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The Development of a Single-Well Oil Production System [and Discussion]

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The development of a Single-Well Oil Production System

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Since early 1980, BP has been developing the conceptual design of a Single-Well Oil Production System or Swops. This paper outlines the concept and discusses the design and the operational criteria that have been applied in this early work. It further examines some of the innovative areas of technology that have been included in this new approach and outlines the work of the detail design phase, which has just started.

Introduction

There are a number of examples in the relatively short history of North Sea oil where the appraisal and the consequent development costs of offshore fields have escalated dramatically. More often than not, this has been associated with the development of reservoirs of a highly heterogenous or faulted nature.

The conventional methods of testing these reservoirs, relying as they do on high-cost semi-submersibles and small, portable test units, has at best been a compromise between generating a maximum of useful reservoir data and minimizing the cost of obtaining it. Despite the demand for a vessel to carry out reservoir testing, it is prudent to allow it an additional role, that of a 'mini'-production system. There exist many small but well defined oil accumulations that cannot, even in these days of early and relatively low-cost production systems, exhibit a viable economic return.

As a possible solution to these problems, the concept of a Single-Well Oil Production System (Swops) was born. It is essentially a self-contained itinerant test and production vessel whose function is primarily to produce and store oil from completed exploration wells and then transport it to the nearest shore terminal.

To operate in the North Sea and to be able to exhibit a reasonable return on investment the vessel must be able to continue producing in all but the most severe of weather conditions, and likewise offer a reasonable service speed so that periods away from the producing well are minimized. Moreover, to reduce costs whilst maintaining station above the well, the fullest use of associated gas as a fuel for the dynamic positioning machinery must be made.

Design and operating criteria

(1) Environmental: production operations to continue up to sea state Beaufort Force 9 (middle North Sea).

(2) Water depth 75–200 m.

(3) Dynamic positioning (d.p.) excursion limits: 6% of water depth.

(4) Oil production rate: 3000–15000 stock tank barrels per day (1 barrel $\approx$ 0.159 m^3).

(5) Gas production rate: 6.0 million standard cubic feet per day (1 $ft^3 \approx$ 0.028 m^3).

(6) Water cut, 15% by volume.

(7) Well pressure rating: 5000 $lbf\,in^{-2}$ (*ca.* 34.5 MPa).

System description

The major subsystems or components of Swops are the same whether it operates in the test or production mode. They are (see figure 1):

(1) a subsea well, completed with a special Swops-type production wellhead;

(2) a rigid riser system deployed through a moonpool in the tanker hull;

(3) a dedicated, dynamically positioned tanker with integral process equipment and storage facilities.

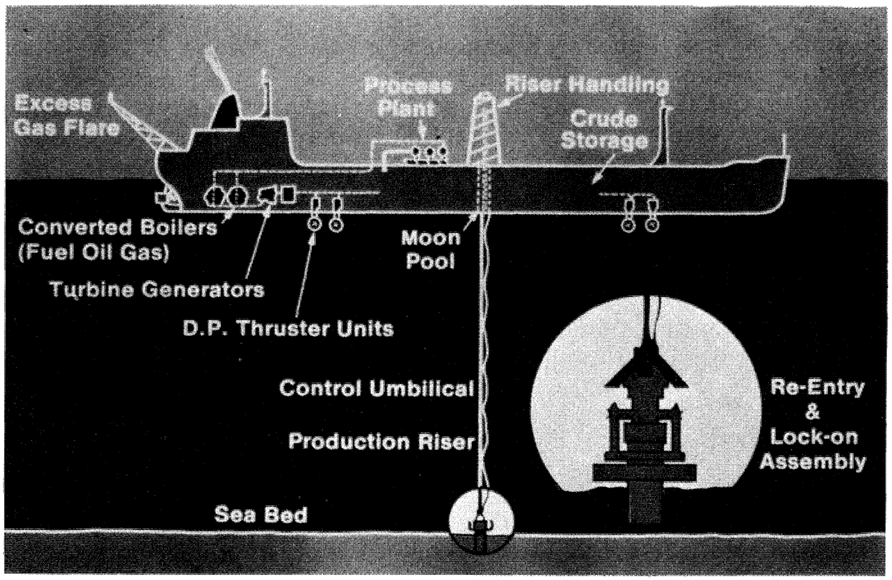

Figure 1. Swops components (conversion).

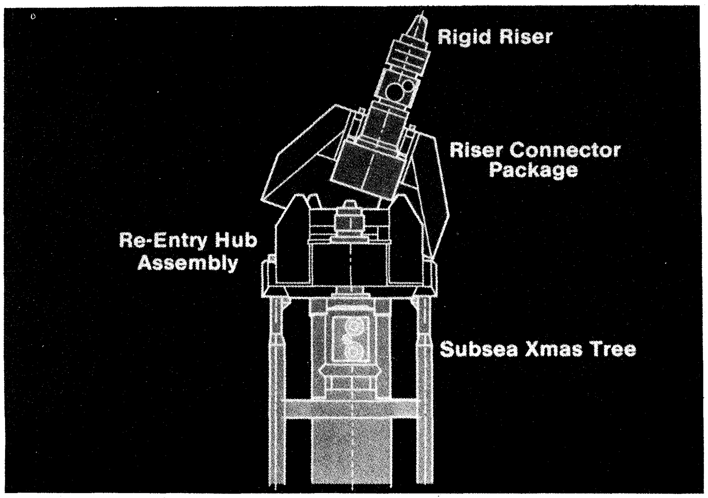

Figure 2. Swops wellhead.

The subsea equipment

An exploration or appraisal well will be completed in the conventional manner from a drilling vessel. The Swops wellhead will be lowered down conventional guidelines and capped with a special re-entry hub (REH) (see figure 2). If the wellhead is to be left for any length of time before production begins a retrievable corrosion cap will be installed.

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As can be seen from figure 3, the wellhead is a conventional 4 in × 2 in (1 in = 2.54 cm) completion through the main valve body, but the production and annulus bores are joined and offset to exist through the mid-line of the REH hub together with the control ports. This permits re-entry and connection of the production bore with the riser without the need for rotational orientation of the riser connector package (RCP) before mating with the wellhead.

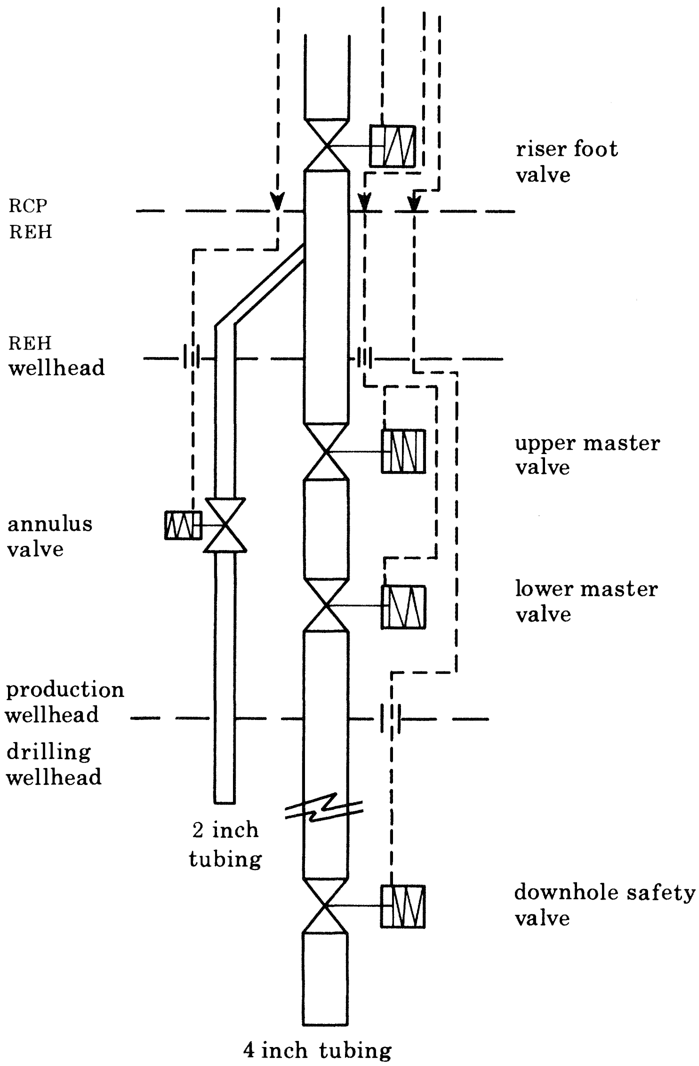

FIGURE 3. Schematic of the hydraulics in a SWOPS wellhead.

An additional novel feature of the re-entry arrangement is the simultaneous interface connection of the wellhead hydraulic controls together with the production bore and riser. This is achieved by arranging the hydraulic control ports concentrically around the central production bore, so that when connection is made, surface control of the wellhead valves is automatically established.

As with all subsea wellheads, the master valves are fail-safe close, i.e. should any disruption occur to the hydraulic supply the master valve will automatically shut leaving the well in a safe condition. A surface-controlled subsurface safety valve installed some 150–300 m below the

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mudline will provide additional protection should any catastrophic damage occur to the wellhead.

Although most of this development appears totally novel it is essentially an adaptation of earlier development work carried out and successfully tested by BP in conjunction with other oil companies in the North Sea in 1978. Prototype tests carried out during 1981 also confirmed the practicality of the design.

Riser system

The function of the production riser is basically to conduct the well fluids to the shipboard process plant. Figure 4 shows a riser consisting of a series of jointed tubulars with a stress joint or universal joint at the lower end and a flexible joint immediately below the vessel's keel. Further investigation is now underway to consider alternative flexible and stress joint arrangements.

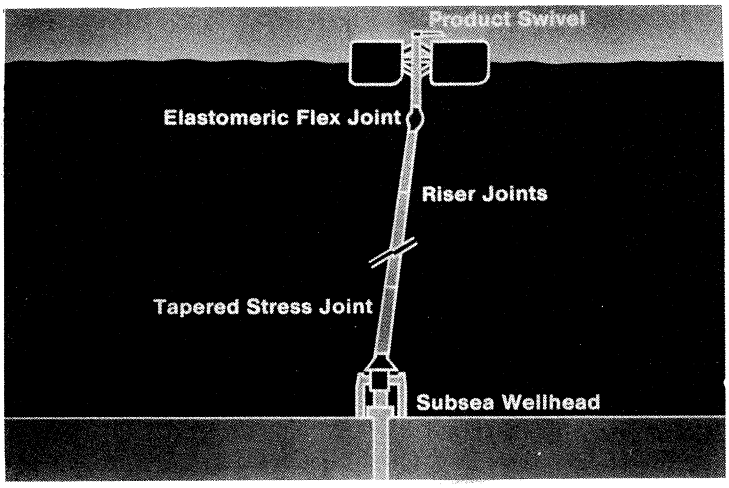

Figure 4. Rigid production riser.

The sequence of re-entry and connection operations would be roughly as follows.

(1) The riser with RCP at its foot would be lowered through the moonpool and suspended some 20 m above the mudline. The vessel would not be directly above the well at this time.

(2) A cable-suspended television–sonar unit would be run through the riser bore until it protruded from the end of the riser foot.

(3) The sonar would be activated and with the use of its information the vessel would be manoeuvred above the well.

(4) Once in this position the television camera would be activated and the riser gently lowered under visual control until connection is achieved.

(5) Once connected, the riser would be tensioned to its operating level, the television–sonar removed, the riser pressure tested and finally the wellhead valves would be opened to allow production.

The vessel will be free to rotate about the riser by virtue of a swivel at the upper end. Heave compensation will be provided and the stress and flex joints will allow it to oscillate laterally under d.p. control. These methods should avoid unduly high stress levels in the riser body.

Disconnection is essentially the reverse operation after oil in the riser is displaced to the surface through a flushing line in the umbilical. The RCP connector is designed to allow

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disconnection at high angles of vessel offset and additionally there is a safety joint or 'weak link' in the riser, which will fail before high loads can be imparted to the tree and wellhead.

Flex riser

During detailed conceptual and feasibility studies, consideration was given to the use of a flexible riser, which would have its lower end permanently connected to the wellhead and would be retrieved from the seabed every time the vessel returned to the well. This solution appeared to have significant advantages in that it would permit greater vessel excursions and its deployment and retrieval could take place in higher sea states.

After detailed consideration, however, the adoption of the flexible riser solution was dropped, chiefly owing to the high costs of its installation, which would be repeated whenever the well location was changed. Furthermore the inability to introduce pressure-monitoring equipment into the well through the riser bore would require permanently installed electronic gear down the hole. This could be a serious drawback to Swops operation in the reservoir testing mode.

Process plant

The process plant will be housed below main deck level adjacent to the moonpool area.

The incoming crude stream is cooled after its pressure is reduced to separator conditions across the choke (see figure 5). Thereafter it passes to the first-stage separator where up to 80 % of the gas content is separated off and fed to the main propulsion system after it has been conditioned to fuel quality.

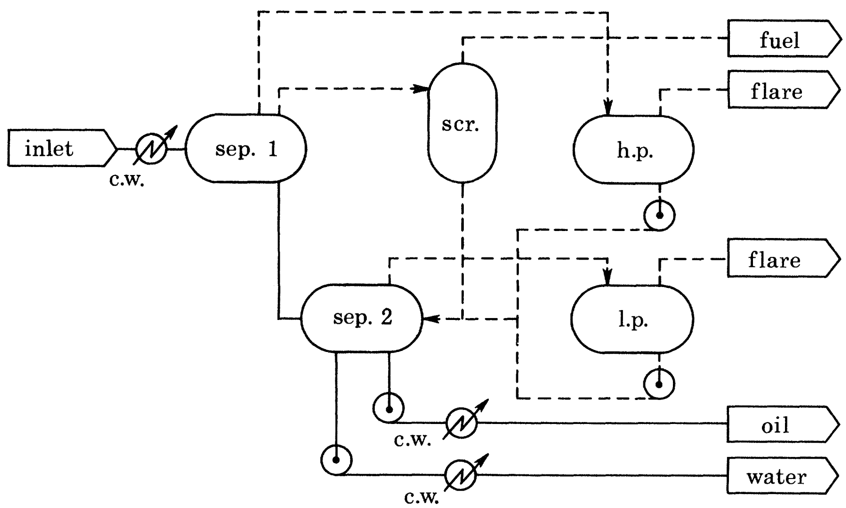

Figure 5. Process flow diagram.

The liquid stream is fed to the second-stage separator where the remaining gas and water phases are removed. The crude is cooled to tanker loading specification and led directly to the cargo tanks.

The process is straightforward and simple and based upon well proven conventional equipment. Produced water is fed into the tanker's slop tanks where natural separation is allowed to occur.

The flare and its associated structure requires careful design to avoid problems of heat radiation and noise. Alternatives such as gas incineration are available, but indications are that their performance has not been entirely satisfactory so far: they may have difficulty in handling the volume transients required for instantaneous pressure relief.

Systems analysis and efficiency

Obviously, when considering systems of this type, which have to deal with the vagaries of North Sea weather patterns, it is extremely difficult to predict with any certainty the levels of efficiency that one might attain with such a system.

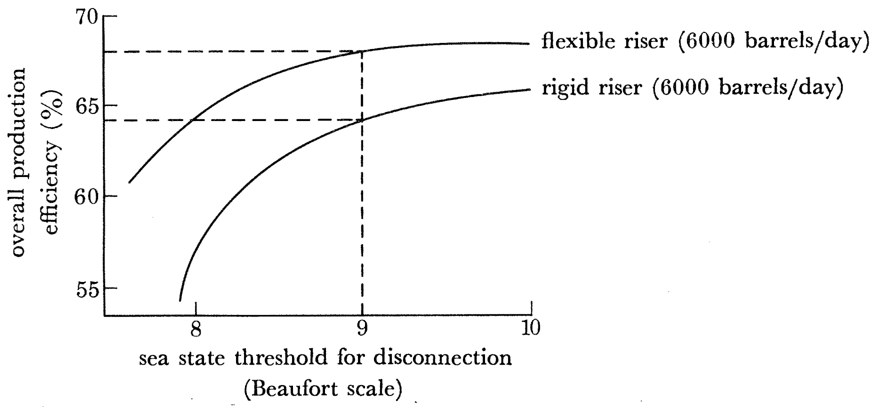

Figure 6. System efficiencies for Swops, with efficiency as defined in the text.

However, to arrive at a realistic economic assessment of the project prospects it is necessary to attempt to quantify this efficiency. Adapting an existing BP computer program that models ocean transportation systems, it is possible to take account of real-time weather and wave data collected over a continuous five-year period, well production rates, vessel speeds and turnaround times, and limiting vessel motions for the operations associated with the running and retrieving of the riser.

The output of this model is in the form of an annual production efficiency, defined as

$$\text{efficiency (\%)} = \frac{\text{actual oil delivered daily}}{\text{daily well production rate} \times 365 \text{ days}}.$$

Essentially it compares Swops production with that of a fixed platform producing at full capacity through a pipeline for a period of one year without interruption.

As can be seen from figure 6, prepared for a typical central North Sea area, efficiency varies with the well production rate and ability to operate in certain sea states. It is also readily apparent that efficiency declines rapidly if the vessel is unable to continue operations at the higher sea states, hence the need for an effective dynamic positioning and control system.

Dedicated tanker

Considerable effort has been expended on examining the alternative configurations for the Swops vessel. Initial studies were based on the conversion of a 50000 tonnes deadweight tanker. The results of these studies were not encouraging for a number of reasons, and the option was rejected. Among the reasons for rejection, the following were considered the most problematical.

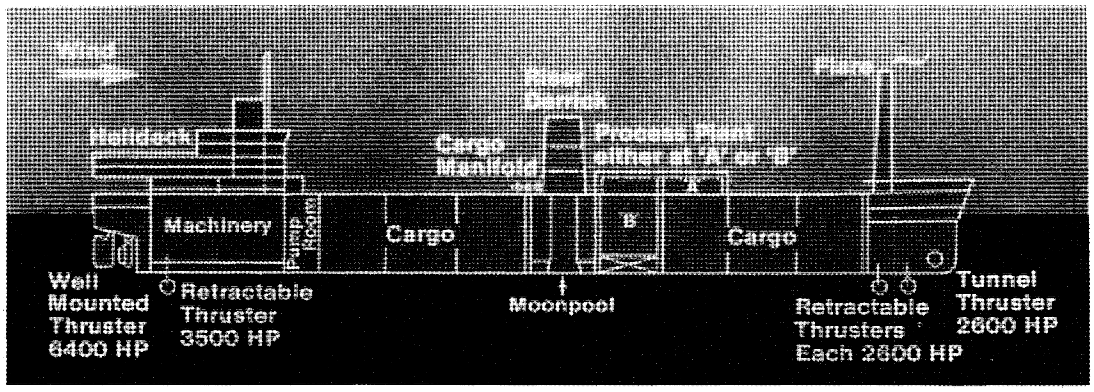

Figure 7. Preliminary profile of a Swops process tanker. HP = horse power = 746 W.

(1) Allowable bending moments restricted the position of thrusters/equipment/cargo and ballast patterns and resulted in a compromise solution that did not match requirements entirely.

(2) The need to incorporate additional power generation facilities within the limited confines of an existing machinery spaced created severe noise and space problems.

(3) The intended programme constituted a 'major conversion' in the view of the statutory authorities. This led to a more stringent application of the relevant legislation, both maritime and petroleum production, than would otherwise have occurred.

As a consequence of these difficulties and the high costs associated with resolving them, the decision was taken during 1981 to pursue the design development of a custom-designed new building.

Taking into account the need to optimize the system efficiency and recognizing the limitations of attempting to maintain large vessels in a fixed position by dynamic positioning alone, sensitivity analyses were applied to the system efficiency model described earlier. These analyses resulted in an optimum vessel size of about 40000 t cargo capacity, which in a segregated ballast ship would lead to a vessel of some 70000 t displacement (see figure 7).

Available information about stationary tanker motions in a seaway and the power requirement to maintain station for a tanker-type vessel is extremely scarce. By using the NMIWAVE program (National Maritime Institute, Feltham, Middlesex, U.K.) estimates of significant responses and accelerations together with mean drift forces for the vessel in irregular seas at Beaufort Forces 5, 7 and 9 were prepared. The expected maximum responses and accelerations for storms of 3 and 24 h duration were also modelled.

From the results of this program, the thruster power requirements were calculated for the vessel. These requirements are summarized in a polar diagram (see figure 8).

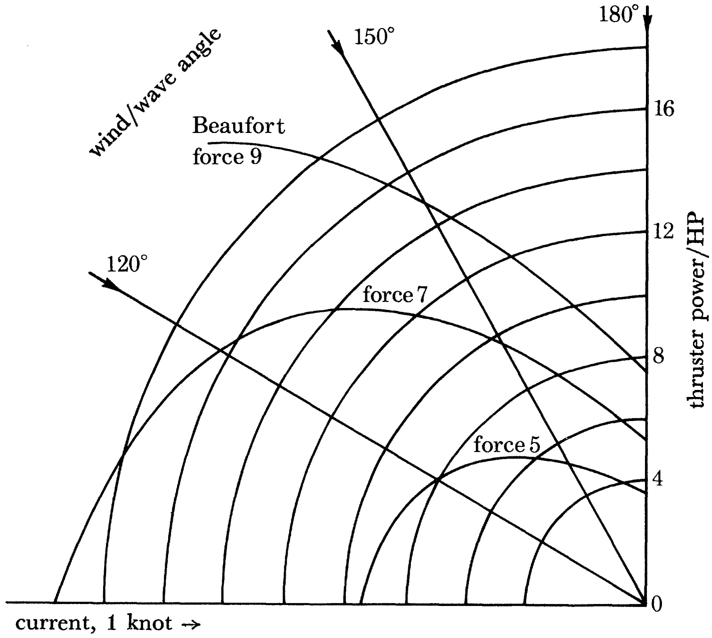

FIGURE 8. Polar plot of thruster power requirements. 1 knot ≈ 1.9 km h^{-1}.

FUTURE WORK

At the end of 1981 a SWOPS Detailed Design Study was started, with a target of producing by the end of 1982 a detailed design specification for the complete system. This will be used to obtain realistic bids from shipbuilders before the decision to proceed further is taken.

The translation of the conceptual work reported here into the detailed design and, it is hoped, construction, is a complex and demanding task. Several areas will require very close examination and among the more significant are:

(*a*) the estimation of gas quantities and qualities for use as fuel in ship's machinery;

(*b*) the selection of optimum machinery configurations to meet widely varying operating and weather conditions;

(*c*) provisions to facilitate retrofit of enhanced production equipment;

(*d*) the development of safe operating procedures and compliance with all relevant offshore and marine regulations;

(*e*) the design of a riser and riser-handling system, subsea equipment and controls.

A key factor is to provide a high degree of flexibility so that SWOPS has the ability to move from field to field as required without costly adaptation. The project has the support of the E.E.C.

It is believed that SWOPS fulfils a need of the offshore operator and could provide an elegant solution to many of his problems.

Discussion

J. R. DADSON (*New Civil Engineer Magazine, The Institution of Civil Engineers, London, U.K.*) Can Mr Smith suggest why the idea of obtaining oil from the seabed using a boat was only considered a couple of years ago? Instead, offshore operators have chosen to design and build complicated steel and concrete fixed structures involving equally complicated float-out procedures and

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long installation periods. On the face of it, SWOPS seems to be such an obvious solution. Why was it not assessed 11 or 12 years ago when North Sea offshore work was really starting in earnest?

P. J. SMITH. In the early 1970s, when operators were beginning to appreciate the potential of North Sea oil and gas, most exploration effort was concentrated on drilling the larger geological structures capable of containing reserves in excess of say, 500 million barrels (*ca.* 80×10^6 m^3). Many of these large structures realized their potential, and giant fields such as Forties, Ninian and Brent have resulted. In the course of this activity many smaller reservoirs were discovered that did not at the time warrant development, with most oil company resources being devoted to the larger, more profitable fields.

Now that most of the larger reservoirs have been discovered and in most cases are under development, it is timely to return to the smaller accumulations and for the oil companies to review the precepts on which the large-scale developments were based. It is just such a review that has resulted in the SWOPS concept.

Finally, to put SWOPS firmly in perspective, a typical daily production rate from a single North Sea well is 5000 barrels (*ca.* 800 m^3). Peak daily production from the Forties Field is 500000 barrels (*ca.* 80000 m^3).

H. H. PEARCEY (*Flat* 4, 4 *Church Road*, *Teddington*, *U.K.*) B.P. are to be congratulated on their foresight and achievement in bringing to such an advanced stage already a system that is destined to play a key role in the recovery of North Sea oil and gas resources in the 1990s and beyond, and of those from other offshore areas.

Presumably Mr Smith would include in the attributes of SWOPS the ability to recover oil and gas from outlying pockets that cannot be reached by deviation drilling from the main platforms on large fields?

Mr Smith's figures for the efficiency and performance of SWOPS compared with those for a fixed platform are presumably based on a specific location and a specific availability of gas to power the dynamic positioning system. For other locations with different statistics for the exceedance of given sea states or for a different availability of excess gas, or both, different values of efficiency and performance would emerge and a different design compromise might therefore be required. Has he studied how the optimum specification might change for other locations, and what the sensitivities in the performance of a given design might be if it were to be used in different locations?

P. J. SMITH. Certainly, Mr Pearcey's suggestion that SWOPS could be used to recover oil from outlying pockets beyond the reach of deviated wells in large fields is well within the capability of the system. Whether it is used in this manner, however, would depend on the complex taxation arrangements that prevail. Under the current U.K.C.S. tax régime it may well be uneconomic to do so.

The efficiency figures for SWOPS performance presented in the paper are site-specific. Sensitivity analysis carried out during our efficiency studies, however, showed that the weather conditions chosen for our model were sufficiently representative of the Central North Sea region to be applied generally to any location within that region.

The optimum specification might well change marginally for other locations, but we feel sure that designing for North Sea winter operations should result in a system that can readily be applied to other offshore provinces.

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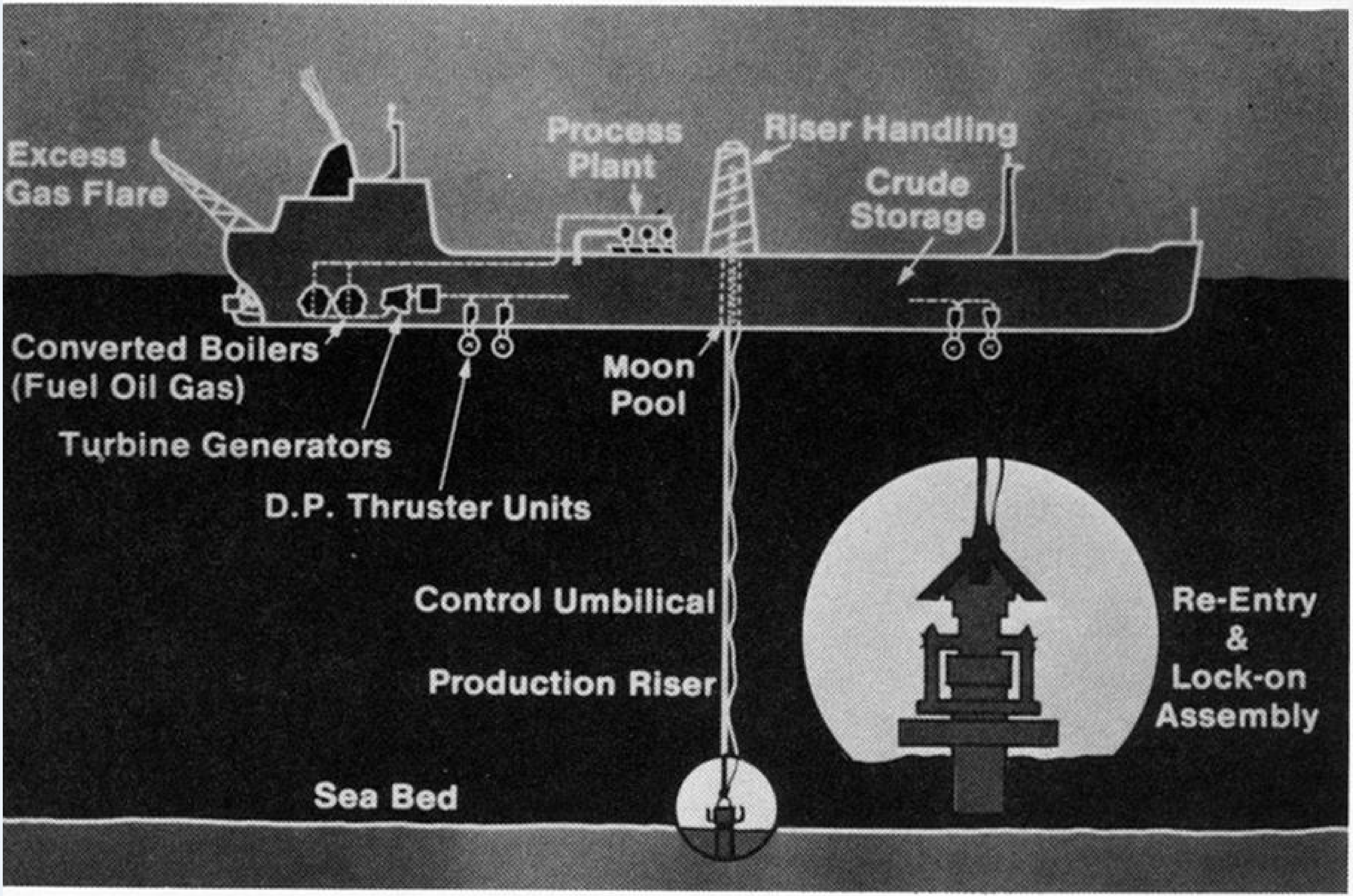

FIGURE 1. SWOPS components (conversion).

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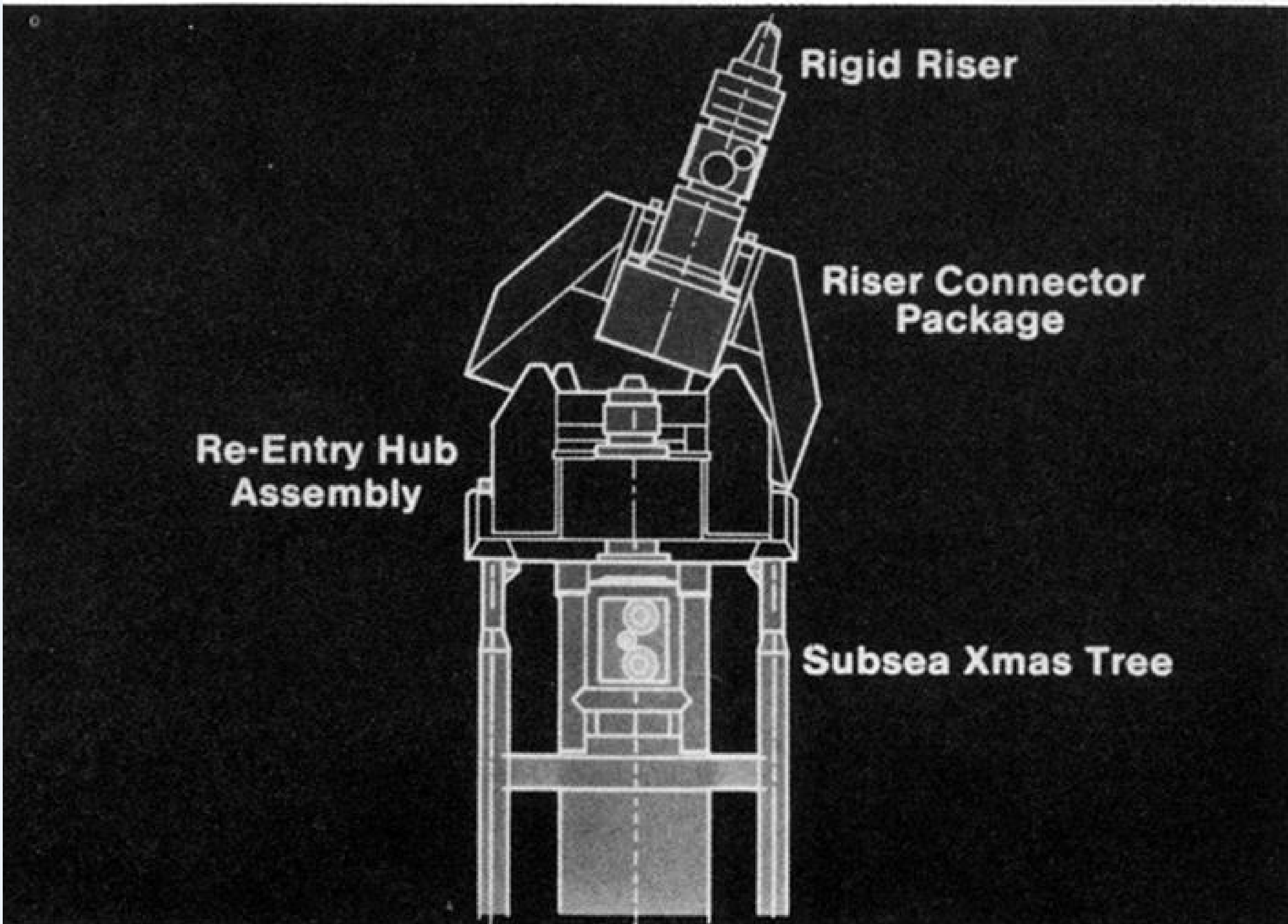

FIGURE 2. SWOPS wellhead.

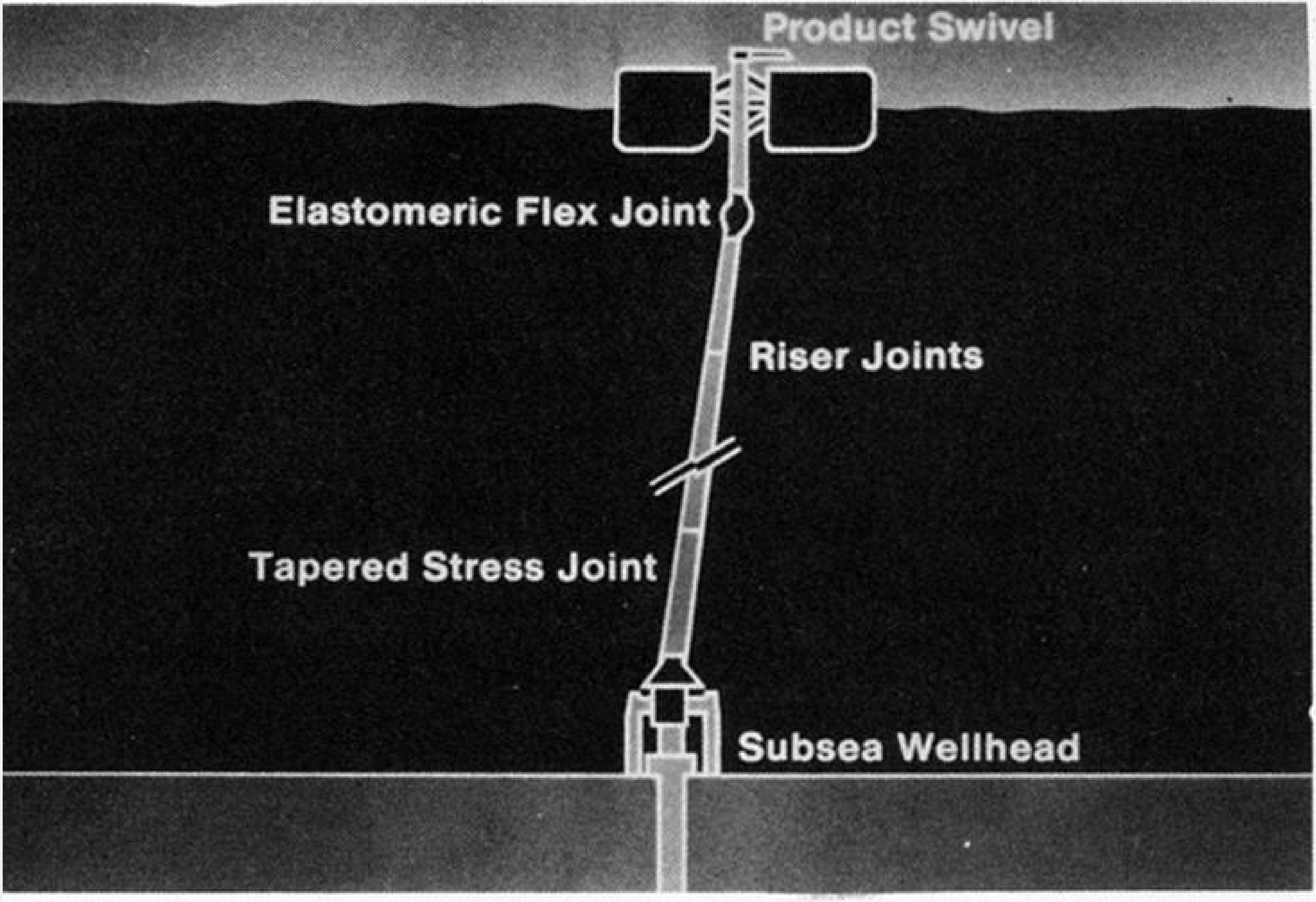

FIGURE 4. Rigid production riser.

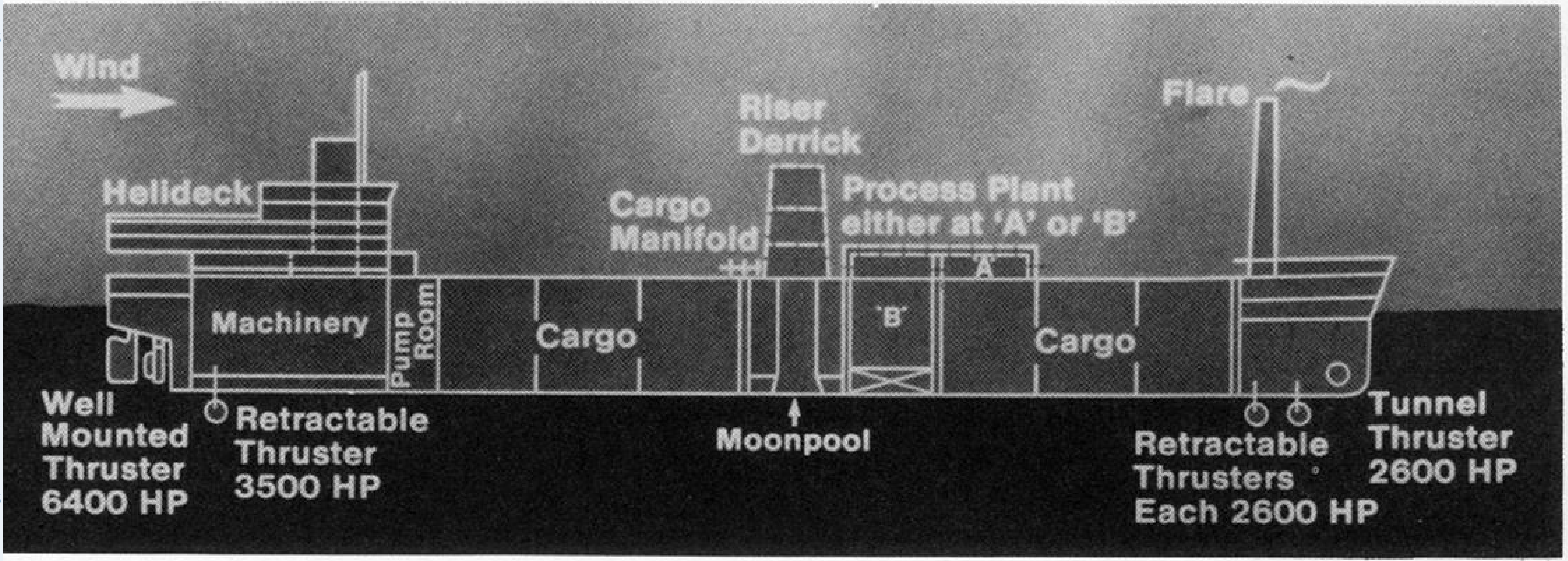

FIGURE 7. Preliminary profile of a SWOPS process tanker. HP = horse power = 746 W.