB for the FPSO,
- Providing sufficient deck space to mobilize, store and operate all equipment required for commissioning the subsea system in one mobilization,
- Ability to maintain position alongside the FPSO for extended durations with sufficient power to be able to perform positioning in the currents and squalls encountered in the region,
- Providing Work Class ROV (WROV) support for any Commissioning operation, and
- Providing construction support as required.

The Skandi Aker as shown in Figure 10 was selected as the Attendant Vessel. It has a large back deck capable of holding all the equipment required for pre-commissioning the subsea systems with 100 additional bed spaces available, 2 WROVs and suitable craneage to allow for any heavy lifts or light installation work.

Attendant Vessel nonproductive time was put under the URF Contractor control to be utilized to perform and expedite subsea installation operations to optimize schedule and perform activities such as Jumper and Tree Installation. By providing a construction vessel as the Attendant Vessel with 10 hour work windows, the project was able to optimize the schedule with the benefit of having another construction vessel in the field rather than a vessel or barge with less capability.

The choice of utilizing a large pre-commissioning DP2 support vessel together with the high collaboration between the IHUC Team and FPSO and URF Contractors proved to be very successful.

**Figure 10: Skandi Aker Multi-Purpose Attendant Vessel**
**Personnel Transfers**

During IHUC operations, thousands of personnel movement from the constructions vessels working on the field and the personnel based on the FPSO were safely performed. This involved fixed wing transfer of personnel between Accra, where all in-country arrival and departures were taking place, and the Air Base in Takoradi. The transfer of personnel to the field was either performed by helicopter from the Air Base in Takoradi or by a short 3 hour journey onboard a fast crew boat from the Sekondi Naval Base.

In 2010 the Unit Operator provided contract services of fixed wing aircraft and conducted more than 15,000 personnel movements and there were also over 12,000 personnel movements offshore by helicopter; these movements covered both project and drilling rig requirements. A senior Unit Operator Representative was embedded in the IHUC Team to ensure that a high standard of support service was provided to the project during this key phase of activity. Despite the high quantity of personnel movement, the robust personnel transfer system enabled all rotations to be performed without accidents.

**Simultaneous Operations (SIMOPS)**

SIMOPS between ongoing IHUC activities and Drilling Operations were identified as a concern very early in the project, due to the quantity of ongoing activities in the field, and needed to be closely managed. Workshops were conducted early with all the potential stakeholders during the engineering phase which led to the following two strategies:

1. SIMOPS would be avoided whenever possible through:
   - Modification of the sequence of operations of either the rig or the installation vessel
   - Standby/delaying operations/maintenance activities if a SIMOPS is unavoidable and cannot be properly managed with reasonable risk

2. Where SIMOPS where identified and unavoidable and could be managed within reasonable risk for all parties:
   - Procedures for SIMOPS developed, reviewed and HAZOP carried out by all parties involved
   - Contingency procedures for “what if” scenarios developed ahead of operations
   - Meetings conducted with all the relevant parties immediately prior
   - Safeguards put in place including blow-off scenario, additional transponders and telemetry, subsea video links, etc.

The success of this approach resulted in the following:

- Early rescheduling of drilling sequence
- Schedule of BOP maintenance to allow site access
- Rescheduling of flowline installation sequence
- Rescheduling of flowline installation direction
- Modification of umbilical target boxes and temporary lay-down of umbilical terminations
- Rescheduling of number of jumper and flying leads installation
- Installation of jumpers in SIMOPS condition
- Installation of flowline using the “swing-under” method
FPSO Installation and Hookup Strategies

**FPSO Mooring**

The FPSO arrived on location late June 2010 and the installation of the nine (9) mooring lines started in early July during a period of high Gulf of Guinea surface currents. Overcoming the currents and maintaining a high level of operability during June and July was identified early as a project risk, and project planning therefore led to the need to select Anchor Handler Tugs capable of operating during the worst case conditions in order to minimize any downtime due to surface currents. Additionally, use of four (4) Anchor Handler Tugs in a region with limited support was a concern, as a vessel failure would delay the FPSO mooring operations and potentially impact the mobilization window of the riser installation vessel. Failing to meet this contractual window was recognized as a significant schedule and commercial exposure. Therefore, the IHUC Team selected two types of sister vessels (2x A-Type and 2x C-Type) for spare parts interchangeability and utilized the same Contractor for all four vessels to simplify contractual and commercial work. A list of vessels in the region capable of performing the work scope was maintained by the vessel broker including present location, availability and performance.

The Skandi Aker pre-installed the nine Suction Piles along with the first length of mooring chain connected to a ball grab receptacle parked on the seabed. The four Anchor Handler Tugs were used to perform the positioning of the FPSO while the Olympic Zeus vessel was used to run chain and synthetic mooring lines, connecting to the suction piles via the ball grab and performing the hand-over to the FPSO mooring/riser pull-in winch. The FPSO mooring installation was performed by sub-contractor Aker under direction from FPSO contractor MODEC.

Due to the critical nature of the FPSO positioning, the greatest challenge for the success of this work scope was to ensure Anchor Handler crew competency. The IHUC Team therefore hired their own experienced and competent masters early in the project to assess crew competencies and vessel performance, and perform the vessel inspections. These masters were also used by the FPSO Contractor to perform the mooring installation utilizing a DOF-supplied positioning system. Communication, competency and experience played a vital role in the successful execution of the mooring operations despite the high surface current conditions.

**FPSO Positioning and Riser Pull-In Activities**

Per the Contracting Strategy, the positioning of the FPSO and handover of the risers from the Deep Pioneer vessel to the FPSO pull-in winches was assigned to the URF Installation Contractor (Technip). The IHUC Team coordinated several interface workshops in the months prior to the pull-in activities which were critical to ensuring proper communication and alignment between the FPSO and URF Installation Contractors.

Riser pull-in Operations started near the end of July at the peak period of the Gulf of Guinea surface currents. Based on detailed engineering performed by the URF Contractor which defined key requirements to increase operability, the two A-Type Anchor Handler Tugs used during the mooring operations met the requirements and were retained for the riser pull-in operations. This also helped maintain continuity of the vessel experience with operating in the high surface currents.

The DOF positioning system used during mooring installation was also kept onboard and used for FPSO positioning during riser pull-in operations, minimizing unnecessary demobilization and remobilization of equipment. During the riser pull-in operations, it was critical to maintain an accurate vessel position in order to achieve the required +/- 2 degree alignment tolerance between upper and lower turret hawser pipes containing the winch synthetic rope when pulling in the riser during the final hang off steps.

Riser installation operations lasted approximately 5 months, and although tight heading control was only critical during the actual pull-in operation, some heading control was maintained for the entire period by at least one Anchor Handler Tug at any time to facilitate other FPSO IHUC operations in need of increased vessel stability. The extended period of heading control lead to failures of parts of the positioning equipment which had to be repaired on site. However, these had no adverse effects on the operations.

Concerns over riser pull-in operations were mainly due to heading control issues regarding the strict tolerances required at the turret rather than the vessel operations performed by the Deep Pioneer. The main points of concern during the engineering phase related to the winch and the rope. Issues encountered during factory acceptance test (FAT) of the winch and its spooling system led to last minute replacements and modifications. Lack of track record and industry standards applicable to synthetic pull-in ropes led the IHUC Team to keep a very conservative approach and procure two additional spares, which were not used.

**Equipment Staging and Work on the Turret**

The FPSO has a bow-mounted turret, which includes riser hawser pipes mounted on the exterior of the chain table and umbilical I-tubes located in the center well. Riser and umbilical hang-offs were installed using two split
collars between the hang-off flange and the riser termination. Bend stiffener adaptors for the risers were attached using a flanged interface at the base of the pull-in tube below the chain table. This operation required flange pullers to attach the bend stiffener to the riser end fitting. Umbilical bend stiffeners attached automatically, yet still required personnel to access below the chain table to facilitate operation of a manual/ROV secondary locking mechanism.

Personnel and equipment risks inside the turret were assessed in great detail during detailed engineering by the URF Installation Contractor both for safety considerations and to reduce time required to perform operations. Operations for the riser installation contractor generally took place on the chain table with the exception of operation of the pull-in winch on the main deck. Modifications or additions of temporary equipment to the turret standard design were necessary and included lighting, lifting aids, utility access, and staging areas. In addition to these physical changes, several key procedural modifications were implemented to improve the safety and efficiency of the installation activities. These changes required good cooperation between the FPSO contractor, the URF contractor, and IPT, which was facilitated by planning meetings and frequent site visits.

**Ready for Startup (RFSU) Strategies**

**General**

The following RFSU activities were on the critical schedule path:

- Getting all FPSO systems required for startup tested and ready.
- Completion of the initial wells required for startup, establishing communication via the control system, valve actuation and chemical displacement where possible.
- Mechanical completion, static commissioning and commissioning of the water and production systems

It is important to note that the startup philosophy was a critical deliverable in order to identify early and plan the sequencing of the works for the different FPSO and subsea systems. For example, it was determined that prior to startup and bringing one of the initial wells online, the project needed uninterrupted water injection capability for almost a week. Conversely, gas injection and export functionality were not required for some time later. Early identification of the systems required for startup allowed effective planning at the beginning of the project.

**Operational Readiness and Assurance**

Production Operations members from the Unit Operator (UO) were integrated very early into the IPT which ultimately was a critical strategy for ensuring RFSU conditions of the FPSO. The key benefits of this included:

- Continuity of personnel throughout engineering, execution, commissioning, startup and steady-state production, working to a structured Operations Readiness and Assurance (OR&A) Plan with the main activities integrated into the project’s master schedule
- Ability for Production Operations to influence design, functionality and desired flexibility of the system.
- Close involvement with the IPT in the development of the Jubilee Safety Case where all major accident hazards and controls were identified and assessed demonstrating risks were being managed to as low as reasonably practicable (ALARP) through:
  - Management of integrity through identification and management of Safety Critical Elements (equipment, people and procedures) via Performance Standards and compliance with Maintenance and Integrity Management Systems, competency standards and procedure reviews/validation.
  - Competency of Operations personnel
  - Internal and external verification of the Safety Case

*(Note: Further details on the Jubilee Safety Case can be found in OTC 23463, - Jubilee Development HSE Management and Safety Case)*

- Local Ghanaian staff development
- Ability to attend and witness FATs and SITs of critical subsea and topside components
- Ability to use synergies between activities and support vessels planned by Operations and those planned by the Project
- Seamless transitions between phases and ability to sign-off of systems as they were commissioned
- Ability to exercise Operations HSE Management systems, e.g. Permit to Work, implemented on departure from Ship Yard
- Clearer understanding between all parties that when hydrocarbons were introduced into the subsea infrastructure, the Unit Operator’s, Operations Manager would be accountable and responsible for all Jubilee field SIMOPS and activities under the Jubilee Safety Case and Permit to Work system.

**Subsea Mechanical Completion- Subsea Operations**

In order to optimize the project schedule, it was recognized that there were potentially significant gains to be realized by performing some of the testing activities ahead of the arrival of the FPSO, thereby not only reducing the duration of the critical path activities, but also reducing risks associated with post installation testing (leaks in connections).

In order to expedite the pigging and hydrotesting of the flowline systems and remove these activities from the critical path, the IHUC Team decided to procure equipment and service that would allow subsea pigging and testing of all the systems up to the riser base. Therefore only the testing of the risers themselves would remain on the critical path. The ability to complete subsea pigging and testing operations was ultimately determined by the flowline jumper fabrication and installation schedule. Flowlines were laid in advance but delays in onshore jumper fabrication meant that not all the planned subsea pigging and testing operations were completed as planned. As such, the project was not able to realize all the schedule benefits that subsea pigging and testing would have provided.

While the interfaces to perform subsea pre-commissioning were rather minor, the challenge was to ensure that the subsea pre-commissioning equipment was compatible with the different ROVs from the various vessels available in the field. This was accomplished by ensuring that the interface requirements of the WROV systems on the different vessels were identified early so that any special provisions or adapter plates could be made as well as to ensure that the equipment packages would not impede the deployment of the ROV.

During the planning phase, the subsea testing philosophy also led to pre-loading pigs into the PLETs at the fabrication yard, removing the need to install pig launchers offshore. Considerations were also given to the pig positioning within a PLET, flooding directions so that pig discs flipped in the direction of travel required, ensuring that batteries in acoustic pingers had sufficient life, and that the pigs were pre-loaded in a position not to interfere with existing valves.

**Subsea Mechanical Completion-FPSO Operations**

The following sequence of operation was planned for each riser:

- Riser second end pull-in using FPSO winch and securing of the end fitting on the hang-off flange.
- Leak test of the riser or hydrotest of the system, if not already performed during subsea testing operations.
- Flushing of the risers
- Dewatering of the gas injection flowlines
- Install top spool between FPSO turret connection and riser end fitting.
- \( \text{N}_2\text{He} \) tests of the spool connections at the riser topsides interface of Production and Gas Systems
- Test Umbilicals and route tubing from turret bulkhead to topside end termination.

Each of the above operations had to be completed in a small work area on the turret chain table or in the turret center well at the riser or umbilical hang off point. Large equipment was positioned on the Attendant Vessel due to FPSO deck space constraints and FPSO crane limitations.

The planning philosophy was to complete as much work as possible between riser pull-in operations and not to interfere with daily personnel transfers between the Attendant Vessel and the FPSO. As such, the daily re-scheduling and planning activities were intensive and required collaboration of several Contractors and the multiple rigs and vessels in the field.
**Subsea Systems Static Commissioning**

Early mechanical completion of the controls system was paramount to ensure communication to the significant amount of subsea control modules within the field. Early planning and effective scheduling coordinated the necessary resources in the field to facilitate the static commissioning or energizing and valve function testing of the trees and manifolds. A light intervention vessel with single WROV was employed to monitor and verify these activities as well as perform light intervention work for later phases.

One of the main challenges encountered was linked with the pin philosophy used in the subsea electrical connectors. The pins could be damaged if exposed inadvertently by an ROV snagging a flying lead or if the system was energized with some pins not protected by a fully mateable cover. This also led to having to power up and down a side of the field every time a connection was to be made or flying lead swapped out. Effective work planning minimized the number of times that powering down and discharging the control system was required.

Static commissioning of the subsea system also highlighted crosstalk and communication issues within the field. Management and traceability of what had been installed was critical to resolving the issue. Trouble shooting finally determined that a specific batch of EFL conductors was twisted incorrectly. Early completion of static commissioning using a dedicated vessel allowed for the equipment to be remanufactured and installed without affecting other vessel work in the field.

Subsea valve management in the field during commissioning operations was important, and tracking of valve positions through a master valve list maintained by a responsible party meant that no re-checks were required on the multiple manual valves on PLETS, manifolds or trees. This ultimately saved vessel time off the critical path prior to startup.

**Subsea Dynamic Commissioning**

These operations included the flushing of MeOH and Corrosion Inhibitor systems. As per the Subsea Mechanical Completion section, the start-up philosophy removed unnecessary operations from the critical path that could be completed after startup. The Skandi Aker vessel used for static commissioning was also employed in the commissioning operations, which involved flushing umbilical preservation fluids back into the flowlines utilizing a flushing flying lead or flushing stab plates.

Recognizing the interfaces between parties and their respective needs of chemicals for commissioning and startup, the IHUC Team held various workshops to ensure alignment between topsides and subsea personnel. This effective communication helped to manage the introduction of MeOH onboard the FPSO systems without impeding any remaining topsides activities which may involve outstanding hot work.

Dewatering of the production systems with diesel was later performed as a startup activity.

**FPSO Commissioning**

One key to the Jubilee fast-track schedule was the successful systematic commissioning of the FPSO topsides, which was completed offshore over a four-month period. The commissioning work was completed with a small core team of four to six personnel on the IHUC Team who utilized up to 80 craftsmen rotating to the FPSO. Preparing the FPSO for the RFSU condition was part of the larger Operations Readiness and Assurance effort designed by Unit Operator. Once the FPSO was installed offshore Ghana, RFSU activities focused on safely commissioning all production and utility systems. This required first that each system move through pre-defined stages to complete a rigorous dossier containing completion certificates and witnessed test results. Daily and weekly meetings revealed the status of all systems and identified the near-term priorities.

As part of the preparation for achievement of RFSU, a Pre-Startup Review (PSUR) was conducted by a multi-disciplined team of personnel from outside the project and led by the IPT’s Facilities Manager for expediency and immediate buy-in by the Project and Operations. This PSUR was conducted during September 2010, about two months prior to first production, and allowed a “cold-eyes” review of the status of all physical and procedural systems associated with the entire production system. The outcome of the PSUR was a validation of most known readiness status results and the identification of previously unknown issues that had to be addressed prior to Startup.
Compiling the results of the PSUR and the commissioning dossier status allowed a real-time monitoring of the RFSU status with a simple spreadsheet. An excerpt of this spreadsheet from late September is shown in the Figure 11 below used to quickly reveal a simple red-yellow-green grading of the various systems with respect to their overall functionality. Once each primary system achieved the final (green) commissioning completion status, a RFSU certificate was issued. Once all systems had this final certificate, the Project Director and Operations Manager jointly approved the entire Production System as “Ready for Startup”.

![Figure 11: Excerpt from RFSU Spreadsheet used to Track FPSO Systems Readiness](image)

Incidents and Significant Challenges

General

Despite careful planning and execution with a heavy focus and overall good HSE and quality performance, the Jubilee project did encounter a few unexpected events which caused major challenges to the IPT and to keeping the project on schedule. In all cases, these challenges were successfully resolved through intense collaborative efforts between the IPT and the Contractors involved.

Jumper Insulation Damage

In January 2010 in Ghana, during yard preparation, the site team discovered soft/sticky GSPU material on most of the production jumper bends insulation that was poured in Houston in below-freezing conditions. Remedial actions taken included:

- Immediate mobilization of a joint task force with the IPT and Contractor to identify the causes and remediation plans
- Prompt selection of the solution resulting in:
  - Mobilization of insulation repair Contractors and equipment to Ghana
  - Resurfacing with hard GSPU and heat shrink sleeves of all 6" jumper bends (36 in total) in Ghana
  - GSPU insulation of all 12" flowline jumper bends (80 in total) stripped out completely and entirely replaced in Ghana
Crane Failure/Riser Damage

In July 2010 at the Technip Le Trait, France facility where the Jubilee flexible pipe was spooled and waiting for mobilization to Ghana by the Deep Pioneer, a catastrophic failure of a major Le Trait dockside crane occurred, resulting in significant damage to the gas injection flexible riser and carousel. Fortunately, there were no injuries sustained during the event. Remedial actions taken included:

- Moving the Deep Pioneer to Rouen to finish the mobilization
- Inspection of all flexible pipes and procure repair/spare material
- Launching of an urgent remanufacture of the gas injection riser, which was a total loss
- Resequence load out, riser installation and commissioning operations to implement mitigation plans
- Urgent repair of the carousel damage
- Mobilization of mobile crane for next riser mobilizations
- Chartering of two additional HLVs to maintain schedule

Flowline Expansion and Walking Mitigation

Based on actual temperatures and further analysis generated by an independent design review, the IPT decided to implement and retrofit a late remediation program to the flowline system, designed to prevent the increase in the forecasted expansion and flowline walking from potentially damaging the flowlines.

A design was developed by Technip using a locking mechanism interfacing with their PLETs and with piles procured by Company using existing project drawings.

The remediation mechanism was built on location at the Ghana jumper fabrication site and installed using a Contracted vessel of opportunity, the Normand Installer.

Riser End Fitting Damage

In October 2010, after successful hydro test of the West Project Riser – A (WPRA) riser, the IHUC testing team onboard the FPSO discovered flaws on the surfaces of the WPRA and East Production Riser – C (EPRC) production risers end-fitting. Remedial actions taken included:

- Mobilizing a task force and sending experts to the FPSO to assess the issue
- Contractor and IPT review of risks and repair scenarios
- Prompt decision on the replacement of the two end-fittings
- Launch of an accelerated procurement of new end-fittings
- Selection of the optimum replacement end-fittings and repair equipment transportation scenario from France to the Jubilee Field
- Development of a procedure and hazard review for transfer back to the riser installation vessel and onsite replacement
- Transfer of selected personnel to perform the repair
- Identification of the least disruptive time to successfully perform end-fitting replacements from the Deep Pioneer

Conclusion

The successful execution of the IHUC Phase and RFSU is attributable to many factors, and although no single one of them is truly innovating on its own, the proper execution of all of them was certainly the key to meeting the challenges encountered.

In summary the following elements can be considered key factors in the successful fast track execution and handover from the IHUC Phase to the Startup Phase:

- Early recognition of the importance of planning for commissioning and start up through involvement as early as practical of key members of the actual commissioning and operations team on the project
Adapting the organizational structure to best cope with the demands for each phase to ensure most responsive and decentralized decision making

- Empowering the IPT members to make decisions within their areas of responsibilities and within their levels of authority
- Adopting a fit-for-purpose approach which enables the use of field proven technology without the need for optimization and thus avoiding second guessing the chosen approaches
- Selecting top Suppliers and Contractors and fostering a win/win relationship and open lines of communication at different levels
- Recognizing budget gaps due to lack of definition and unresolved interfaces early and funding them via allowances, thus allowing for quick and appropriately funded resolutions
- Planning the logistics early
- Hiring top experienced personnel either as staff or as Independent Contractors

These same elements which enabled meeting an aggressive schedule for the complex planned activities were also key to dealing successfully with several unexpected adversities that occurred during the in-country IHUC phase. Any one of the issues could have seriously delayed First Oil. Instead the experienced team achieved first oil at Jubilee in under 3.5 years from first discovery, within the planned budget, with an enviable safety record.