HOD DEVELOPMENT - RESOLUTION OF TARIFF ISSUE

Arbitration Procedure

With the goal of submitting the Hod Field Development Plan (FDP) to the Ministry of Petroleum and Energy in a timely manner and resolving the outstanding tariff issue, Amoco/Amerada Hess/Texas Eastern and Norwegian Oil Consortium A/S & Co. (NOCO) have agreed the following arbitration procedure:

1. Sole arbitrator to be agreed upon by Amoco and NOCO. The arbitrator shall be a reputable Norwegian lawyer with expertise in matters relating to the petroleum industry. If the parties fail to agree on the arbitrator within 13 April 1988, the arbitrator shall be appointed by the Chief Justice of the Oslo City Court.

2. Each party shall submit its case in writing to the arbitrator, with the opportunity to respond in writing to the other party's submission, and be given the opportunity to have witnesses testify before the arbitrator. The parties shall meet with the arbitrator promptly after his appointment to agree on the further arbitration procedure. Failing such agreement, the arbitrator shall decide the procedure.

3. Issue to be resolved

   The arbitrator will render a final decision, such decision to be limited to the choice between each party's previously made offer, as follows:

   1. Amoco/Amerada Hess/Texas Eastern's previous offer as described in their letter to NOCO dated 2 February 1988 (a tariff based on the Hod and Valhall Fields sharing the depreciation and operating costs of the Valhall facilities on a relative production throughput basis), or

   2. NOCO's previous offer to pay operating expenses on a shared production throughput basis as mentioned in NOCO's letter to Amoco dated 12 February 1988, and reflected in the above-referenced letter dated 2 February 1988.

   The basis of such decision will be the agreements between the parties and such considerations as the arbitrator may deem relevant in the interpretation of such agreements.

4. The arbitrator's fees shall be paid one half by Amoco/Amerada/Texas Eastern and one half by NOCO. Other costs associated with resolution of the issue shall be borne by the party incurring such costs.

5. Save as expressly provided herein, the issue shall be settled in accordance with the provisions of Chapter 32 of the Norwegian Civil Procedure Code of 13th August 1915.

HOD FIELD

DEVELOPMENT AND OPERATING PLAN

VOLUME 1: Text
VOLUME 2: Exhibits
VOLUME 3: Enclosures
APPENDIX: Konsekvensutredning
(Consequence Analysis)

February 1988

Amoco/NOCO Group

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CHAPTER AND EXHIBIT NO.

HOD FIELD DEVELOPMENT AND OPERATING PLAN

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Volume 3A

Volume 3B

HOD FIELD DEVELOPMENT AND OPERATING PLAN

UNIT ABBREVIATIONS AND CONVERSION FACTORS

1. Standard Conditions

For the purpose of this document, the definition of standard or stock tank conditions is as follows:

Standard temperature = 60°F (15.5°C)
Standard pressure = 14.7 psia (1.013 bar absolute)

2. Unit Abbreviations

bbl	barrel(s)
BCF	billion (10^9) standard cubic feet
BLPD	barrels of liquid per day
BOPD	barrels of oil per day
MCFD	thousand standard cubic feet per day
MMBBL	million barrels
MMCFD	million standard cubic feet per day
MMSTB	million stock tank barrels
SCF	standard cubic feet
STB	stock tank barrel

3. Conversion Factors

Quantity	English Unit	Metric Unit	Conversion Factor*
Length	foot (ft)	meter (m)	0.3048
	inch (in, ")	millimeter (mm)	25.40
Mass	pound (lb)	kilogram (kg)	0.4536
Area	acre (ac)	hectare (ha)	0.4047
Volume	barrel (bbl)	cubic meter (m^3)	0.1590
	cubic foot (CF)	cubic meter (m^3)	0.0283
Temperature	degrees F(°F)	degrees C(°C)	0.556(°F-32)
Pressure	lb per sq.in.(psi)	bar	0.0689
Formation Volume Factor	bbl/STB	m^3/m^3	1.000
Gas-oil ratio	SCF/STB	m^3/m^3	0.1781
Viscosity	centipoise (cP)	Pa.s	0.0010
Permeability	millidarcy (md)	μm^2	91.7

* Multiply English unit by Conversion Factor to obtain metric unit.

1 INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

This report constitutes the Amoco/NOCO Group's evaluation of the Hod Field, and presents an optimum plan for economic development of the field.

The Hod Field is located in Block 2/11 of the Norwegian Sector of the North Sea, about 270 kilometers south-west of Stavanger. This location is only 13 kilometers south-east of the Valhall Field. (See Exhibit 1.1). The Hod Field was discovered by Well 2/11-2 in 1974 and comprises two hydrocarbon bearing structures, East Hod and West Hod. To date a total of five wells have delineated these structures. The latest well, 2/11-6(ST-1) was drilled as a deviated well from a 12-slot template located between the two structures in 72 meters of water. Oil reserves are estimated at 25.4 MMSTB (4.04 million Sm^3).

It is envisioned that the Hod Field will be developed by installing a small well protector platform over the Hod template. Production from the development wells will be routed via a two phase pipeline to the Valhall 'A' facility for processing. This concept enables Hod expenditures to be minimized, and ensures that the small field can be developed economically. Without the presence of the Valhall 'A' facility, it would be impossible to economically develop the Hod Field. The proposed concept is in line with the development plan for the Valhall/Hod Fields outlined in Storting Report No.92 (1976-77) dealing with export of petroleum, which also included the tentative Hod Field development as a future extension to the Valhall Field development. Consent for landing of petroleum from Valhall and Hod in accordance with Storting Report No. 92, was granted on 6 January 1978.

The Amoco/NOCO Group envision the Hod Field development presented in this document as being the first in a series of satellite field developments to Valhall. Other cretaceous chalk prospects such as South East Tor, "Balder", Mode and Trud together with possible Jurassic sandstone deposits identified in blocks 2/5, 2/8 and 2/9 close to Valhall are likeliest candidates (See map, Exhibit 1.2). It is planned to appraise these prospects over the next few years with the aim of developing commercial prospects within the duration of the Production Licence. Utilization of the design concept proposed for the Hod Field will enable some of these prospects to be deemed commercial.

This Hod Field Development and Operating Plan (FD&OP) presents the results of the work Amoco Norway Oil Company has performed,as Operator of Production Licence 033, to explore, evaluate and define a plan for development of the hydrocarbon accumulations in the Hod Field. The FD&OP has been prepared with the cooperation and approval of the Licencees. It consists of a main volume of text with supporting Exhibits and Enclosures in separate volumes. Compared to most Field Development Plan document submissions, this document contains a fairly comprehensive and rigorous discussion of the facility/equipment concepts and aspects. This is considered appropriate in view of the fairly significant differences in this proposed concept as compared to those anticipated in the Regulations. Departure from normal past practices are appropriate in certain areas as addressed in Chapter 5 of this document.

The "Konsekvens-utredning" (Consequence Analysis) which provides a self standing summary of the FD&OP and an assessment of its impact on the environment and on the Norwegian society is written in Norwegian and presented as an appendix to this report. All other volumes are written in English.

1.2 BACKGROUND

The Amoco/NOCO Group filed for a two-platform development of the Valhall Field in December 1976. Following lengthy discussions with the Authorities, a revised development plan consisting of three platforms was filed and accepted in 1977. On the Authorities insistence, the three platform development was designed for 168,000 BOPD (26,709 Sm^3 oil per day) to permit simultaneous development of the central area of Valhall, together with the less defined flanks of Valhall and the nearby Hod Field.

Fabrication of the Valhall 'A' facilities was then initiated, together with the delineation of the Hod Field and the flank areas of Valhall Field. As it was demonstrated that these areas contain less hydrocarbons than initially anticipated, the simultaneous development of these areas was not undertaken. In addition, the Valhall 'A' development proved to be more costly and time consuming than anticipated, as a fourth platform (2/4-G) had to be installed at the Ekofisk Center in order to receive Valhall 'A' production. The actual cost of the Valhall development, through to the end of 1987 is $ 1245 MM.

When production commenced at Valhall, numerous well completion problems were evident due to the unconsolidated nature of the high porosity chalk reservoirs. Diligent attempts have been made over the years to solve this problem, culminating in the evolution of the 'gravel packing under pressure' technique currently being used. As a result the yearly average peak production rate of about 70,000 BOPD (11,129 Sm^3 oil/day) was achieved two years late compared to the 90,000 BOPD (14,308 Sm^3 oil/day) originally anticipated. Exhibit 1.3 shows the oil production profile prepared for the field development plan in 1977 together with the actual and present forecast of Valhall oil production.

All of the factors discussed above together with changes in the tax regime and an enforced cutback in production have reduced the economic attractiveness of the Valhall development to yield an Internal Rate of Return (IRR) of about 5%.

These results assume a future (1988 forward) oil price of $17.50 per barrel, escalated at 5% per annum.

In addition, the proposed development of the Hod Field is along the lines envisioned in the development of the Valhall/Hod Fields approved originally and provides an opportunity to slightly improve (by about 0.2 % IRR points) the economics of the Valhall Field Development. This is done by minimizing expenditure for Hod and by treating the field as a satellite to Valhall, thus utilizing the existing Valhall 'A' facilities.

About $50 MM has been spent to date at Hod, with the drilling of the discovery well and four delineation wells, including the installation of the 12-slot template. The Hod Field is considered a new field in respect of the revised Petroleum Tax Regime. In Odelsting Recommendation (Innst.O) No. 18 (1986-87) the Storting's Finance Committee has (in consultation with the Minstry) assumed that Hod should be allowed production allowance insofar as a development plan is presented that can be approved (chapter 6.3). The Amoco/NOCO Group has further presupposed that Hod production is not subject to any royalty. With the base case development concept proposed in this plan, the Hod Field full cycle economics yields an IRR of slightly over 5 %.

These economic results indicate that both fields are in the 5 to 6 IRR-range. It should be noted, however, that these values include escalation. In real terms, which are difficult to quantify when historical results are incorporated, the projects both probably earn close to a zero IRR.

1.2.1 Licence History

The Hod Field underlies Block 2/11, awarded to the Amoco/NOCO Group as Production Licence 033 (PL 033). PL 033 was awarded on May 30, 1969 in the second Norwegian licensing round. The members of the Amoco/NOCO Group hold the following percentage interests:

	Interest, %
Amoco Norway Oil Company (operator)	25
Amerada Petroleum Corporation of Norway	25
Texas Eastern Norwegian, Inc.	25
Norwegian Oil Consortium A/S & Co.	25

As an integral part of the PL 033 licence terms, the Norwegian Government holds a 10 % net profit interest in the licencees' net profit arising out of operations under the licence. With effect from July 9, 1973, the Government transferred its right to the 10 % net profit interest to Den norske stats oljeselskap a.s (Statoil).

Effective as of July 31, 1987, Amerada Petroleum Corporation of Norway has transferred its shares in inter alia PL 033 to Amerada Hess Norge A/S. Both companies are wholly owned daughter companies of Amerada Hess Corporation. The Ministry of Petroleum and Energy has accepted, in accordance with Section 61 of the Petroleum Act, the transfer of these shares. (Cf. letter of July 22, 1987 from the Ministry to Amerada Hess).

In view of the fact that the unitized Valhall Field underlies both PL 006 (no net profit interest for the Government) and PL 033, the Amoco/NOCO Group and Statoil executed an agreement on September 28, 1982 governing the allocation of production, income, costs, charges and expenses arising out of Valhall operations under PL 033. This agreement does not call for any financial obligation by Statoil. PL 033 covers 7.18713 % of the Valhall Field Unit area.

Pursuant to Royal Decree of April 9, 1965, the initial licence term was six years, with the option to extend part of the licence for a forty year period. In accordance with the 1965 Decree, the Amoco/NOCO Group requested that 25 % of the acreage be relinquished, and that the licence terms be extended. Also, the Amoco/NOCO Group requested, within three years after the initial six year term in accordance with the 1965 Decree, that a further 25 % of the acreage be relinquished. These relinquishments took place on February 28, 1975, and May 20, 1978 respectively. The Group was granted a forty years extension of the licence terms, i.e. until May 31, 2015. The remaining licence area is 103.2 km^2 (25,501 acres) as shown on Exhibit 1.1. There are no remaining well obligations.

1.2.2 Consent to Export Petroleum

The Hod and Valhall Fields were discovered in 1974 and 1975, respectively. On behalf of the Amoco/NOCO Group, and in accordance with Section 34 of the Royal Decree of December 8, 1972, Amoco requested the approval of the King to export oil and gas produced from the Valhall/Hod Fields to Teesside, Great Britain and Emden, West Germany, respectively. The Amoco/NOCO Group's application was filed on October 4, 1976, and supplemented by a letter to the Ministry dated January 28, 1977. The application assumed that all products would be shipped through the Norpipe transportation system via the Ekofisk Center.

The original plan to develop Valhall/Hod presented in Storting Proposition No. 425 (1976-77) outlined the following four phases: The initial development phase (Valhall A) included the exploitation of the central part of the Valhall structure. The second phase (Hod) included the exploitation of the Hod structure in block 2/11, contingent upon positive results from delineation drilling. The third phase (Valhall B) comprised the development of the south-west portion of the Valhall structure, contingent upon positive results from the 1977-78 delineation drilling. The fourth phase (Valhall C) comprised the development of the south-east portion of the Valhall structure, contingent upon drilling one delineation well.

Although the initial development was being reviewed at the time of the application, the Amoco/NOCO Group in their October 4, 1976 application emphasized that additional appraisal drilling in both the Valhall and Hod field structures would be required to fully evaluate the scope of operations in the area. Based on the Amoco/NOCO Group's application, the Ministry of Industry submitted Storting Report No. 92 (1976-77) to the Storting, dealing with the landing of petroleum from the Valhall and Hod Fields. In the Report, the Ministry recommended to the Storting that permission for landing of such petroleum to Teesside and Emden be granted in accordance with certain conditions. One of the conditions was that option agreements regarding delivery of NGL to Norway must be entered into between the individual licencees and the Government. In 1982, the State assigned their right to buy all NGL from Valhall and Hod to I/S Noretyl (joint venture between Statoil and Norsk Hydro) and Norsk Hydro, the latter company being a second priority buyer after I/S Noretyl.

Another condition committed the licencees to carry out the different steps of development, "unless drilling and production results prove that the profitability of the total project will be significantly lower than assumed in the application", cfr. "Phase III - Total Field Development" (Page 17 of the English translation of the Report). In the Amoco/NOCO Group's January 28, 1977 letter, under the headline "Stage III - Full Field Development" - it is stated that "Hod Field will be considered to be economically viable if within a 4000 acre platform drainage area, at least 70 million stock tank barrels of oil are proved recoverable by delineation drilling and if average sustainable flow rates of 2500 barrels/day per well are probable, and provided that the effect of any changes in values from those in effect today, for oil and gas prices, recovery factors, investment costs (including the cost of capital), pipeline tariffs and other operating costs and taxes and other factors, does not result in less beneficial economics than those of today." The Hod development was later deferred as delineation drilling did not prove up the previously estimated reserves. In addition, increases to Norwegian taxes reduced the viability of development. Other conditions for the landing of petroleum were inter alia that agreements concerning sale of gas, transportation and processing agreements should be approved by the Ministry, that the Ministry could require that other fields may use the Valhall/Hod facilities and pipelines for treating and transportation, that royalty petroleum shall be shipped and treated by the licencees, that the Valhall Field should be unitized, that the Group be obliged to drill at least three delineation wells in the Valhall/Hod area, and that the Group should submit a plan to increase the recovery rate of oil through injection of gas, water or other substances.

By Royal Decree of December 2, 1977, permission to export petroleum was granted, with provisions of licencees accepting all conditions attached thereto. The Amoco/NOCO Group accepted the conditions on January 6, 1978.

Over the years the Amoco/NOCO Group has effectively followed the conditions of the Report, i.e. drilled Wells 2/11-3, 2/11-3A, 2/11-4, 2/11-5 and 2/11-6 and explored different development alternatives for the Hod Field without identifying any viable alternatives until recently.

Storting Proposition (St.prp.) No. 56 (1987-88) regarding phasing-in of field developments (and the development of Snorre) mentions the development of Hod under Chapter 6 - Report on Fields under Consideration. Sub-chapter 6.7 states i.a. that the Government is aiming at deciding on the Hod Field development and its various aspects in the spring of 1988.

1.2.3 <u>Contractual Frame-Work</u>

1.2.3.1 Agreements and Conditions Applicable to the Hod Field

1.2.3.1.1 Concession (and Associated) Agreements

1) Production Licence 033 (dated May 30, 1969)

   - signed by the Ministry of Industry and accepted by the Amoco/NOCO Group.

2) Attachment to PL 033 regarding 10 % net profit interest to the State

- Attached to PL 033 dated May 30, 1969.

3) Transfer of 10 % Net Profit Interest to Statoil (July 9,1973)

4) Attachment to PL 033 regarding extension of the licence

- signed by the Ministry of Industry (May 23, 1975) and accepted by the Amoco/NOCO Group (June 11, 1975).

5) Royal Decree of December 2, 1977 permitting petroleum from the Valhall and Hod Fields to be exported, under certain conditions (See Section 1.2.2 above)

6) NGL Option Agreement (dated November 12, 1982)

- This agreement is entered into between the State and the individual members of the Amoco/NOCO Group regarding sale of all NGL from Valhall/Hod to Norway. The establishment of such an agreement constitutes one of the conditions for exporting petroleum from said fields. (See Section 1.2.2 above). This agreement is also listed under Section 1.2.3.1.3 below for cross reference purposes.

1.2.3.1.2 Agreements between the members of the Amoco/NOCO Group

7) Amoco/NOCO Group Operating Agreement (dated August 17, 1965)

- Originally, this agreement governed the relationship between the Amoco/NOCO Group members regarding PL 006.

The agreement was subsequently amended inter alia to incorporate PL 032 and PL 033 (as of May 30, 1969). The Valhall Field Unitization and Unit Operating Agreement of September 28, 1982 governs only those portions of PL 006 and PL 033 that cover the Valhall Field. The Amoco/NOCO Group Operating Agreement governs the remainder of PL 006 and PL 033 which are non-unit areas and include the Hod Field as well as PL 032.

8) Article XII of the Valhall Field Unitization and Unit Operating Agreement (dated September 28, 1982)

- Article XII (Non-Unit Operations) establishes on certain conditions inter alia the right to have Unit Operator conduct Non-Unit Operations relating to Production Licences 006 and 033 on or from Unit Equipment.

9) Letter Agreement regarding certain matters supplemental to Valhall Field Unitization and Unit Operating Agreement (dated September 29, 1982)

- This agreement establishes inter alia that if equipment in Valhall is to be used for transportation/processing of petroleum produced from another reservoir than Valhall, all losses or liabilities suffered by the parties in their capacity as Valhall owners and arising out of the use of such unit equipment, shall be borne in accordance with the Valhall Unit interests.

1.2.3.1.3 Sales Agreements

10) Agreement for sale of gas from the Valhall and Hod Fields (dated September 2, 1982)

- Both the Valhall and Hod gas is sold to the Phillips Group at the Ekofisk Center. The Amoco/NOCO

Group pays the associated transportation/processing tariffs downstream of Ekofisk Center delivery point. The Phillips Group is prepared to take the Hod gas when the field comes on stream.

11) NGL Option Agreement (dated November 12, 1982)

- See Section 1.2.2 above. The State's right to buy all NGL from Valhall and Hod under the terms and conditions of this agreement was in 1982 transferred to I/S Noretyl and Norsk Hydro a.s in 1982. This transfer assumed that the NGL Option Agreement could be used as a sales agreement, but in the event the parties deemed it necessary to enter into a supplemental agreement (see item 12 below), the State reserved the right to approve such agreement.

12) Heads of Agreement regarding sale of NGL (dated March 23, 1983)

- In recognition of the fact that further terms and conditions were needed for the sale of Valhall and Hod NGL, the members of the Amoco/NOCO Group and I/S Noretyl/Norsk Hydro entered into the Heads of Agreement to govern the relationship between the parties.

1.2.3.1.4 Transportation, Processing and Handling Agreements

The Hod products will be transported to Valhall in a single pipeline. At Valhall, the products will be separated, processed commingled with the Valhall stream to meet the specification required by the Phillips Group and the Norpipe/Norsea companies, and shipped to Emden and Teesside, respectively, via the Ekofisk Center.

The Phillips Group is responsible for transporting the Valhall/Hod products from the Amoco owned 2/4 G Riser Platform (connected to the Ekofisk Tank with a bridge) and across the Ekofisk Center. The owner of the vapour and liquid pipelines, Norpipe A/S, will be responsible for transporting the products from the Ekofisk Center to Emden (gas) and Teesside (oil and NGL). The crude oil will be processed and terminalled by Norpipe Petroleum UK Limited in Teesside, and the NGL will be processed and terminalled by Norsea Pipeline Ltd. in Teesside. The gas will be further processed to a marketable product by Norsea Gas A/S in Emden.

The gas and oil pipeline agreements for Valhall products (with Norpipe A/S), as well as the crude oil processing and terminalling agreement at Teesside (with Norpipe Petroleum UK Limited) do not yet include Hod products. This issue is addressed under Section 1.2.3.2 below.

The Hod crude oil will be sold out of Teesside on a FOB basis. NGL will be transported to Rafnes, Norway (to be sold to I/S Noretyl/Norsk Hydro) under the Valhall Contract of Afreightment with Helge Myhre A/S.

The following agreements include Hod products:

13) Ekofisk Center Transportation Agreement (Valhall and Hod) (dated September 2, 1982)

- This agreement, entered into between the Phillips Group and the Amoco/NOCO Group, governs the transportation of Valhall and Hod products from the Amoco/NOCO Group owned 2/4 G Riser Platform across the Ekofisk Center.

14) Processing Agreement (Emden Facilities - Valhall/Hod) (dated September 2, 1982)

- This agreement, entered into between the Amoco/NOCO Group and Norsea Gas A/S, governs the processing of Valhall and Hod gas at the Emden plant.

15) Processing Agreement (Other Teesside Facilities - Valhall/Hod) (dated September 2, 1982)

- This agreement, entered into between the Amoco/NOCO Group and Norsea Pipeline Ltd., governs the processing, storage and terminalling at Teesside of Hod and Valhall NGL products.

1.2.3.1.5 2/4 G Riser Platform Agreements

16) Riser Platform and Bridge Agreement (dated December 8, 1981)

- This agreement is entered into between the Phillips Group and the Amoco/NOCO Group. The agreement governs the installation and removal of the riser platform. The Phillips Group agrees to receive petroleum produced by the Amoco/NOCO Group.

17) Operating Agreement (Valhall Riser Platform) (dated December 8, 1981)

- This agreement is entered into between Phillips Petroleum Company Norway and the Amoco/NOCO Group. Under the agreement, Phillips will operate the riser platform for the Amoco/NOCO Group. The agreement sets forth the rights and obligations of the parties associated with the operation and maintenance of the riser platform. The Phillips Group agrees to receive petroleum produced by the Amoco/NOCO Group.

1.2.3.2 Agreements to be Finalized

In order to ship Hod products to the market, the following transportation and processing agreements need to be entered into (in addition to those that already cover Hod and are addressed under Section 1.2.3.1 above):

18) Valhall Center Processing and Transportation Agreement

- The intention of such agreement, which should be entered into between the members of the Amoco/NOCO Group, would be to establish a fee for the Hod owners' use of the Valhall facilities. The amount of the fee is currently the subject of arbitration between Amoco/Amerada Hess/Texas Eastern and NOCO.

19) Pipeline transportation agreement for Hod crude oil

- Such transportation agreement for the pipeline from Ekofisk Center to the Teesside facilities has been entered into between the Amoco/NOCO Group and Norpipe A/S for Valhall crude oil. This agreement should be expanded to include Hod crude oil. Amoco has formally requested that such agreement be expanded via Phillips Petroleum Company Norway, Operator and part-owner of Norpipe. Draft amendments to include Hod have been agreed with Phillips, who have forwarded the draft amendments to the Norpipe administration for their comments. As the inclusion of Hod crude oil in the said agreement should only be a formality, we expect to have a positive response from Norpipe in the near future.

20) Transportation Agreement for Hod gas

- Such agreement exists for Valhall gas (between the Amoco/NOCO Group and Norpipe A/S), and should be expanded to include Hod gas. This has been accepted by Phillips, who have forwarded a draft amendment to this effect to the Norpipe administration for their comments, as for item 19 above. We expect a positive response from Norpipe in the near future.

21) Processing and Terminalling Agreement for Hod crude oil

- Such agreement is entered into between the Amoco/NOCO Group and Norpipe Petroleum Company for the processing and terminalling of Valhall crude oil at Teesside, and should be expanded to include Hod crude oil. As under 19 and 20 above, Phillips (as operator and part-owner of Norpipe) have agreed to include the Hod products under the said agreement, and have forwarded to Norpipe a draft amendment to that effect for their comments. We expect a positive response from Norpipe in the near future. The processing and terminalling of Hod NGL are covered by the Processing Agreement (Other Teesside Facilities - Valhall/Hod).

It should be noted that the Amoco/NOCO Group is not a party to the Teesside Crude Oil and Lifting Agreement and the Teesside NGL Storage and Lifting Agreement. However, by reference to these agreements in the applicable Teesside Valhall (and Hod, where applicable) agreements, the procedures under the two Storage and Lifting Agreements apply to the Amoco/NOCO Group. The procedure under the Crude Oil Storage and Lifting Agreement will automatically apply to Hod products when the Processing and Terminalling Agreement (Valhall) (Teesside line) is expanded to include Hod crude oil.

1.2.3.3 Approval by the Ministry

Although a number of the agreements listed under Section 1.2.3.1 above apply for the Hod Field, the Ministry of Petroleum and Energy have stated, in connection with their approval of the agreements, that the approval applies to the Valhall Field only.

The Ministry's letter of April 25, 1985 states that "to the extent the agreements also cover petroleum from the Hod Field, the question of approval must be presented to the Ministry when a decision to develop the Hod Field is presented".

HOD FIELD – DETAILED LOCATION MAP

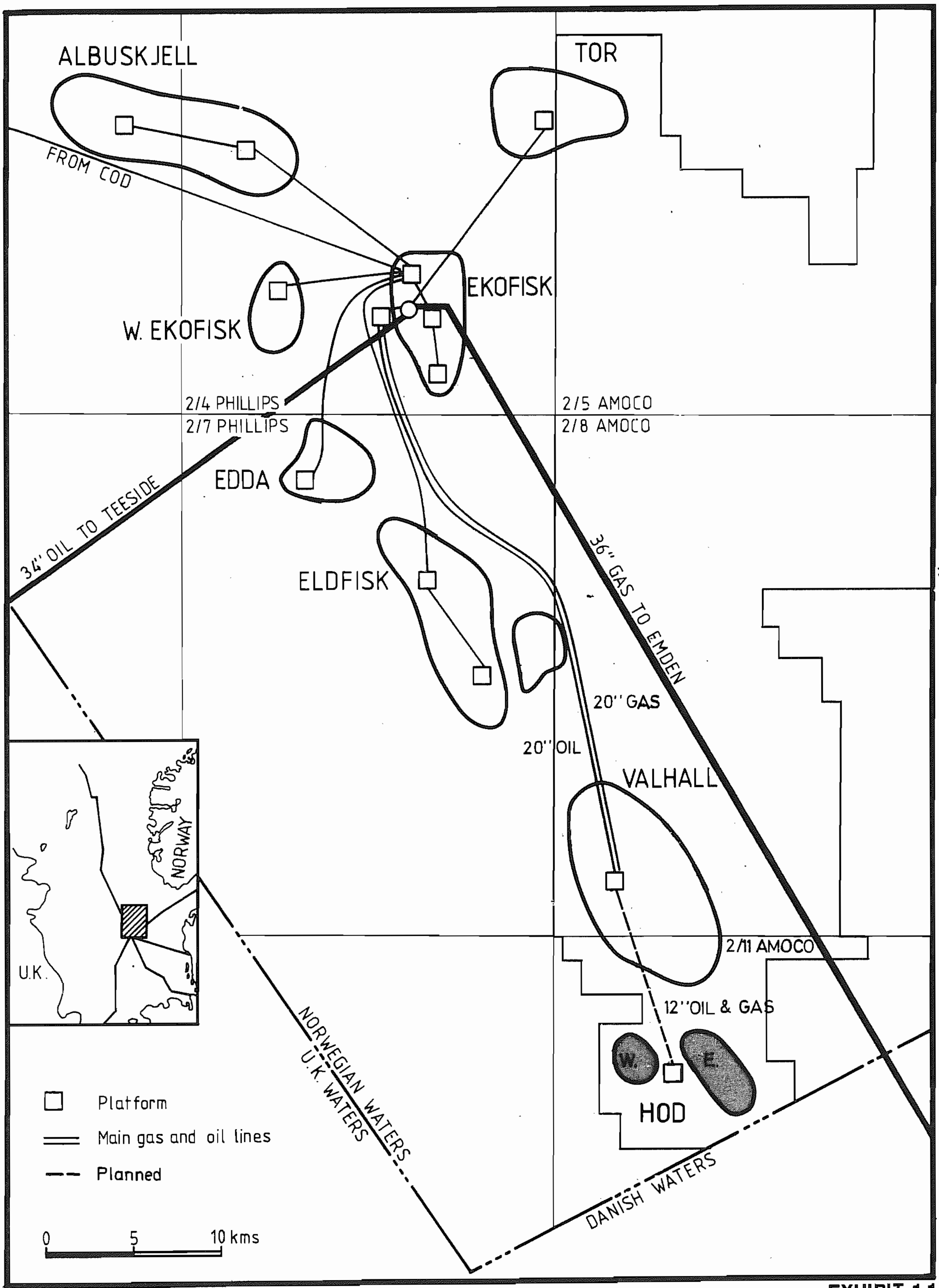

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EXHIBIT 1.1

LOCATION OF FIELDS AND PROSPECTS IN THE "EKOFISK/VALHALL AREA"

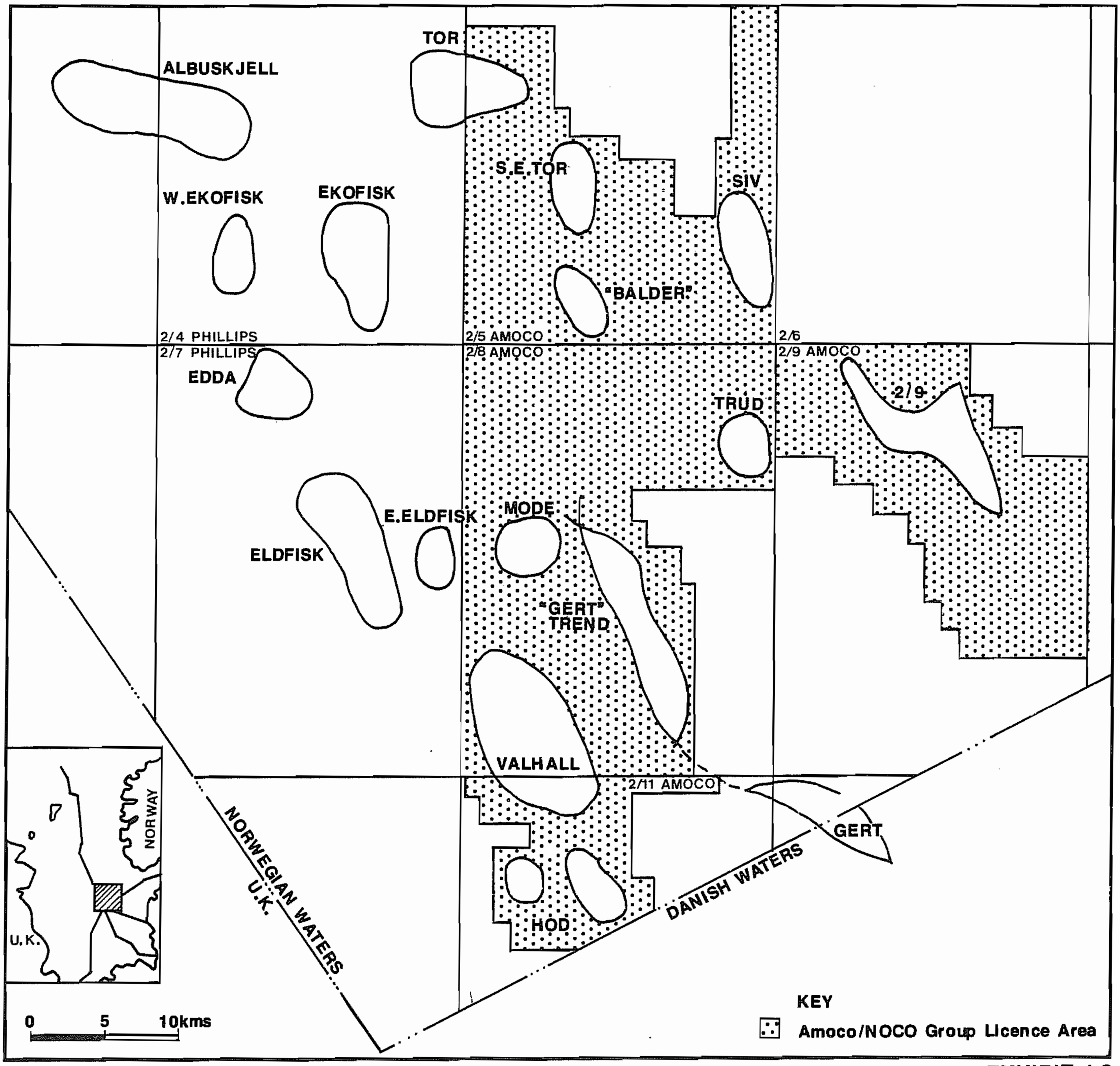

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EXHIBIT 1.2

VALHALL FIELD PRODUCTION PROFILE

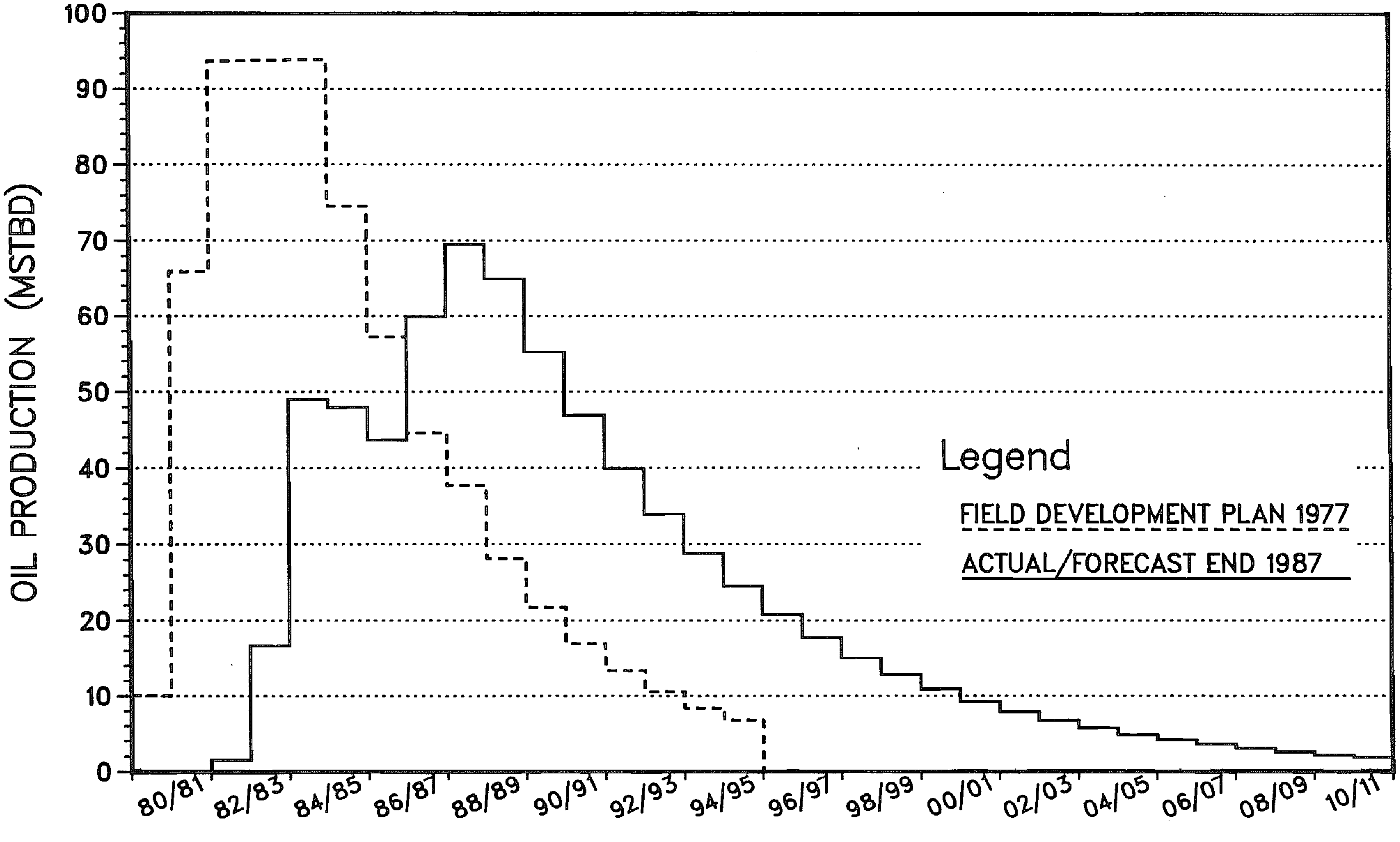

EXHIBIT 1.3

2 SUMMARY

This Hod Field Development and Operating Plan (FD&OP) is divided into eight chapters of which this summary is the second with "Introduction and Background" preceeding it. Starting with the third chapter the order is:

- Geological Conditions
- Reservoir Engineering
- Field Installations and Operations
- Safety Evaluation
- Economic Evaluation
- Environmental and Socio-Economic Consequences

Exhibits relating to the text are compiled in Volume 2 entitled "Exhibits". Full size geologic maps are provided in Volume 3 entitled "Enclosures". Copies of the same maps reduced to A4 size are incorporated in the Exhibits volume.

The Consequence Analysis ("Konsekvensutredning") is presented in Norwegian as a supplement to the FD&OP. An English translation is included in the Exhibits volume.

The following is a description of the contents of each chapter as well as some of the important points made.

2.1 SUMMARY OF LICENCE HISTORY (Chapter 1)

The Hod Field underlies Block 2/11, awarded to the Amoco/NOCO Group as Production Licence (PL) 033 in 1969. Members of the Group are Amoco Norway Oil Company (operator), Amerada Hess Norge A/S, Texas Eastern Norwegian, Inc, and Norwegian Oil Consortium A/S & Co. (NOCO), each holding a 25 % interest in PL 033. Statoil, on behalf of the Norwegian State, holds a 10 % net profit interest in the licence.

Half of Block 2/11 is relinquished (25 % in 1975, and 25 % in 1978). The remaining area is 103.2 km^2 (25,501 acres). PL 033 expires in 2015. There are no remaining well obligations.

By Royal Decree of December 2, 1977, permission to export petroleum was granted by the King in Council, subject to certain conditions. One of the conditions was that NGL from Valhall and Hod should be delivered to Norway. The Amoco/NOCO Group accepted the conditions on January 6, 1978.

2.2 SUMMARY OF CONTRACTS AND AGREEMENTS (Chapter 1)

The agreements applicable for Hod may be divided into the following categories:

* Concession agreements: Licence agreement; Agreement to extend PL 033; Agreement regarding 10 % net profit; Permission to export petroleum; NGL Option Agreement.
* Amoco/NOCO Group agreements: Operating Agreement for PL 033; Article XII of the Valhall Field Unitization and Unit Operating Agreement; Letter Agreement regarding certain matters supplemental to the Valhall Unitization and Unit Agreement.
* Sales agreements: Gas sales agreement with the Phillips Group; NGL sales agreement with I/S Noretyl and Norsk Hydro a.s. (of which the NGL Option Agreement is part).
* Transportation, processing and handling agreements: Transportation agreement for crossing Ekofisk Center with the Phillips Group; Processing agreement for gas at Emden with Norsea Gas A/S; Processing agreement for NGL at Teesside with Norsea Pipeline Ltd.
* 2/4 G Riser platform agreements: Agreement with Phillips Group covering installation and removal of 2/4 G; Agreement with Phillips Petroleum Company Norway covering operation and maintenance of 2/4 G.

Agreements to be finalized:

It is intended to finalize an agreement establishing a fee for the Hod owners' use of Valhall facilities. The amount of the fee is currently the subject of arbitration between Amoco/Amerada Hess/Texas Eastern and NOCO.

Furthermore, the Hod products would need to be included in the three Norpipe agreements already applicable for Valhall products, i.e. the pipeline agreement for oil/NGL covering the distance from Ekofisk Center to Teesside, the pipeline agreement for gas covering the distance from Ekofisk Center to Emden, and the processing and terminalling agreement for oil at Teesside.

2.3 SUMMARY OF GEOLOGICAL CONDITIONS (Chapter 3)

The Hod Field consists of two separate anticlinal features located in the southern portion of Block 2/11. Both features are of similar size and structural appearance, however, the West Hod structure is thought to be related to reversal of movement along the Lindesnes Ridge, whereas the East Hod structure is felt to be salt related. The reservoir section consists of Danian to Turonian chalks of the Ekofisk/Tor and Hod Formations. A reservoir correlation with Valhall Field, located immediately to the north has subdivided the Tor Formation into two units (T1 and T2) and the Hod Formation into five units (H1, H2, H3, H4 and H5/6).

The assessment of Hod Field is based on data from five wells located within the field area. The structural interpretation is based on several vintages of seismic data, the most recent being acquired in 1982. The data quality is poor to good, but mapping is possible with a reasonable degree of confidence over much of the field. However, a strong gas cloud effect decreases the quality of the seismic data in the West Hod feature.

Petrophysical parameters for Hod Field are consistent with other chalk fields in the area even though existing wellbore data are limited and spread over two closures. Net pay criterion is based on a water saturation value equal to 80%. Porosity and water saturation equations and hence the Hydrocarbon Pore Volume Maps for Hod Field were derived by using modified equations for Valhall, as the reservoir subdivisions and characteristics are similar. The resulting most likely Stock Tank Oil Originally In Place (STOOIP) estimate for the Hod Field is 187.4 MMSTBO (29.8 million Sm^3) with 58.9 MMSTBO (9.4 million Sm^3) in West Hod and 128.5 MMSTBO (20.4 million Sm^3) in East Hod. Because the potential Ekofisk/Tor Formation in West Hod is unproven, it is not included in the base case. This implies however that there is potential for an additional 75.4 MMSTBO (12.0 million Sm^3) STOOIP.

2.4 SUMMARY OF RESERVOIR ENGINEERING (Chapter 4)

Five wells have to date been drilled in the Hod Field, 2/11-2, 2/11-3, 2/11-3A, 2/11-5 and 2/11-6(2/11-6(ST-1)). Based on the latest geologic interpretation, it is believed that the field consists of two separate hydrocarbon bearing structures, East Hod and West Hod. This interpretation tends to be supported by fluid property data which suggest that the two structures contain different fluids.

Two wells have been drilled in West Hod, 2/11-2 and 2/11-5. Well 2/11-2 penetrated hydrocarbon bearing Upper and Middle Hod Formations while Well 2/11-5 which was drilled downdip penetrated wet Tor and Hod Formations. It is postulated that the Tor section may be hydrocarbon bearing updip from Well 2/11-5. However, since the updip Tor Formation has not been proved it has not been included in the base case oil-in-place or reserve calculations.

A full field reservoir simulator has been used to generate production profiles and show the impact of changing parameters such as the number of development wells. The simulator used is Amoco's Black Oil Model. Gross thickness, porosity and water saturation data from the geologic maps were used as input data to the model. Other data such as matrix permeability, relative permeability, pore compressibility and fluid properties were also input from the available Hod/Valhall Field database.

The reservoir fluids are undersaturated therefore the Hod Field does not have an initial gas cap. Likewise the main reservoirs (Tor and Upper Hod) are not completely underlain by an aquifer, hence any water influx that does take place must occur via the low permeability flank areas. Therefore, substantial water influx is not expected to take place to influence the reservoir depletion mechanism. Secondary recovery and artificial lift methods are also addressed, but considered not viable at this time.

A base case reserve of 25.4 MMSTB (4.04 million Sm^3 oil) is estimated assuming that two wells are drilled in West Hod and three wells in East Hod. This represents a recovery factor of around 14% which is comparable to predictions for the Valhall Field. A peak rate of 24,000 BOPD (3816 Sm^3 oil/day) and a field life of 15 years are predicted.

Numerous sensitivities were also performed to ascertain the impact of changing the number of development wells, the pore compressibility and the geologic description. These show that the influence of the number of development wells is not a critical parameter and since it is under our control additional wells can be drilled if upside potential is discovered. The upside reserve case where Tor Formation is present in West Hod was also examined. A reserve of 37.1 MMSTB (5.90 million Sm^3 oil) is estimated for this geologic interpretation in which 3 wells are required to drain each of the East and West Hod structures. A peak rate of 37,000 BOPD (5882 Sm^3 oil/day) and a field life of 15 years are predicted.

2.5 SUMMARY OF FIELD INSTALLATIONS AND OPERATIONS (Chapter 5)

This chapter discusses development alternatives and describes the selected concept, including drilling and production operations.

2.5.1 Development Alternatives Evaluation

A number of field development studies have been performed since the presence of producible hydrocarbons in the West Hod structure was proven by Well 2/11-2 in December 1974. The four delineation wells drilled subsequently led to reduced estimates of reserves. All cases have assumed partial or full processing of the production stream at the Valhall Field. The Hod Field installations studies have ranged from self-contained platforms to subsea production systems and intermediate alternatives involving a well protector platform. Representative cases are outlined in Section 5.1. Production problems at Valhall raised well completion concerns which further discouraged the development of the Hod Field.

However, following the successful introduction of the gravel-packing technique at Valhall in 1986, these technical concerns have been mitigated and a small, low cost development is considered economically and technically viable. The Hod development concept is planned to use a "normally unmanned wellhead protector platform". This concept strikes a balance between the attractiveness of a subsea development and the operating flexibility of a fixed platform. This combined with the recent change in the Norwegian tax structure provides for an economic development of the Hod Field.

2.5.2 Field Installations Description

Plans for Hod development are for an unmanned wellhead protector platform tied back to Valhall by a single two-phase pipeline. The current platform design is a slim, four legged x-braced jacket with one main pile in each leg. The topsides will have two small decks with production and utility equipment on the cellar deck and a shelter module on the main deck. Much of the main deck is left clear for access by a cantilevered jack-up rig. Facilities on Hod are kept to a minimum to increase reliability and minimize human intervention. Production is transported the 13 kilometers to Valhall via a 0.3 m (12-inch) pipeline and enters the Valhall processing system upstream of the first stage separators. No additional processing facilities are required at Valhall because Hod satellite production was included in the original Valhall design.

Section 5.2 includes conceptual design details and justifications. Drawings of the Hod platform are located here as well as the explanation of metering and allocation plans. This section systematically describes every major item on the platform as well as the environmental and structural design parameters used. The Hod platform design relies on minimizing equipment and activities to produce an inherently safe and reliable concept. The only items of production equipment on board are wellheads, headers, test/production separator and a pig launcher. Total produced liquid inventory on the platform is 9 m^3 (56 bbls) representing 2.2 minutes at peak production. Utilities include electric power generation, potable water, seawater and diesel fuel. All systems are designed to be as simple as possible to minimize the need for human intervention. The environmental/structural design of Hod reflects a detailed analysis of Valhall data and experience, and allows fine tuning of design parameters to reduce platform weight.

2.5.3 Drilling and Well Completion Considerations

This section presents a description of the proposed drilling operations including preliminary drilling, casing, and completion designs. Amoco has experience in drilling highly deviated wells at Hod having previously drilled five exploration wells including the deviated 2/11-3A and 2/11-6, the latter through the Hod template. A jack-up rig is planned to be used to drill, complete, and/or tie back the wells to the platform whether the wells are pre-drilled or drilled after the platform is installed. A market survey has ascertained that several jack-ups have the capability to cantilever over the Hod platform. Current completion plans are modelled on Valhall experience, calling for perforating in diesel, proppant fracturing all formations, and placing gravel-packs across Tor Formation perforations using a snubbing unit on the jack-up. Simultaneous drilling and production procedures modelled after the successful

Valhall procedures will be submitted for approval at a later date.

2.5.4 Field Operations Considerations

The Valhall Production Operations organization will assume the responsibility for the operation and maintenance of the Hod Field installations following handover from the Construction organization.

This section explains the operating philosophy envisioned for the Hod platform. This platform can best be likened to a subsea development with the wellheads brought to the surface. The design was chosen for simplicity and reliability. Normally all operational aspects will be handled from Valhall and only four to six visits per month to the platform are planned for maintenance, well testing, and replenishment of diesel fuel, water, and chemical stocks. Timing of these visits are flexible and will be scheduled to avoid periods of inclement weather. Drilling or major workovers will be performed using a cantilevered jack-up rig where accommodation etc. is supplied on the jack-up. Wireline work and some coiled tubing work can be done from the platform without the presence of the jack-up. There are no planned occasions where personnel will stay overnight at the Hod platform and sleeping facilities are provided only for the very unlikely case where, despite all precautions, a work crew is stranded at the platform and has to stay overnight.

Tying the unmanned Hod platform to the Valhall facilities will have only minimal impact on the structure of the existing production operations organization. Maintenance and logistic functions will also be fully integrated with those in effect for the Valhall Field.

2.6 SUMMARY OF SAFETY EVALUATION (Chapter 6)

The Safety Evaluation presents a probabilistic risk analysis compiled to demonstrate the safety of the proposed Hod development. An attempt was made to identify all relevant accident scenarios and using consistently conservative assumptions, evaluate both their probability and consequences. The end result showed a total probability for fatal accidents of 0.42×10^{-4} per year which is well below the NPD criteria of 1×10^{-4}. Totally dominating this probability of fatal accidents are well blowouts which are more a function of downhole tool integrity and procedural practices than of platform design. On a manhour basis the total fatal accident probability is 0.67×10^{-8} per manhour or about six times better than the historical figures for general industry in Norway. The results of the safety studies verify that the Hod concept of open decks with minimal process facilities results in a safe work place. Helicopter safety was also evaluated even though this is only remotely related to the platform design. Note that although the results of the Safety Study were largely accepted, both inhouse Amoco personnel and NPD requested the addition of a water based personnel protection system for the wellhead area on the cellar deck and a simple foam system on the helideck. In response to these concerns Amoco has added a water based personnel protection system and a simple foam system to the concept described in the Hod Development Study dated November 1987.

The assessment that the proposed concept provides a safe working environment was expected, since this concept is already widely used throughout the rest of the world including the UK-sector of the North Sea as exemplified by a recent approval of Amoco's Indefatigable 49/23-D platform.

2.7 SUMMARY OF ECONOMIC EVALUATION (Chapter 7)

With the Base Case production, prices and costs, the Hod Field Development Project is expected to generate the following economic results:

Internal Rate of Return - 20%

Net Present Value (discounted at 15%) - US$ 8.7 million

In addition, the following Net Present Value results were generated for lower discount factors :

Discount Factor 10% - US$ 21.4 million

Discount Factor 7% - US$ 31.3 million

The level of income to the State is calculated to be US$ 75.7 million (escalated) in the form of various taxes. In addition, the 10% Net Profit Contribution to Statoil is calculated to be US$ 16.8 million (escalated).

The main input items on which these economic results were generated are as follows :

Total Oil Production - 25.4 million stock tank barrels (4.04 million m^3 at standard conditions).

Oil Price - US$ 17.50 per barrel at the beginning of 1988, escalated at 5% per annum thereafter.

Total Revenue - US$ 769.8 million.

Total Capital Expenditure - US$ 94.3 million (escalated).

Total Expenses - US$ 631.3 million (escalated).

Several other economic cases were generated, to address sensitivities to changes in the above parameters. These are described in Chapter 7 of this document, in addition to the Base Case results quoted above.

2.8 SUMMARY OF CONSEQUENCE ANALYSIS (Chapter 8)

In conjunction with the Field Development and Operating Plan (FD&OP) a Consequence Analysis is required. It is provided as a separate supplement in Norwegian (Konsekvensutredning). This document will be public and be used for the political evaluation of the application for developing the Hod Field. The Consequence Analysis gives a summary of the Field Development and Operating Plan and in addition provides description, evaluation and conclusions on the impacts the execution of the plan may have. (An English translation of the document is provided in the Exhibits volume, Chapter 8).

3 GEOLOGICAL CONDITIONS

3.1 GEOLOGY AND GEOPHYSICS

3.1.1 Seismic Data

3.1.1.1 Database

Four wells, one sidetracked well and the SSL seismic survey shot during July and August 1981 form the primary database for Hod Field. The survey consists of 16 northeast-southwest trending lines spaced 500 meters apart, one east-west trending line and six randomly orientated tie lines, two of which tie wells 2/11-1 and 2/11-4 in Valhall Field to the north. Several lines from the 1975 and 1978 surveys were used where the seismic coverage, which is oriented parallel to the structural trend, is poor. In addition, several lines from the 1982 Norsk Hydro seismic survey were utilized on West Hod. The seismic control is shown on the Top Chalk Depth Map included as Enclosure 3.1 and Exhibit 3.31.

3.1.1.2 Data Quality

Data quality is generally poor to good but mapping is possible with a reasonable degree of confidence over much of the field. Although the 1981 survey had some acquisition problems, it provides better resolution than earlier surveys and therefore make it possible to identify intra-chalk events and features. The two older surveys provide valuable character correlations although in some cases time shifts make it difficult to time-tie lines of different vintages. In extreme cases, sections of strike lines affected by both "sideswipe" and time shifting were not digitized.

3.1.1.3 The Interpretation

3.1.1.3.1 Top Chalk

The top of the reservoir is marked by a strong reflector at the boundary between Tertiary shales and Cretaceous chalk. This reflector is generally a straightforward event to map as it is largely unaffected by faulting. Within the gas cloud on West Hod however, only a few lines are available to carry the interpretation around the crest of the structure. On several Norsk Hydro lines, the Top Chalk event appears to be lying flat within the gas cloud. This apparent lack of relief is due to the low velocity gas charged sediments above the West Hod structure. The severity of the pull-down effect can be demonstrated on post Paleocene reflectors, where several gently dipping, coherent events sag on the time section over the crest of the structure.

Depth conversion was carried out by contouring the velocities obtained from well control and extrapolating the contours away from the control (Enclosure 3.2). On West Hod the velocity field was built taking into account the lateral distribution and severity of the gas effect (Enclosure 3.3). When the time sag as seen on post Paleocene events is removed from the Top of the Chalk, the crest of the structure is shown to be south-west of well 2/11-2 (Enclosure 3.1). Dipmeter readings at the well confirm this. Enclosures 3.4, 3.5, and 3.6 are interpreted seismic lines selected to incorporate existing well control.

3.1.1.3.2 Tor Isopach

Resolving the base of the Tor Formation is difficult because the thickness of the formation at elevations above the oil water contact is about the limit of seismic resolution at this depth (Enclosure 3.7). The situation is aggravated by interference from the high amplitude top Chalk reflector and the loss of higher frequencies within the gas cloud on West Hod. Consequently the first continuous event below top Chalk was chosen and interpreted over the field. Depth conversion was carried out in the same fashion as was done for the Top Chalk seismic event.

Structure, isopach and midpoint structure maps for each horizon are included as Exhibits 3.32 to 3.48 and Enclosures 3.12 to 3.14.

3.1.1.3.3 Measured Depth to True Vertical Depth Conversion

The method used to correct measured depth to true vertical depth in deviated wells is the Minimum Curvature method. This technique was used in wells 2/11-3A and 2/11-6 (ST-1) as well as on all production wells on the Valhall Field, and is the method that also will be used for deviated production wells on the Hod Field.

Isopach maps of the stratigraphic intervals are based on actual true vertical thickness (TVT) values measured in the exploration and development wells.

3.1.2 Stratigraphy

3.1.2.1 Regional Structure

Hod Field is located along the southwest flank of the Norwegian Central Graben (Exhibit 3.1). The Central Graben is a Mesozoic-age rift basin. The most prominent structural feature in the Hod Field area is the Lindesnes Ridge. Structural inversion along the Lindesnes Ridge is the structural mechanism responsible for five oil fields along its trend (Hod, Valhall, Eldfisk, Edda and Tommeliten/Gamma) containing reserves totaling about 600 MMSTBO (Exhibit 3.2).

The relationship of the Lindesnes Ridge with these chalk fields and the nature of the Lindesnes Ridge and its structural history have been discussed in the literature. Based upon the structural trends in the Valhall and Hod area, the Lindesnes Ridge appears to be an inversion feature directly to the east of a major Jurassic or older normal fault. Reverse or inversion movement was initiated in the Lower Cretaceous and continued through Chalk time to the Miocene. A detailed analysis of the Lindesnes Ridge movements can explain the structural history of Valhall and West Hod.

The salt induced anticline is a second type of structure common to the Central Graben, accounting for a total of about 1.25 billion barrels of oil reserves from seven fields including one billion barrels from Ekofisk Field alone. Seismic analysis suggests that East Hod is an example of such a field, implying that East Hod therefore has a less complex and possibly unrelated structural history to Valhall and West Hod. Salt tectonics could play a role in the structural development of West Hod as well, however the seismic evidence is inconclusive.

3.1.2.2 Regional Stratigraphy and Depositional Environment

The chalk reservoirs in the oilfields of the Norwegian Central Graben are not homogeneous. There are considerable variations in the texture and in the mineralogy of the rock. The variations occur both in time and in geographic distribution.

Chalk depositional environments range from slump and debris flows, characterized by high rates of deposition and highly folded and fractured bedding planes or no internal bedding, to pelagic chalk, slowly deposited with consistent bedding and lateral continuity over long distances. An intermediate rock type is the turbidity current or channel flow. Depositional rates for this rock type are variable, and while bedding surfaces are present, angular unconformities and dip changes are common. These depositional environments can most easily be identified by core studies or less conclusivly by dipmeter analysis. The slump and debris flow deposits have the highest porosity and permeability of all the Central Graben chalks. This is primarily due to the high rates of deposition, lack of consolidation and cementation and larger grain size. The source material for the Maastrichtian age slumps are interpreted to be derived from local faulted highs related to structural inversion. The Danian units possibly have a significant contribution from the eroded Valhall/Hod area. The youngest Maastrichtian unit is the primary reservoir unit in the Hod area.

In the Ekofisk - W. Ekofisk area where structural movement post-dated Tor deposition, chalk thickness is fairly constant. Further south in the Eldfisk, Valhall and Hod field areas, however the structural configuration of these fields at the time of chalk deposition strongly influenced the area of thickest slump/debris deposition.

A factor in the variation of reservoir quality is the mineralogy of the chalk. While certain formations, such as the upper Tor are composed of almost 100 percent calcium carbonate, other zones contain secondary components of mainly clay and silica which form a significant proportion of the rock. In extreme cases such as the Ekofisk tight zone or the tight zone separating the Tor and Hod Formation at Hod, this non-carbonate fraction can reach 50 percent.

The origin of the non-carbonate fraction probably has two sources, detrital and biogenic. Both silica and clay can be derived from terrestrial sources such as the Scandinavian Shield or smaller isolated high blocks such as the Mandal High or Mid-North Sea High, and may be deposited in the Central Graben via marine turbidity currents. Much of the silica is probably biogenic in origin, due to dissolution of radiolarian tests. In either case, rate of deposition is crucial, as slow rates of chalk deposition would allow a greater proportional accumulation of clay and silica. High sea level would also help to reduce detrital clay and silica as the source area would be further removed from the Central Graben. The Tor Formation shows a consistently low non-carbonate fraction of less than 5 percent, while the Ekofisk and Hod Formations have an average of about 20 percent non-carbonate fraction of which over 90 percent is silica. There does not appear to be a major geographic variation in these fractions. The thinner chalk section at Hod, however, points to a slower rate of deposition resulting in slightly higher silica and clay content for the Tor and Hod Formations.

3.1.2.3 Hod Stratigraphy and Sedimentology

3.1.2.3.1 Well Correlation

The Hod correlations are based upon the Valhall stratigraphic divisions and tied to Valhall via the 2/8-3 well (Enclosure 3.8). Three major differences are seen between Valhall and Hod: (1) The presence of Danian age Ekofisk Formation in the 2/11-5 and 2/11-3A wells compared to the absence of Ekofisk at Valhall; (2) the presence of a Santonian-Campanian age dense zone in all Hod wells except well 2/11-2, while the comparable section on the crest of Valhall is absent; and (3) the superior rock quality of the Upper Hod Formation on Hod Field (primarily in Well 2/11-2) as compared to Valhall Field.

The present well correlations (Enclosure 3.9) are based on a paleontological re-analysis of Valhall and Hod Fields by Robertson Research in 1984 plus an updated correlation done in 1986. The Hod correlations provide a reasonable geologic model at this time that is consistent with the log and paleontological data.

3.1.2.3.2 Depositional Environment

Depositional environments of the Hod Field chalks were studied using the model developed for Valhall Field. In particular, the fault/channel model was used to help predict the presence of Tor Formation. Tor chalk texture appears to be more of a depositional nature than an erosional one in that the Tor does not appear to cut into the Upper Hod on seismic data. The presence of a Santonian-Campanian dense zone in all the wells except 2/11-2 appears to preclude the erosional model. If channels existed, they would feed into local synclinal or graben areas as determined by structural trends existing during Maastrichtian and Danian time.

Dipmeter data are limited at Hod. Although five wells have been drilled to date, well 2/11-6 was drilled with oil based mud, and well 2/11-3A is a highly deviated well, which probably adversly affected the reliability of the dipmeter. The 2/11-5 dipmeter shows a number of zones with dips in excess of 50 degrees throughout the chalk section, which renders the log somewhat suspect. By using all the data, however, some generalizations can be made (Enclosure 3.10). The Hod Formation appears to be predominantly pelagic in nature, while the Ekofisk/Tor zones show some indications of channel or current bedded features, particularly at the base of the zones. The high quality Upper Hod reservoir in 2/11-2 is almost featureless on the dipmeter log.

The reservoir quality of the Ekofisk/Tor and Hod Formations at Hod Field was probably affected by paleostructure, as appears to be the case at Valhall Field. In West Hod, the paleocrest was located to the south of the present day crest as evidenced by the thin Hod and Tor intervals in the 2/11-5 well. The chalk interval in the 2/11-5 well is the thinnest interval yet penetrated in the Valhall/Hod area. In the West Hod area at the time of chalk deposition the 2/11-2 well would have been located downdip relative to the 2/11-5 location, and thus received redeposited chalks shed off the 2/11-5 paleocrest. As mentioned earlier redeposited chalks are generally of superior reservoir quality and could account for the better quality of the upper Hod section in the 2/11-2 well, now located on the north flank of the present day structure. Similarly on East Hod, the paleocrest was located to the southeast of the present day structural crest as evidenced by well data. The slightly improved reservoir quality in 2/11-3A as compared to 2/11-6 supports the hypothesis of better reservoir quality on the north flank of East Hod for a given structural elevation.

3.1.2.4 Reservoir Formations

3.1.2.4.1 Ekofisk Formation (Exhibit 3.3)

Age: Danian

The Ekofisk Formation was cored in the East Hod well 2/11-3A, and identified in the West Hod well 2/11-5 on the basis of paleontological age dating of side-wall core samples. The overlying reservoir cap rock of the Maureen Formation equivalent (a finely conglomeratic calcareous mudstone of late Paleocene age), seals the buff oil-stained chalk of the Ekofisk Formation. The contact is interpreted as a submarine erosion surface between relatively shallow water chalks of the Ekofisk Formation and deeper water mudstones of the Maureen Formation equivalent. The Ekofisk Formation is characterized by bioturbation, and burrows are delineated by differential oil-staining. The oil staining testifies to the reservoir potential of the section despite the relatively low porosity (2/11-3A and 2/11-5).

3.1.2.4.2 Tor Formation (Exhibit 3.3)

Age: Maastrichtian - Late Campanian

The Tor Formation is the primary reservoir of Valhall Field with an estimated two-thirds share of the total oil-in place for the field. In Hod Field the Tor is of primary interest on East Hod, but is absent in the crestal well of West Hod. The Tor Formation is characteristically a high porosity, deeply oil-stained chalk cut by numerous burrows. The top of the section in well 2/11-3A contains exotic chalk intraclasts and nodules.

The Tor Formation, like the Ekofisk, is interpreted as having had a relatively shallow water environment of deposition (maximum of a few hundred meters water depth). Decreasing water depth and increasing energy toward the top of the section account for the increase in burrowing and the reworking of intraclasts to create the mottled conglomeratic appearance that characterizes the upper section of the Tor in well 2/11-3A.

3.1.2.4.3 Dense Zone (Exhibit 3.3)

Age: Early Campanian Santonian

The base of the Tor Formation grades into a dense tight zone illustrated by core samples from well 2/11-6, the only Hod Field core cut in this interval. The zone shows no oil staining and has very low porosity of less than 10 percent. The dense zone has been cut by an intensive fracture system that has subsequently been sealed with calcite, possibly as a result of pressure solution. These fractures are the widest and most obvious of any seen in all the cores studied for Valhall and Hod. On the basis of the 2/11-6 core, however, there appears to be no flow path through the dense zone. The zone is likely to be a permeability barrier between the Tor and Hod formations.

In thin-section, the dense zone shows complete calcite filling of fractures and foram chambers, suggesting intense diagenesis. Oil permeabilities for a sample of the dense zone were generally less than 0.0001 millidarcies.

This boundary between the Tor and Hod formations is postulated to correspond to a hiatus in the Hod fields. Paleontological age dating of nannoplankton proved to be very difficult owing to poor preservation of coccoliths in this interval. The depositional environment of the dense zone has been interpreted as a submarine erosion surface overlain by a current-winnowed lag. The water depth for this interval at the time of deposition is interpreted as a transition between the deeper water deposition of the Hod formations (600 meter water depth?) and the shallower water deposition (300 meter ?) of the Tor and Ekofisk formations.

3.1.2.4.4 Upper Hod Formation (Exhibit 3.3)

Age: Coniacian

The Upper Hod Formation is illustrated by core samples from Valhall well 2/8-9 to be a laminated sequence of wispy solution seams and bands of oil-stained chalk separated by tight or marly zones. The section is cut by slickensided fractures and high and low-angle coated fractures. In Valhall Field this zone is generally rated as having relatively low reservoir potential.

The laminated nature of the Upper Hod is evident from the high resolution open-hole logs run across this zone. In East Hod, the Upper Hod Formation appears to be a better reservoir than that found in Valhall. The Upper Hod found in the wells of East Hod, viz. 2/11-3A, 2/11-6 and 2/11-6 (ST-1), contains intervals with porosities and oil saturations comparable with the lower porosity intervals of the Tor Formation. Routine core analysis of Well 2/11-6 (Exhibit 3.4) shows porosities and permeabilities of the Upper Hod to be similar to those for the Tor Formation.

The Tor Formation in the 2/11-6 well has considerably lower porosity, permeability and oil saturation than that generally found in Valhall, but the Upper Hod is conversely of higher porosity and oil saturation than that generally present in Valhall. The Upper Hod found in Hod Field, like the Tor Formation, has only a minor amount of non-carbonate constituents as opposed to the high percentage seen in the Upper Hod Formation of Valhall.

3.1.2.4.5 Middle Hod Formation (Exhibit 3.3)

Age: Coniacian - Turonian

Toward the base of the Upper Hod the degree of lamination and apparent shaliness increases as the Upper Hod grades into Middle Hod. There is no sharp dividing line between these two formations. The Middle Hod has been described as marly and shaly, but the clay content in both Valhall and Hod is very low. The major non-carbonate contaminant in this interval is about 20 percent clay-sized quartz.

The depositional environment for both Middle Hod and the lower portion of the overlying Upper Hod is interpreted to be rhythmic deposition in deeper water (less bioturbation) than the upper portions of Upper Hod. The occasional bands of more homogeneous bioturbated and burrowed chalk suggest infrequent alternation to more oxygenated conditions.

The reservoir potential of the Middle Hod is low. Oil staining is totally absent. A high frequency in the occurence of solution seams testifies to increased diagenetic effects, and the high quartz content results in a reduction of permeability due to the infilling and blockage of pore throats.

3.1.2.4.6 Lower Hod Formation (Exhibit 3.3)

Age: Turonian

The prevalent characteristic of the Lower Hod observed from cores is the laminated or banded nature of the formation. Bands of "pay" and "nonpay" are delineated by oil staining. Oil has entered the higher permeability bands but did not have sufficient buoyant pressure or height of oil column to exceed the threshold pressure of the tight bands.

The reservoir potential of some portions of the Lower Hod is high. The rock exhibits similar porosity/ permeability characteristics to the Tor Formation and has a low content of quartz and clay. The primary difference in productivity between Tor and Lower Hod is believed to be attributable to depth of burial and intensity of fracturing.

The depositional environment of the Lower Hod was one of relatively deep water, probably in excess of 600 meters. The banding of the cores indicates an alternation of oxygenated bottom waters (bioturbated zones) and oxygen depleted waters (laminated zones). The laminations suggest phases of pelagic sedimentation interspersed with turbidite influxes of resedimented material from some local "paleo high".

3.1.3 Hod Structure

The Hod Field consists of two separate anticlines, both oriented northwest to southeast and each with a closure area of about 6.9 square kilometers (Enclosure 3.1). Despite apparent structural similarities at the top chalk level, the two fields are interpreted to have a different structural origin. West Hod directly overlies the Lindesnes Ridge, and its structural history is related to movements on the ridge. East Hod appears to be a salt related anticline as evidenced by seismic. However, the interpretation of the structural history at Hod must be considered speculative because of poor well control at chalk level and poor quality seismic data resulting from the strong gas cloud overlying much of West Hod.

3.1.3.1 West Hod

The structural history of West Hod (Exhibits 3.5 to 3.8) is similar in many ways to that of Valhall. West Hod lies just to the northeast of the Lindesnes Ridge bounding fault (Exhibit 3.9). While the fault is interpreted to have normal movement with a thick Upper Jurassic Section deposited on the downthrown side, the initiation of wrench faulting along the ridge in Cretaceous time induced uplift of the West Hod structure. The uplift was particularly severe during chalk time due in large part to the bending of the Lindesnes Ridge bounding fault in the Hod Field area. As shown in Exhibit 3.9, this bending causes severe compression at an area in the vicinity of the 2/11-5 well. Well 2/11-5 in fact has a chalk section of only 98 meters, the thinnest chalk section penetrated by any well in the Valhall/Hod area. The paleocrest of the West Hod structure is south of the present crest. Residual oil in the Tor Formation of 2/11-5, almost 75 meters below the base of the present oil column, indicates that in early to middle Tertiary, the structural crest had not yet completely shifted northward to its present location. Some of the Tertiary movement at West Hod may be associated with salt movement, but the lack of any deep well penetration and the poor seismic data due to gas effects make it very difficult to substantiate this. The intense uplift at West Hod has apparently produced a crestal graben. The location of the graben to the southwest of the present crest is another indication of the shifting of the crest to the northeast during the Tertiary.

3.1.3.2 East Hod

Even though a major period of structural uplift at East Hod occurred in the Tertiary, seismic data indicates movement may have occurred during the Cretaceous (Exhibits 3.7 and 3.8). The close correlation of the top chalk closure and the Oligocene closure, however, indicates that much of the uplift occurred after the Oligocene (Exhibit 3.10 and 3.11).
The evidence for salt movement causing the late uplift is based solely on seismic interpretation, as there is no penetration below the Cretaceous in any of the East Hod wells.

3.1.3.3 Fault Pattern and Tor Formation Distribution

The Hod Field is largely unaffected by faulting at the top chalk and base Tor levels except at the crest of the structures. On East Hod a crestal graben had developed as a result of uplift and crestal extension. Subsequent erosion removed Tor from the upthrown side of the western bounding fault, but Tor is interpreted to be preserved in the graben and along the eastern flank.

Indications are that the distribution of Tor to the east of the crestal graben is controlled at least in part by fault/channel deposition.

On West Hod, fault definition is made difficult by the poor data, but several seismic lines indicate that a graben had formed along a paleocrest as a result of uplift and crestal extension. The graben is situated to the west of the present day crest, but the Tor total thickness does not seem to be effected by the formation of the graben.

3.1.3.4 Fracture Studies

One of the important factors determining the economic potential for development of the chalk reservoirs is the existence or non-existence of an open natural fracture network. Despite the high porosities and oil saturations seen in the chalk in the Valhall/Hod area, the permeability of the matrix rock is generally less than five milliarcies (md) and often less than one md. Well tests in fractured areas of the Hod Field, however, show higher permeabilities in the range of 13 to 17 md.

Despite the importance of fractures to productivity, the description of the fracture system in the chalk reservoirs is still largely uncertain. The existence of fractures in the Valhall/Hod area is deduced more often from a lack of core recovery rather than from physical observation of fractures in cores. The comparison between well test permeabilities and core permeabilities has been the main guide to the estimation of the degree of permeability enhancement by fracturing, but this does not provide a fracture description. To date, well log analysis has failed to provide a description of the fracture system and core descriptions have often been unsatisfactory owing to a lack of recovery. By implication, the open fractures responsible for higher permeabilities measured in well tests must be more widely spaced than the core sample size.

3.1.4 Geological Field Model

The subdivision of the reservoir in the Hod Field into the Ekofisk, Tor, and Hod formations is based on changes and variations during deposition and later diagenesis of the chalk. There are changes in lithology, sedimentology, biostratigraphy and petrophysics that can be correlated between the East and West Hod structures as well as up to the Valhall Field. (Enclosure 3.8).

For geological reservoir modeling, the reservoir is subdivided into eight reservoir zones (Exhibit 3.3). This zonation is the same as that used on the Valhall Field, except that the Ekofisk Formation is present in the Hod Field and not in Valhall. The division into production zones is based on changes in reservoir quality, reflected in the log responses. These variations are due to changes in lithology and depositional environment and are often associated with breaks in deposition and development of unconformities and hard grounds.

Only a very thin Ekofisk Formation has been seen in wells 2/11-3A and 2/11-5. Because of its marginal thickness and reservoir characteristics, it has been combined with the underlying Tor Formation.

The Tor Formation at Valhall has been divided into an Upper Tor (T1) and a Lower Tor (T2). A similar division has not been done on the Hod Field, mainly due to lack of well control.

The Hod Formation in the Hod Field can be subdivided, as in Valhall, into the six reservoir zones H1 through H6. Between the Upper Hod and the Tor, a dense zone is indicated by an increased gamma ray response, a reduction in porosity, and very low permeability determined from core data. The boundary between Upper Hod (H1) and Middle Hod (H2) is determined by an increase in lamination and reduction in porosity. The resistivities, in combination with other log data, assist in determining increasing lamination.

The boundary between the Middle Hod and the Lower Hod is determined by a porosity increase along with a reduction of the gamma ray response and a more stable resistivity response delineating the top of the Lower Hod. Other log responses are also used to detect this top.

Due to the fact that the upper and the lower part of the Lower Hod have a higher degree of lamination, it is desirable to separate the Lower Hod into the three zones, H3, H4 and H5/6. The boundary between the H3 and H4 units is characterized by a combination of porosity, gamma ray, and resistivity tool responses. As can be seen on logs from the Valhall well 2/8-8, this boundary is apparent from the gamma ray and the sharp increase in porosity. The resistivity tool response also indicates an increasing amount of lamination.

At the base of the H4 zone, there is a minor increase in the gamma ray response, a marked reduction in porosity and an increase in density, which marks the top of the H5 zone. The H5 and H6 zones are both of minor interest due to their generally very poor reservoir characteristics. They show a high degree of lamination similar to the H1 zone, and also have a relatively high argillaceous content.

The top of the H6 zone is difficult to pick in many wells on Valhall, but is normally indicated by a higher gamma ray response and lower porosity. The reservoir zones H5 and H6 are grouped together as H5/6 due to their similar reservoir characteristics. The Base of zone H5/H6 coincides with the Plenus Marl marker.

3.2 FORMATION PARAMETERS WITH PETROPHYSICAL INTERPRETATION

This report has endeavored to use the findings of the Valhall/Hod Field petrophysical study as a basis for generating porosity, saturation and permeability equations. The previous study was documented as part of the 1985 "Valhall/Hod Geologic Reanalysis and Discussion of Future Field Development" report. The use of the expanded digital log data base from Valhall has provided a larger statistical base for prediction of porosity and water saturation. The greater number of production wells has also provided a larger pressure transient analysis data base with which to calibrate core derived permeability estimates. A summary of the Hod Field petrophysical parameters used in this report is shown in Appendix I.

3.2.1 Discussion

3.2.1.1 Water Saturation Computation

Water saturations were determined by the Archie equation and the same log analysis procedures as for Valhall. Studies indicate that the Archie equation provides a suitable estimate of water saturation in the chalk. This equation is of the following form:

$$S_w^n = \left(\frac{a}{\phi^m} \right) * \frac{R_w}{R_t}$$

where Sw = fractional water saturation
a = constant
m = cementation exponent
Ø = fractional porosity
Rw = formation water resistivity at formation temperature
Rt = true formation resistivity
n = saturation exponent

Formation factors derived from core data suggest that conventional values of a = 1.0 and m = 2.0 can be considered reasonable approximations to these parameters. Saturation exponent was set equal to 2.0 by convention, and Rt was set equal to the deep induction log response. As in Valhall, porosity has been derived from the density log with a correction applied for the mud system used. Chalk completions to date have produced little or no water. As a result the data base of measured formation water resistivity is small. A petrophysical study of the Valhall chalk indicates that Rw = 0.045 at 195°F, based upon measurements of water samples recovered from a drill-stem test in Well 2/8-8. More recently, a sample of produced water from Valhall well 2/8A-13 had a measured Rw = 0.046 at 200°F. Using the Rw measurements from the 2/8-8 and 2/8A-13 wells and the Arps formula,

$$Rw = Rtr * (Tr + 7)/(Tf + 7)$$

Rtr = formation water resistivity at referenced temperature

Tr = temperature to which measure water resistivity is referenced in °F

Tf = formation temperature of water in °F

The Arps equation results in the following equation for Rw used in this study:

$$Rw = 9.31/(0.25 * \text{DEPTH (in ft)} - 3)$$

3.2.1.2 Porosity Computation

The density log was used to estimate porosity in the chalk. Specifically in the Hod Field it was found that using a limestone matrix density of 2.71 g/cc and a fluid density of 1.0 g/cc the density log provided a superior correlation to core porosity than could be achieved with either the neutron or the acoustic logging tools. It is necessary, however, to make a correction to density logs where oil based muds were used.

This correction factor takes the following form:

$$\varnothing_{TRUE} = .73809*\varnothing_{APPARENT} + 7.595$$

where

$\varnothing_{APPARENT}$ = density log porosity of oil base mud system using RHODE = 2.71 g/cc and RHOW = 1.0 g/cc

$\varnothing_{TRUE}$ = corrected apparent density porosity

This is not a linear regression equation. This correction provides a porosity reduction of zero at 29 percent apparent porosity and 5.5 percent porosity reduction at 50 percent apparent porosity. Above 50 percent porosity a uniform reduction of 5.5 percent is assumed.

3.2.1.2.1 Other Porosity Logs

The neutron log tends to over-estimate porosity in lower porosity chalk, while at higher true porosity levels it tends to grossly under-estimate porosity. This is probably due to the clay content in the matrix resulting in an artificially high porosity reading in the lower porosity rocks, while excavation effects and tool design (calibration error) are potential causes for under-estimated porosity in the higher porosity chalks.

The sonic log tends to read excessively high porosity throughout the entire porosity spectrum. The disparity becomes even greater with increasing true porosity. This effect is probably due to poorer cementation in higher porosity rock and due to the relatively low net overburden stress.

A nonlinear relationship seems to exist between the acoustic log response and porosity, and equations such as the Hunt-Raymer Transform are recommended for porosity estimation. This empirical relationship suggests that porosity is proportional to reciprocal transit time. As an extension to this argument we have found through linear regression of reciprocal acoustic transit time with density-derived porosity (corrected) that an improvement in acoustic derived porosity can be achieved with the following equation:

$$Ø = 68.12 - 3497/Ac; \; R^2 = 83\ \%$$

Where

R^2 = correlation quality

Ø = percent porosity

Ac = acoustic transit time in µs/ft

3.2.2 Hod Field Results

3.2.2.1 Water Saturation

Unlike the Valhall Field where numerous wells have been drilled, Hod Field has limited data. The existing wellbore data are spread over two closures (East and West Hod), thereby further reducing the amount of data with which to generate statistical water saturation functions.

The saturation prediction equations for the Hod Field were derived by using the equations for Valhall as presented in detail in the 1985 study. Since the geologic subdivisions used in Hod are similar to those used in Valhall, it is surmised that similar saturation versus depth correlations occur within these formations of equivalent depositional time. Since the reservoirs exist on separate closures, however, and do not necessarily have the same buoyant columns acting on each structure, the equations would have to be altered to take this into account. These equations are shown in Appendix II.

The H1 horizon appears to be of a superior quality on both Hod field closures as opposed to Valhall. Even at the crestal position in Valhall, H1 rocks of 40 percent porosity have 40 to 50 percent water saturation. The crestal H1 horizon in the Hod Field has water saturation below 20 percent, at porosities in the 30 to 35 percent range. This variance is not attributable to greater buoyant column in Hod Field but to superior rock quality. The H1 equation in Hod Field was replaced by the H4 horizon equation from Valhall, and a suitable depth reference was then found for each closure. The East Hod H2 was also found to be of superior quality to that in Valhall, and the H3 equation was ultimately selected to generate saturation versus depth for the East Hod H2 horizon.

For mapping purposes the T1 and T2 horizons in East and West Hod were combined. The T2 (Lower Tor) equations from Valhall were used to estimate the water saturation versus depth relationships. Water saturation maps for each horizon are included as Exhibits 3.61 to 3.72 and Enclosures 3.17 and 3.18.

These equations were then used to compare empirical and actual log-derived saturation estimates as displayed by Enclosure 3.11. Amolog strip plots (CPI logs) show, in the far right hand track, a comparison of the log derived estimate (solid line) with the estimate from the correlation (dashed line).

These plots generally show fair agreement with a few notable exceptions. The H1 horizon in East Hod actually has two distinctly different rock types. The upper section has much lower water saturation (at lower porosity) than the lower section of the H1. The prediction equation was depth-referenced to split the difference between the two, such that a projection of water saturation into the interwell areas would give a better estimate of the average water saturation in those areas. In future work on Hod Field it may be desirable to subdivide the H1 further to account for this stratigraphic variation. The other area of poor agreement is in the down dip well 2/11-5. This well indicates oil saturations as high as 40 percent in portions of the Tor, H1, and H2 horizons. None of the Valhall prediction equations can reconcile oil saturation levels present in this well with the fact that 25 percent porosity rock contains 40 percent oil saturation. Two scenarios can be envisaged to account for this variation. One is that the Tor and Upper Hod formations in the Hod Field are of a superior quality to the Tor Formation in Valhall. Another, more plausible explanation is that the oil present in well 2/11-5 is residual oil. Geologic interpretation suggests that the region around well 2/11-5 once existed on the paleocrest of West Hod. With time the crest of the reservoir has migrated into its' present position just south of well 2/11-2. Depending on the structural position of well 2/11-5 during the time of oil migration, it is possible that higher oil saturations once existed in the region of well 2/11-5. With continued structural movement, most of the oil migrated updip and the well 2/11-5 was left with only residual oil. The second explanation is favoured because of the fact that the fluorescence of the samples indicated by the mud log was orange, which is usually indicative of a residual oil.

3.2.2.2 Porosity Versus Depth Relationships

The porosity versus depth relationship observed in the Hod Field is affected by structural history, depositional environment (compositional constituents), mechanical compaction and diagenesis (cementation). As in the prediction of oil saturations, minimal data are available to develop porosity versus depth relationships for the Hod Field.

The two closures within Hod Field are also likely to vary uniquely with respect to porosity versus depth performance. However, using data combined from both structures the following linear relationships were generated:

T1,2: $\varnothing = 408.8 - 0.0424*DEPTH$
(Combined T1 & T2)
H1: $\varnothing = 215.3 - 0.02096*DEPTH$
H2: $\varnothing = 131.3 - 0.01207*DEPTH$
H3: $\varnothing = 217.3 - 0.02096*DEPTH$
H4: $\varnothing = 217.3 - 0.02096*DEPTH$
H5: $\varnothing = 190.8 - 0.0183*DEPTH$
H6: $\varnothing = 66.39 - 0.0051*DEPTH$
H5/6: $\varnothing = 65.25 - 0.00512*DEPTH$
(Combined H5 & H6)

With respect to the equations for horizons H3 and H4 the best fit equations were not used to project a porosity relationship because the only H3 and H4 data available were from two wells on the East Hod structure. The regression using only these data would have suggested a porosity versus depth gradient of nearly five porosity units per hundred feet which exceeds the Tor - Ekofisk gradient in the same field.

In Valhall it was observed that the Tor Formation had nearly two times the porosity gradient of the Hod horizons (See Exhibit 3.12). By comparison, in the Hod Field the Tor - Ekofisk porosity gradient is about 2.5 times the average of the H1, H2 and H5. On this basis a more reasonable approximation of the Hod Field H3 and H4 porosity gradients would be similar to those of the Hod Field H1, H2 and H5 horizons. The gradient of the H1 horizon was selected as the gradient for the H3 and H4 horizons.

Plots of the data scatter and associated best-fit lines are shown in Exhibits 3.13 through 3.20. Although the correlation quality (R^2 value) of the equations is poorer than that achieved in Valhall, it is probably more a reflection of the relatively narrow depth range over which data are available than in a reduction in accuracy compared to Valhall.

Beyond the depth limits over which data are available, the prediction will be less certain. Within the depth limits, however, accuracy is expected to be close to that achieved in Valhall. Porosity maps are included as Exhibits 3.49 to 3.60 and Enclosures 3.15 and 3.16.

3.2.2.3 Net Pay Criteria and Cut-offs

The net pay criterion used in this study is an 80 percent water saturation cut-off. The rationale for using a pore water saturation cut-off is based upon fractional flow considerations and is discussed in detail in the 1985 Valhall/Hod report. In effect it satisfies a constraint beyond which the reservoir is expected to produce negligible oil volume with respect to the total voidage (oil and water) through depletion by solution gas drive. This method is independent of porosity and permeability of the reservoir.

Due to the fact that lower porosity rock increases in water saturation with depth more rapidly than higher porosity rock the water saturation cut-off eliminates much of the lower level porosity rock. In effect, a porosity cut-off becomes progressively immaterial with increasing depth.

Estimates were made on individual wellbores to assess their net porosity, saturation and thickness by excluding rock with greater than 80 percent water saturation. Net pay was extrapolated away from well control. Ultimately it was found that a ratio of net to gross thickness could be statistically related to the gross saturation. The equations for estimating net to gross ratio are contained in Appendix III.

Composite plots of net to gross ratio (NGR) versus gross water saturation for horizons H1 to H5/6 on Valhall are provided as Exhibits 3.21 to 3.25. Insufficient data (NGR less than 1.0) are available to create functions for the T1 and T2 horizons. The equation for the H4 horizon, due to its higher reservoir quality, was assumed to be a satisfactory estimate for the T1 and T2 horizons. Also due to the poor fit of the regression of the H5/6 horizon, the H2 horizon best fit line was substituted for the H5/6.

As the gross water saturation progressively increases, the fraction of rock with water saturation greater than 80 percent is expected to increase as well. This expected relationship is borne out by the above equations. It is noteworthy that the departure from a ratio of 1.0 occurs at between 50 and 60 percent water saturation. In effect the statistical wedge on the net pay maps occurs between 50 percent and 90 percent water saturation. Therefore, inside the mapped wedge, net thickness, porosity and saturation will be equal to the gross value calculated. Net to Gross and Net Pay Isopach maps for each horizon are included as Exhibits 3.73 to 3.84 and Enclosures 3.19 and 3.20.

It should be recognized that the method of net pay estimation does not account for water levels as typically considered. Water levels, as would occur in high permeability rock, provide uniform point contacts. The elevation at which chalk reaches 100 percent water saturation in a given rock type is dependent upon its porosity and permeability. Therefore, in a given horizon, rocks at 100 percent water saturation may be interspersed with rock at less than 100 percent water saturation depending upon the distribution of porosity at the section observed. Point contacts or rather oil-water contacts cannot be picked by an observation in a single wellbore, as an apparent water level may be due to lithological variation (porosity and/or permeability) and not the presence of the reservoir's true zero capillary pressure point. With the assumption that porosity is vertically uniform in a horizon (as dictated by the porosity map), a statistical estimate of 100 percent water saturation can be made with the correlations used in Section 3.2.1.1. In this same sense, estimates made in this study of a point contact of zero net pay (based upon 80 percent water saturation criteria) are purely based upon a statistical relationship of gross water saturation and the fraction of net rock observed in existing wellbores penetrating a given horizon. For the purpose of comparison, the statistically calculated oil-water contacts based on an 80 percent water saturation criteria are listed below.

Statistically Defined Oil-Water Contacts
(meters TVD Subsea)

	West Hod	East Hod
Tor/Ekofisk	-2766.5	-2766.5
H1	-2690	-2759
H2	-2638	-2781
H3	Combined with H2	-2815
H4	NP	-2840
H5/6	NP	-2840

Thus far, the petrophysical discussion has provided for methods of estimating gross porosity, gross water saturation and net pay in interwell areas. Although no statistical estimates were derived for net porosity, it is clear that the only purely interpretive mapping will be required in the areas where the net to gross ratio is less than 1.0 or similarly in areas where gross water saturation varies between 50 and 80 percent (mainly wedge areas). A statistical relationship was, however, generated to establish a correlation between net to gross ratio and net water saturation (Appendix IV).

Composite plots of net to gross ratio versus net water saturation for horizons H1 to H5/6 on Valhall are provided as Exhibits 3.26

to 3.30. Again similar to the relationships of net to gross ratio to gross water saturation, the H4 equation has been used for horizons T1 and T2, and the H2 equation has been substituted for H5/6.

If the net to gross ratio is estimated from the gross water saturation, then a mapping of NGR can be produced. By virtue of these equations, an approximation of net water saturation can then be made by solving the quadratic equations. As Exhibits 3.26 to 3.30 indicate, if net to gross ratio is accurately mapped, then in the region of net to gross ratio less than 1.00 the error in net water saturation should be five saturation units. Where net to gross ratio is equal to 1.00 the net saturation equals the gross saturation.

Reasonable confidence in net hydrocarbon pore volume can be attained with the approach outlined above, although estimation of water saturation in Hod Field is as previously discussed, an extrapolation derived from Valhall field equations, and therefore provides less certainty than in Valhall.

3.3 HYDROCARBONS IN PLACE (HCPV)

3.3.1 Base Case

The base case original oil-in-place for the Hod Field was determined by planimetering the hydrocarbon pore volume maps (Exhibits 3.85 to 3.90 and Enclosure 3.21).
The base case original oil-in-place is shown in the following table:

Formation		West Hod MMSTBO	West Hod 10^6 Sm^3	East Hod MMSTBO	East Hod 10^6 Sm^3
Ekofisk/Tor		0	0	58.1	9.2
Upper Hod	(H1)	48.5	7.7	35.9	5.7
Middle Hod	(H2)	10.4	1.7	15.0	2.4
Lower Hod	(H3)	0	0	4.9	0.8
	(H4)	0	0	10.0	1.6
	(H5/H6)	0	0	4.6	0.7
		------	-------	------	------
		58.9	9.4	128.5	20.4

Total Hod Field = 187.4 MMSTBO, 29.8 x $10^6 Sm^3$

The base case assumes no oil-bearing Tor Formation present in the West Hod structure as the 2/11-2 well on the crest contained no Tor and the 2/11-5 well on the flank had only water-bearing Tor.

3.3.2 Upside Potential

Upside potential exists on the West Hod structure based on the last updated Ekofisk/Tor Formation and isopach maps by Humphreys in January 1986. The possible original oil-in-place for the Ekofisk/Tor Formation in West Hod was determined by planimetering the structure map and using porosity and water saturation values as determined at midpoint depth. For West Hod the average mid-point structure was calculated to be 2675 meters TVD subsea, with an average gross porosity of 37 percent, and an average gross water saturation of 13.5 percent.

From this upside potential in West Hod exists for an additional 75.4 MMSTB (12 x $10^6 Sm^3$) original oil-in-place in the Ekofisk/Tor pinchout wedge updip from the 2/11-5 well.

4 RESERVOIR ENGINEERING

Note: Abbreviations and conversion factors are listed after Table of Contents.

4.1 INTRODUCTION

As discussed in the geologic section of this report, the Hod Field is composed of two independent structures, East Hod and West Hod. The two structures were formed by different geologic processes. The East Hod structure is deeper than West Hod and exhibits different reservoir properties.

A reservoir database has been formulated for the Hod Field from wireline logs, cores, production tests and fluid samples from the exploration wells drilled in the field. As a result, the field has been mapped, and a full field 3D Black Oil Model has been built to predict the performance of the field. This section will discuss the main reservoir properties and the formulation of the reservoir model. Base Case production profiles and several sensitivities will then be discussed to show the impact of uncertainties.

4.2 DRILL STEM TEST RESULTS

Five wells have been drilled to date in the two accumulations that comprise the Hod field, see Exhibit 4.1. Wells 2/11-2 and 2/11-5 were drilled on the West Hod structure while wells 2/11-3, 2/11-3A and 2/11-6(ST-1) were drilled on East Hod. Three of the wells penetrated hydrocarbon bearing chalk: 2/11-2, 2/11-3A and 2/11-6(ST-1). Well 2/11-3 was drilled to the west side of the East Hod structure but encountered wet chalk sections and was subsequently sidetracked to the 2/11-3A location. Well 2/11-6(ST-1) is a sidetrack of the original well 2/11-6 which had to be abandoned due to mechanical problems after penetrating the top of the chalk section. Both wells had essentially the same bottom hole location.

4.2.1 Well 2/11-2

This well was spudded in November 1974 and drilled to a total depth of 2770.0 m TVD SS in 37 days. The top of the chalk was encountered at 2604 m TVD SS while drilling the 12 1/4 inch (311 mm) hole. The 12 1/4 inch (311 mm) hole was therefore terminated at 2623 m TVD SS. After logging and setting the 9 5/8 inch (244 mm) casing at 2601 m TVD SS, a 9-meter core was cut from 2625 to 2634 m TVD SS. The 8 1/2 inch (216 mm) hole was then drilled to TD, logs were run and a 7 inch (178 mm) liner was set.

This well resulted in the discovery of the West Hod structure. Only Upper and Middle Hod Formations were encountered. A total of 51.5 m of pay was observed and log calculations indicated that the average net porosity and water saturation were 34.4% and 24.2% respectively, see Exhibit 4.2. Two production tests were conducted in the chalk - Test 1 was conducted in the lower portions of the pay to determine if the highly water saturated zone would flow and Test 2 was conducted to determine the productivity of the main pay section. A third test was performed on the silty shales of Oligocene age located at 1464 to 1487 m TVD SS to determine whether this zone contained commercial quantities of hydrocarbons.

The results of Test 1 confirmed that water free oil could be produced from the lower sections of the pay where water saturations are 55% to 75%.

In Test 2, the well flowed at 1435 BOPD (228 Sm^3/d) prior to acidizing. Following the acid stimulation, the highest reliable flowrate measured was 2700 BOPD (429 Sm^3/d). The well did flow at higher rates, probably in the order of 4500 BOPD (715 Sm^3/d), but these could not be accurately measured due to oil carry-over to the gas outlet in the test separator.

The results of Test 3 strongly indicate that the silty shale interval does not contain commercial quantities of oil or gas. Oil and gas were produced for a short period of time, but the flow fluctuated rapidly and was too low to measure accurately.

Additional details are given in Exhibit 4.3.

4.2.2 Well 2/11-3

The primary objective of Well 2/11-3 was to determine the extension of the chalk section to the east of Well 2/11-2, since at this time the Hod Field was mapped as one structure. West Hod had been proven oil bearing by Well 2/11-2 and seismic data at the time suggested an extension of the chalk section towards the east. Well 2/11-3 was spudded in October 1977 and drilled to a TD of 3051.7 m TVD SS in 47 days. The chalk objective was encountered at 2739 m TVD SS but only minor hydrocarbon shows were observed, see Exhibit 4.4. Although the chalk section was found to be 244 m thick compared to only 112 m at Well 2/11-2, the Tor and Ekofisk formations were still absent. Three conventional cores were cut through the chalk section from 2741 to 2775.5 m TVD SS. No tests were performed on this well.

4.2.3 Well 2/11-3A

This well was a sidetrack of Well 2/11-3. The sidetrack started below the 13 3/8 inch (340 mm) casing shoe in December 1977. The well was drilled to a TD of 2821 m TVD SS at a maximum hole angle of 50° and resulted in the discovery of East Hod. Top chalk was encountered at 2676 m TVD SS and seven cores were cut through the hydrocarbon bearing chalk with an average recovery of 80%. Prior to running logs, the drill pipe became stuck at TD and could not be recovered. The well (still called 2/11-3A) was therefore redrilled to bypass this obstruction, to a TD of 2776 m TVD SS. This redrilled hole also encountered top chalk at 2676 m TVD SS. Exhibit 4.5 shows the log section from this well. Two production tests were performed, Test 1 to determine the productivity of the Upper Hod Formation and Test 2 to determine the productivity of the Tor Formation.

The Upper Hod Formation was tested at a rate of 628 BOPD (100 Sm^3/d) after hydraulic fracture stimulation. In Test 2 the Tor Formation produced over 5700 BOPD (906 Sm^3/d) after acid fracture stimulation.

Details of the tests are given in Exhibit 4.6.

4.2.4 Well 2/11-5

This well was spudded in May 1979 and drilled to the south flank of the West Hod structure in 40 days. The well was drilled to a TD of 2920 m TVD SS and top chalk was encountered at 2797.5 m TVD SS. Only minor hydrocarbon shows were observed with average water saturations in the range of 70% - 80%, see Exhibit 4.7. No cores were cut in this well and no production tests were performed as it was considered that only residual oil was present, based on the available log data at that time. Although the total chalk section was only 98 m thick, Ekofisk and Tor sections were encountered in this well.

4.2.5 Well 2/11-6 (2/11-6(ST-1))

This well was directionally drilled to the East Hod structure from a subsea template installed between the two Hod structures. The well was spudded in September 1981 and reached its TD of 4076 m MD (2955 m TVD SS) in a sidetracked hole in December 1981. The original well penetrated top chalk at 2706 m TVD SS and seven cores were cut through the hydrocarbon bearing section. The well was later drilled to 3690 m MD (2879 m TVD SS) where the drill pipe became stuck. Subsequent attempts to free the pipe were unsuccessful, hence the pipe was severed and the 8 1/2 inch (216 mm) hole was sidetracked below the 9 5/8 inch (244 mm) casing.

The sidetracked hole encountered the top chalk at 3685 m MD (2706 m TVD SS) and encountered a chalk interval almost identical to that found in the original hole. Exhibit 4.8 shows the log section from this well. No cores were cut in this sidetracked hole.

Two tests were conducted in Well 2/11-6(ST-1). Test 1 was conducted in the Lower Hod Formation and Test 2 in the Tor/Upper Hod Formations. Both the Tor/Upper Hod and Lower Hod zones were stimulated by acid fracturing. In Test 1, the acid job improved the production rate from less than 100 BOPD (16 Sm^3/d) to over 2200 BOPD (350 Sm^3/d). In Test 2, the acid improved the productivity from 1400 BOPD (223 Sm^3/d) to 5850 BOPD (930 Sm^3/d).

There are questions, however, as to the validity of the Lower Hod test (Test 1). Pressure transient analysis for this test yields a permeability, which appears more representative of the Tor Formation. It is thought that this could be the result of a poor cement job, allowing flow to channel behind the casing.

Details of the well test results are given in Exhibit 4.9.

4.3 ROCK PROPERTIES

Cores were obtained from four of the five wells drilled in the field:

- West Hod: 2/11-2
- East Hod: 2/11-3
  : 2/11-3A
  : 2/11-6

Details of the intervals cored and the resultant recoveries are summarized in Exhibit 4.10. Routine core analysis was performed for each of the cores, with the porosity/permeability results summarized in Exhibits 4.11 to 4.14. Relative permeability and capillary pressure measurements were taken for wells 2/11-2, 2/11-3A and 2/11-6. Core data were used together with log data to establish a porosity relationship with depth for each of the reservoir layers. These relationships are shown in Exhibits 4.15 to 4.18. Although the two Hod structures are likely to vary with respect to porosity versus depth performance, a linear relationship was generated from the available data. The data does show considerable scatter, and since the data is only available over a narrow depth range, there is some uncertainty related to the predictions outside of this range. Exhibit 4.19 shows the average gross porosity distribution for each of the exploratory wells.

The relative permeability data obtained from core samples from Wells 2/11-2, 2/11-3A and 2/11-6 are shown in Exhibits 4.20 to 4.34. It should be noted that these are all gas-oil relative permeability data. Water-oil relative permeability tests could not be performed because the core plugs had permeabilities below the low end of the range necessary for performing such tests.

A limited number of pore volume compressibility tests were conducted on Hod Formation samples from the Well 2/11-2 core. These tests showed that the compressibility averaged 10.3 x 10^{-6} psi^{-1} (10.3 microsips or 149.4 x 10^{-6} bar^{-1}) over the majority of stress conditions anticipated at Hod; from initial reservoir conditions of 1500 psi (103.4 bar) net confining pressure (overburden pressure - pore pressure) to around 5000 psi (344.7 bar) net confining pressure for samples with an average porosity of 36.8%. Compressibility did then rise to around 27 microsips (391.6 x 10^{-6} bar^{-1}) at a confining pressure of 6500 psi (448.2 bar), but this approximates abandonment conditions at Hod. However, this apparent plastic behavior is consistent with the observations for the other high porosity chalk fields in the Valhall/Ekofisk area.

Gross average water saturation data for each of the exploratory wells is summarized in Exhibit 4.35. Since the field database is small, saturation prediction equations generated for the Valhall field were used to extrapolate water saturation throughout the East and West Hod structures, as the same geologic subdivisions used at Valhall exist at Hod. More details of the petrophysics are provided in Section 3.2.1.

Samples of Tor and Upper Hod Formation from the 2/11-6 core have also been tested for water imbibition properties. The tests show that in both cases less than 5 percent of the pore volume was imbibed, see Exhibit 4.36. These results suggest that an imbibition waterflood would not be successful at the Hod Field.

4.4 FLUID PROPERTIES

Samples of reservoir fluid were collected from each of the drill stem tests conducted on the exploration wells. Laboratory analyses show that the East and West Hod structures contain different fluids, with the West Hod fluid having apparently a higher volatility then the East Hod fluid. Exhibit 4.37 summarizes the fluid properties for both structures and Exhibits 4.38 - 4.41 show the different relationships for solution gas-oil ratio, oil formation volume factor, oil density and oil viscosity respectively. These plots show that the oil in the West and East Hod structures is undersaturated, with bubble point pressures of around 4648 psia (320.5 bar a) and 3927 psia (270.8 bar a), respectively.

Contact angle tests were conducted on two oil samples collected from Well 2/11-3A Test 2 to estimate the wettability of the reservoir. Measured contact angles of 140° and 150° suggest that the reservoir crude oil has a tendency to oil-wet the reservoir rock surface preferentially.

4.5 RESERVE CALCULATIONS

4.5.1 Stock Tank Oil Originally in Place (STOOIP) - Summary

As mentioned in the geological section of this report, the most likely Base Case STOOIP estimate for the Hod Field is 187.4 MMSTB (29.8 million Sm^3), with 58.9 MMSTB (9.4 million Sm^3) in West Hod and 128.5 MMSTB (20.4 million Sm^3) in East Hod. The bulk of the West Hod STOOIP is in the Upper Hod Formation whereas the bulk of the East Hod STOOIP is in the Tor Formation. A summary of the STOOIP split is provided in Exhibit 4.42. This STOOIP distribution was used as the basis for calculating reserves using numerical simulation techniques.

As discussed in Chapter 3 and summarized in the next paragraph, there is an uncertainty with respect to the presence of Tor Formation in the West Hod structure.

On West Hod, two wells have been drilled to date. Well 2/11-2 proved the presence of reserves in the Hod Formation on the eastern side of the structure. This well did not encounter Ekofisk or Tor Formation. The other well, 2/11-5, was drilled downdip on the south flank of the structure. This well penetrated 36 meters of Ekofisk/Tor Formation, but the section was water-bearing and was not tested. It is postulated that this Ekofisk/Tor section may be oil-bearing updip from 2/11-5. However, since this updip Ekofisk/Tor Formation has not been tested, it has not been included in the base case reserves. Also, owing to poor seismic quality due to the presence of a gas cloud over the structure, it is not possible to identify the presence of this formation with any degree of confidence from geophysical measurements. Nevertheless, there is a calculated upside potential of approximately 75 MMSTB (12 million Sm^3) of oil-in-place if the Ekofisk/Tor Formation is present in West Hod. This is one of the major uncertainties prevailing in the reservoir description of the Hod Field.

As a sensitivity it was also considered that no hydrocarbon bearing pay will be discovered to the west of the major fault mapped in West Hod. This occurrence results in a 58 percent reduction in West Hod oil-in-place to 24.7 MMSTB, (3.93 million Sm^3), and this interpretation represents the downside case for reserve estimates. This occurrence will be addressed in the sensitivity studies.

4.5.2 <u>Depletion Mechanism</u>

A primary solution gas drive is assumed for generating production profiles. Both the East and West Hod structures are undersaturated, thus no free gas exists in the reservoir. However it is possible that a secondary gas cap may form, once the reservoir pressure drops below bubble point pressure, which would provide additional reservoir energy.

Although high pore volume compressibility has been observed at the nearby Valhall Field, this is not expected to occur to the same magnitude at Hod. Pore volume compressibility appears to increase with higher porosity, and the extremely high porosity levels observed at Valhall (up to 50%) have not been observed to date at Hod. In addition the initial net confining pressure at Hod is 1500 psi (103.4 bar), compared to only 500 psi (34.5 bar) at Valhall. This would tend to suggest that the Hod Field rock is more consolidated than that at Valhall. This being the case, yield point will occur at a higher net confining pressure (or lower reservoir pressure), thus will be 'masked' by the presence of gas coming out of solution as bubble point pressure is approached. These observations suggest that Hod Field pore volume compressibilities will be lower than those at Valhall. A rock drive mechanism is therefore not expected to dominate performance at Hod.

Neither of the two main reservoirs, Tor or Upper Hod, are entirely underlain by an aquifer. This implies that any water influx which may occur will take place via the flank areas, where the permeability is generally extremely low due to the absence of natural fractures.

Well 2/11-3 was drilled into a water column on the west side of the East Hod structure, and based on RFT data exhibited little permeability. Likewise the objective of Test 1 from Well 2/11-2 was to ascertain whether water free production could be achieved from a highly water saturated zone. The zone tested 1500 BOPD (238 Sm^3/d) with zero water from a zone averaging 55 to 75% water saturation. This further demonstrated the low relative permeability to water exhibited by the chalk. Significant water influx is therefore not expected to occur and thus will not significantly influence the reservoir drive mechanism.

4.5.3 <u>Reservoir Simulation Input Data</u>

4.5.3.1 Overview

A full field reservoir simulation model was built to predict the performance of the Hod Field. Numerous sensitivities were run to predict field and well performance under various development schemes, to determine well requirements and evaluate ultimate recovery potential.

The reservoir model used is Amoco's Black Oil Model, a three dimensional, three-phase numerical simulator. The model consists of a 23 x 15 block areal grid system, with four vertical layers: Ekofisk/Tor, Upper Hod (H1), Middle/Lower Hod (H2+H3) and Lower Hod (H4). The remaining Lower Hod (H5+H6) layers were not included in the reservoir simulator, due to their poor reservoir quality and negligible effect on overall field performance. The grid system, shown superimposed on the Top Chalk structure map in Exhibit 4.43, has a minimum block size of 250m x 250m over the crest of the East and West Hod structures.

Structural depth, gross thickness, porosity and water saturation data were input for each grid block location to form the basic description of the Hod Field reservoirs. These data were obtained from the geologic maps developed for the Hod Field, as were described in Chapter 3.

4.5.3.2 Relative Permeability

Available gas-oil relative permeability data from the Valhall/Hod Field database were used for the Tor and Hod Formations in the model. No oil-water relative permeability data have been measured for the Hod Field wells, therefore data from the Valhall Field have been used. Oil-water relative permeabilities for the Tor Formation were measured on three native state core samples from Valhall Well 2/11-4 and three from Well 2/8A-1. In addition three samples from the Hod Formation of Well 2/8A-1 were tested. These data have been normalized and used for the Tor and Hod Formations of the Hod field. A curve normalized to a connate water saturation of 20% was used for the crestal area of the Tor Formation, while the curves were normalized to 50% for the high porosity areas of the Upper Hod Formation and to 70% for the other Hod Formations and for the flanks. Exhibits 4.44 and 4.45 show the gas-oil and water-oil relative permeability relationships used.

4.5.3.3 Pore Volume Compressibility

The pore volume compressibilities used in the model are 10 microsips (145×10^{-6} bar^{-1}) for the crestal portion of the Tor Formation and high porosity areas of the Upper Hod Formation present in West Hod, and 6 microsips (87×10^{-6} bar^{-1}) for the flank areas of the Tor Formation and the remainder of the Hod Formation. There are insufficient data available at this point to suggest the extremely high pore compressibility as has been observed at the Valhall Field. However, it is recognised that pore compressibility does represent an unknown parameter, therefore a sensitivity is run to ascertain its impact on field performance.

4.5.3.4 Permeability Distribution

Exhibits 4.46 to 4.49 are plots of the core porosity versus core horizontal permeability used for the four layers included in the model. These curves are based on the relationships observed at Valhall where a larger database is available. The results of the core tests performed on the high porosity Upper Hod of West Hod Well 2/11-2 have however been incorporated since this rock type appears to be somewhat different to that which exists at Valhall. The results of the DST's performed in the Valhall and Hod Field exploration wells generally show that Tor Formation permeabilities calculated from the pressure build-up's are higher than core permeabilities. It is believed that this difference can be attributed to natural fractures existing in the formation. The porosity/permeability relationship for the Tor Formation was therefore adjusted to account for the higher permeabilities observed at the higher porosities.

Vertical transmissibility between layers is dependent on the continuity and deposition of the formations. Therefore vertical permeabilities measured in the laboratory on small core samples are not representative of the vertical tortuous flow path between the layers. In the absence of measured data on vertical transmissibility in the reservoir, the following values for vertical permeabilities have been assumed, based on experience from the Valhall Field and taking into account the lithology of each layer.

Tor Formation	=	10%	of horizontal permeability
Upper Hod Formation	=	1%	of horizontal permeability
Middle Hod Formation	=	2.5%	of horizontal permeability
Lower Hod Formation	=	2.5%	of horizontal permeability

Based on simulation runs, field recovery is not sensitive to vertical permeability values in the 1 to 10% range used.

4.5.3.5 Fluid Properties

PVT analyses were performed on Tor and Hod fluid samples collected from Wells 2/11-2, 2/11-3A and 2/11-6(ST-1). This showed that the West Hod fluid is different from East Hod fluid. A summary of the fluid analysis results is provided in Exhibit 4.37.

The PVT data for Wells 2/11-2 (Test 2) and 2/11-3A (Test 2), corrected for surface separator effects, were used as the base data for the West and East Hod structures respectively. These data are shown in Exhibits 4.50 and 4.51. Although a bubble point variation with depth relationship is observed at Valhall, insufficient data are available to substantiate a similar effect at Hod. For this reason, it was assumed that the fluid properties shown in Exhibits 4.50 and 4.51 are constant for each structure. Valhall model sensitivity studies have shown that the overall field performance will not change drastically if a constant bubble point fluid is assumed rather than a variable bubble point fluid, although the gas-oil ratio response will be somewhat different.

4.5.3.6 Pressure

Reservoir pressure data were collected for each of the wells tested in the Hod Field. This was done by extrapolating the pressure observed during the pressure build-up tests for each of the wells. These data are shown in Exhibit 4.52 and have been plotted against depth together with some Valhall data as shown in Exhibit 4.53. It is clear from this plot that the East Hod data from Wells 2/11-3A and 2/11-6(ST-1) follow a pressure gradient trend roughly equivalent to the bulk of Valhall data. West Hod data from Well 2/11-2, however, do not fit this trend, but appear to follow another pressure gradient observed by a few of the exploratory wells at Valhall. The data used in the model are shown in Exhibit 4.54.

4.5.4 Recoverable Resources

Recoverable resources are defined as the volume of hydrocarbons which can be made available for delivery by means of currently available technology without application of economic criteria. In this case therefore, it is assumed that the field can be produced by primary recovery methods through to the expiration of the production licence (PL 033) in the year 2015. This assumes that the Hod Field development is not dependent upon the Valhall Field as is suggested by the development concept. Two cases are run to estimate recoverable resources as discussed below :

Case A. Assuming no Tor Formation is present in West Hod, a five well development concept is envisioned. Three of the five wells are located in East Hod with the remaining two wells in West Hod. This well pattern is illustrated in Exhibit 4.55.

Case B. Assuming that Tor Formation is present in the western part of West Hod, a six well development program is envisioned. These wells are distributed equally between the East and West structures as shown in Exhibit 4.56.

Assuming that for this ideal case no production downtime will occur, the following recoverable resources (sales resources) are estimated for the two cases described above :

CASE A:	Oil	30.7 MMSTB	(4.88 million Sm^3)
	Gas	38.7 BCF	(1100 million Sm^3)
	NGL	4.1 MMBBL	(0.65 million Sm^3)

CASE B:	Oil	42.4 MMSTB	(6.74 million Sm^3)
	Gas	71.1 BCF	(2013 million Sm^3)
	NGL	7.5 MMBBL	(1.2 million Sm^3)

4.5.5 Reserves

4.5.5.1 Introduction

Due to the shape and small size of the Hod Field, it is expected that the majority of the recoverable resources will be produced as reserves. All wells will be drilled from the 12 slot subsea template already installed between East and West Hod. It is envisioned that the wells will flow via a well protector platform to the nearby Valhall complex for processing. Factors such as drilling reach, availability of platform or template well slots, or availability of processing capacity do not impact the economics of the project as the capacity is already available. Given this situation, the major factor influencing reserves is the economics of drilling wells.

Owing to the small scale of this project, it is assumed that the field will be produced by primary solution gas drive. As discussed in Section 4.7, economics do not support enhanced recovery methods.

It has been assumed that development wells will drain the Tor, Upper Hod and Lower Hod Formations. Economic development of the Middle Hod unit cannot be confirmed due to its tight nature and high water saturation. Production data from the Valhall Field suggests that the Middle Hod cannot be effectively drained. Commingled production is assumed from dual Tor and Hod well completions, thus minimizing the number of wells required. This philosophy has been successfully applied at Valhall. A more detailed discussion of the proposed completion strategy for Hod is found in Section 4.6.1.

4.5.5.2 Well Spacing

Based on experience from the Valhall Field, well spacing for the Base Case model run was set at 1000 metres, representing a drainage area of 200 acres (81 hectares) per well. Formation properties and thicknesses between Hod and Valhall Fields appear to be similar. It is therefore believed that this well spacing assumption is well-founded. Sensitivities were run to show the effect of changing the number of production wells.

Well 2/11-6(ST-1) is currently temporarily suspended, and it is intended to convert this well to a production well. Based on the well spacing pattern shown in Exhibit 4.55, four wells are required in addition to 2/11-6(ST-1) to drain both Hod structures. Two of the East Hod wells viz. E1 (completion of well 2/11-6(ST-1)) and E2 will be completed in the Tor, Upper Hod and Lower Hod Formations. The remaining East Hod well, E3, will be a single zone Tor completion. The two West Hod wells W1 and W2 will be single zone Upper Hod completions.

4.5.5.3 Initial Production Rates

Based on the results of the drill stem tests and other data available for the Hod Field, initial production rates have been estimated for each of the proposed development well locations. Performance history from Valhall has been taken into consideration. Valhall production performance has shown that rates obtained during short term tests are not necessarily representative of stabilized initial production rates. High short term initial production rates observed at Valhall are believed to be due to flush production from the fracture network. Lower stabilized rates are achieved after some time when pseudosteady-state flow is established. For this reason the productivity indices observed during the tests at Hod cannot be used directly to calculate initial stabilized production rates. The initial rate assumed for each of the wells is shown below, together with the rate based on the test productivity index (shown in parentheses). The assumed rates were calculated using Darcy's Radial Flow Equation.

E1 - 4,000 BOPD (636 Sm^3/d) - Tor/Hod dual zone completion
(5,700 BOPD (906 Sm^3/d) - Based on 2/11-6(ST-1))
E2 - 8,000 BOPD (1272 Sm^3/d) - Tor/Hod dual zone completion
(13,000 BOPD (2067 Sm^3/d) - Based on 2/11-3A)
E3 - 6,000 BOPD (954 Sm^3/d) - Single zone Tor completion
(10,000 BOPD (1590 Sm^3/d) - Based on 2/11-3A)
W1 - 3,000 BOPD (477 Sm^3/d) - Single zone U. Hod completion
(4,000 BOPD (636 Sm^3/d) - Based on 2/11-2)
W2 - 3,000 BOPD (477 Sm^3/d) - Single zone U. Hod completion
(4,000 BOPD (636 Sm^3/d) - Based on 2/11-2)

4.5.5.4 Minimum Flowing Pressure

The development scheme proposed involves routing Hod Field production via a two-phase pipeline to Valhall for processing. Details of this scheme will be discussed in subsequent sections. Since the inlet separator at Valhall operates at around 100 psig (6.9 bar g) and a pressure drop occurs through the pipeline from Hod to Valhall, the minimum initial flowing wellhead pressure at Hod is set at around 500 psig (34.5 bar g). Using vertical flowing fluid correlations, a surface flowing pressure of 500 psig 34.5 bar g) equates to a flowing bottomhole pressure of around 2000 psig (138 bar g). This value is therefore assigned as the minimum flowing bottomhole pressure for each of the Hod Field production wells.

4.5.5.5 Production Downtime

A number of factors can contribute to production downtime in a producing oil field. These include the following :

- Well associated problems
- Process system upsets
- Transportation related problems
- Control and communications
- Weather related problems

All of the above causes of downtime can be predicted to some degree. Weather related downtime could be a significant factor in fields with a tanker loading oil export system. However, since export of hydrocarbon products from Hod will be by pipeline, weather downtime is considered zero. The breakdown of total downtime into the above listed components is shown in Exhibit 4.57.

In summary the following numbers have been used for downtime:

Oil	7.0 %
Gas	8.5 %
NGL	8.5 %

4.5.5.6 Abandonment Criterion

It is assumed that a production well will cease flowing once the production rate drops below 300 BOPD (47.7 Sm^3/d). This is based on economics which suggest that there is no economic incentive to work over a well to maintain a production rate of 300 BOPD (47.7 Sm^3/d).

On a field-wide scale, the economic cut-off criterion has been to continue production, as long as the field's net revenue exceeds operating costs plus processing and transportation tariffs. For the Base Case, this criterion suggests that the Hod Field should be abandoned at a rate of around 1500 BOPD (238 Sm^3/d).

4.5.5.7 Base Case Reserves

Exhibits 4.58 and 4.59 show the field's yearly oil, gas and NGL sales rates, in graphical and tabular form respectively. Field reserves on a zonal basis are summarized below.

	Oil		Gas		NGL	
	MMSTB	10^6Sm3	BCF	10^6Sm^3	MMBBL	10^6Sm^3
West Hod						
-Tor	0.0	(0.00)	0.0	(000)	0.0	(0.00)
-U. Hod	9.2	(1.46)	12.2	(345)	1.3	(0.20)
-M. Hod	0.0	(0.00)	0.0	(000)	0.0	(0.00)
-L. Hod	0.0	(0.00)	0.0	(000)	0.0	(0.00)
East Hod						
-Tor	11.9	(1.89)	14.0	(396)	1.5	(0.24)
-U. Hod	2.7	(0.43)	2.7	(77)	0.3	(0.05)
-M. Hod	0.0	(0.00)	0.0	(000)	0.0	(0.00)
-L. Hod	1.6	(0.26)	2.3	(65)	0.2	(0.03)
Total	25.4	(4.04)	31.2	(883)	3.3	(0.52)

This equates to an overall oil recovery of around 14% which is comparable to predictions for the nearby Valhall Field.

4.5.5.8 Sensitivities

A number of sensitivities were performed to evaluate the impact of increasing or decreasing the number of wells draining the field. This was done in order to optimize the economics for development of the field.

a. Sensitivity A1

This case examined the effect of draining the West Hod Upper Hod reserves with only one well. The well locations are shown by Exhibit 4.60. This sensitivity generated a reserve of 24.1 MMSTB (3.83 million Sm^3) which is 1.3 MMSTB (0.21 million Sm^3) lower than the Base Case.

b. Sensitivity A2

This case examined the effective drainage of the East Hod structure with two wells rather than the three assumed for the Base Case. The well locations are shown in Exhibit 4.61. This case recovered 24.3 MMSTB (3.86 million Sm^3) which is 1.1 MMSTB (0.17 million Sm^3) less than the Base Case.

c. Sensitivity A3

This case examined the inclusion of a third well in West Hod to drain the Upper Hod reserves. The well locations are shown by Exhibit 4.62. This case recovered 25.7 MMSTB (4.09 million Sm^3) which is 0.3 MMSTB (0.05 million Sm^3) more than the Base Case.

d. Sensitivity A4

This case represents the downside reserve where no hydrocarbon bearing formation is discovered to the west of the major fault mapped in West Hod. It is assumed that the four well drainage pattern shown by Exhibit 4.60 represents the development well locations for this scenario. This case recovered 21.6 MMSTB (3.43 million Sm^3), which is 3.8 MMSTB (0.60 million Sm^3) less than the Base Case.

e. Sensitivity A5

This case examined the impact of increased pore compressibility on field reserves. It was assumed that pore compressibility for the crestal areas of the Tor Formation and the crestal area of the Upper Hod Formation in West Hod was 10 microsips (145 x 10^{-6} bar^{-1}) at initial conditions (net confining pressure = 1500 psi (103.4 bar)), but at a net confining pressure of 4000 psi (275.9 bar) would rise to 30 microsips (435 x 10^{-6} bar^{-1}) and remain constant thereafter. Pore compressibility for all other areas remained constant at 6 microsips (87 x 10^{-6} bar^{-1}). The five well drainage pattern shown by Exhibit 4.55 was assumed. This case recovered 27.2 MMSTB (4.32 million Sm^3) which is 1.8 MMSTB (0.29 millon Sm^3) more than the Base Case.

These sensitivities suggest that the reserve level is not particularly sensitive to the number of development wells. This is a parameter within our control so it can be adjusted as our understanding of the reservoir improves. It is intended to drill a well into the west side of the West Hod structure in an attempt to prove up the presence of the Tor Formation. Depending upon the results of this well, a decision will be made whether West Hod will be drained by one, two or possibly even more wells. At this point in time therefore it is assumed that for the Base Case development concept where no Tor Formation is present in West Hod, two wells are required to drain West Hod and three wells are required for East Hod.

Sensitivites d. and e. show that the reserves are more sensitive to uncertainties in geology and rock properties which are parameters outside of our control. Sensitivity d. examines possible downside to the Base Case oil-in-place hence represents the most pessimistic geologic interpretation of the available data. Sensitivity e. suggests that higher pore compressibility will result in slightly higher reserves. However, the impact of higher pore compressibility is not overly significant, as based on the limited data available the chalk's yield point appears to be over 4000 psi (276 bar) net confining pressure which is close to the bubble point pressure of the reservoir fluids. The presence of high pore compressibility will therefore tend to be masked by gas evolving out of solution in the reservoir.

4.5.5.9 Upside Potential Reserve Sensitivities

As mentioned already in Section 4.5.1 it is possible that hydrocarbon bearing Tor formation is present on the west lobe of West Hod. If this was the case, the West Hod structure contains significantly more oil than is assumed for the Base Case. The Black Oil Model was therefore adjusted to account for this interpretation and further cases were run to determine the reserve level and number of wells required for an optimum development. Based on the geologic maps the presence of Tor Formation on West Hod increases the original oil in place from 187.4 MMSTB (29.8 million Sm^3) to 262.8 MMSTB (41.8 million Sm^3) (i.e. an increase of 75.4 MMSTB or 12.0 million Sm^3).

a. Case B1

With Tor Formation present in West Hod, it is estimated, that 3 wells are required to drain the West Hod structure based on 1000 meter well spacing. Since it is still assumed that 3 wells are required to develop East Hod, this equates to a six well development. Two of the three wells in West Hod (W2 and W3) are assumed to be dual completions in the Upper Hod and Tor Formations, while the remaining well (W1) is a single zone Upper Hod Formation completion as was assumed in the Base Case. Wells W2 and W3 are expected to produce up to 8000 BOPD (1272 Sm^3/d). A schematic of the well drainage pattern is given in Exhibit 4.56.

This case generated a reserve of 37.1 MMSTB (5.9 million Sm^3), which represents a recovery of around 14 %. Exhibits 4.63 and 4.64 show the yearly average oil, gas and NGL sales rates, in graphical and tabular form. Details of the production from each zone are shown below :

	Oil		Gas		NGL	
	MMSTB	10^6Sm^3	BCF	10^6Sm^3	MMBBL	10^6Sm^3
West Hod						
-Tor	14.8	(2.35)	26.4	(748)	2.7	(0.43)
-U. Hod	6.1	(0.97)	11.2	(317)	1.2	(0.19)
-M. Hod	0.0	(0.00)	0.0	(000)	0.0	(0.00)
-L. Hod	0.0	(0.00)	0.0	(000)	0.0	(0.00)
East Hod						
-Tor	11.9	(1.89)	14.0	(396)	1.5	(0.24)
-U. Hod	2.7	(0.43)	2.7	(77)	0.3	(0.05)
-M. Hod	0.0	(0.00)	0.0	(000)	0.0	(0.00)
-L. Hod	1.6	(0.26)	2.3	(65)	0.2	(0.03)
Total	37.1	(5.90)	56.6	(1,603)	5.9	(0.94)

Three further sensitivities were performed to ascertain the impact of the number of development wells for this geologic interpretation. Based on an economic evaluation it would then be possible to choose the optimum scheme.

b. Sensitivity B2

This case examined the effect of draining the West Hod structure with only two wells. The locations of the wells are shown by Exhibit 4.65. It is assumed that well W1 is a single zone Upper Hod producer while well W2 is dual zone Tor and Upper Hod producer. This case yields an oil reserve of 36.2 MMSTB (5.76 million Sm^3) which is 0.90 MMSTB (0.14 million Sm^3) lower than case B1.

c. Sensitivity B3

This case examined the effect of increasing the number of development wells on West Hod to four. Three of the wells, W2, W3 and W4 are dual completions - Tor and Upper Hod producers, while well W1 is still a single zone Upper Hod completion. Well W4 is expected to produce up to 8000 BOPD (1272 Sm^3/d). A schematic of this drainage scenario is shown in Exhibit 4.66. This case yielded an incremental reserve of 0.9 MMSTB (0.14 million Sm^3) over case B1.

d. Sensitivity B4

This case examined the impact of increasing the number of development wells on East Hod to four. Two of the wells, E1 and E2, are completed in the Tor, Upper Hod and Lower Hod Formations. Wells E3 and E4 are completed only in the Tor Formation. A schematic of the well locations is shown in Exhibit 4.67. This case yielded a reserve of 40.3 MMSTB (6.41 million Sm^3) which is 3.2 MMSTB (0.50 million Sm^3) higher than case B1.

Again these runs show that the field development is not very sensitive to the number of development wells. Additional sensitivities examining the effect of even more development wells were not addressed, since well spacing would become unacceptably small - based on comparison to Valhall and the uncertainties in the geologic description of the field would make such runs meaningless. However, as for the Base Case, there exists sufficient capacity available to increase the number of development wells should upside potential be identified. The economic evaluation presented in Section 7.4.2 shows that the most economic option (five wells) has been selected for the base case oil-in-place, i.e. no Tor Formation in West Hod.

4.5.5.10 Rate Sensitivities

The Hod Field platform facilities are designed for a maximum rate of 27,000 STBOPD (4300 Sm^3/d). This represents a nominal capacity at a wellhead pressure of 500 psig (34.5 bar g). At higher wellhead pressures the facilities can handle higher rates. Therefore, at early times in the field life when the field is flowing at its maximum rate and the wellhead pressures are high, the facilities can handle more than 27,000 STBOPD (4300 Sm^3/d). The maximum instantaneous rate anticipated for the Base Case is 24,000 STBOPD (3820 Sm^3/d), based on the individual well rates stated in Section 4.5.5.3 and assuming that all wells are producing at their maximum rate at one time. However, if the hydrocarbon bearing Tor Formation is present in West Hod, an instantaneous well capacity of up to 37,000 STBOPD (5880 Sm^3/d) is anticipated assuming a six well development and again assuming that all wells will be producing at their maximum rate at the same time. This would result in the field rate being restricted by the surface facilities. The duration of any well restriction is anticipated to be less than one year, but it is believed that this will not result in any significant economic disadvantage.

It is believed that coning of gas is not likely to be a critical problem. Since there exists a general relationship with permeability decreasing with depth, it would appear more economic to reap the benefits of rate acceleration by drilling a well to a structurally high location, with the option of sidetracking to a downdip location if the well begins to gas-out, rather than drilling to the downdip location initially. For this reason problems associated with restricting production due to unacceptably high gas-oil ratios are not anticipated.

Likewise we do not anticipate water coning problems as the main reservoirs, Tor and Upper Hod, are not completely underlain by an aquifer. Any water influx would therefore have to take place via the low permeability flank areas. Also, as was mentioned previously, drill stem test results suggest that relative permeability to water in the highly water saturated areas is very low.

4.6 PRODUCTION STRATEGY

4.6.1 Completion Strategy

The completion strategy for the Hod Field is expected to be similar to the current strategy pursued for the Valhall Field, i.e. the Hod Formation will be completed by hydraulic fracturing, and the Tor Formation will be completed by hydraulic fracturing followed by gravel packing. However, the possibility of using different completion techniques (e.g. acid fracturing), especially in the Hod Formation, will be investigated prior to drilling the wells.

After the well is perforated, a hydraulic fracture stimulation will be performed. Any excess proppant left in the wellbore will be cleaned out using a hydraulic workover (snubbing) unit, following a similar procedure to that currently employed on Valhall. If the well is completed only in the Hod Formation, it will then be placed on production. If the well is a Tor Formation completion, or a dual Hod/Tor Formation completion, the Tor Formation will be hydraulically fractured and then gravel packed through-tubing, again using the snubbing unit. A gravel pack log will then be run on wireline to evaluate the integrity of the pack, and the well will then be placed on production.

The production from dual Hod/Tor completions will be commingled, i.e. fluid from both zones will be produced up a single tubing string. If necessary, the relative production from each zone can be determined by running a wireline-conveyed flowmeter tool.

The criteria for possible recompletion of Hod wells are casing collapse and depletion of the drainage area of the well. These instances would lead to an appraisal of the potential of side-tracking the well to a new bottomhole location. No other criteria for recompleting a well can at present be identified, except for repair of damaged tubing or downhole equipment.

To minimize the possibility of excessive gas production, the wells will be perforated a sufficient distance from the top of the formation bed, within the constraints of achieving optimum flowrates and recoverable reserves from the well. It must be recognized, however, that much uncertainty still remains regarding the rock and fluid properties on Hod, and that accurate predictions of gas-oil ratio performance will be difficult to make without a significant production history. Should excessive gas production become a problem, methods of solving this will be evaluated at the time with the aim of optimizing future production and ultimate economic recovery.

4.6.2 Reservoir Monitoring

Monitoring of the Hod Field reservoirs, including measurement of rock, fluid and wellbore properties, will be undertaken to ensure optimum depletion of field reserves. This process will commence during the drilling and completion phase, by means of open-hole well logging (including the RFT), reservoir pressure measurements and fluid sampling. It is also expected that slug tests will be undertaken upon initial well perforation to determine reservoir permeability, similar to the procedure that has been followed on some Valhall wells.

During the production phase, periodic surface flow tests of individual wells will be undertaken to monitor well performance. The following reservoir data collection programs will also be undertaken as and when necessary to optimize field performance and ultimate recovery:

- Fluid sampling and analysis
- Pressure transient analysis
- Flow profile surveying
- Fluid contact level measurement

The results of these surveys will be provided to the Norwegian Petroleum Directorate for its information and use.
It is possible that the Hod development wells could be pre-drilled prior to installation of the platform. In this case, the following plan for collecting reservoir information would be implemented:

- Run a full suite of open-hole logs on each well.
- If the log results show a significant deviation from the expected formation, rock or fluid properties, consideration would be given to performing a production test to determine flow capacity and rock/fluid properties by pressure transient analysis, and fluid sampling.

The results of the above data collection would be used to update the geological model of the reservoir, as well as update the reserves and production profiles for the field. If necessary, the completion program for the well(s) may also be revised. If the differences are so great that they would justify the drilling of additional wells to deplete the reservoir effectively, e.g. if the presence of a productive Tor Formation in West Hod were proven, then these additional wells would be considered for inclusion in the development plan.

4.6.3 Treatment Capacities

All produced fluids from the Hod Field will be treated on Valhall after combination with the Valhall fluid streams. The Valhall treatment capacities are sufficiently large that they will not influence the production rate or total recovery from Hod.

There are no plans at the present to inject water, gas or enhanced recovery solvents into the Hod Field reservoirs.

4.6.4 Gas Sales Agreement

Hod Field gas will be sold under the terms of the Valhall/Hod Gas Sales Agreement currently in force, since this agreement includes provision for the sale of produced gas from Hod. The sale of Hod gas will not influence production, or the rate of production, from the Hod reservoir. More details are provided in Chapter 1.

4.7 ENHANCED OIL RECOVERY

4.7.1 Secondary Recovery

The overall objective of the Licencees would be to obtain maximum economic recovery of hydrocarbons from the Hod Field, as it has been for Valhall. The field production profile and estimate of recoverable reserves, as well as the design of the facilities, are based on primary depletion of the field. As is discussed in subsequent chapters, the facilities proposed to develop the Hod Field are limited, to enable the field to be commercially developed. Therefore, the scope for including enhanced recovery equipment at Hod is also limited. The feasibility of increasing Hod Field reserves by secondary recovery methods was considered in the light of previous studies performed for the Valhall Field. The conclusions reached regarding secondary recovery potential for Valhall can be summarized as follows:

4.7.1.1 Gas Injection

A detailed study of gas injection was undertaken in 1980 and is documented in the report "Valhall Field Scoping Study of Potential Crestal Gas Injection" dated January 1981. The report concluded that gas injection could potentially recover an additional 2 percent of the original oil-in-place. However, the high level of capital expenditure associated with the project resulted in unfavorable economics and gas injection was therefore not included in the development plan for Valhall. The situation in the Hod Field would be even less attractive since the field is composed of two structures. A much larger increase in capital investment on a proportional basis would therefore be required for wells and equipment to implement a gas injection program in this relatively small field.

4.7.1.2 Water Injection

Various studies and reports have been prepared by Amoco Norway and other specialist groups within the Amoco organization on the subject of Valhall waterflooding, especially in the light of the waterflood project currently underway in the Ekofisk Field.

Owing to the fractured nature of the Tor Formation in the crestal areas of both Valhall and Ekofisk, the primary means of displacing the oil from the matrix of the formation would be by capillary pressure imbibition. Water imbibition tests on core samples from the Tor Formation in the Ekofisk Field showed a high degree of imbibition (40 to 50 percent of pore volume) resulting in efficient displacement of oil by water from the matrix. These results were later confirmed by the apparent success of the water injection pilot project on Ekofisk. Similar tests on Valhall cores, however, showed that less than 10 percent of pore volume of water was imbibed by the Tor Formation core samples. This result was not unexpected considering the non-water-wet nature of the crestal Tor Formation on Valhall. Valhall rock also appears to be sensitive when contacted with water. Water injection may therefore lead to a reduction in matrix permeability. Therefore, very little additional recovery could be expected from a full scale Valhall waterflood, and indeed such a project could potentially result in lower ultimate field recovery as a result of water channelling through the high-permeability fracture system and leaving oil behind in the matrix.

Contact angle test results from samples of oil from Well 2/11-3A suggest that the Hod Field chalk could also be oil-wet. These results have been further substantiated by imbibition tests conducted on samples from Well 2/11-6 suggesting that an imbibition waterflood will not be successful at Hod (less than 5 percent of pore volume of water was imbibed). Therefore, such a project would have an adverse effect on the Hod Field economics owing to the large increase in capital investment which would be required for wells and equipment, together with the limited additional recovery anticipated.

Therefore, all indications are that secondary recovery would not be a viable economic option for the Hod Field, and consequently no plans have been made to implement such projects. This option could only be re-evaluated after sufficient production performance data are available so a proper technical and economic evaluation to be made.

4.7.2 Artificial Lift

It is not anticipated that any form of artificial lift will be required to develop the Hod Field economically. Consequently, the field production profile, reserve estimate and facilities design do not include any provision for artificial lift, as was indeed the case for the Valhall Field Development Plan.

However, should the potential for artificial lift arise at some point in the producing life of Hod, then the viability of extending the economic life of the field by installing artificial lift facilities would be evaluated at that time.