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## The Terra Nova FPSO Turret Mooring System

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### Abstract

The Terra Nova FPSO consists of a new-build vessel with a disconnectable internal turret mooring system. Nineteen risers and umbilicals from four drill centers are connected to the turret with a maximum design throughput of 150,000 bopd. The turret system is designed to allow the vessel to quickly disconnect from its moorings and risers to avoid impact with unacceptably large icebergs, and to allow the FPSO to remain moored on station during the severe 100-year storm conditions. These unique requirements for Terra Nova have resulted in the development of one of the most sophisticated turret mooring systems to date.

This paper presents some of the key drivers that led to the unique design of the Terra Nova turret mooring system, and provides a detailed description of the various components of the turret, focusing on both the structural and mechanical, and the fluid-transfer systems. The paper also provides an overview of the disconnection and reconnection of the turret mooring system, illustrating its compliance with the stringent requirements in the design basis. Finally the paper provides a summary of the turret design, fabrication and installation milestones over the life of the project.

### Introduction

The Terra Nova FPSO will be located in approximately 95 meters water depth on the Grand Banks off the East Coast of Newfoundland, Canada. The harsh environment at the Terra Nova location is much like the northern North Sea with a 100-year significant wave height of 16 meters, and 1-hour mean wind speeds of 40 m/s. The FPSO is situated in “iceberg alley” where large icebergs from Greenland and Ellesmore Island drift south with the Labrador current. Surveys have shown the presence of iceberg scour marks on the seabed, and statistics indicate that the site could see as many as 66 large

icebergs in a single season (April – July). Table 1 provides a summary of the design storm conditions for both the 1-year and 100-year return intervals.

The Terra Nova FPSO system consists of a new-build FPSO vessel with a disconnectable internal turret mooring system. The turret supports 14 risers and 5 umbilicals servicing wellheads in four or more glory holes, with a maximum design throughput of 150,000 bopd. The turret mooring system has been designed to maintain station in the 100-year storm environment, and to be disconnectable to avoid an approaching iceberg on a collision course. Once the FPSO disconnects, the mooring and riser system is supported by the spider buoy that has an equilibrium depth of 35 meters below sea level.

This paper provides a detailed description of the unique turret mooring system designed by FMC SOFEC Floating Systems for the Terra Nova FPSO, focusing on both the structural and mechanical system, and the fluid-transfer system. The paper also provides a description of the disconnection and reconnection of the turret mooring system, and the design, fabrication and installation milestones over the life of the project.

### Turret Mooring System Design Basis

The key drivers for the design of the turret mooring system as dictated by the Terra Nova design basis are summarized below:

- The FPSO is required to disconnect from its mooring and risers to avoid collision with icebergs with a mass greater than 100,000 MT;
- A *controlled* disconnect must be accomplished in seastates up to the 1-year ice season storm (7.5 meters significant) in approximately 4 hours, with all risers flushed and de-pressurized, without damage and external assistance. Damage will be accepted for disconnection in higher seastates;
- The system must also provide a fail-safe *emergency* disconnect that must be accomplished in approximately 15 minutes;
- The system must be designed to allow for reversibility of the disconnect procedure up to the final disconnect command;
- The FPSO is required to reconnect to the mooring and

risers in seastates up to 2.1 meters significant using vessels that are in the field.

- The FPSO vessel and mooring must be designed to withstand the impact of icebergs less than 100,000 MT, and pack-ice less than 5/10 coverage and 0.3 meters thick;
- The FPSO must be moored on station in a 100-year storm, requiring the turret mooring system to be designed for the 100-year environment. The mooring system can depend on the full capability of the thruster system. In seastates up to the 1-year storm the mooring system can only utilize the heading control mode;
- The turret must support a total of 14 risers and 5 umbilicals;
- All fluid conductors will be hard pipe;
- All connections between the risers and the fluid transfer system will be easily connected/disconnected without damage to the connections;
- The connectors between the risers and production piping will provide a fluid blocking valve on both sides of the connection. This fluid blocking system shall operate to shut-in both sides of the line whenever the connection is broken, including emergency disconnects;
- Turret must provide structure and space for all manifolding and turret process equipment;
- Permanent pigging facilities on board the turret must be provided for round-trip pigging of production and test flowlines;
- The design life of the system is 25 years; and
- Design philosophy is one of “Fit for Purpose” as dictated by the applicable codes and standards.

As described in the following section the turret mooring system provided by SOFEC for Terra Nova is a unique design, developed to meet the stringent requirements for the Terra Nova field. The Terra Nova turret system has been designed to meet or exceed the requirements from the Terra Nova Alliance Design Basis, Lloyd’s Register, Transport Canada, CSA International, and CNOBP (Canada Newfoundland Offshore Petroleum Board) guidelines and regulations.

### Description of the Turret System

The major driver for the design of the turret mooring system was the requirement to disconnect for icebergs only; thus requiring the FPSO to remain moored in the 100-year storm. This is a unique requirement for a disconnectable turret mooring system. Previous disconnectable systems designed for the South China Sea have been designed to disconnect for typhoons, resulting in reduced environmental criteria and lower loads for the turret system. Terra Nova has required the design of a high integrity disconnect system that would perform as detailed in the design basis, and a permanent turret mooring system that would perform as required in the 100-year storm conditions. This has resulted in the development of

several specialized components to provide the high load carrying capacity and safety required for the Terra Nova turret mooring. The stringent disconnect and reconnect criteria, coupled with the large and complex fluid-transfer system, have resulted in the design of a very sophisticated and automated disconnectable turret mooring system.

The Terra Nova vessel was specially designed for the harsh environment on the Grand Banks. The 960,000-barrel storage vessel has a length of 292 meters, a beam of 45.5 meters, and a depth of 28.2 meters. The operating drafts vary from 12.7 meters to 18.6 meters. At full load condition the displacement of the vessel is 193,000 MT. Additional details of the vessel and its performance are provided in Reference 1.

The disconnectable turret is located 74 meters aft of the forward perpendicular of the vessel. Figure 1 provides a general arrangement of the FPSO system indicating the location of the turret, and the layout of the mooring and riser systems.

The turret system provides four major functions:

1. Allow the vessel to weathervane and serve as a load transfer mechanism between the vessel and the mooring system;
2. Provides a quick disconnection and reconnection between the FPSO and its mooring and risers;
3. An efficient fluid-transfer system from the risers to the production systems on the vessel; and
4. Interfaces for control systems and utilities between vessel, turret and subsea systems.

The turret serves as a central link in the FPSO for several systems, thus indicating the criticality of a robust turret system design. All of the interfaces have to be considered when designing the turret mooring system to meet the stringent disconnect and reconnect criteria. The following paragraphs provide an overview of the turret, its components and subsystems, and illustrate the complexity of the various interfaces.

Figure 2 provides a schematic of the Terra Nova turret and indicates the major components and systems. The turret has a total elevation of approximately 70 meters from the bottom of the connected spider buoy to the top of the swivel stack. The lower turret comprises all components of the turret system at or below the main deck level of the FPSO. This includes the mooring system, the spider buoy, the QCDC room, the connector-tensioner and the buoy retrieval equipment. The lower turret is also the major load transfer mechanism to transfer loads from the turret to the vessel. The lower turret varies in diameter from 12 meters at the main deck to 21.5 meters at the vessel keel where it interfaces with the spider buoy. The connector-tensioner assembly connects the spider buoy to the lower turret during normal operation. When the spider buoy is released from the lower turret it free-falls to its design depth.

The upper turret is a three deck structure mounted on the lower turret structure that supports the turret piping and manifolds, pig receiving and launching systems, the swivel

stack, the turret equipment room, and various hydraulic and electrical systems required for operation of the turret and subsea equipment. The upper turret structure has a diameter of 23 meters and a height of approximately 32 meters above the main deck.

The turret is interfaced to the vessel via two bearing systems that transfer the load to the FPSO hull, and the swivel access structure that supports the product piping from the swivels to the vessel topsides. The turret, vessel and topsides engineers optimized these interfaces through a joint effort.

The following paragraphs provide a description of the major turret components, systems, and interfaces:

**Mooring System.** The mooring system consists of nine anchor legs in a 3X3 arrangement, with each group 120 degrees apart. Each anchor leg consists of studless Grade R4 chain (146 mm diameter) terminating in an anchor pile. The mooring system is designed with a heavier section of chain at the touchdown point that is optimized to reduce vessel offsets and mooring loads. Each driven anchor pile is 2.1 meters in diameter, and is 37 meters long.

The mooring system is designed to be assisted by the thruster system on the vessel. The FPSO has five 5MW thrusters, two at the bow and three at the stern, which have a combined total thrust available of approximately 450 MT. In seastates up to the 1-year storm the system has been designed to provide heading control (to minimize loads and motions), with mooring system providing stationkeeping. In storms up to the 100-year storm, the thruster system will provide heading control and some offset control by providing additional damping in the low-frequency surge mode of the vessel response, and/or providing some mean force reduction. References 2 and 3 provide details on the global analysis of the Terra Nova FPSO mooring and riser systems respectively.

**Spider Buoy.** The spider buoy is a twelve-compartment buoy, 17 meters in diameter and approximately 8 meters high. The buoy has a displacement of 1700 MT and a mass of 1250 MT, providing net buoyancy of 450 MT. When connected to the lower turret the spider buoy provides the interface for the mooring load transfer into the turret structure, and for the nineteen risers and umbilicals to the turret fluid-transfer system. When disconnected from the turret the spider buoy supports the nine anchor legs, and nineteen risers and umbilicals at an equilibrium depth of 35 meters below sealevel. The spider buoy is designed to support the anchor legs and risers with one compartment damaged.

The spider buoy is connected to the lower turret using a specially designed connector-tensioner. The connector latches on to a hub mounted on the top of the spider buoy. Load transfer between the spider buoy and the lower turret is also provided through the mating of machined profiles between the two structures. The risers are connected to Jtubes at the bottom of the spider buoy, and the lower QCDC valve is mounted on the end of the J-tube on the top of the buoy. After the buoy is connected to the lower turret, the turret is de-watered and the lower QCDC valves are connected to the

upper valves mounted on the piping in the QCDC room.

The spider buoy also contains a chain locker that stores the retrieval chain that is used to pull the buoy into the turret. The buoy was installed by pulling the mooring chains through the flapper-type chain stoppers, eliminating the need for an active ballasting system during installation.

**Lower Turret Structure.** The lower turret structure provides the load transfer between the turret system and the vessel, and houses the equipment required for disconnection and reconnection of the FPSO and the spider buoy.

The turret shaft is a cylindrical reinforced steel structure, suspended from the upper bearing assembly. The lower portion of the turret shaft is restrained laterally by the lower bearing assembly and provides a safe connection to the spider buoy via the connector-tensioner assembly and the specially designed mating surfaces.

The spider buoy – turret interface includes a water seal arrangement to allow a watertight connection between the buoy and the turret. Upon connection of the buoy to the turret, a sealed room, 13 meters in diameter and 2.8 meters in height is created between the top of the spider buoy and the bottom of the lower turret. This room, called the QCDC room, encloses all the QCDC Valve Assemblies and Umbilical J Plate Assemblies, and contains all potential leak sources in a sealed area. In addition, the QCDC room is nitrogen inerted at all times to minimize potential hazards.

The lower turret structure supports the turret piping from the QCDC room to the upper turret, and additional support systems for the turret. The chain jack and winches used to retrieve the spider buoy are also located in the lower turret structure.

**Upper and Lower Bearing Assemblies.** The vessel's loads are reacted into the turret through an upper bearing assembly and a lower bearing assembly. The upper bearing assembly reacts axial and radial loads while the lower bearings react only radial loads. The upper bearing assembly consists of a 12.5-meter three-row roller bearing mounted on a stiff support ring, which is in turn supported by elastomer springs mounted onto the deck of the FPSO. The upper bearing support ring is supported on elastomer springs to isolate the roller bearing from the hog and sag induced deflections in the FPSO hull. Forty-eight elastomer springs are used to support the downward axial loads and sixteen elastomer springs are used to react the uplift axial loads. Twenty-four radial elastomer springs react the radial turret loads. The elastomer springs are mounted in the assembly in a manner that prevents them from being loaded in tension. All loads on the elastomer springs are compressive and shear.

The lower bearing assembly consists of eighteen individual self-lubricating bearing segments arranged evenly around the bottom of the turret. These bearing segments rotate with the turret and slide against a corrosion resistant surface on the moonpool. The bearing segments are mounted on radially adjustable gimbals to compensate for manufacturing tolerances and angular misalignment between the turret and

the journal surface on the moonpool. The lower bearing segments are mounted on the turret rather than the moonpool to allow the center of rotation of the lower bearings to be adjusted to match the center of rotation of the upper bearing.

**Connector-Tensioner Assembly.** The connector-tensioner assembly is comprised of a large FMC Torus connector and a specially designed large bore hydraulic cylinder (tensioner). The assembly is powered by redundant oil-based and water-based hydraulic systems (5,000 psi).

After the connector is mated to the hub on the spider buoy, the tensioner is activated hydraulically, pulling the spider buoy tight against the mating profile on the lower turret. Engaging the lock nut on the connector-tensioner then completes the connection. The connector-tensioner does not require any hydraulic pressure to maintain the connection to the spider buoy. This results in a preload in the connection of approximately 7,700 MT that minimizes the fatigue loading on the connector-tensioner assembly and its support.

The connector-tensioner was extensively full-scale tested before being installed in the lower turret. A test load of 12,000 MT was applied to the connector to prove its capacity, and then a series of tests were performed where the connector-tensioner was preloaded to 7,700 MT and then released under this preload more than twenty-five times to comply with the Certifying Authority and project requirements.

**Spider Buoy Retrieval System.** The main components of the spider buoy retrieval system are the chain jack, the retrieval winch, and the associated hydraulic and electrical control systems. Additional components such as the turret drive mechanism, the buoy alignment pin, and the buoy stabilizer pins are used to ensure correct alignment and connection of the spider buoy to the turret.

The chain jack is the primary piece of equipment that retrieves the spider buoy to the turret. The chain jack is powered by the oil-based HPU (Hydraulic Power Unit) on the turret. It has a maximum capacity of 1,300 MT and is designed to operate with the 178 mm studless Grade R4 retrieval chain. The chain jack has a maximum retrieval rate of 0.8 meters/minute.

The retrieval winch is used to hoist the retrieval chain from the locker in the spider buoy into the chain jack on the turret. This is a traction winch with a maximum capacity of 100 MT. Once the chain jack is in operation the retrieval winch is designed to maintain constant tension on the chain section before it reaches the temporary storage locker on the turret.

**QCDC Assemblies.** The QCDC (Quick Connect Disconnect) assemblies used for the Terra Nova turret are constructed from standard FMC products or extrapolations of existing FMC designs. The basic construction is FMC manifold ball valves on either side of an FMC Torus connector.

For production and production/test risers, two ball valves are fitted into a single body on the riser side of the QCDC assembly to provide double block and bleed isolation for the disconnected riser. This double ball single body configuration

reduces the size of the valves to better accommodate the confines of the QCDC room. The design connects two FMC valves in a single body instead of joining two valves with an FMC connector. The lower ball is actuated in a hydraulic open fail close/spring close configuration, and is designated as an ESV. The upper ball is fitted with a double acting hydraulic actuator. There is a standard single ball valve connected to the turret side of the QCDC assembly with a similar hydraulic actuator. All valves have an API 6FA fire rating confirmed by API 6FA fire tests conducted at FMC testing facilities.

The mechanical connector of the turret side components and riser side components is an FMC Torus connector. The Torus connector used in this application has valve flanges integrated into the two ends of the Torus connector. To contain the process fluid, the connector utilizes a pressure activated metal seal ring and a second elastomeric O-ring. The mechanical connection does not require hydraulic pressure to maintain the connection. Full-scale prototype tests were conducted on a QCDC assembly to verify that this assembly would connect and seal at specified misalignments and loads. The prototype test of this assembly also included a disconnect under full design pressure.

The QCDC assemblies for the other risers (gas lift, gas injection, water injection and future water alternating gas [WAG]) are similar to the assemblies for the production and production/test risers except that the riser side of the assembly is fitted with a single ball fail closed/spring closed valve assembly.

An externally mounted stab plate (J-plate) is used to make hydraulic and electric/instrument connections between the turret side and riser side of the QCDC assembly. The stab plate allows for some adjustment after reconnect so that small differences in alignment between riser side and turret side can be tolerated.

**QCDC Room.** To reduce the risk of catastrophic explosion in the turret, all mechanical pipe connections in the lower turret, including the QCDC's used to connect the risers to the turret piping, are contained in a small enclosed portion of the lower turret which has been named the QCDC Room.

The QCDC room incorporates two large (36-inch [914 mm]) vent connections from safe areas on the upper turret to the QCDC room. In normal operations these vent lines are closed to the atmosphere, and the QCDC room is inerted with nitrogen with an oxygen content less than 4%. During normal operations a small flow of nitrogen is maintained in the QCDC room at a small overpressure. Oxygen content and presence of hydrocarbon gases are monitored continuously.

In the event of detection of hydrocarbon gases, production is shut down and inventories depressurized, gases blown down. Built-up hydrocarbon vapor in the QCDC room is allowed to vent under its own pressure through vent ducts and safely disperse into the atmosphere. After the source of the leak is isolated and blown down completely, the nitrogen system is switched from pressure demand to regulated flow to purge residual hydrocarbon vapors from the QCDC room. The QCDC room can then be supplied with fresh air to prepare the

QCDC room for entry. This process preserves the IMO rule for inerting: never mix both air and hydrocarbons during operations, but insert inert gas between air and hydrocarbon phases of an operation.

Ventilation fans are provided to remove nitrogen from the QCDC room. The ventilation fans initially displace the excess nitrogen and then continue to provide ventilation to maintain adequate ventilation for a hazardous area for the times that the QCDC room is entered.

The top of one of the 36-inch vent lines is fitted with a bursting disc to provide over pressure protection for the QCDC room in the event of a sudden very large release of high-pressure gas in the QCDC room. This allows relatively unobstructed flow in the main trunk of the 36-inch to maintain the QCDC room internal pressure below 2 bar (29 psig).

**Upper Turret Structure.** The upper turret structure supports all turret components located above the main deck of the vessel. The upper turret structure consists of three decks built around the swivel stack along the centerline of the vessel. The first two decks are dedicated to the turret piping, manifolding, and the pig launching and receiving stations. The upper deck is a control and equipment deck and houses the LER (Local Equipment Room) and other turret related equipment.

The swivel access structure located on the vessel reacts the torque from the swivel stack and provides support for all the piping and cabling from the swivels to the vessel.

**Turret Piping and Process.** The process piping in the turret serves to form a bridge between the risers and the vessel topsides piping and process. The turret piping also provides for utility services (air, instrument air, open and closed drain, fire water/deluge, chemical injection etc.). Aside from flow alignment, the process in the turret provide for drain collection and disbursement, overpressure protection, occasional pigging operations on the turret, and metering some flowrates for process control/feedback. FMC compact manifold valves are used to significantly reduce the deck area required for turret piping.

Major process piping can be divided into incoming production lines from the subsea wells, and outgoing lines for gas lift, gas injection and water injection. Provision has been built into the turret piping to allow for the future installation of a WAG riser. Hydraulic lines for subsea control and chemical injection lines are routed to connections for umbilicals, which connect to the subsea templates.

The production and production/test lines are routed from the QCDC room at the bottom of the turret to chokes on a deck of the upper turret structure. To reduce the risk of catastrophic explosion in the lower turret, there are no flanges or other mechanical connections in the hydrocarbon piping between the QCDC room and open areas of the decks on the upper turret. In normal operations, flow from the chokes continues to a production header on a deck of the upper turret.

In the case of the production/test risers, flow can be routed to either the production header or the test header. There are connections from the production and test headers to swivels

that connect the geostationary turret piping to the piping fixed to the vessel. From the vessel side of the swivels, the piping is run across a bridge structure and connected to topsides piping. The pipe configuration and the use of mechanical joints accommodate relative movement between the turret and vessel.

At the connection of the separate flowlines to the production and test headers, there is a pressure class break. Piping upstream of this class break is designed to the shut-in pressures of the connecting risers. Piping downstream of the class break is designed to the design pressures of the topsides process piping.

This class break allows the use of more economical lower pressure swivels. The swivel seal design pressures are closer to the actual operating pressures as opposed to the higher shut-in pressures. The class break is made possible by providing unobstructed connection between the swivels and overprotection systems (relief valves) on the topsides.

Pressure transmitters mounted on the incoming production piping will close ESV's at the QCDC's on high pressure. The protection is set up so that high pressure of individual risers will shut down the individual risers associated with that drill center while allowing remaining drill centers to produce. High pressure in the production manifold will isolate all incoming risers from the drill centers.

One important aspect of the protection system is to allow for complete choke washout. As it is not feasible to design a relief/flare system to accommodate the high flowrates associated with complete choke washout, the ESD system is designed to shut valves to isolate the incoming flow if choke washout occurs. It should be noted that this system is not required to be a true HIPPS. As long as flowrates are not excessive, overpressure will be prevented by the topsides relief system. Thus, while it is most probable that complete flow and pressure isolation will be achieved by the turret side ESV's and other actuated valves that will be closed, complete bubble tight isolation is not required for safety.

A combination launcher/receiver is provided for each production and production/test riser. This allows round trip pigging for cleaning, water displacement for disconnect, and hot oil circulation at start-up.

Gas from the topsides passes through higher-pressure swivels to the turret. Gas for gas injection and gas lift is manifolded to different risers on the turret. The gas is metered on the turret for process control purposes. High-pressure water from the topsides passes through higher-pressure swivels to the turret and is manifolded to different water injection risers. The injection water is metered on the turret for process control purposes.

The turret is provided with an open drain system and a closed drain system. Common methods (seal pots etc.) are used for isolation of different areas of the systems. The turret also provides for distribution and metering of various chemicals received from topsides to individual umbilical paths or turret piping injection points. This greatly reduced the number of high pressure swivel paths required.

**Swivel Stack.** The swivel stack assembly transfers produced oil and gas from the risers to the production plant on the weathervaning FPSO. The swivels also transfer water and gas for subsea injection, chemicals for well treatment, electrical power and control signals, utilities (compressed air, nitrogen, etc.) and provide an optical communication link between the turret and the FPSO. The swivel stack consists of toroidal low-pressure swivels, high-pressure swivels, and high- and low-pressure utility swivels. An electrical power and control swivel, and a fiber optic swivel are also included. Figure 3 provides an illustration of the swivel stack and its components and indicates the geostationary (turret-fixed) and the vessel-fixed components. The swivel stack is approximately 20 meters tall and has a weight of 200 MT.

The toroidal swivels consist of an inner and outer housing with a heavy-duty bearing to allow rotation of the outer housing around the inner housing. The inner housing is stationary with respect to the lower turret structure. The outer housing rotates with the FPSO. The fluid path is the annulus formed between the inner and outer housing. Primary and secondary face seals seal the annulus top and bottom. Fluid enters the annulus through a pipe and elbow inside the inner housing. The fluid exits the annulus through an outlet in the outer housing. A torque arm between the outer housing and the vessel-fixed structure allows it to rotate the housing with the vessel. The high-pressure swivels are of a similar design to the toroidal swivel.

The utility swivels are multi-path swivels using axial-style seals between the paths providing separate paths for the various chemicals, service air, nitrogen, methanol, water based hydraulic fluid, and fresh water. The electrical and control swivel is purpose built for the marine environment and is a slip-ring style design having multiple rings for both power and control functions. The optical swivel is of a similar design having multiple optical paths.

The stack consists of the following (from bottom to top):

- Two 16-inch production swivels (740 psi);
- One 12-inch and one 10-inch production and test swivels (1,480 psi);
- One 12-inch, flare swivel (285 psi);
- One 10-inch, fresh water swivel (285 psi);
- One eight-path utility swivel (285 psi) for air, hydraulic oil, nitrogen, etc.;
- One combination electrical and control swivel;
- One high pressure water injection swivel (5,000 psi);
- One gas lift swivel (4,200 psi);
- One gas injection swivel (5,930 psi);
- One high pressure utility swivel (5,000 psi) for chemical injection; and
- One fiber optic swivel.

**Electrical and Instrumentation Systems.** Interface to the FPSO Central Control Room for control and safety monitoring

of all subsea and turret control systems is via a fiber optic swivel for dual data highway communications to all the topsides DCS (distributive control systems). There are also a large number of slip rings provided for hardwire interface of the following functions: subsea, sub-surface, safety valve control, ESD signals, buoy disconnect and reconnect, process shutdowns, electrical isolation, telecommunications, and general alarms.

Electrical power is fed from topsides to the turret via slip rings to power motors, heat trace, lighting, all the control systems, including subsea controls, fire and gas, and telecommunications. This power consists of normal and key service/emergency 600 volt, plus dual 220 volt UPS.

The turret has a prefabricated control building designated as the LER (Local Equipment Room) with dual pressurization and HVAC systems for climate control. The LER building walls are constructed for a fire rating of H60 with the ability to withstand a non concurrent jet fire for 30 minutes, and a blast peak over pressure of .344 bar. The LER is located on the upper most deck of the turret and houses all the electronic instrument process control systems, fire and gas, ESD, telecommunications, along with motor control centers, lighting distribution panels, and UPS distribution panels. The fire and gas, and ESD systems, inside the LER building have additional air purge units to meet the requirement of remaining in operation for some period of time after an incident, such as gas ingress into the building.

### FPSO Disconnect and Reconnect

This section of the paper provides a description of the mechanics of the disconnection and reconnection of the spider buoy from the turret. The FPSO has been designed to disconnect from its mooring and risers to move away from ice hazards (sea ice concentration greater than 5/10 or icebergs greater than 100,000 MT). The disconnect feature also allows the vessel to depart for major maintenance in dry-dock, etc.

Reference 4 provides information on ice-detection and management on the Grand Banks. The operators have determined ice alert zones that place the FPSO in various states of readiness, with zones that determine the start of both a controlled and emergency disconnect.

The turret system has been designed to allow a controlled disconnect of the FPSO from its mooring and risers in under four hours, in seastates up to a 1-year ice season. The system has also been designed to allow an emergency disconnect of the spider buoy in under fifteen minutes.

**Spider Buoy Disconnect.** The control of the disconnection of the spider buoy can be achieved from either the central control room on the FPSO or the LER on the turret. The disconnection mechanisms are fully redundant and sensors monitor the process at all stages. The controlled disconnect goes through the following stages:

1. Shutdown production;
2. Depressurize gas injection, gas lift, and water injection lines;

3. Pig and flush hydrocarbons from production/test lines;
4. Close upper and then lower QCDC valves;
5. Disconnect QCDC valves;
6. Depressurize and vent umbilicals and disconnect J-plates;
7. Flood turret to waterline;
8. Maintain vessel in 7.5 meter disconnect watch circle; and
9. Disconnect main connector that releases spider buoy.

After the buoy is released from the connector (less than 5 seconds from the instant the connector is powered), the buoy free-falls to its equilibrium depth with the top of the spider buoy approximately 35 meters below sealevel. Note that the procedure is reversible until the very last step.

The majority of the time during the controlled disconnect (four hours) is spent in pigging and flushing the production/test lines. For an emergency disconnect the procedure is similar to the controlled disconnect except that the production/test lines are not pigged and flushed, and that the vessel does not need to release the buoy within a 7.5 meter watch circle.

**Spider Buoy Retrieval and Reconnect.** The Terra Nova FPSO is required to reconnect with assistance from vessels available in the field. An ROV will be available to assist in retrieval and monitoring of the retrieval process. The design basis defines the maximum reconnection seastate to be 2.1 meters significant. However, the system designed will allow reconnection in seastates up to 3 meters significant. Prior to the reconnection sequence, the riser pipes in the turret are raised to prevent clashing between the turret piping and the piping on the spider buoy.

Once the desired weather window is forecast, the vessel will position itself directly over the buoy using the full DP mode of the thruster system maintaining a watchcircle of 2.5 meter radius, with the desired heading. The reconnection sequence can then be summarized as follows:

1. Rotate the turret using the turret drive mechanism to orient the turret with the buoy within 10 degrees;
2. Deploy retrieval line from winch to spider buoy;
3. ROV connects retrieval line to chain end fitting;
4. Using the retrieval winch, hoist the retrieval chain from spider buoy into chain jack;
5. The chain jack pulls the buoy towards the turret;
6. Pull buoy into turret against buoy stabilizer pins and then position buoy approximately 25 mm below turret structure;
7. Engage alignment pin and rotate turret until pin drops into matching hole in buoy, and then pull buoy against turret mating profile;
8. Open connector and lower assembly onto buoy hub;
9. Close buoy connector and verify connection; and
10. Pressurize tensioner to desired preload and lower lock nut

in position.

At this stage the FPSO is now moored to the spider buoy. This phase of the reconnection operation takes approximately two hours from the time the retrieval line is connected to the chain end fitting. The turret is now de-watered and following detailed procedures developed by the Terra Nova Alliance, the riser QCDCs are connected, the QCDC room inerted, and the FPSO is ready to produce.

### Turret Design and Fabrication Milestones

A major driver of the turret design and fabrication schedule was the shipyard schedule for the vessel that required the lower turret to be delivered to the shipyard at the commencement of the dry-dock construction phase. This required acceleration of the lower turret optimization phase and a freeze of the lower turret design before the final design of many interface systems, e.g., topsides, subsea, riser, and vessel were complete. This led to further optimization and rework once the various systems were engineered, but provided acceleration of the project schedule to first oil. Another driver was the short weather window each year for efficient offshore operations that required installation of the mooring and spider buoy in the summer of 1999.

Table 2 provides an overview of the turret fabrication, installation and commissioning milestones over the life of the project that illustrates the overlapping schedules of the various FPSO systems. The table also indicates how the turret design and fabrication schedule was tailored to match the overall project schedule.

The Terra Nova Alliance was formed between the members of the Grand Banks Alliance (Contractors) and the Owners and Operator in early 1997. The various engineering teams immediately began a detailed design optimization phase that led to final development of the Terra Nova FPSO system and the high-level design basis. To meet the project schedule for first oil, contracts had to be awarded for the vessel and long lead items for the turret, e.g., main bearing, the forged bearing support ring, and the anchor leg chain. This required that the global analysis of the FPSO, mooring design and turret design loads had to be completed and verified (via model tests) before the award of these contracts.

The Terra Nova project was sanctioned in Canada in February 1998 and fabrication of the spider buoy and the lower turret structure, in three modules to meet maximum lift capacities in the dry-dock, was started in April 1998. Figure 4 shows the installation of the main bearing on the forged support ring (upper lower turret module).

As the project schedule dictated that the spider buoy be installed in the summer of 1999, a major project-critical interface that had to be verified was the connection between the spider buoy and the lower turret. The design and fabrication schedules for the various components made it impossible to actually test the complete system at once. However, each individual interface was tested extensively with the prototype components. The major interfaces for the lower turret – spider buoy connection are:

- Mating profiles on spider buoy and lower turret;
- Connector-tensioner – spider buoy hub; and
- Lower and upper QCDC valves and turret piping alignment.

The mating profiles of the spider buoy and the lower turret structure were verified during a trial fit-up stage during the fabrication in Abu Dhabi. When the mating profiles on both structures were finished the almost-complete lower module of the lower turret structure was lifted and placed on top of the spider buoy structure as shown in the two photographs in Figure 5. This allowed a detailed inspection of the mating between the two profiles and the alignment of the two structures to verify that they met the tolerances specified by the design. The two structures were then separated and completed.

The connector-tensioner assembly was tested extensively during the winter of 1999 with a duplicate hub built to the same specifications of the hub installed in the spider buoy. As described in an earlier section the individually QCDC valves and connectors were tested, and the final minor adjustments to the QCDC valve alignment, if required, will be made once the FPSO has hooked-up to the spider buoy.

Figure 6 shows the three lower turret modules in the dry-dock in Korea at various stages of assembly with the vessel structure. The lower turret module was fitted with a turret cover plate that was installed against the mating profiles on the lower turret and the water seals, providing a dry environment in the lower turret until just before hook-up with the spider buoy. After the vessel was launched, outfitting of the lower turret commenced with installation of turret piping, cabling, and various other systems, until the vessel set sail for Bull Arm, Newfoundland in March 2000.

The spider buoy fabrication was completed in March and the spider buoy was shipped to Bull Arm where the connector hub and other mechanical components were installed. The spider buoy and the anchor legs were successfully installed by June 1999 as illustrated by the photograph in Figure 7. The lower QCDC valves were installed on the spider buoy using divers during the riser installation phase in the fall of 2000.

The fabrication of the upper turret structure commenced in Abu Dhabi during the summer of 1999, and the upper turret was delivered to Bull Arm in April 2000. The FPSO arrived in Bull Arm from Korea in May 2000. First the connector-tensioner and retrieval equipment was installed in the lower turret. Then the upper turret structure was installed as part of the FPSO heavy-lift program in June 2000 as shown in Figure 8. From the summer of 2000 to the present time most of the turret activities have focused on hook-up and commissioning, conducted in parallel with the hook-up and commissioning of the FPSO. As shown in Table 2 the FPSO is scheduled for final seatrials in the late spring 2001, with hook-up to the spider buoy scheduled for the summer. First oil is expected shortly after hook-up of the spider buoy to the FPSO.

## Summary

The paper presents a detailed description of the unique disconnectable turret mooring system designed for the Terra Nova FPSO. This is the first disconnectable turret system to be designed to be disconnectable for icebergs only and to moor the FPSO in the harsh 100-year storms.

The paper illustrates the complexity involved in the design of a turret mooring system built to meet the very stringent requirements of the project design basis. The design of the turret mooring system for Terra Nova illustrates a unique solution to a complex engineering and operational challenge. This system sets the standard for the development of future fields on the Grand Banks and other regions with harsh environmental conditions.

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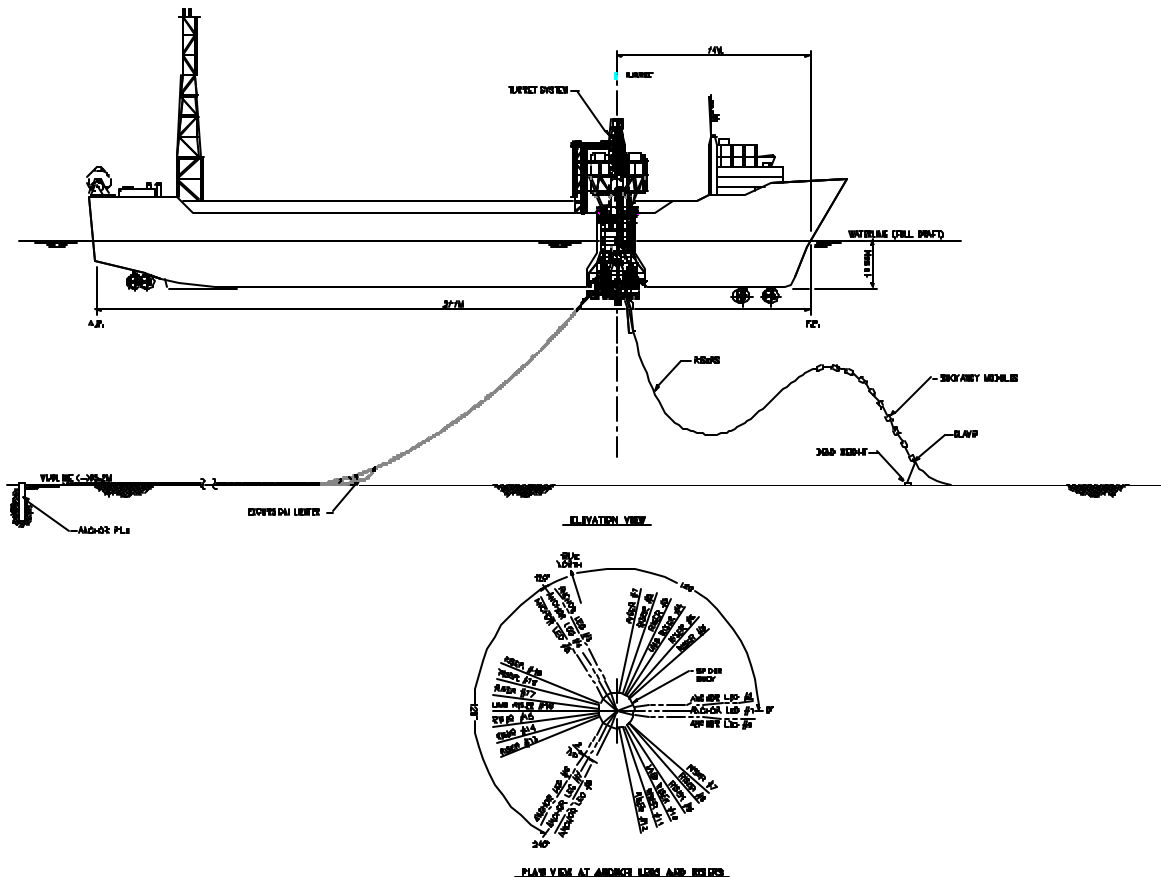
**Table 1 - Terra Nova Environmental Data**

Parameter	Return Period (Years)			Units
	1 (Ice)	1 (All)	100	
<b>Wind Velocity</b>				
1-hour mean wind speed	22.2	28.8	39.6	m/s
<b>Wave Parameters</b>				
Spectrum Model	JONSWAP	JONSWAP	JONSWAP	meters
Significant Wave Height	7.5	10.9	16.0	meters
Peak Period Range	9.5 - 16.5	12.9 - 16.6	15.7 - 20.2	seconds
Peakedness Parameter, $\gamma$	1.0 - 1.7	1.0 - 1.7	1.0 - 1.7	
Maximum wave height	14.2	20.7	30.4	meters
Associated period range	8.5 - 17.5	11.5 - 17.6	14.1 - 21.3	seconds
<b>Current Velocity</b>				
Near surface (20 m)	0.85	1.00	1.30	m/s
Mid depth (45 m)	0.64	0.86	1.09	m/s



**Table 2 – Milestones for Turret Design, Fabrication and Installation**

Turret Fabrication/Installation Milestones	Date
Grand Banks Alliance (Contractors) Selected for Terra Nova Field	December 1996
Terra Nova Alliance Formed (Contractors, Owners, Operator)	Spring 1997
Design Optimization Period	Spring - Fall 1997
Turret Long Lead Items Ordered (Bearing, Mooring Chain, etc.)	Fall 1997
Terra Nova Project Sanctioned	February 1998
Lower Turret Fabrication Commenced (Abu Dhabi)	April 1998
Vessel Construction Commenced	August 1998
Trial Fit between Spider Buoy and Lower Turret	December 1998
Dynamic Riser Configuration Finalized	December 1998
Lower Turret Shipped to Korea	January 1999
Vessel Keel Laying in Dry Dock/with Lower Turret	February 1999
Spider Buoy Shipped to Bull Arm, Newfoundland	April 1999
Vessel Launched	May 1999
Topsides Engineering Complete	May 1999
Anchor Legs and Spider Buoy Installed at Site	June 1999
Upper Turret Fabrication Commenced (Abu Dhabi)	Summer 1999
Lower Turret Partial Outfitting in Korea	Spring 1999 - March 2000
Vessel Departs Korea	March 2000
Connector-Tensioner and Retrieval Equipment Arrives in Bull Arm	Spring 2000
Upper Turret Arrives Bull Arm	April 2000
Vessel Arrives Bull Arm	May 2000
Connector-Tensioner and Retrieval Equipment Installed in Turret	May 2000
Upper Turret Installed on FPSO	June 2000
Risers Connected to Spider Buoy	Summer - Fall 2000
Lower QCDCs Installed on Spider Buoy	Fall 2000
Final Outfitting of Upper and Lower Turret	In Progress
Commissioning of Turret Systems	In Progress
Final Seatrials for FPSO	Spring - Summer 2001
Vessel Hook-up to Spider Buoy	Summer 2001
First Oil	Summer - Fall 2001



**Figure 1 – General Arrangement of the Terra Nova FPSO and Turret Mooring**

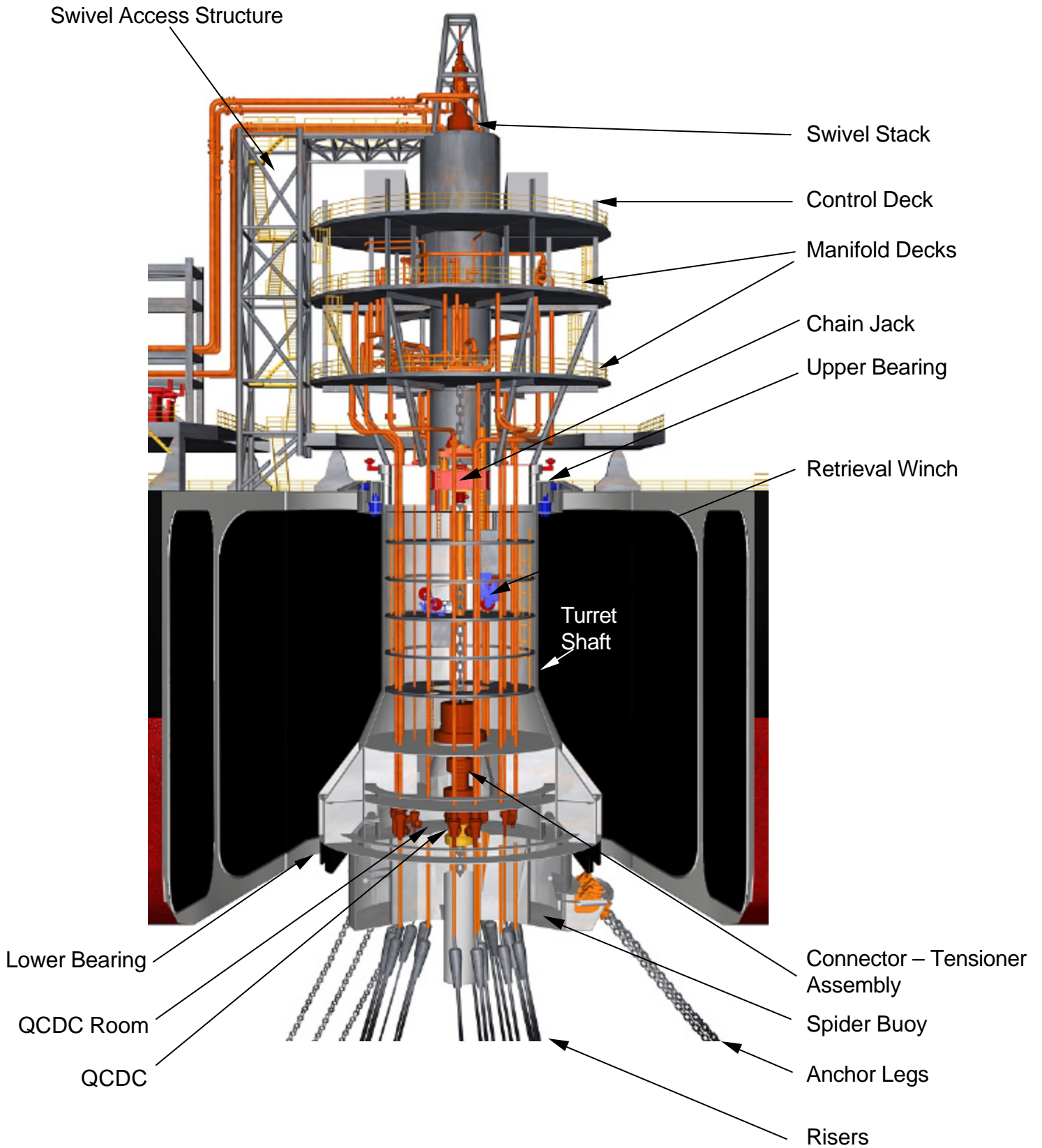


Figure 2 – The Terra Nova Turret System

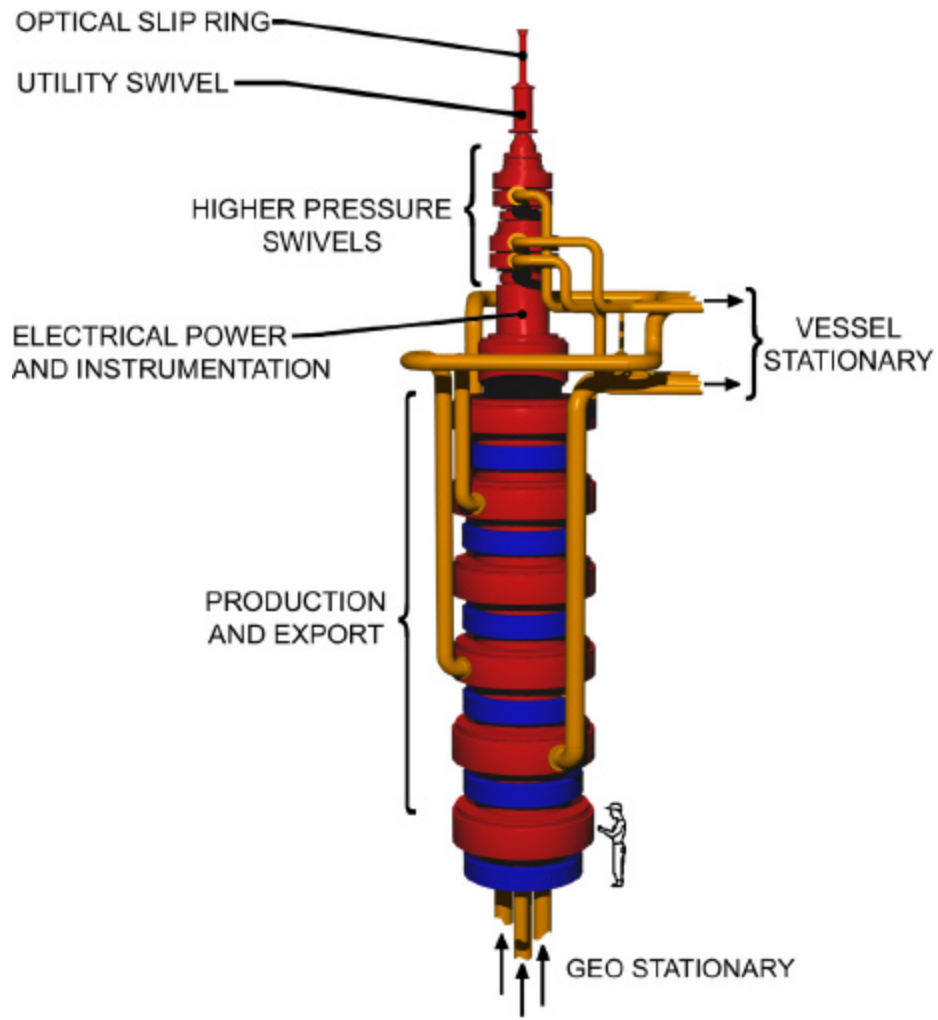


Figure 3 – Illustration of the Swivel Stack



Figure 4 – Installation of the Main Bearing



(a)

(b)

Figure 5 (a) and (b) – Trial Fit of the Lower Turret Module and Spider Buoy



(a)

(b)

Figure 6 (a) and (b) – Assembly of the Lower Turret Modules with Vessel in Dry Dock



Figure 7 – Installation of the Spider Buoy



Figure 8 – The Upper Turret Structure being Installed on the FPSO