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ARCTIC OFFSHORE FIELD DEVELOPMENTS IN DEEPER EURASIAN WATERS

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ABSTRACT
The last decade has seen an increasing public and commercial focus on the Arctic regions. Politically, Norway and the other countries bordering the Arctic are demonstrating their interests and needs for a presence which will result in increased activities relating to industry, population and transport in a vulnerable area. The United States Geological Survey has assessed the area north of the Arctic Circle and concluded that about 30% of the world's undiscovered gas and 13% of the world's undiscovered oil may be found there, mostly offshore at water depths less than 500 m. Undiscovered natural gas is three times more abundant than oil in the Arctic. Examples on offshore field developments in deeper waters are the different projects in the Barents Sea. In the Western part of the Barents Sea open water prevails, but winterization problems such as sea spray icing on structures and vessels may impact the technical solutions. Moving North and East in the Barents Sea exposes the field development to waters where sea ice and icebergs may be present parts of the year. This put constraints on the development itself as well as the environmental issues including oil spill preparedness. The keynote lecture focuses on how technical learnings from offshore field developments in temperate waters may contribute to safe and sound drilling, petroleum production and transport from the Arctic region.

DEVELOPMENTS ON THE NORWEGIAN CONTINENTAL SHELF
The Norwegian Continental Shelf was originally developed with the use of fixed bottom supported platforms such as concrete Condeep platforms and fixed steel jackets. The concrete platforms provided for room for storage of oil and for support on very dense sea bottom where pile penetration was difficult. Subsea facilities have later been installed to drain smaller distant parts of the main reservoirs or reservoirs in the vicinity of the main platforms. The development of the Tampen area of the North Sea (150 to 300 m water depth) is typical for this approach (see Figure 1). While the production from the fixed platforms have been very successful with up to 70 % recovery of oil in place at the Statfjord field, it has been considerably more difficult to maintain the production from the subsea templates, since well intervention and maintenance are more difficult than for fixed platforms due to the need for assistance from semi submersible drilling rigs. A challenge in the Tampen area is the rough sea state with a design wave height (annual probability of exceedance of 10^{-2}) in the order of 29 m (Gudmestad and Løset, 2006).

When the oil industry moved into deeper waters on the Haltenbanken area off Mid Norway, the use of floating production facilities required subsea wells and floating storage units. The Norne field was developed with the use of a floating production and storage unit with offloading of oil directly from a FPSO unit (see Figure 2a). The Åsgard field, somewhat more to the south, was developed with the use of a combination of a FPSO for the oil reservoir and a semi submersible for the subsequent gas development. Extension of riser technology to large diameter gas export risers from floating units was a key for the successful Åsgard development (Gudmestad and Løset, 2006). Figure 2b shows the main features of the development.

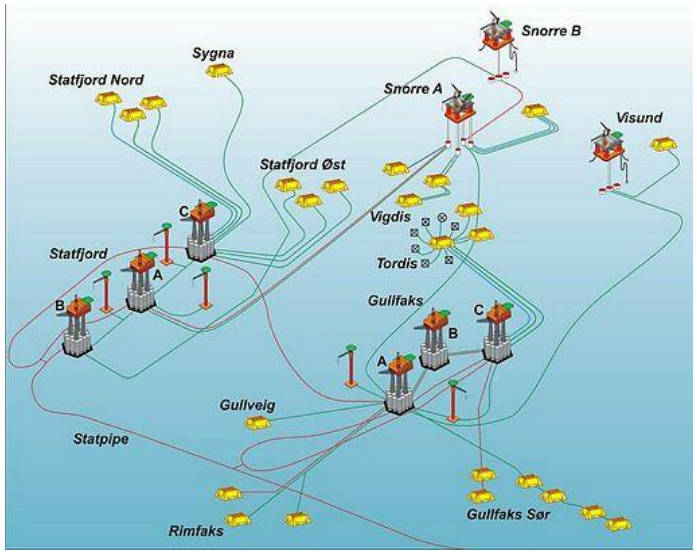

Figure 1. Development of the Tampen area in the Northern North Sea (150 to 300 m water depth) with a combination of fixed platforms and subsea units.

(a) (b)

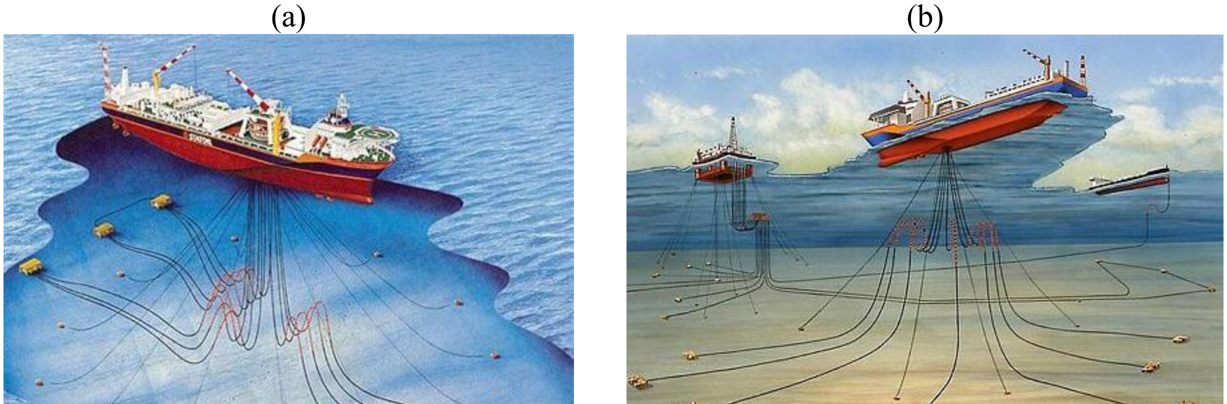

Figure 2. a) Development of the Norne field, 315 m water depth, off Mid Norway. b) The Åsgard development in 350 m water depth. A FPSO unit for the oil development, a semi submersible unit for the gas development and a storage unit for stable condensate (Gudmestad and Løset, 2006).

THE DEVELOPMENT IN THE BARENTS SEA

Ice-free waters

Off Northern Norway the Snøhvit field is developed without the use of surface facilities. The full well stream is transported to shore (at Melkøya near Hammerfest) in a multiphase pipeline. The distance from the Snøhvit field to the onshore LNG facilities at Melkøya is 145 km and this is considered to represent the state-of-the-art for the full well stream technology in case of gas with some condensate. For even dryer gas, the distance for full well stream could, however, be increased. MEG (Mono-Ethylene Glycol) is injected at the wellheads at Snøhvit to avoid the formation of hydrates in the pipeline. Separate pipelines from the shore are carrying MEG, hydraulic fluid and electricity to the subsea units.

Further, as seen from Figure 3, the Goliat oil and gas field is located 85 km off the coast in water depths ranging from 320 m to 420 m. The partners of the Goliat field has chosen the Sevan FPSO 1000 floater concept with mooring for the Goliat development, a fully winterized development built to meet the conditions in the Barents Sea (see Figure 4). The design and engineering of the unit have been based on the highest standards for safety and environment. The FPSO will be provided with electrical power supply from shore which will lead to significant reduction of emission of greenhouse gases.

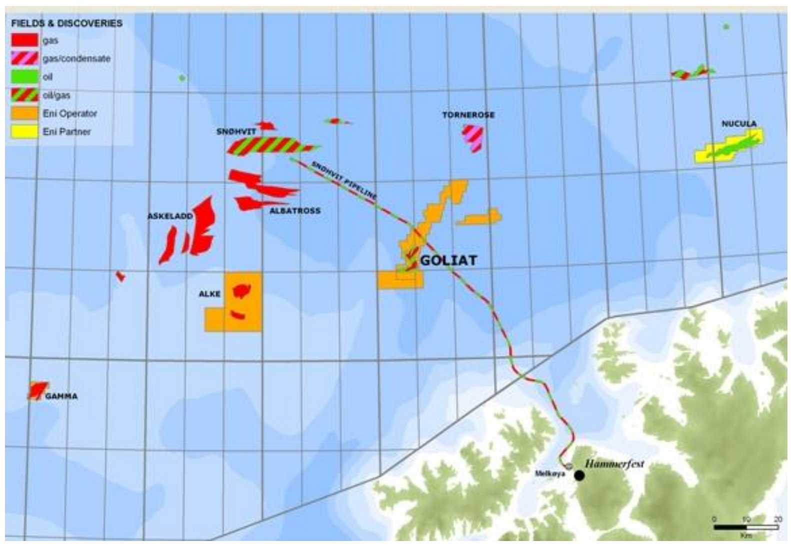

Figure 3. The Snøhvit full well stream to shore development in 305 m water depth.

Figure 4. Ilustration of the Goliat FPSO (Photo: Sevan Marine).

The spring 2011, Statoil along with the partners Eni Norway and Petoro, made a significant oil discovery on the Skrugard prospect in the Barents Sea. The breakthrough discovery is one of the most important findings on the Norwegian Continental Shelf in the last decade. The Skrugard prospect is located approximately 100 kilometres north of the Snøhvit gas field in the Barents Sea.

Ice-infested waters

An example on planned offshore field development in the Barents is the Shtokman Gas Condensate Field (SGCF) located 610 km from Murmansk in the Barents Sea with field reserves estimated to be 3700 GSm^3 (Liferov and Metge, 2009). The water depth at location is around 340 m. The offshore facilities of the SGCF Phase 1development will include ice-resistant dis-connectable moored floating production unit (FPU). Significant sea ice invasions occur at Shtokman in approximately 3 out of 10 years and ice stays at location for an average of about 5 weeks. It consists mainly of first-year ice, but a few second-year ice floes have also been observed in the region. The sea ice thickness and keel depths of ice ridges may reach 2 m and 21 m, respectively. Design will ensure that the FPU can safely withstand actions from nearly all sea ice situations without physical ice management assistance. Ice management will be carried out to detect and manage rare but potentially hazardous situations, and thereby increase the reliability (Liferov and Metge, 2009). In addition emergency disconnection may be triggered if an ice threat is about to enter the emergency disconnection limit.

Icebergs may also occur in the SGCF area. The probability of iceberg impact on the FPU is estimated to be less than once in the 50 years life of the project, and it can be further reduced by ice management. Almost half of the icebergs observed were surrounded by pack ice. This is important for design and operations since icebergs in pack ice are difficult to detect and manage. In general, iceberg probabilities at Shtokman are around 50 times less than in Canada's Grand Banks, but sea ice is around 30 times more likely at Shtokman than in the Grand Banks (Liferov and Metge, 2009).

TRENDS IN THE FIELD DEVELOPMENT OF DEEPER ARCTIC WATERS

A substantial part of the Arctic offshore is located in waters deeper than 100 m. Considering actions from sea ice and possibly icebergs, a bottom founded structure may suffer a substantial load from these ice features and thus accompanying a large overturning moment for such water depths. This calls for floater solutions; either ship-shaped or buoys.

A ship-shaped floater may keep a geofixed position either being on mooring or by means of dynamic positioning (DP). The latter requires marine propulsion units consisting of electrically driven propellers mounted on a steerable pod. A DP solution is more attractive for drilling operations than production. A major reason is the short get-ready and decommissioning time for DP which is more relevant for a short drilling operation compared to a typical lifetime of say 20-40 years for a production field. In waters with accidently extreme ice features that cannot be handled by ice management one should take the advantage of disconnection or move off in case of DP. This is illustrated in Figure 5 where huge peak loads are removed by such a design philosophy.

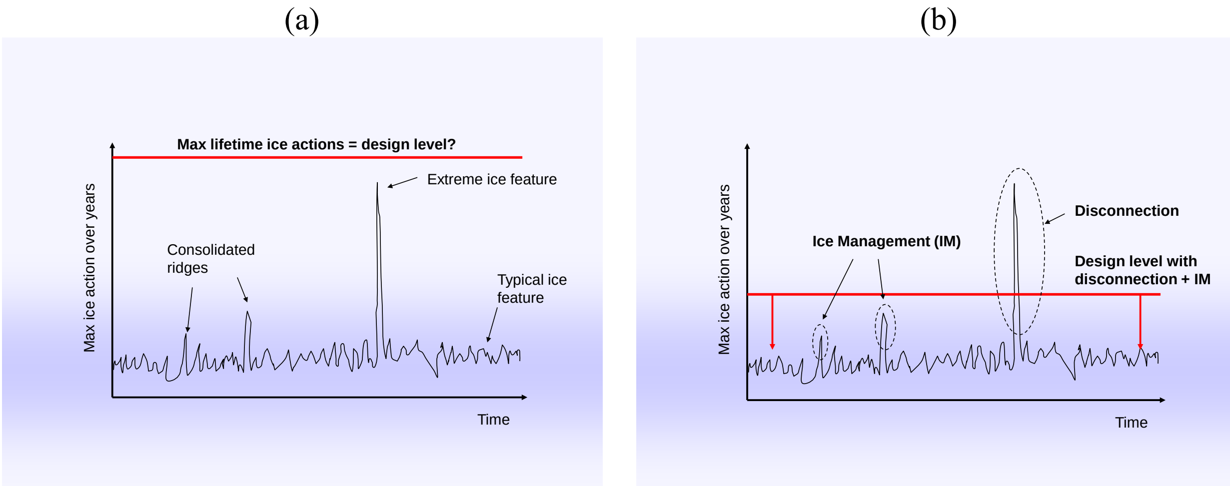

Figure 5. Ice actions – possible design philosophy.

Ship-shaped structure

The actions from sea ice exerted on a structure are highly governed by the failure mechanism at the ice-structure interface. A bending failure of the ice may e.g. reduce the horizontal load by a factor five or higher compared to a crushing failure. Thus it is very important for a ship-shaped structure to ice vane and in that way meet drifting ice with a flared part of the hull which in most cases means the foreship. The consequence is that a ship should always be heading towards the drifting ice.

An example on a novel concept tested for offshore offloading in ice is the Arctic Tandem Offloading Terminal (ATOT) concept. The concept has been tested in the large ice tank at the Hamburg Ship Model Basin (HSVA). The test scale was 1:24, and the model was equipped with propulsion and a dry mooring system (Jensen et al., 2008). The ATOT comprises two units; a moored offloading icebreaker (OIB) and an offloading tanker moored in tandem (Figure 6). The three basic operational modes of the ATOT are; the OIB moored alone, close loading mode and distant loading mode. These modes are related to the following physical environmental conditions: 1) the OIB moored alone in severe ice conditions, 2) close loading in medium and heavy ice conditions, 3) distant loading mode in light ice conditions and open water. The system is disconnectable making it promising for year-around operation in challenging environments such as the Eastern Barents and Kara Seas.

The OIB is connected to a sub-surface turret mooring and riser system while the tanker is moored on a dry mooring through deck winches on the OIB. The OIB is a purpose designed vessel for operation in ice with azimuth propulsion units fore and aft with an installed power of 20-40 MW depending on the ice conditions to operate in. The subsurface mooring system of the OIB contains a heavy duty spread mooring system with a preliminary horizontal station keeping load capacity up to 40 MN. The mooring system is connected via a quick disconnectable turret system to the OIB. During the summer of 2007 a series of model testing of the concept was performed showing promising capabilities.

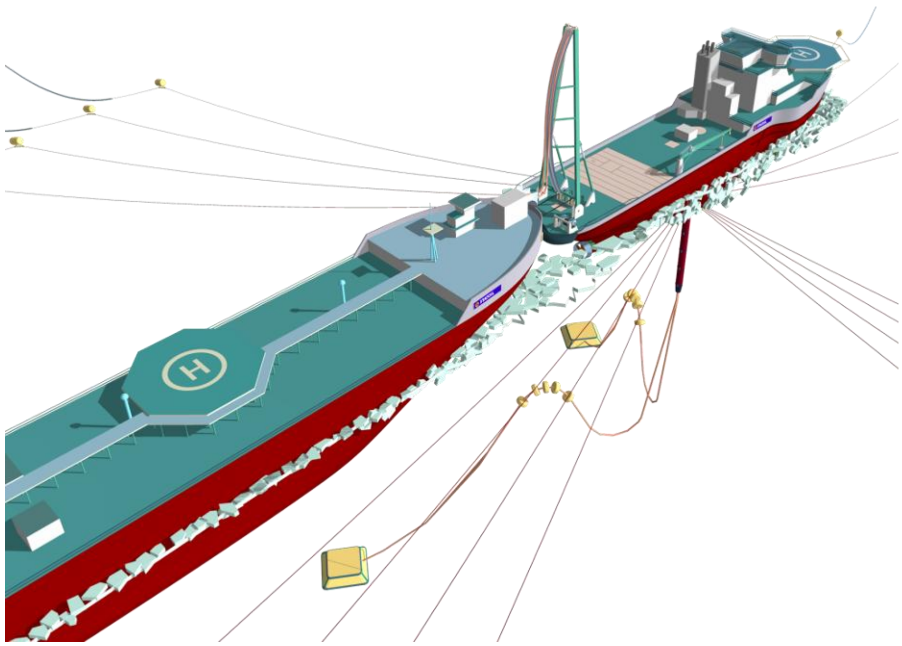

Figure 6. Illustration of the ATOT concept in full-scale.

Buoys

A buoy shaped structure may be omni-directional and in that case there is no need for ice vaning. In this way a buoy concept may be more environmental friendly when in operation due to the fact that no propulsion is needed for vaning. The Kulluk exploration vessel was the first full-scale example on such a structure. The diameter at the main deck level is about 100 m while the diameter at the water line is about 70 m (Wright, 2001). Kulluk, equipped with 12 mooring lines hooked up subsurface, operated in the Beaufort Sea from the mid 1970ies to the early 1990ies in water depths of 20 m to 60 m (Wright, 1999). Kulluk was typically supported by two to four icebreakers during operations in heavy ice. This is the only moored buoy, on a worldwide basis, that has been station-kept in a near full range of moving pack ice conditions and represents an unparalleled source of relevant full-scale experience (Jensen, 2002). However, the open water performance of Kulluk is rather poor and in waters where ice may be absent most of the year, such a drawback will not be accepted for a sound floater solution.

With the Kulluk learnings in mind a new concept for operations in ice and open water has been studied in model-scale. It is a moored circular structure with a downward sloping water line, based on the design of the Sevan Marine platforms. The structure (Sevan FPU-Ice buoy) is moored on a disconnectable submerged turret as shown in Figure 7. The buoy is intended to operate in two drafts; a shallow draft (15 m) in open water (Figure 7b) and an ice draft of 26 m (Figure 7c). It presents a displacement of 172 700 tons in ice draft. It has a high metacentric height (high GM), ensuring a good stability that limits the structure tilting (basically pitching) during interaction with ice. The purpose of the open water draft is to optimize the buoy response in waves while ballasting till the deeper draft is used when ice is present to ensure breaking of the ice in bending by having a significant part of the ice actions on the conical part of the buoy.

(a) (b) (c)

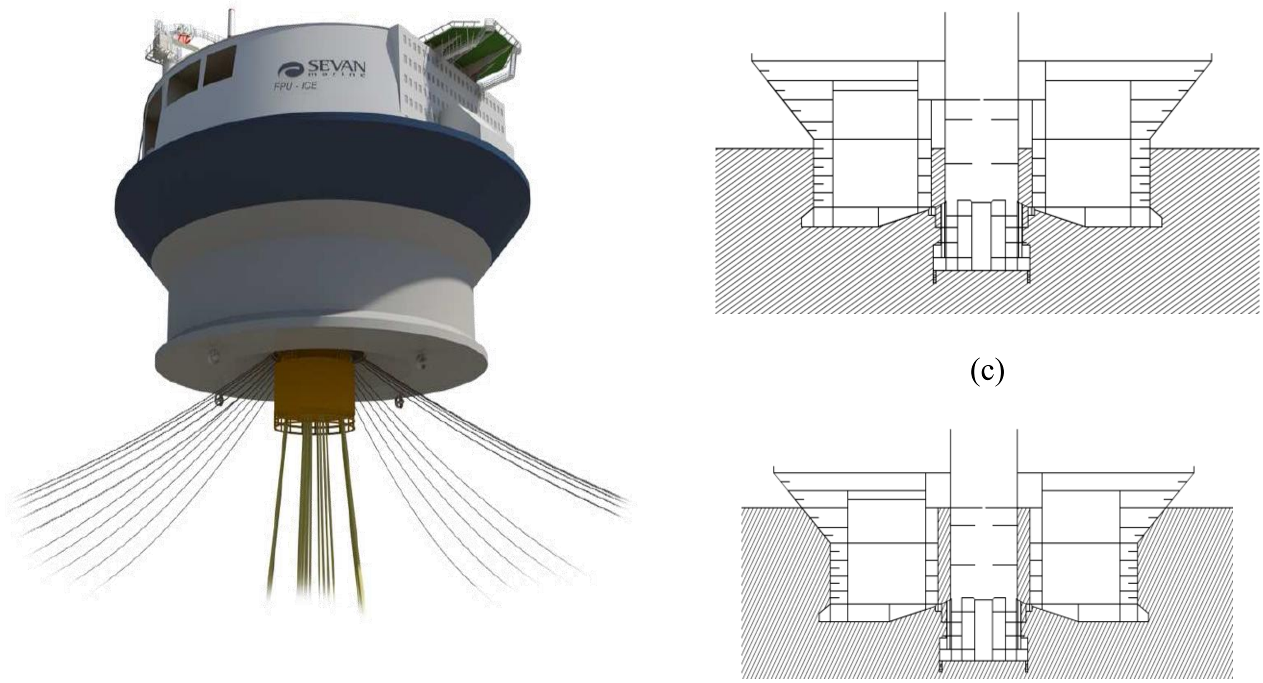

Figure 7. a) Layout of the Sevan FPU-Ice hull, b) open water draft, and c) ice draft.

The diameter of the main hull cylinder is 87 m and the diameter at the water line in ice draft is 103 m. The cone angle above the main cylinder is 45º. The characteristics of the open water and ice drafts are found in Løset and Aarsnes (2009).

Model tests with the FPU-Ice structure was carried out in scale 1:62 in the ocean basin at Marintek, Trondheim. The main purpose of the tests was to verify the motion performance of the buoy. This includes comparison with the traditional Sevan FPSO open water design and the results from simulation of motion response using state-of-the-art numerical codes (WAMIT and Simo).

The FPU-Ice was tested in the spring 2008 at HSVA. The purpose of the ice tests performed in scale 1:40 was to study the ice load level on the structure and its response in extreme (design) first-year ice (up to 1.9 m thick) including the interaction with unmanaged ice ridges exceeding 20 m draft as well as successive ridges (Figure 8).

Tidal currents and wind may cause pack-ice to change drift direction relatively rapidly (Løset and Onshuus, 1999). A ship-shaped moored structure in ice may therefore need to change heading (ice vaning) towards the ice drift. The FPU-Ice concept is completely independent of any ice vaning; a great advantage of the concept. Due to the open water and ice draft flexibility the FPU-Ice buoy achieved the following results from the open water and ice tests (Løset and Aarsnes (2009):

- Comparing Sevan FPU-Ice with the traditional Sevan FPSO shows that the open water motion characteristics are kept.
- Open water pitch < 11°.
- The buoy worked well in all ice tests.
- Level ice – low accumulation, small mooring forces.

- Rubble fields – low accumulation, moderate mooring forces.
- Managed ice ridges – low accumulation, moderate mooring forces.
- Unmanaged ice ridges – low accumulation, heavy mooring required.
- Pitch < 5° with -3° counter-ballasting (unmanaged ridge).
- No ice under the buoy, except minimal amounts for high-speed (1 m/s) in level ice.

Based on the cited model-scale tests a disconnectable buoy may be a good option in Arctic deeper water field developments.

(a) (b)

Figure 8. Photos from Test 3100; a) entering Ridge 2, b) passing Ridge 2 with managed ice behind the ridge (Løset and Aarsnes, 2009).

Another example on development of floaters for ice is the Joint Industry Project project reported by Bruun et al. (2011). Two large ice model test campaigns were performed in the period 2007-2010 in the HSVA Ice Tank. The objectives of the project were to investigate different floater geometries and ice model test set-ups (model fixed to a carriage and pushed through the ice vs. ice pushed towards a floating model moored to the basin bottom) and their influence on the ice failure mode and structure responses in the various tested ice conditions. See Figure 9 for an illustration of a typical SPAR platform developed during the project.

The study performed, including the ice model test, raised several questions regarding the existing methods of determining the ice-induced responses of a moored floater operating in first-year level ice and ice ridges, including the validity of using ice model test results from structures in fixed conditions compared to results from structures in moored floating mode.

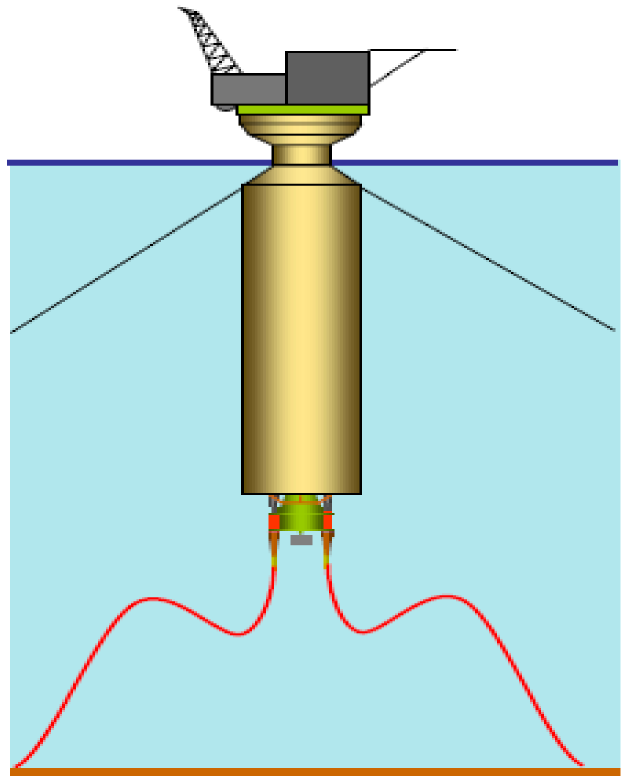

Figure 9. Typical Arctic SPAR Platform (summer season waterline shown).

REMARKS

How does Norway meet the technological challenges in the Arctic? One measure taken by the Research Council of Norway is to establish and fund a centre over the next 8 years for research based innovation. The Centre is hosted by NTNU, and the objectives of the centre named "*Sustainable Arctic Marine and Coastal Technology – SAMCOT*" are to provide the necessary research based knowledge as required by the industry to develop Arctic technology for the energy sector in particular and for society as a whole. The implications of the presence of ice and permafrost will be specifically addressed, and SAMCOT will produce knowledge to ensure sustainable and safe exploration, exploitation and transport from and within the vulnerable Arctic region. SAMCOT will also be the basis for the development of environmentally adapted coastal infrastructure.

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