A stepping stone for the industry
A stepping stone for the industry
INTRODUCTION

In December 1992, a consortium of international oil companies, led by Elf Aquitaine (now Total) of France, acquired the rights to explore a large license area of offshore acreage, designated Block 17, in waters off the West African state of Angola.

Even before the first seismic surveys were conducted and before a drilling unit put its marine riser in the water to begin the initial exploration well, Elf Aquitaine knew that if significant quantities of hydrocarbons were found at this location, any development would present challenges that the offshore oil and gas industry had not been confronted with before.

It has been the meeting of these challenges – technical, environmental and commercial – which make the development of the Girassol field worthy of note and a project that will be a benchmark for others in the future.

In the early part of 1996, following one unsuccessful drilling attempt, the exploration well GIR-1 was spudded by the drillship “Neddrill 3” in 1,300 meters of water. Drilled to a depth of 2,500 meters, the well encountered a classic deepwater shallow reservoir with unconsolidated, but hydrocarbon-rich sands. The well was tested at 12,500 barrels per day of 32° API oil. Subsequent appraisal wells, GIR-2A and GIR-2B, drilled by the semi-submersible drilling rig “Jim Cunningham”, proved very significant reserves of oil in place.
and set in motion what would be the first major deepwater project in West Africa and the biggest development employing a Floating Production Storage and Offloading (FPSO) vessel and subsea wells anywhere in the world.

The challenges confronted by Total, though, in the development of the Girassol field were greater than simply the technical problems presented by a deepwater field with a reservoir with a large areal extent. Total was faced with working in an offshore sector with little support infrastructure and with managing four large fabrication and supply contracts with suppliers spread around the globe.

Yet it is the technical challenges that make this development stand out. The water is deep (1,400 meters) and cold, presenting significant flow assurance problems that had to be overcome with a number of technical innovations that were “firsts” in the industry. The unconsolidated reservoir is expected to produce enough sand to make this an issue to be overcome by the completion specialists. The reservoir chemistry is such that new measures had to be taken to treat the injection water necessary to support the production of up to 40,000 barrels per day per well.

While not the deepest seabed conditions in the world, the field employed a new generation of subsea production hardware including the deepest oil production manifolds in the industry. And the task of bringing the crude oil to the surface at a temperature to prevent the formation of hydrates, required the fabrication of specially insulated flowlines and the first deployment of a type of deepwater riser system that will be copied again and again in upcoming projects.

The production vessel is one of the largest of its type in the world and its fabrication required the joint shipyard and offshore fabrication skills of one of the major shipbuilding companies in the world with project management provided by a consortium of international contracting companies.

The export system, often a part of an offshore production development that can appear mundane, took on a significance equal to many of the other innovations in this project. It included another industry first in the form of midwater transfer lines to the largest export buoy ever built.

From the reservoir to the export system, Girassol has presented a series of challenges to the development team that had to be met and overcome in order to bring the large reserves in the field to the world energy market. No step along the way was easy. Each one had to be measured and reflected upon.

In December 2001, less than six years from discovery, Total brought the Girassol field into production and within a month it was producing in excess of 100,000 barrels per day. Six weeks later, plateau production of 200,000 barrels per day was reached. This has been a world-class achievement.

**Less than 6 years from discovery Total brought the Girassol field into production.**
**A FEW SUPPLIERS OF THE PROJECT**

<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>COMPANY</th>
<th>SUPPLY</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANGOLA</td>
<td>Sonamet</td>
<td>Riser tower fabrication</td>
</tr>
<tr>
<td>ANGOLA</td>
<td>Petromar</td>
<td>Bundle fabrication</td>
</tr>
<tr>
<td>BRAZIL</td>
<td>Mc Dermott</td>
<td>Polyester mooring lines</td>
</tr>
<tr>
<td>DUBAI</td>
<td>Mc Dermott</td>
<td>Module support frame fabrication</td>
</tr>
<tr>
<td>ENGLAND</td>
<td>Murray</td>
<td>Structural beams</td>
</tr>
<tr>
<td>FRANCE</td>
<td>Teclam</td>
<td>Export line flexjoints</td>
</tr>
<tr>
<td>FRANCE</td>
<td>Kvaerner Heurtey</td>
<td>Process vessels</td>
</tr>
<tr>
<td>FRANCE</td>
<td>Alto Mar Girassol</td>
<td>Flowlines, risers and umbilicals: design, manufacture and installation</td>
</tr>
<tr>
<td>FRANCE</td>
<td>Mar Profundo Girassol</td>
<td>FPSO: design, build and installation</td>
</tr>
<tr>
<td>Germany</td>
<td>Dikema BV</td>
<td>Structural plates</td>
</tr>
<tr>
<td>FRANCE</td>
<td>NuovoPignone</td>
<td>Turbogenerators</td>
</tr>
<tr>
<td>ITALY</td>
<td>NuovoPignone</td>
<td>Turbocompressors</td>
</tr>
<tr>
<td>KOREA</td>
<td>Hyundai Heavy Industries</td>
<td>FPSO hull</td>
</tr>
<tr>
<td>KOREA</td>
<td>Hyundai Heavy Industries</td>
<td>Topsides construction</td>
</tr>
<tr>
<td>NORWAY</td>
<td>FMC Kongsberg</td>
<td>Subsea Production System</td>
</tr>
<tr>
<td>NORWAY</td>
<td>Frank Mohn AS</td>
<td>Crude pumps</td>
</tr>
<tr>
<td>NORWAY</td>
<td>Frank Mohn AS</td>
<td>Fire water pumps</td>
</tr>
<tr>
<td>SCOTLAND</td>
<td>Balmoral</td>
<td>Insulation foam</td>
</tr>
<tr>
<td>SCOTLAND</td>
<td>Oceaneering multiflex</td>
<td>Umbilicals</td>
</tr>
<tr>
<td>SWEDEN</td>
<td>Emtunga</td>
<td>Electrical and instrumentation building—Passive Fire Protection</td>
</tr>
<tr>
<td>USA</td>
<td>US filters</td>
<td>Water injection treatment—Sulfate Removal Units</td>
</tr>
<tr>
<td>USA</td>
<td>Nu – Chem, Inc.</td>
<td>Passive Fire Protection</td>
</tr>
</tbody>
</table>
The Girassol project is a deepwater development in 1,400 meters (4,600 feet) water depth, located 150 kilometers (93 miles) off the coast of Angola in the license area of Block 17. As a result of the technical challenges presented by the environmental conditions at this location, a number of industry “firsts” have been required to achieve the target of producing crude oil here. The reservoir is of a turbidite nature with an estimated 1.55 billion barrels of 32° API crude oil in place. Prior to the start-up of production, the estimated recoverable reserves were 725 million barrels.

The development, the first of this scale in West Africa, is based on a barge-shaped Floating Production, Storage and Offloading (FPSO) vessel and a subsea production system. The export of processed crude oil is via two rigid midwater pipelines, an industry first, to a CATenary Leg Mooring (CALM) buoy.

The Girassol reservoir is made up of unconsolidated sands and the well completions have been equipped with a number of different sand control devices to prevent damage to production tubing and other equipment beyond the wellbore. Sand detection monitors have been installed on each subsea xmas tree. Due to concerns about other flow assurance issues, such as hydrate formation and wax deposition, the production fluids must be kept above 40°C (104°F) for arrival at the FPSO. As a result, the wellstream is fully insulated from the subsea xmas trees on the seafloor all the way to the FPSO’s processing system.

The deepwater location required a number of installation scenarios for the various pieces of seabed hardware and different connection techniques for the range of requirements, such as
well jumpers between the subsea xmas trees and the production manifolds, the manifolds and flowline bundles, the bundles and the riser towers. The production wells are linked to seabed manifolds, the deepest oil production manifolds installed anywhere in the world, which are arranged in a “daisy chain” configuration. The wellstream is then transported through flowline bundles to a series of riser towers, another industry “first” to be deployed on this project. Flexible jumpers link the top of the towers to the FPSO. Water injection wells provide pressure support for the production wells which are expected to produce at a rate of up to 40,000 barrels per day. The water injection wells are supplied by a series of flowlines.

The philosophy of Total on *Girassol* has been to reduce its impact on the environment to a minimum. As a part of this effort, a non-flaring policy has been adopted. Associated gas is used for gas lift and injected for pressure maintenance in the reservoir. In the future, gas may be exported to shore to provide feedstock for a proposed Liquefied Natural Gas (LNG) plant.

The development is in two phases. The first phase includes eight production wells, two water injectors and one gas injector. Phase two is ongoing and will be completed in the middle of 2003. The production system will eventually consist of 23 subsea completed wells linked to 11 seabed manifolds. This system, an advance on the HOST 2500 concept, has been qualified by its manufacturer, FMC Kongsberg Subsea, for applications to 1,500 meters of water. This is the first use of this equipment.

In order to ensure a high reliability and availability, a qualification program was undertaken on 40 different items of hardware. There was also extensive verification testing including integration testing of subsea xmas tree systems and shallow water testing to demonstrate interface compatibility.
The production system is controlled by an electro-hydraulic multiplexed control system. Each subsea xmas tree has its own subsea control module which is fully retrievable. The system provides data from a range of sensors – down each well, on each tree and from each manifold. It will also be able to communicate with “intelligent” completion systems which may be installed on some wells in Phase two. It can also interface with the Subsea Acoustic Monitoring System (SAMS) which is used to record data from downhole gauges prior to hookup with the FPSO. The link with the subsea control modules is by a network of 54 kilometers of seabed umbilicals. Each production umbilical has four hydraulic lines – two high pressure and two low pressure – plus six chemical injection lines to provide a scale and corrosion inhibitor to each well and four electrical cables for power and communications. The umbilicals which link the water injection wells are simpler, with the same four hydraulic lines and electrical cables plus a single 1-inch service line. All of the tubes within the umbilicals are made of super duplex steel.

The well fluids travel through 11 flowline bundles, of 27 kilometers in total length, to the base of the riser towers. Each bundle is based on a 30-inch carrier pipe which has two 8-inch production flowlines and one 2-inch service line. These lines are encased, inside the carrier pipe, in a syntactic buoyancy foam specially developed for the flow assurance requirements of this project. The water injection system is based on four 12-inch flowlines with in-line tees. Each tee is connected to one injection well. The interface between the seabed flowline system and the FPSO is a system of riser towers, the first of their type ever used in such a development. The system is comprised of three vertical “bundles” of pipes. At the core of each riser is a 22-inch pipe around which are four 8-inch production lines with four 3-inch gas lift lines plus two 8-inch injection lines and two 2-inch service lines. All of these lines are encased in the same syntactic buoyancy foam as used in the flowline bundles. At the top of each riser tower is a complex of flexible jumpers (for production and water injection) and bundles of super-duplex pipes for the service and gas lift lines which link up with the FPSO. The FPSO is believed to be the biggest in the world in which a loading buoy is used to export the processed crude oil. The unit is 300 meters

The first riser towers of their type ever used in such a development.

The system of riser towers is comprised of three vertical “bundles” of pipes (1,250 m high).
The oil processing train can accommodate 200,000 barrels per day of crude.
of polyester fiber and chain, is located 1.6 kilometers from the FPSO at a water depth of 1,320 meters (4,330 feet). The export lines were installed by a new offshore construction vessel, “SaiBOS Offshore’s Field Development Ship” (FDS) using its j-lay tower.

This innovative landmark project has been supported by an international team of contractors and suppliers from Europe, North America, Africa and Asia. Some were asked to qualify existing equipment for the requirements created by Girassol’s deepwater location. Others were asked to develop new concepts, equipment and materials that had to meet new, even more demanding criteria. The result has been to create a new catalog of concepts and systems for use by the offshore industry in deepwater developments around the world.
The key design parameter for the flow assurance program is the arrival temperature of the fluids at the wellhead: 58°C (136°F). While the hydrate formation temperature is 20°C (68°F), of greater significance is that the Wax Appearance Temperature (WAT) is 40°C (104°F). The seabed temperature is a standard 4°C (39°F) at the 1,400 meter location.

This meant that the thermal design of the system required that the arrival temperature of the well fluids at the FPSO’s process system had to be above 40°C (104°F). In the event of a production shutdown, the well fluids had to remain above 20°C (68°F) during a 16-hour cool-down period. After this period, hydrate formation is prevented by circulation of dead crude and methanol injection.

To minimize temperature loss in the wells, conventional brine was replaced with gelled diesel oil in the production annulus. This reduces the effect of convection in the annular spaces after well startup. The subsea xmas

**FLOW ASSURANCE**

Flow assurance is a subject that is never far from the lips of any engineer. Even before Girassol became a development, Total knew that dealing with flow assurance issues would be a key to the success of this project. These would eventually be divided into a number of areas. There would be a need for thermal insulation for temperature maintenance to prevent hydrate formation and wax deposition. Control of sand particles from the unconsolidated reservoir would have to be dealt with. The chemistry of the reservoir was not compatible with the use of untreated or conventionally-treated seawater for water injection purposes. In addition, there had to be a slug management strategy and a corrosion inhibition program.

An analysis of well fluids gathered during the exploration period revealed that there would be a need for a significant thermal insulation strategy from the wellhead to the Floating Production Storage and Offloading (FPSO) vessel, including the injection of chemicals and methanol in the wellbore and at the xmas tree.

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**OVERALL CHALLENGES**

**FLOW ASSURANCE & OFFSHORE INSTALLATION**
trees were identified as potential “cold spots”, or heat-loss locations, within the system, notably on add-on hardware items, such as subsea choke valves. It was thus necessary to insulate these items and similar ones on the subsea manifolds.

Of greater concern was the design of the insulation for the flowlines and riser towers. At the time the project was launched, Total believed there was no insulating material available on the market that had the correct characteristics that could provide both the insulating properties of low-density foam and the pressure resistance for the deepwater location of high-density material. The requirements were also to be able to withstand the external temperature (90°C / 194°F) of the gas lift risers.

The material finally chosen was a glass syntactic foam with a pure amine hardener developed by the Balmoral Group of Aberdeen. The development of the material – with a density of 590 kilograms per cubic meter and a thermal conductivity of 0.12 watt per meter kelvin – was only one problem solved. Balmoral had to develop a manufacturing process for this new material and to provide 4,000 foam modules for the three riser towers and 7,800 foam modules for the flowline bundles. In all, Balmoral had to deliver 10,000 cubic meters of foam modules.

The issue of sand control was solved through the use of two different methods for the production wells. For horizontal wells, open hole designs with sand screens were employed. In low angle wells, gravel-packed completions were used. In addition, acoustic sand detectors are installed on each xmas tree to provide an operational warning should sand production commence.
Of quite significant importance has been scale management. As previously mentioned in the project description, the water injection capability of the process plant is 390,000 barrels of water per day. The typical sulfate content of the seawater in Block 17 is 2,800 milligrams per liter while the Girassol formation water composition contains sufficient quantities of barium, strontium or calcium – 4,000 milligrams per liter, 230 milligrams per liter and 225 milligrams per liter, respectively – to suggest a sulfate scale deposition potential of 320 grams of barium and calcium sulfate per cubic meter of produced water. This presented a threat of deposition from the production tubing to the topsides.

The use of downhole chemical injection would not have sufficiently protected the entire system. The only answer was to remove the sulfates from the water. There have been other sulfate removal systems used offshore in the Gulf of Mexico and the North Sea, but neither had to deal with such large quantities of injection water or meet such a low sulfate objective (40 parts per million). The result was the design and installation on the FPSO of the largest sulfate removal system ever built.

The final aspect of the flow assurance challenge is slug management. Simulation suggested possible adverse effects of slugs on the FPSO topside. The slug management strategy on Girassol relies on preventing the formation of slugs, not dealing with them. The use of riser base gas lift and riser choke attenuation combine to form a slug suppression strategy.

**INSTALLATION**

At a 1,400-meter water depth location, the installation of equipment was always going to be an important element. This included not only the setting up of equipment on the seabed, but the connection of the various elements of the system to one another.

During Phase one of the development, for example, 127 subsea connections had to be executed between the various subsea components – xmas trees to manifolds, manifolds to flowline bundles and flowline bundles to the riser towers. Two different connection systems were deployed for this work – the MATIS (Modular Advanced Tie-In System), developed by Stolt Offshore, was deployed for the bigger flanged connections, while FMC Kongsberg Subsea’s CAT (Connection Actuation Tool) was used primarily for the mechanical tie-ins associated with the subsea xmas
trees and the manifolds. Each had to be qualified – for shallow water trials and deepwater tests in a fjord in Norway – before being taken to offshore Angola.

Other key elements of the system – the flowline bundles, the riser towers and the export lines – were either totally new technology or had never been deployed at such water depths. As a result, new procedures had to be engineered and developed to cope with all of the uncertainties associated with each of these elements. These included deepwater bottom tow of the flowline bundles, the tow and upending of the riser towers and the installation of the midwater export lines by the j-lay method. None of these techniques had been attempted before. The full details of these installations are described in separate sections.

One of the organizational challenges confronted by the installation contractors – Stolt Offshore and Bouygues Offshore – was the large number of vessels that were to be used for the activities. These included:

- **“Seaway Polaris”**, lowering of a variety of subsea packages including suction anchors, manifolds, spools and jumpers...
- and j-lay of the injection lines;
- **“Seaway Eagle”**, lowering of subsea packages;
- **“Seaway Explorer”**, towing of production bundles and riser towers, tie-in of spools and jumpers using MATIS and CAT systems;
- **“Seaway Kestrel”**, diving activities at top of riser towers, installation of insulation covers on connectors;
- **“Seaway Legend”**, metrology and support to other vessels;
- **“Malila”**, tie-in of spools and jumpers with CAT system;
- **“SaiBOS FDS”**, installation of flexible jumpers between FPSO and riser towers, installation of umbilicals, j-laying of export lines, tie-in of umbilicals with CAT system.

“SaiBOS FDS”, one of the numerous specialized vessels used by the installation contractors.
These were only the main vessels. A fleet of supply boats, tugs, barges and other surface diving support vessels were involved and their operation had to be organized, coordinated and deployed.

A number of the vessels deployed also had to undergo modifications to ensure their suitability for these deepwater operations. For example, “Seaway Polaris” was fitted with a new j-lay tower for the installation of the water injection flowlines and with an active heave compensation system to ensure the correct location and orientation of the seabed equipment.

Deepwater handling tests were also carried out in 1,500 meters of water off West Africa with “Seaway Polaris” to confirm dynamic response of loads hanging from the crane. Each tower is founded on a 20-meter long suction anchor, placed to a positional tolerance of 5 meters. To install these, the crane on “Seaway Polaris” was upgraded to handle a load of 450 tons at 2,000-meter water depth. Numerical modelling showed that a heave compensation system was not necessary off West Africa.

To support the installation program, an array of stands for seabed transponders was installed to allow vessels and drilling units to locate themselves within a unique referencing positioning system. This would allow each vessel to simply install its own locating transponders and be able to begin working with a minimum amount of calibration. These stands have been left in place for field life for the positioning of intervention vessels and for future field development extensions.

“Seaway Legend”, specialized in metrology and support to other vessels.
When Elf Exploration Angola (now Total) began its exploration activities on Block 17, offshore Angola, in 1993, it believed that it had some idea of what it was going to find. Having operated the onshore Block 3, there was a belief amongst its geoscientists that they would find similar geological structures despite the much deeper waters (1,400 meters). They found something different. The reservoir on the Girassol field is turbiditic in nature with unique characteristics. It is made up of unconsolidated sands – coring samples revealed them to be not dissimilar to what might be found on a beach – with a porosity above 30%, a high gas to oil ratio (GOR) and a reservoir pressure near bubble-point. It is also a classic deepwater field with shallow hydrocarbon-bearing structures below the seabed. The submudline location of the structures is between 1,100 meters and 1,200 meters.

Two-dimensional seismic survey of Cretaceous era structures between 3,000 meters and 4,000 meters below the seabed.

Exploration specialists believed these to be gas-bearing with low reservoir potential. It was decided to focus attention on a more shallow Tertiary structure. Elf Aquitaine chose to target this structure in 1995 as part of its four-well commitment program under the license terms. This well, dubbed “Margarita-1”, was not a success in terms of hydrocarbon discovery, but revealed many details about the structure in general. There was excellent porosity and permeability in the target sands and there were sand-prone sequences that pointed the exploration team in the direction of where the next well location should be. This would be in even deeper waters, but at shallower depth below the mudline where the source rock would be easier to find.

In the early part of 1996, the well GIR-1 was spudded aiming at Tertiary structures in the western portion of Block 17. At 1,100 meters below the mudline, hydrocarbon-bearing structures were found. The results from logging, including resistivity and pressure data,
suggested good structure, although it was difficult to recover cores due to the unconsolidated nature of the sands.

These early results convinced the exploration team to undertake a well test, the first on this block. This exercise proved the potential of the reservoir as the well tested at 12,500 barrels per day of 32° API crude.

The success of this well convinced Elf Exploration Angola and its partners to undertake an extensive 3-D seismic survey over target areas in Block 17. The results defined the potential of the Girassol field, i.e. a minimum of 1,000 millions barrels of crude.

In total, the license group drilled 17 exploration wells across Block 17 before Girassol came into production at the end of 2001. Only two of those wells were unsuccessful, providing Total with what will be a string of development opportunities over the next five years.

Despite the success of the drilling program, the reservoir specialists were confronted by some specific challenges in developing this reservoir. The Girassol system is comprised of three different turbiditic structures. Each channel is substantial – several kilometers wide, many kilometers long and around 50-100 meters thick – and separated from each other by regional seals.

The reservoir characteristics were established from wireline logging and coring acquisition gathered during the drilling of the initial development wells. There is, though, a regional fault pattern across the structure with considerable sealing potential which would have a significant effect on communications between development and injection wells and thus their locations in the field. In order to determine the sealing potential, it was decided to under-
take a well interference test between two wells prior to the startup of production by analyzing data from downhole pressure gauges. The development team deployed a Subsea Acoustic Monitoring System (SAMS), another industry first. The SAMS, which interfaces with a subsea xmas tree and its control system, gathers and stores data from the gauges subsea for retrieval at a later time. This could be via acoustic transmission or by direct retrieval by a ROV. A key feature of the SAMS design was its ability to be ROV-retrievable for use at various locations. The operation of the SAMS was a success. In the initial test between wells GIR-101 and GIR-103, which involved shutting in one well and injecting water into the other, the test was able to confirm communication between the structures and show that the faults were non-sealing. This method of well testing avoided the need to burn crude oil, fitting in with Total’s non-flaring philosophy.
The drilling and completion of a program of 39 subsea wells at 1,400-meter water depth would be a challenge for any operator. The fact that the work was to be carried out by a pair of newbuild drillships exaggerated the potential for problems.

The drilling and completion (D&C) team had an impressive set of objectives to meet. It had to drill 8 high-productivity (20 - 40,000 barrels per day) wells before first oil to meet the plateau production target. The well design had to be reliable to minimize workovers. Complex subsea completion equipment had to be installed at a water depth where the industry had little experience. And due to the high cost of rig operations, non-productive time (NPT) had to be kept to a minimum.

What complicated the NPT issue was that the risk factors involved in drilling offshore Angola are totally different from industry experience, for example in the North Sea. In the latter sector, the biggest risk is the environment, meaning the weather. Water depth and infrastructure represent low risks, while logistics are considered medium. At Girassol, a remote deepwater location in an offshore sector with few support services, logistics, water depth and infrastructure all represent high risks, while the benign weather conditions are at the opposite end of the spectrum.

There were two other issues of concern to the operator. One was to limit the complexity of the well design, despite having to cope with two different types of sand control philosophies based on well type. And with a long drilling program planned, there was a need to maintain personnel continuity to ensure that improvements gained by experience and lessons learned during operations were incorporated in general practice.

The amount of capital at risk was substantial. Based on an industry standard of 30% NPT per well, with 39 wells planned at an average of 30 days per completion and US$ 300,000 per day rig rate, the project was exposed to a potential of US$ 105 million of added costs.

The basic problem for the project, though, was rig availability. Early on, it was realized that not only were there a limited number of rigs capable of working in the water depths at Girassol, but many of those which existed were...
already on long-term charter. It was decided that it would be necessary to order newbuild units – dynamically positioned drillships were believed to be the best option to avoid interference with seabed equipment – to execute the drilling program. A contract was signed with Pride International to supply these units.

The main design challenge for the wells was to deal with the unconsolidated sands. Two different types of lower completions were employed – open holes with screen-only for the horizontal wells and gravel-packed (frac pack) completions in the deviated wells. This was complicated by the variation in grain size in the Oligocene reservoir. Screen-only design would not do for finer sands nor could it be used throughout the entire horizontal drain. Essentially specific designs had to be chosen for specific locations.

The issue of NPT proved to be less of a problem than originally thought. Over the first 14 wells, the NPT was just under 19% and improved from the first seven through the second seven.

Another rig cost-related issue – completion time – improved during the project. For the first 12 wells, the average completion time was 192 hours or exactly eight days per completion. The twelfth well in the program was completed in just 110 hours and Total has decided that this should be the future target, a reduction in time of three days or nearly US$ 1 million per well.
The subsea production system at Girassol is an adaptation of the HOST 2500 equipment developed by FMC Kongsberg Subsea. Although the basic HOST (Hinge-Over Subsea Template) system has been deployed in various locations around the world, this adaptation of the equipment for operations to 2,500 meters (8,200 feet) has received its first use on this project.

Each well has a vertical subsea xmas tree – the pressure control device – of a 5 inches by 2 inches design with a design life of 20 years and a minimum pressure rating of 5,000 psi. Each sits on a permanent guidebase. The vertical tree was chosen as it was field proven at the time of the development and it requires only a single trip with the blowout preventer (BOP) for installation, a process which is very time consuming and costly in a deepwater development. Each tree is fitted with a tree cap which is installable and retrievable by a Remotely Operated Vehicle (ROV).

The subsea configuration is two production wells per manifold, connected by a well jumper and an umbilical jumper. The manifolds are then “daisy chained” up to four in a row. The furthest manifold is 6 kilometers from the Girassol field center, the Floating Production Storage and Offloading vessel (FPSO).

Each manifold sits on a manifold support structure with levelling capability which itself is supported on the seabed by a Closed Caisson Foundation (CCF) structure (5.7-meter diameter) with a design penetration of 10 meters in the soft soil conditions at Girassol. The design calculations were validated and the CCF self-penetrated to a depth of 8.5 meters. The installation design was based on an accuracy of +/-5%, as the original basis of +/-2.5% was originally believed to be too stringent. It was subsequently determined that the more stringent accuracy is feasible.

There are also six pig loop modules associated with the network of production manifolds.
These allow for the running of pipeline cleaning pigs through the flowline network. Water injection wells are located individually and linked to the water injection flowline system by a series of in-line tees and well jumpers.

The subsea control system is based on a topside control console which monitors 41 subsea control modules. Each subsea xmas tree has an SCM, as does each manifold. The control system interfaces with sensors at the xmas tree (pressure, temperature, valve position, sand detection) and at the manifolds (pressure, temperature, pig signal, multiphase meters). In total, there will be 39 subsea xmas trees – 23 for production, 14 for water injection and two for gas injection. Each production tree is externally insulated to reduce heat loss and prevent hydrate formation. During cooldown, each production tree is inhibited with methanol with dead crude circulation. Other equipment associated with the production xmas tree includes a retrievable insert choke valve, a sand detector and a Subsea Control Module (SCM).

There are stringent technical requirements on equipment for such a deepwater location due to the cost of replacing equipment and general concern about “infant mortality” which is the failure of equipment at an early stage in its operational life. FMC Kongsberg Subsea and Total decided to subject many individual items of equipment – 40 items in all – to a qualification program. Amongst the items which had to be qualified were the 5.1/8-inch deepwater actuator, the subsea multiphase flowmeter, the riser control module, the workover control umbilical, the compact monobore and multibore connectors, the thermal insulation and the tie-in tools.

In addition, a comprehensive test program was undertaken to verify the elements of the subsea production system before delivery. The test program included factory acceptance tests, sub-system tests, integration tests, shallow water tests, pre-delivery stack-up tests and a range of other tests, such as deepwater tie-ins, ROV interface, thermal insulation of xmas tree, etc.
The production flowlines which transport well fluids from the manifolds to the three riser towers were fabricated, like the towers, onshore as complete and insulated structures.

For the first phase of the development, a total of 18 kilometers of insulated flowline bundles were fabricated and towed for installation at the field. That total was built up from eight separate bundles, varying in length between 700 meters to 3 kilometers with all but two of them exceeding 2 kilometers. In the second phase of field development another three bundles are to be installed, totalling 4 kilometers in length.

One by one, from April to July 2001, the first phase bundles were towed and placed at their appointed positions in the five production loops which link the field’s daisy chain of subsea manifolds. Each bundle takes the form of a 30-inch carrier pipe that contains two 8-inch production lines and a 2-inch service line, encircled by two semi-cylindrical syntactic foam modules.

One of the carrier pipe’s main functions was to protect the package during the 220 kilometers on-bottom tow from the fabrication site to the field, while the syntactic material provided buoyancy (a submerged weight of about 90 kg/m) and insulation. It also helps resist external pressure and contributes to overall thermal performance of the system because it prevents any entry of seawater into the bundle. All voids are filled with inhibited water.

At the ends of each bundle is a 15-meter sled which serves both for the tow-out operation and as structural support for tie-in spools. These sleds weigh 25 tons in air and carry a 20-ton buoyancy module.

Design criteria for the production system is a pressure of 270 bar and a temperature of 70°C (158°F). To minimize paraffin deposits, oil has to arrive at the FPSO at a temperature not less than (40°C / 104°F) for a flow rate of 10,000 barrels per day.

In shutdown conditions, temperature has to remain above 20°C (68°F) for 16 hours at all points in the line to prevent hydrate formation. This means that all potentially cold spots such as spools and connectors also have to be insulated, using insulation shells and covers.
For standardization purposes, the foam modules are the same material as used in the riser towers. After the intensive program to develop a new syntactic foam for the project, the supplier Balmoral had to manufacture some 7,800 modules to insulate the flowlines. Together with the 4,000 modules provided for the riser towers, this represents 10,000 cubic meters of high-density foam in a material never fabricated before. The modules are 6 meters long with profiles designed to interlock and provide a tight fit. When a 12-meter long full-scale section of flowline bundle was tested to assess thermal behavior a convection phenomenon was noted here, undermining insulation performance. Additional seals were fixed to respond to this problem.

In mid-2000, flowline bundle construction began at the Soyo yard, 325 kilometers beyond Luanda. As they took shape on the yard’s 5-kilometer production line, the bundles were pulled in 230-meter increments into a lagoon where they awaited towout. An earlier test tow had set the parameters for the bottom-towing operation to move the bundles to the field. To confirm the tow route and select the best anti-abrasion material, a 12-inch pipe coated with different materials was bottom-towed from Soyo to the field and back again. As a result, a 7-millimeter thick coating of polypropylene was selected for the coating of the carrier pipe.

When the time came for towout of the eight flowline bundles, “Seaway Explorer” was able to carry out the work with a maximum bollard pull in the order of 200 tons. The bottom tows – including hook-up and final positioning – averaged eight days each, with the quickest taking five and a half days.

The concepts developed for this project provide reference points for upcoming deepwater developments. In addition, Girassol has provided invaluable experience, identifying most of the challenges which affect deepwater developments and defining some of the limits of technical solutions.

During the first phase of the Girassol development more than 125 subsea connections had to be executed using three different connection systems. All the tie-in operations were carried out using rigid spool pieces or jumpers, fabricated onshore following the use of subsea metrology.

This project marked the first use of the deepwater version of Stolt Offshore’s MATIS (Modular Advanced Tie-In System). Although sophisticated in operation, this system is a low-cost option as it is based on the use of industry-standard bolted flanges. The system simply aligns two pipe ends, installs a gasket between them and then torques a series of bolts to the proper tension. Deep MATIS consists of two units – a Flanged Alignment Frame (FAF) and the Module Deployment Frame (MDF). The tool is 6.2 m x 3.6 m x 3.8 m and weighs 23 tons. With its handling structure, the weight in air is 51 tons. Work is in progress to decrease the size and weight of the tool. The FAF, a frame with claws at either end, picks up the pipe end or spool and aligns the flanges. The MDF, which can slip into the middle of the FAF, handles all of the bolts, the insertion of the gaskets and
the torquing. In the configuration for this deepwater application, the two units are deployed together.

MATIS is being used for making both horizontal and vertical connections, the former on the top of the sleds at the ends of the flowline bundles and the latter at the base of the riser towers. A total of 52 flanged connections were executed in the first phase of the project.

The connections associated with the xmas trees and manifolds were carried out using FMC Kongsberg Subsea’s Connection Actuation Tool (CAT). The CAT, which weighs 2.5 tons, activates a mechanical connector and allows horizontal connections in line with the pipe. The weight of each connector is around 5 tons including the stabbing system.

There were a number of requirements for this tie-in system. It had to be simple and reliable, reducing the number of connections through the use of multi-bore connectors. There was a preference for horizontal connections which allow module retrieval independently of one another. The system had to have high flexibility regarding the surface support vessel. Its design had to allow deployment from either a drilling unit, or a pipelay vessel or a small supply boat. It had to be able to adapt to seabed conditions with all connections to be performed at a minimum of 2 meters above the seabed, avoiding interference with the soil and thus turbidity.

The tie-in system is a novel ROV-deployed connection tool. The connections included:

- **flowline connection**: monobore 8 inches and multibore 8 inches, 2 inches and four by 1 inch;
- **umbilical**: multibore 10 by 0.5 inch and up to seven electrical quads;
- **production well jumper**: multibore 6 inches, 2 inches, eight by 0.5 inch and two electrical quads;
- and **injection tree**: multibore 6 inches, 2 inches and four by 0.5 inch. The 2-inch and the 0.5-inch lines are terminated in a Multibore Quick Connect (MCQ) plate on the termination head to receive a flying lead.
The manifolds and trees contain the hub while the termination heads includes a 10-inch collet connector. The connector is the same for all except for the bore configuration. The ROV-deployed CAT lands on the termination head and the hub. The tool first strokes the connector and flowline forward and closes the connector. To verify connection, a low-pressure back seat test is performed.

The connection between a bundle head and manifold or tee and tree is a spool piece based on a rigid pipe design. The well jumper has a “Z” shape and is installed horizontally. At a later stage in the project, a U-shaped jumper was developed to eliminate the need for specialist installation vessels.

The jumpers, prefabricated in Norway, have a termination head at each end. Based on metrology of the actual location, the final jumper layout is established and the prefabricated spools are cut to suit and welded together. Insulation is then applied and testing finalized prior to transportation to quayside.

In addition to factory tests, these tie-in systems have been subject to extensive qualification testing in Norway. This included shallow water tests in Bergen and Haugesund and deep water tests in Sognefjord.

Fifty-two MATIS connections were performed – 13 vertical and 39 horizontal. The average duration for a tie-in operation is estimated at 14 hours, while the time to close each flange is about nine hours.

Forty-six CAT connections were performed at an average duration of around five hours.
One of the most challenging aspects of any development in water as deep as at Girassol (1,400 meters) is the riser system which transfers fluids from the seabed to the processing facility on the surface and vice versa.

At Girassol, this challenge was made even greater by the need to provide substantial insulation to the riser pipes – as well as the rest of the flowline system – so that the temperature of the crude oil is maintained as it makes the long journey from wellhead to FPSO deck. These needs have been met by the project’s three unique free-standing riser towers. Girassol’s wellstream comes to the surface via twelve 8-inch diameter steel riser pipes with another six of the same diameter provided for water and gas injection. These are gathered in three groups of six pipes around a central structural core pipe of 22 inches in diameter with the whole assembly encased in an insulating syntactic foam material which also adds buoyancy. The result is three long thin towers, less than 1.5 meters in diameter and measuring 1,280 meters from seabed to their top at a point 50 meters below the water’s surface. These long strands are more or less weightless in water due to the buoyancy provided by the encasing foam.

![Risers Technical Aspects](image)

Each riser tower is 1,250 meters in length and 1.5 meters in diameter.
They are held upright in tension by a steel buoyancy tank at the top that provides 520 tons of uplift, leading the whole assembly to behave like an inverse pendulum, hinged at the top of its suction anchor.

This arrangement also yields the great benefit of relieving the FPSO of nearly 2,000 tons of load which would otherwise hang off the production vessel if a conventional catenary riser system had been used. The top buoyancy tanks provide a connection point for the fairly short shallow water catenaries of flexible pipe which complete the final links between riser tops and the FPSO.

While the riser towers are easy to describe, they presented a pioneering engineering effort to design, qualify, build and install. There was no precedent for Total to go by and the contractor Alto Mar Girassol pushed out into this uncharted territory.

The riser towers have their origin in a design competition set up by Total in summer 1997 and the scope specified stringent insulation requirements. Criteria included preserving a minimum oil delivery temperature of 40°C (104°F) at the FPSO to avoid wax deposit and during shutdown a minimum of 20°C (68°F) for 16 hours.

In July 1998 the riser tower design was selected as the successful proposal from the three submitted. This decision was based on a number of criteria including the overall thermal behavior of the concept. It involved bringing together the risers in three insulated groups, each formed by the six 8-inch pipes, plus four 3-inch gas-lift risers and two 2-inch service line risers.

After winning a design competition at the start of the project, AMG and foam module supplier Balmoral went through a testing period to achieve the desired thermal performance. In summer 2000, not long before tower construction was due to start, tests on a 12-meter long full-scale section of prototype tower revealed that thermal insulation capabilities could be undermined by a “plume” effect.

This phenomenon involved very small movements of warmed seawater rising within the body of the tower in the annuli around the main riser pipes. The adopted solution was to add open-cell foam around the riser pipes to prevent this movement of water. This yielded a dramatic improvement in performance.

Also a bitumen/PVC coating was added to the whole exterior as a further barrier to the flow of water into or out of the tower. This additional work was completed without affecting the project schedule.
To build the *Girassol* towers a mechanized production line was set up at the Lobito yard on the Angolan coast, 450 kilometers south of Luanda. Individual pipes were first welded. These then converged onto a main assembly line where foam modules and final coating were added. As 48-meter long sections of tower were completed, the leading end was steadily fed out into the bay. The first tower took two months to build and the third less than a month, with production averaging 96 meters of tower per day by the end of construction.

With the complete 1,280-meter long towers floating in the bay, the top buoyancy tanks, transported from France, were added. These tanks are complicated structures in their own right, weighing 450 tons and measuring 40 meters long. They taper from 8 meters in diameter to 5 meters, have 28 internal compartments and are pressurized internally with nitrogen. Installation of structures such as these riser towers also took large steps into unknown territory. First there was the challenge of towing these vulnerable 1,280-meter strings for 600 kilometers from construction yard to offshore location. It was essential that as little as possible fatigue life be used up through motions induced by waves and sea currents on this journey.

Once on location, the base of each tower had to be hauled down to its anchor point, maneuvering the 3,400-ton mass so that it was first swung down from horizontal to vertical, then stabbed into permanent position. All this called for extremely thorough pre-planning by AMG and its team.

At the start of the project, AMG identified the riser tower installation as an operation with significant levels of risk as no such installation operation had ever been carried out before. The consequences of any incident would have a severe impact on the project as a whole. In reality, towing and installation were completed without a hitch. In rapid succession over a 25-day period from mid-June to mid-July, the three towers were towed out from
shore, upended to the vertical and latched to their pre-installed seabed anchor points at location. The first tower began its journey from Lobito on June 16th, 2001, latching eight days later. The third tower was latched on July 11th after a five-day operation.

Fatigue, rather than structural strength, had been a critical factor in much of the planning. Fatigue considerations dominated the choice of towout route, which was influenced by the best combination of current, swell direction, significant wave height and exposure time. With one tug at the front and another at the rear exerting 30 tons of back tension, each tower floated on the surface for the journey to the field, apart from the top tank at the rear which was submerged 50 meters. Speed was 3.5–4 knots. In the event, fatigue induced in the tower was less than expected.

Extensive model testing and full-scale trials had been included at the planning stage. This included a full-scale tow test in Scotland to ensure that the external skin of the tower did not peel off and a surface-tow trial with “Seaway Explorer” and “Seacor Voyager” to validate vessel procedures and train offshore personnel. The upending of each tower at the field was extremely spectacular, but as a result of careful detailed engineering it was achieved without any incidents. The weight of an 80-ton deadman anchor, coupled with movement of the tug, was used to make the riser foot dive in a controlled manner with no need for water ballasting. An advantage of this operation was that it was fully reversible.

Docking with the suction anchor was critical as it was difficult to predict the dynamic response of the tower under the excitation loads of the deadman anchor and leading tug. As the tower moved to the vertical and approached the flex-joint assembly on the pre-installed suction anchor, two synthetic rope pull-down slings were passed to the anchor by an ROV. This allowed the tug to pull the tower down and stab its base into the Rotolatch connector.

Once properly secured, deballasting of the top buoyancy tank could proceed, building up tension in the tower. A further unique operation was the placing of large umbilical support arches at hangoff points on each tower. These were deployed off “Seaway Polaris” in horizontal configuration, gently landed on their supports, then allowed to swing down to the vertical and secured by ROV-activated clamps.

The success of the Girassol project establishes the riser tower concept as a real solution.

The success of the Girassol project and the experience gained firmly establishes the riser tower concept as an important solution for deep and ultra-deep field development projects. That success is a direct result of the efforts put into engineering preparation. This presented the twin tasks of meeting the industry’s most challenging thermal insulation requirements and ensuring installation of each tower using conventional spreads. The project team now has a clear vision of how such a large structure behaves in open seas and the knowledge of how to extend the Girassol experience to other fields in even greater depths.
With its vast size and large process capacity, the Floating Production, Storage and Offloading (FPSO) vessel at the center of the Girassol layout can justifiably be called “le plus grand FPSO du monde”. The vessel’s huge oil storage capacity of two million barrels gives it a length of 300 meters and a width of 60 meters. The blunt-nosed, ship-shape unit – with accommodation for 140 people – has a maximum operational displacement of 400,000 tons. On its deck it supports facilities to process 200,000 barrels per day of oil. This is one of the highest oil production rates seen on any floating platform anywhere in the world, quite apart from the impressive volumes of water and gas also handled on the installation (see sub-section on process facilities).

Even though the FPSO (including export buoy) has accounted for US$ 920 million out of the US$ 2.8 billion total project cost, this was below the final target price. And the unit met its revised schedule for completion.

An FPSO such as this can best be described as a refinery on a super-tanker. The building of such a vessel brought together two different cultures – shipbuilding and the oil industry. The clashes between these two cultures have led to a number of unhappy experiences on previous large FPSO projects. So Total and its main contractor, Mar Profundo Girassol, put considerable emphasis on minimizing the potential for such problems on the project. A central part of the strategy was to seek maximum separation between hull and topsides. By minimizing the number of functions in the hull, the shipbuilders would be able to go forward with hull construction in their traditional way, while “oil industry” functions could be concentrated in the topsides.

One innovation at Girassol is the 7-meter high cellar deck concept, using a module support frame to hold all process equipment and most of the utilities above the ship’s main deck. This proved very practical in reducing the amount of interface between hull and topsides – at the heart of so many past problems – and allowed pipework of all kinds to be run in it. In early planning, the complete topsides were expected to be assembled on a 140-meter long Module Support Frame (MSF) on the quayside, then skidded onto the hull as a single piece.
However, the topsides weight increased by about 30% from the initial estimate because of late influences such as the need to add substantial water treatment. It should be noted that this growth – to 25,000 tons – did not have any impact on the hull. This had been designed to accommodate uncertainties in the topsides. Because of the increased size of the topsides, a rebid exercise was undertaken at the end of basic engineering. As a result, in June 1999, the work was relocated to Hyundai’s Offshore Division yard at Ulsan, Korea. This was close to the site of hull construction which had been sub-contracted to Hyundai’s Shipyard Division fourteen months earlier.

In Korea, a modified approach was taken to installation of the topsides. The MSF was lifted onto the hull in ten pieces and the topsides then built on it in a more piecemeal manner over a one-year period. Lift weight of outfitted structures varied from 350 tons to a maximum of 700 tons. Construction of the 42,000-ton hull was completed on schedule in 18 months in October 1999. The safety record was excellent, with a Lost Time Incident (LTI) frequency rate of 0.65. The hull was then immediately towed to the nearby Offshore Division yard for assembly of the topsides above its main deck.

The 25,000-ton topsides had the ambitious target of completion by March 2001, just 21 months after contract award. This required a workforce of more than 2,000 personnel at peak construction time. An outstanding safety record was achieved in this work with an LTI frequency rate of 0.41.

Sailaway from Korea was at a level of completion and commissioning never before achieved for a production unit of such complexity. Overall, a new benchmark was set by completing such a project just 33 months after contract award.

The vessel arrived off Angola on July 10 after a voyage from Korea lasting 100 days. Over the ensuing weeks it was linked to its 16-point catenary spread mooring system. Grouped
four at each corner, these lines maintain the FPSO in a fixed heading and keep its lateral movements within 70 meters (5% of water depth). Each line uses a 1,775-meter length of 125-millimeter sheathed spiral strand wire, with short sections of studless chain at top and bottom, and a 17-meter long suction anchor in the seabed. Anchoring at the field was completed in August, allowing final hook-up and commissioning to get under way. No major problems were encountered and the first well on the P-10 production loop was opened on December 4. This meant that the project achieved the challenge of coming on-stream three and a half years after sanction and award of main contracts. After impressive ramp-up of production, the first cargo of one million barrels of oil was offloaded at the end of December.

Although the FPSO has a 90-meter high flare tower, this was only used until the gas injection system became operational in April 2002. After that early stage, gas will not be flared, but re-injected to await production at a later stage.

PROCESS FACILITIES
Large volumes of oil, water and gas are dealt with by the 25,000 tons (dry weight) of topsides equipment on the Girassol FPSO’s deck. To process the wellstream, the topsides
are designed for an oil production rate of 200,000 barrels per day, and also to treat 180,000 barrels per day of produced water coming up with the oil from the reservoir. The plant includes two very large oil desalters – 30 meters long and 4 meters in diameter.

The gas in the wellstream is dehydrated and compressed by facilities designed to handle up to 8 million cubic meters per day (equivalent to 50,000 barrels per day in oil terms). Then a portion of that gas is channelled to the production risers to provide gas lift while the rest is re-injected at 285 bar to maintain reservoir pressure.

As well as treating produced water, the facilities also have to process a large volume of seawater to make it suitable for injection into the reservoir to help maintain drive pressure there. The nature of the reservoir means that the world’s largest sulfate removal plant – able to treat 390,000 barrels per day of seawater – had to be
added to the process layout after contracts had been awarded (see below). The water injection plant is sized to provide 390,000 barrels per day of water at a pressure of 150 bar.

To deal with all these tasks, deck space on the FPSO is shared out equally between six main functions: manifolds, oil processing, water processing, gas compression, power generation, offloading and metering.

The vessel’s power demand is 40 MW, rising to 50 MW during oil offloading. This is provided by three 26.4-MW heavy-duty turbo generators, along with various secondary and backup generating capacity. Gas compression is performed by two units, each rated at 25 MW.

The sulfate issue was one of the major challenges to emerge during the course of the FPSO project. It arose with the relatively late discovery that substantial amounts of sulfates would have to be removed from seawater before it could be injected for reservoir pressure maintenance.

Studies revealed a high strontium and barium content in samples of water from the reservoir. If seawater with a high sulfate content was injected into this reservoir, there was a significant risk that the ensuing chemical reactions could produce enough barium sulfate to build up and plug the production tubing.

Conventional scale inhibitors would not be effective enough in Girassol’s long daisy chained layout of remote subsea wells. The only reliable solution was to use a nano-filtration membrane process on the platform. Not only is this process uncommon offshore, but the need to treat a mighty 390,000 barrels per day of seawater resulted in the world’s largest water sulfate removal plant.

The filtration system was provided by US Filters plant, using 480 tubes, each containing six membranes from Dow Chemicals. It reduces the sulfate content of the water from more than 2,800 grams per liter to less than 40.

Seawater is taken aboard the FPSO from an inlet 90 meters below the sea surface, where temperature is in the range 13°C-20°C (56°F-68°F). Before reaching the sulfate removal plant, the water passes through several stages of filtration (including 16 multi-media filters) and de-oxygenation. After sulfate removal, the treated seawater is then pressurized up to 150 bar by three injection pumps and directed to the injection wells on the seabed.
There are a number of features of the Girassol development which have established new concepts for the offshore industry and the export system is one of them. As offshore developments have moved into deeper waters, the industry has studied various new methods for exporting production.

There were a number of issues for Total to consider when choosing a method of transporting the processed crude oil 1.6 kilometers from the Floating Production Storage and Offloading system to the export buoy. One was the effect of temperature and its impact when moving dead crude from a floating facility down to the seabed at 4°C (39°F) and then back up to the surface. Another was the installation method of the system and the effect of the installation method on the long-term life of the system. And the final issue was cost. The system was to be based on the largest Catenary Leg Mooring (CALM) buoy ever built and which had never been installed in such deep waters. The buoy weighs 650 tons (715 short tons), is 18 meters (59 feet) tall with a buoy body height of 10 meters (33 feet), an overall diameter of 23.3 meters (76 feet) with the buoy body itself to a diameter of 19 meters (62 feet).

The thermal requirements were such – the temperature loss of the crude oil had to be less than 3°C (38°F) – that it was not possible to take the flowlines to seabed, where the water temperature is 4°C (39°F), and then back to the surface at the loading buoy. This mitigated in favor of a midwater transfer system.

Export system: a large “W” whose upper line is 2,400 meters long and varying in water depth from 440 meters to 530 meters below the surface.
The design of the export system needed to take into account a number of considerations. It had to accommodate different fluids in the lines which had an impact on the shape of the lines. It had to have the flexibility to deal with variations in distance between the two FPSO and the CALM buoy, including in the extreme case, with one line broken. There was also a need to be able to handle the motions induced by the FPSO and the loading buoy. This is particularly critical at the buoy end of the lines.

Detailed analyses were undertaken to assess the overall behavior of the three interacting systems: FPSO, export lines and offloading buoy. The export lines, due to their near neutral buoyancy state, are particularly sensitive to environmental factors. Thorough fatigue calculations were required. Parametric analyses with a set of wave scatter diagrams were performed which resulted in the need to reinforce the export lines at the CALM buoy. The wall thickness of the pipe was increased on the last 300 meters of the export lines close to the CALM buoy and studjoints were added.

After considering the use of flexible pipe, it was decided that this option was too expensive. The decision was taken to install a system comprised of two 16-inch rigid pipelines configured like steel catenary risers in their midwater locations like a large “W”. The upper line is 2,400 meters and varies in water depth from 440 meters below the surface to 530 meters below the surface. The lower line is slightly longer at 2,750 meters and is installed somewhat deeper in a range of 630 meters below the surface to 740 meters below the surface. The main sections of the export lines leaving the FPSO. The export lines are particularly sensitive to environmental factors.
The lines, made of API 5L X65 steel, have a wall thickness of 14.3 millimeters, but the final 300 meters of the pipeline at the CALM buoy increase to 25.6 millimeters. The lines, which have flexjoints at each end, are coated with 6 millimeters of polypropylene and each has a series of 29 buoyancy floats to create the desired shape of the pipelines.

Once the concept was chosen, the decision on how the lines were to be installed had to be made. The initial plan by contractor Alto Mar Girassol was a subsurface tow to site. Structural analysis subsequently revealed that a significant amount of the fatigue life – up to one-third – of the pipeline would be consumed by this method and it was decided instead to opt for the j-lay method using Bouygues Offshore’s new installation vessel, the “Field Development Ship”. Detailed calculations had to be performed and static analysis used to determine the installation program including the angle of the j-lay tower, the allowable vessel movements and the lay tension. It was also determined that the most critical phases of the installation would occur while passing the buoyancy modules through the lay vessel’s stinger and at the final transfer of the export lines to the CALM buoy.

The installation of the first line – the upper one – required 10 days. One lesson learned was the time necessary to handle and install the 12-ton / 6-meter long flex-joints. After a period in which the “FDS” was used on other activities, it returned and installed the lower line. Operations were optimized based on the experience from the first installation and this work was even more successful. In order to continue to monitor the most vulnerable section of the upper line, strain gauges have been installed. Data from these gauges and from metocean buoys will provide validation of the fatigue design of these pipelines.
INTEGRATING THE PROJECT INTO THE COMMUNITY

To ensure that Girassol plays a longer term role in the sustainable development of Angola and its energy resources, Total and its partners made every effort to foster know-how transfer via training for local personnel as well as integration of Angolan engineers and technicians into project teams. Local construction was also a priority for all project partners.

TECHNOLOGY TRANSFER
As operator, Total was committed to providing Angolan managers and technical staff with training and hands-on experience and to give professional opportunities to local staff as soon as they were suitably qualified. During the pre-production phase, engineers, cost-controllers and a contracts specialist were posted to the Pau project HQ in southern France, several engineers were part of the HQ operations team in Luanda, and a large number of Angolan drilling technicians working with Pride Foramer gained invaluable experience of offshore drilling and completion techniques. Total helped to train Angolan personnel working on both drilling vessels and has guaranteed them employment for the next five years.

This policy of Angolanization has continued with ongoing recruitment and via training programs for local employees as well as Oil Ministry and Sonangol personnel, costing $4-5 M each year. By the end of 2000, 75% of project personnel in the country were Angolan nationals, including 44% of managerial staff and foremen-supervisors. So Girassol will not only generate a significant increase in Angola’s crude production, but will give a considerable boost to the local oil industry’s ability to pursue future projects.

STRENGTHENING THE LOCAL ECONOMY
At the two onshore construction sites, local companies were encouraged to participate in the construction and assembly work as well as logistics and transport. Preference was given to local contractors whenever competitive, resulting in the creation of hundreds of jobs for people in surrounding communities. Both the local companies and their employees will be able to use participation in this high-tech project as an invaluable reference in future projects.
The Soyo construction yard, operated by Petromar (an Angolan-registered company with Sonangol and Bouygues Offshore as shareholders), where the flowline bundles for the subsea production system were assembled, was set up specially for the Girassol project. Some 150 workers were recruited locally and trained by Petromar in welding, coating and other assembly techniques, with Total supervising qualification. The existing construction site at Lobito, managed by Sonamet (an Angolan-registered company with Sonangol and Stolt as shareholders), was equipped with a mechanized production line for assembly of the complex riser towers. The loading buoy and suction anchors were also constructed there by local contractors and using Angolan labor. The workers were given additional metallurgical skills to meet the stringent specifications and standards involved in offshore work (i.e. welding techniques required for equipment that must withstand high water pressure). Here again, the contractor Sonamet handled training with Total monitoring qualification. With 800 people employed at the Lobito site during peak activity, Girassol has significantly stimulated the regional economy.

Towards Responsible Use of Resources

With the Girassol project, Total and its partners have proved that deep-offshore hydrocarbons can be produced economically and responsibly under extreme conditions. This resounding success makes Girassol a reference for future oil development, demonstrating the role that technology can play in optimizing Angola’s resources, in opening up responsible development of Block 17 and further offshore discoveries, whether in the Gulf of Guinea or elsewhere, thus leaving other resources for future energy consumption. For that is what sustainable hydrocarbon development is all about – using all available technology (3-D seismic acquisition, reservoir modelling, multiphase pumping and transport, horizontal and multidrain wells, assisted recovery) to explore, assess and produce oil and gas. Making the most of resources available in each reservoir, each deposit, each oil province, and so leaving further resources to be tapped by coming generations.

Like extra-heavy oil, deep-offshore hydrocarbons (and a fortiori, very-deep offshore deposits) were regarded until recently as uneconomic resources that could not be considered as reserves. Technology is now available to produce both economically, and these “frontier” resources are beginning to make a meaningful contribution to a more diversified world oil supply. Any serious commitment to sustainable development requires that these resources be tapped.
In all its activities wherever it operates, Total considers safety in regard to operations and human health and respect for the environment as paramount priorities. No development project is ever undertaken without prior assessment of all risks to safety, health and the environment over the entire life of the project, implementation of all necessary preventive measures and preparation of relevant contingency plans. Total complies with all applicable laws and regulations wherever it operates, as well as applying the Group’s own stringent Health, Safety, Environment and Quality Charter.

SAFETY: A PARAMOUNT CONCERN
On Girassol, full safety audits were carried out at the Soyo and Lobito construction yards onshore, at the shipyard building the FPSO in Korea, as well as aboard all vessels operating on the project. Safety was given particular emphasis at Lobito and Soyo, where large numbers of local staff were working with what, for many of them, were new techniques and equipment. Project team Safety Managers were appointed for each site to ensure that contractors and subcontractors complied with safety standards regarding prevention, accident response and awareness training for all relevant personnel. As operator, Total insisted on full reporting of accidents and subsequent remedial preventive measures.

PROTECTING THE ENVIRONMENT
At each stage of the project, every effort was made to protect the environment by carrying out comprehensive preliminary studies and taking all necessary measures. Environmental studies, carried out in cooperation with a number of specialist international consultants, included site baseline surveys and environmental impact studies, both offshore and at the onshore sites, as well as an oil-spill contingency plan.

Protection of the environment was given top priority throughout the project.
Offshore and Onshore

Environmental measures taken offshore include:

- Gas re-injection to eliminate flaring and valorize energy resources;
- Use of low-toxicity, oil-based drilling mud;
- Treatment of drill cuttings discharged;
- Treatment of all water discharged;
- Recovery of turbine exhaust heat and reuse in various FPSO processes.

In addition to regular monitoring, a follow-up eco-audit will be carried out after drilling is completed in 2004, again at field half-life after 7-8 years, and another on cessation of activity. Among the measures implemented onshore were detailed precautions at Soyo to protect the mangroves and adjacent area – shown by the baseline study to be a breeding ground for tortoises – when the sealine bundles were transferred from the lagoon to the sea. Care was also taken to minimize channel width and avoid creating a continuous link between the sea and the lagoon while cutting the transfer channel, as seawater would have disturbed the lagoon's sensitive brackish-water ecosystem.

Deep-Sea Milieu Study Program

Given the potential for future development in the area, Total is carrying out a wide-ranging regional study of the deep-offshore milieu. Deep-sea ecosystems are among the most biodiverse on Earth, but little is known about them. In conjunction with the French oceanographic institute Ifremer, Total has undertaken a 3-year oceanographic campaign offshore from Gabon, Angola and Congo covering water up to 4,000 m deep. The aims are to categorize (inventory and analysis) marine life at great depth and assess the potential impact of oil exploration and production activities.

The Girassol project is using specialized surface vessels and unmanned submersibles, probes and sensors for marine-life sampling, drift-buoys for particle analysis and quantification, drift modules to study biodegradability of drilling mud and cuttings, and sea-bed sampling apparatus. It also involves colonization experiments to study and compare the response of benthic organisms to the addition of fish-meal (enriching their milieu with organic matter without any toxic effects) and to drilling mud (organic matter with a potentially toxic effect).

On comparison of the quantity, diversity and composition of the benthic fauna following each phase of enrichment, researchers observed no evidence of toxic effects (particularly concerning direct mortality on the most abundant species).