FOUs – LNG Developments

RINA London Branch Presentation – 21 January 2016

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Lloyd's Register Energy

Working together
for a safer world

Presentation - Overview

- Introduction
  - Safety moment
  - Scope of the presentation – FLNG and FSRU
- FLNG developments
  - Hull and general arrangement
  - LNG storage
  - Topsides and process - cryogenics
- FSRU developments
  - Where new challenges are arising
- Shell video?

Introduction - Safety moment

In less than 2 hours – 167 fatalities

Introduction - FLNGs

- What is a FLNG?
- What does the FLNG do?
  - Seabed hydrocarbon extraction (turret)
  - Fractionation and cleaning the feed gas (modules)
  - Liquefaction (refrigeration)
  - Storage – LNG, LPGs and condensate (oil)
  - Offloading – liquefied gases and oil

Introduction - FSRUs

- What is a FSRU?
- What does the FSRU do?
  - Storage of LNG (ship to ship transfer)
  - Pressurisation (pumps)
  - Vaporization (modules)
  - Ancillary systems – calorie control, oderization, dew point correction
  - Send out

Overview - World's first's in floating systems (Oil & gas)

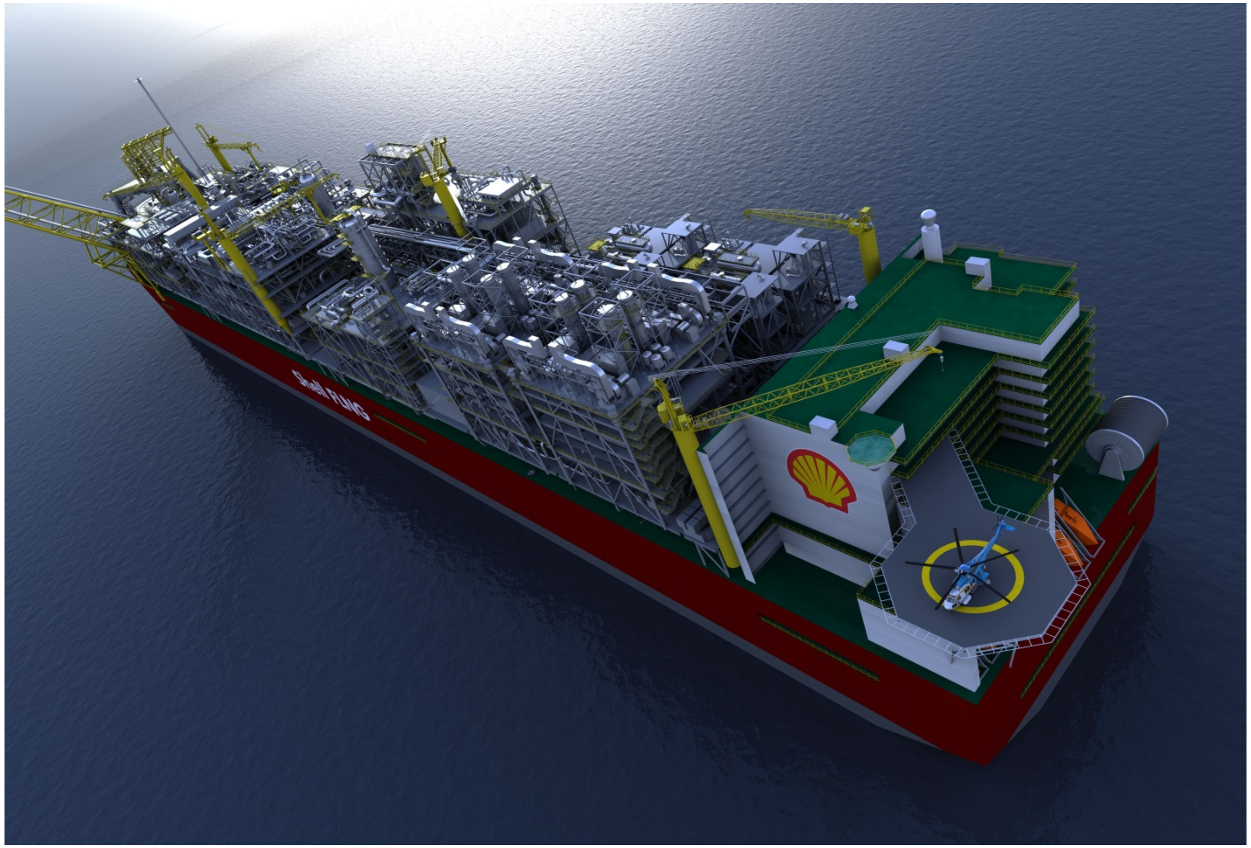
1977	World's 1st FPSO '*Castellon*' for Shell (Spain)
1984	World's 1st TLP '*Hutton*' for Conoco (UK)
1986	World's 1st Disconnectable FPSO '*Jabiru Venture*' for GAR (Australia)
1989	World's 1st Dynamically positioned FPSO '*Seillean*' for BP (UK)
1996	1st Purpose Designed FPSO for the North Sea – '*Captain*' for Texaco (UK)
1998	1st Purpose Designed FPSO for West of Shetland – '*Schiehallion*' for BP (UK)
1999	1st set of 'Risk Based' Rules for Floating Offshore Units
2001	1st FPSO for North American waters '*Terra Nova*' for Petro-Canada
2005	World's largest FPSO '*Bonga*' for Shell (Nigeria)
2014	1st Deepwater Semi-FPS '*Gumusut*' in Malaysian Waters for Shell
NOW	1st FLNG Unit for Australian Waters, '*Prelude*' for Shell
NEXT	2nd & 3th Lloyd's Register FLNGs in AiP design stage

Overview - Some noteworthy gas process & production facilities

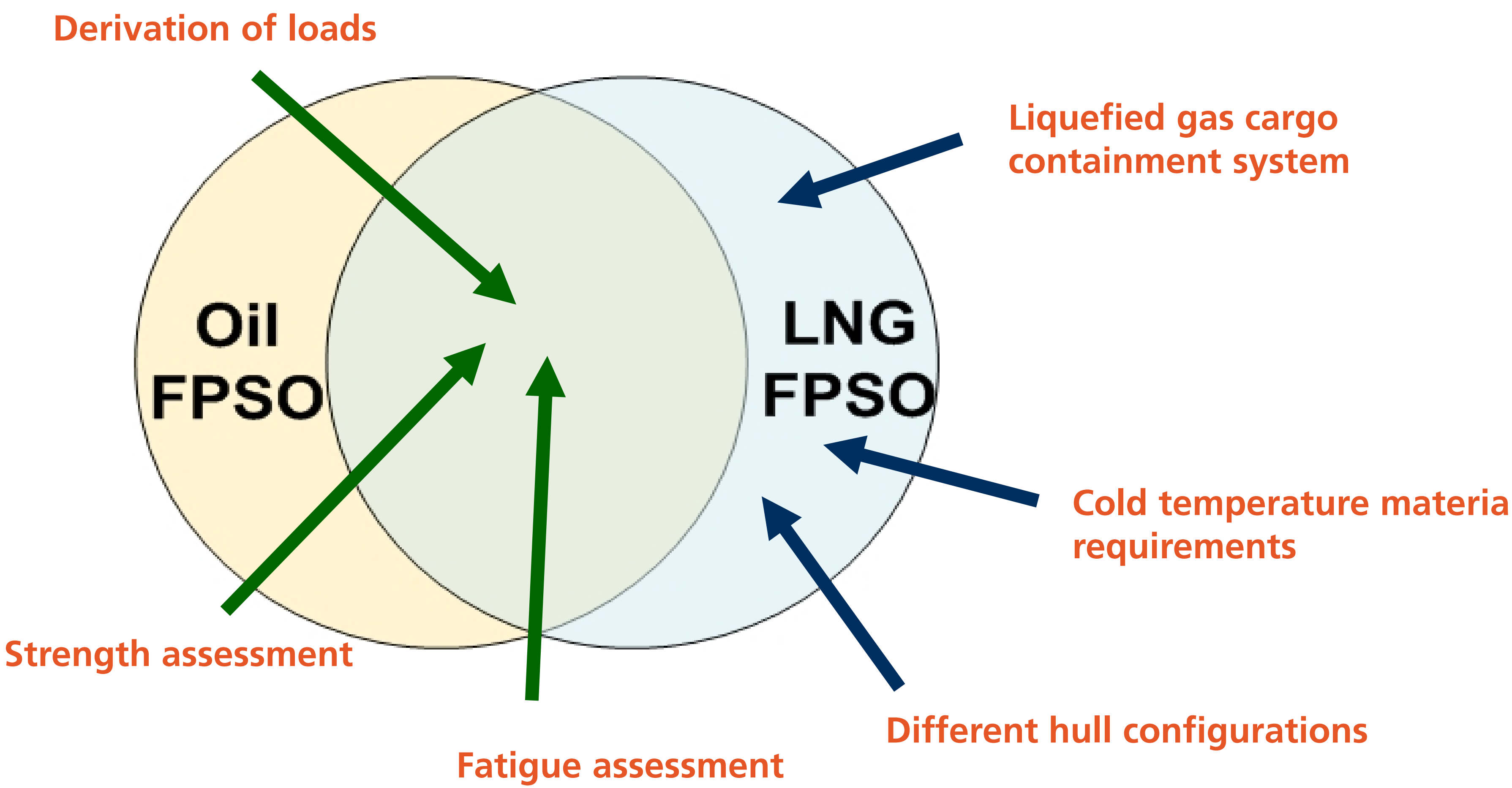
- LPG
  - '*N'kossa II*' (Congo) – 1996, 0.29 mtpa propane, 0.2 mtpa butane, 78,000 m^3
  - '*Liberdade*' (Bayu-Undan) – 2003, 3.2 mtpa, 95,000 m^3 propane & 47,500 m^3 butane
- NG
  - '*Agosto 12*' (Malaysia) - Jack up rig, gas reinjection
  - '*Jangkrik*' (Indonesia) – 2016, Floating gas supply unit, 450 mmscfd
- FLNG
  - '*Caribbean FLNG*' (La Creciente - Columbia) – 2016, 0.5 mtpa, 16,500 m^3
  - '*FLNG Satu*' (Serawak - Malaysia) – 2016, 1.2 mtpa, 177,000 m^3
  - '*FLNG Dua*' (Sabah - Malaysia) – 2017, 1.5 mtpa, 150,000 m^3
  - '*Prelude*' (Browse - Austrialia) – 2017, 3.6 mtpa, 220,000 m^3 LNG & 90,000 m^3 LPG

FLNG developments – Hull and topsides

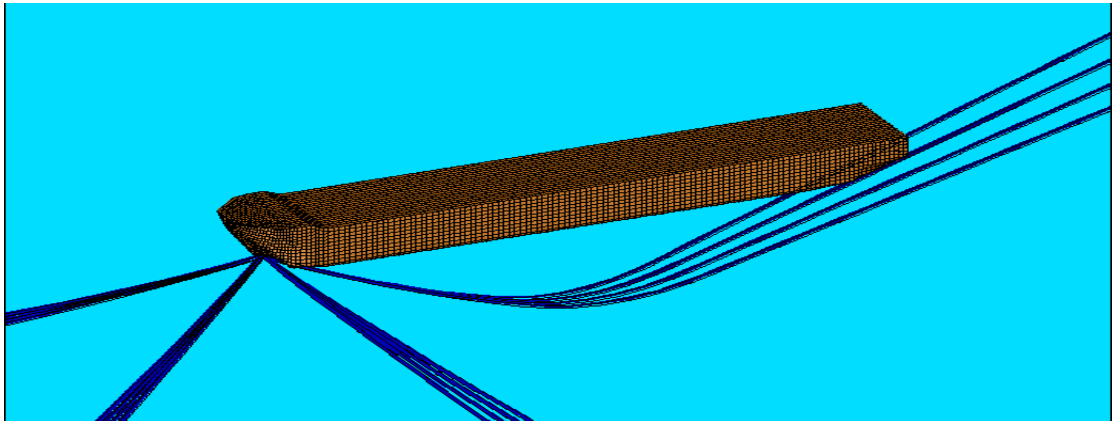
- Hull
- Topside modules mounted on hull structure
- LNG, LPG and condensate storage in hull structure
- Turret – weathervaning
- Thrusters – to allow either dynamic positioning or vessels heading to be altered to assist berthing

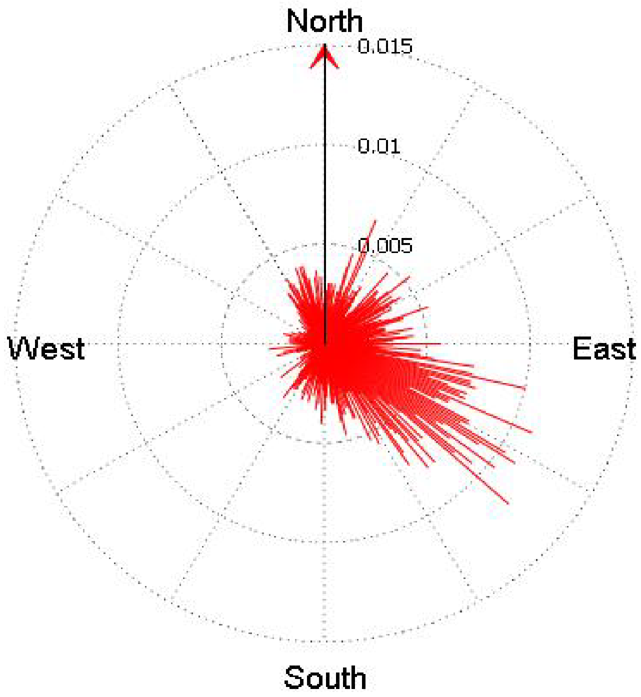


FLNG developments - Comparison between Oil and FLNG

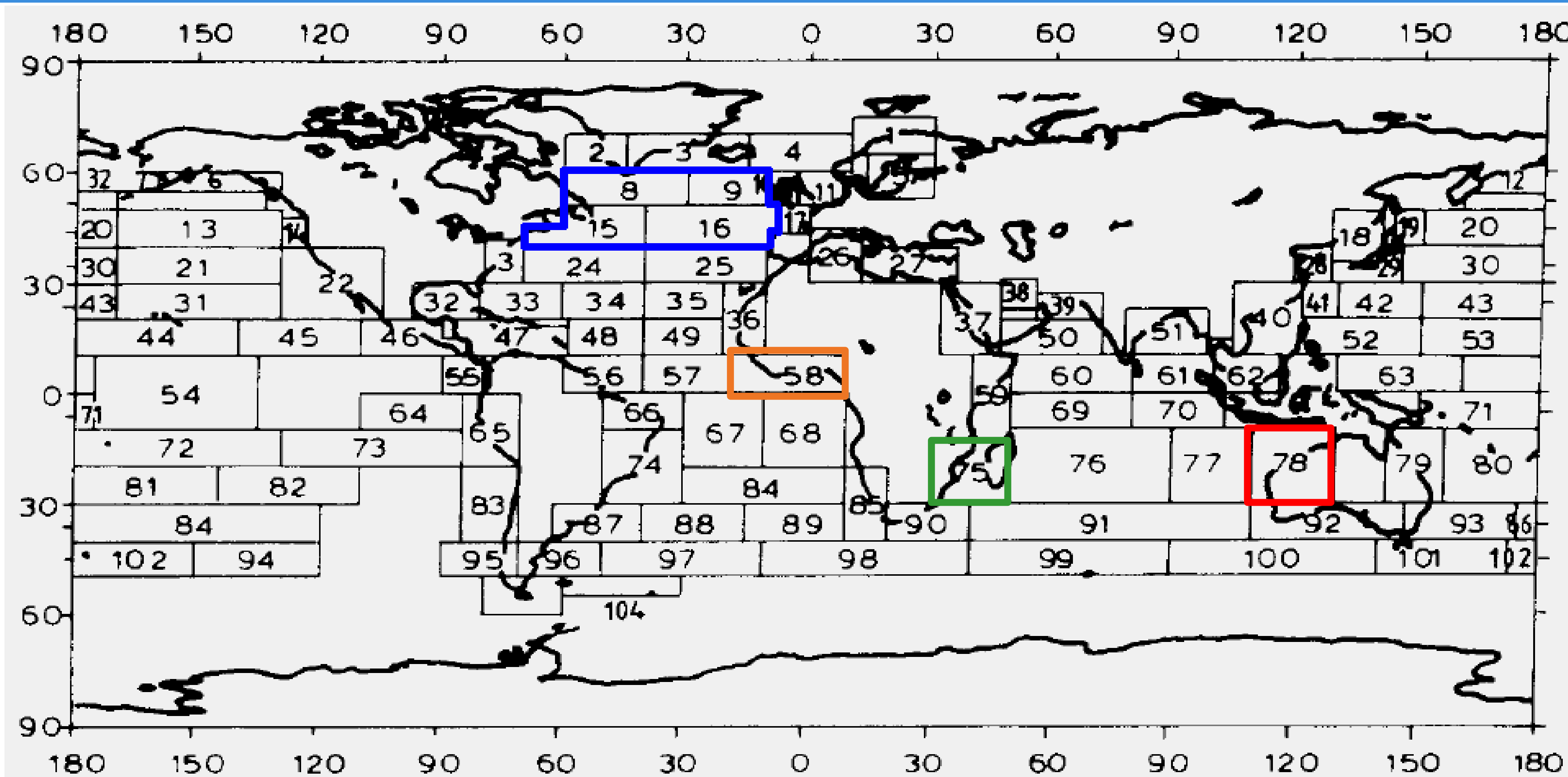


FLNG developments - Response to waves, wind and current





FLNG developments - Site-specific wave data

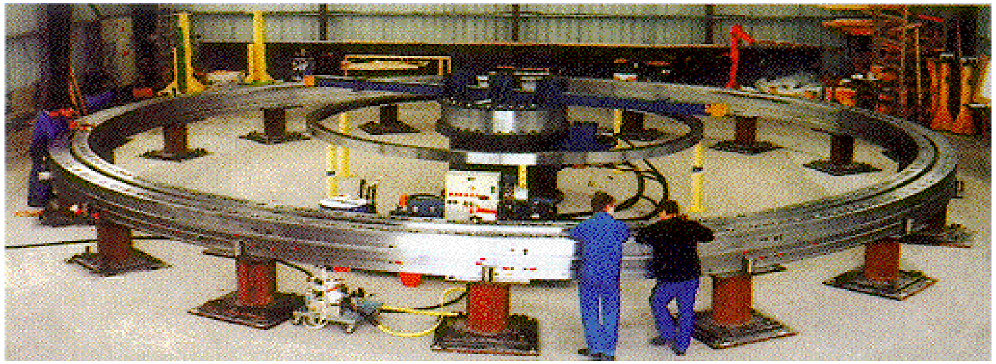


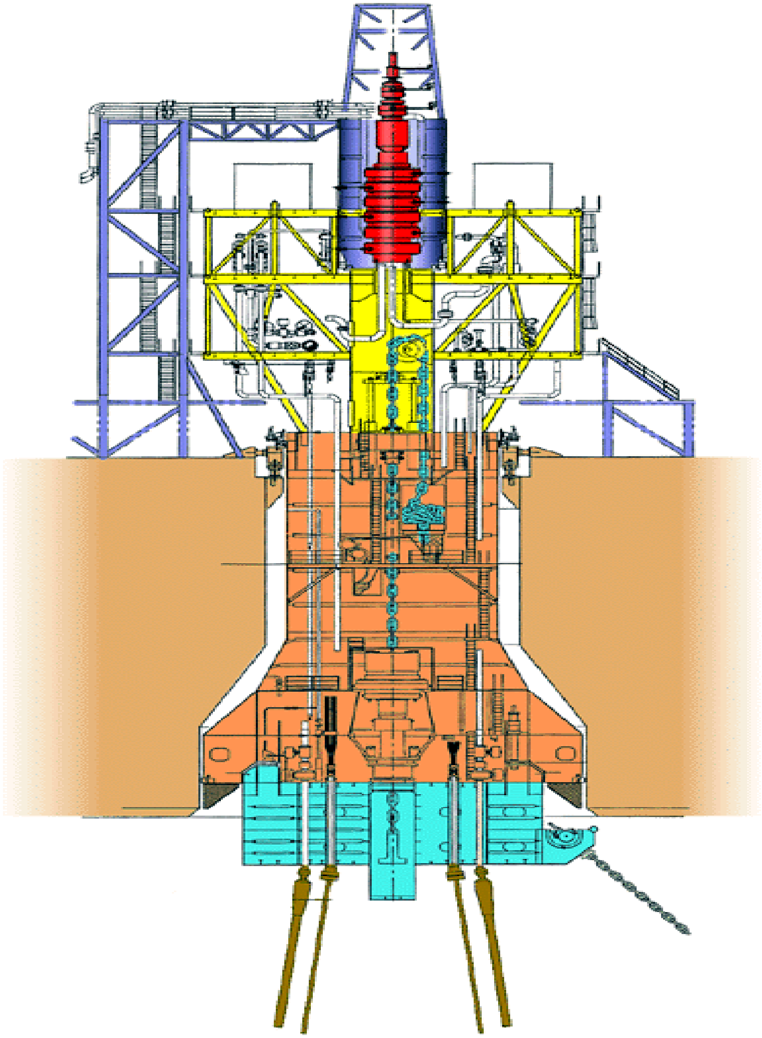
FLNG developments – Size and scale

LNGC **50 m x 30 m**	**LNGC 330 m**
Oil FPSO **60 m x 40 m**	**Oil FPSO 330 m**
FLNG **75 m x 45 m**	**FLNG 480 m**

FLNG developments – Additional loads due to offshore outfitting

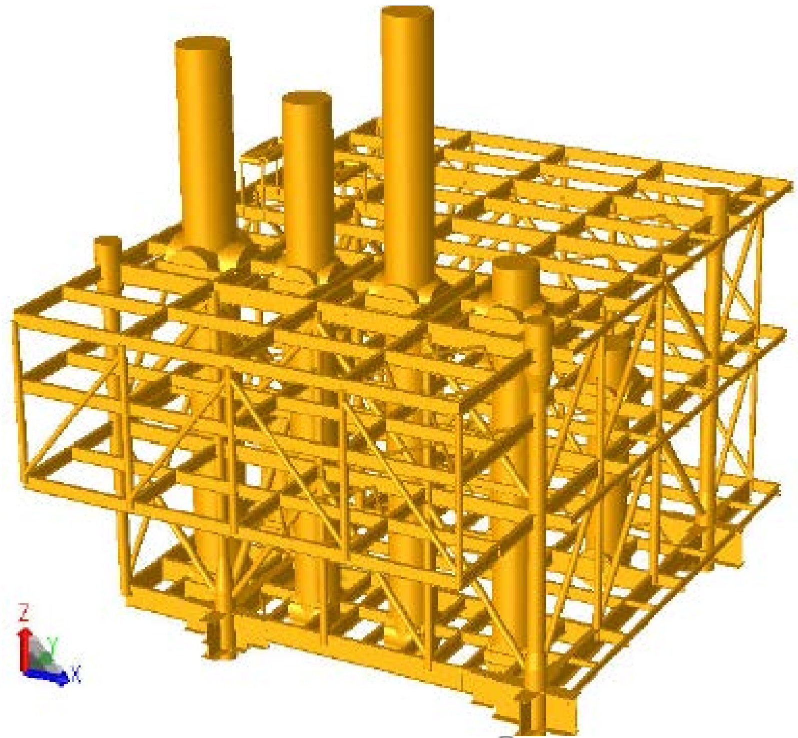
- Turret bearings
- Crane pedestals
- Lifeboat platforms
- Helideck
- Topside plant
- Flare stack

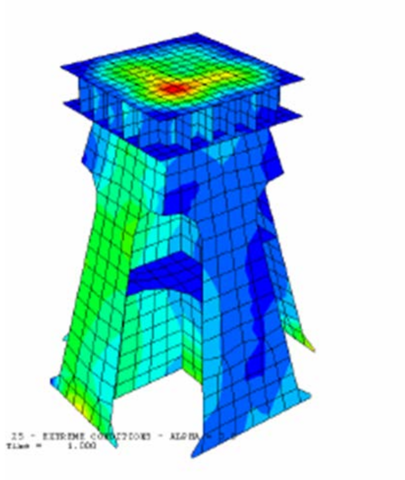


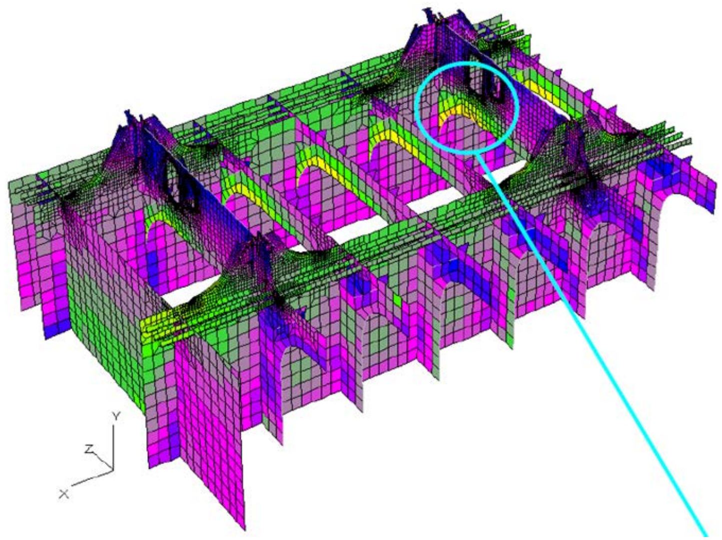


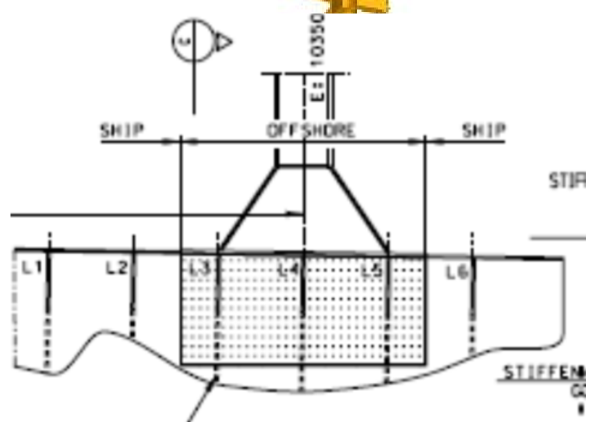
FLNG developments - Typical topside layout and loads

- Oil FPSO topsides - 40,000 tonnes
- FLNG topsides – totalling about 90,000 tonnes
- Module weights are of around 4,500 tonnes and are supported at four points
- Liquefaction modules form around 25,000 to 30,000 tonnes of the total
- Topside modules point load up to 4,000 tonnes



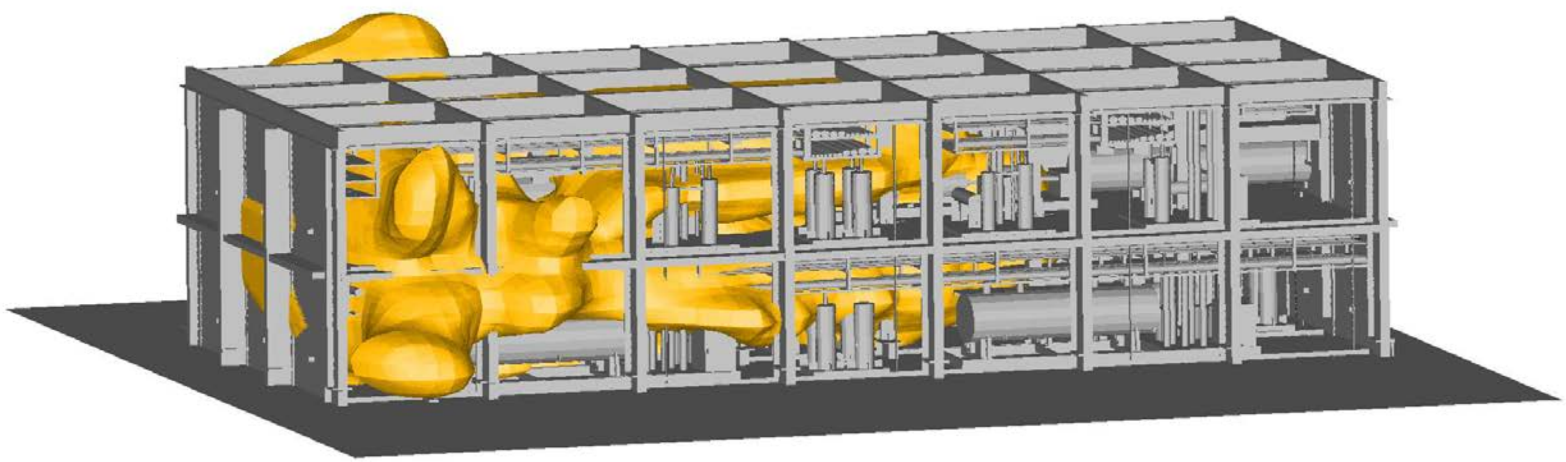






FLNG developments - Loading conditions particular to floating offshore installations

- Various types of loading to be considered in the design.
  - Dead loads, wind loads, inertial load
  - Loads associated with station - ship motions (cyclonic) and green water
  - Metocean data – accelerations
- Accidental load cases such as:-
  - Hull damage due to ship to ship transfers
  - Helicopter impact
  - Blast
  - Cryogenic spill
  - Jet fire



FLNG developments - Floating offshore installations loadings

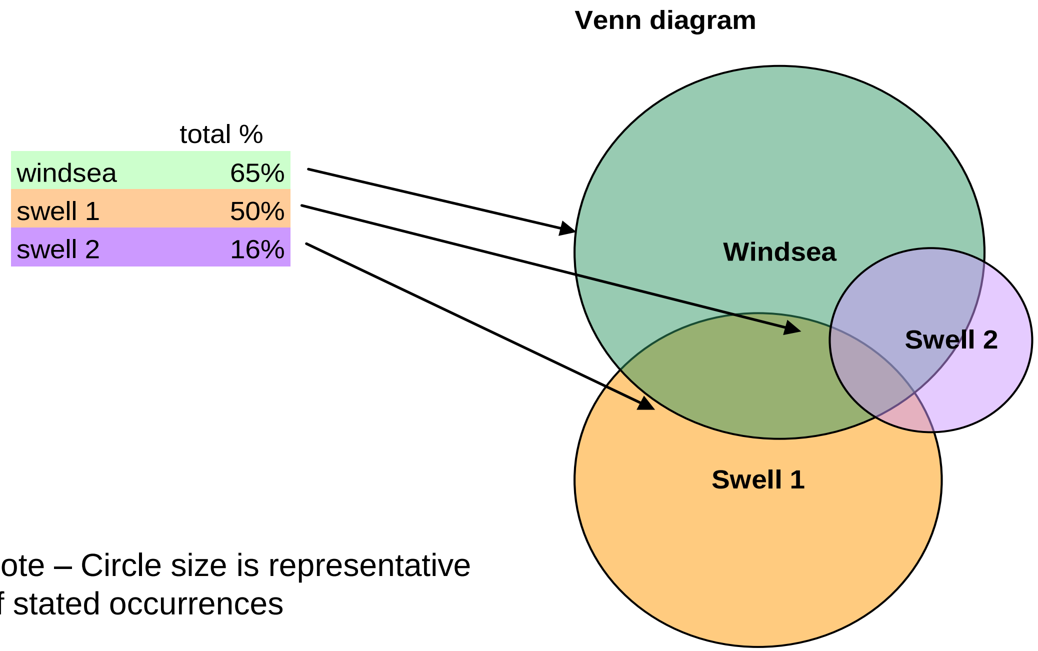
- Acceptance criteria under extreme or accidental load case
  - Similar to trading oil and LNG gas tankers – some differences in accidental load cases but significant differences in weights and masses
- Location specific
  - Operating condition = 1 year return period
  - Extreme condition = 100 year return period
  - Abnormal condition = 10,000 year return period
  - Damage condition = 1 year return period with hull damage
- Partial filling
  - Tanks may well be in the normal barred filling range defined by tank designer

FLNG developments - Environmental data for FLNG applications

- Environmental data analysis
  - Identify trends in the data
  - Take an example
    - Uni-direction sea states exist for 61% of the time
    - Multi directional sea states exist for 34% of the time
    - Comprised of combinations of Swell 1, Swell 2 and wind waves systems

Example data	Occurrence
Windsea	33%
Swell 1	26%
Swell 2	2%
wind + swell 1	18%
windsea + swell 2	10%
windsea + swell 1 + swell 2	4%
swell 1 + swell 2	2%
calms	5%
total	100%

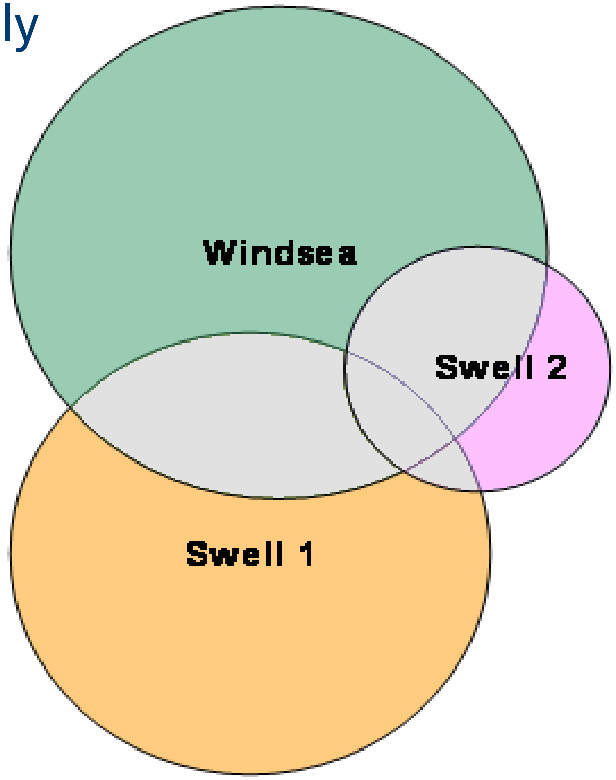
Percentage of uni directional sea states	61%
Percentage of multi directional sea states	34%



Note – Circle size is representative of stated occurrences

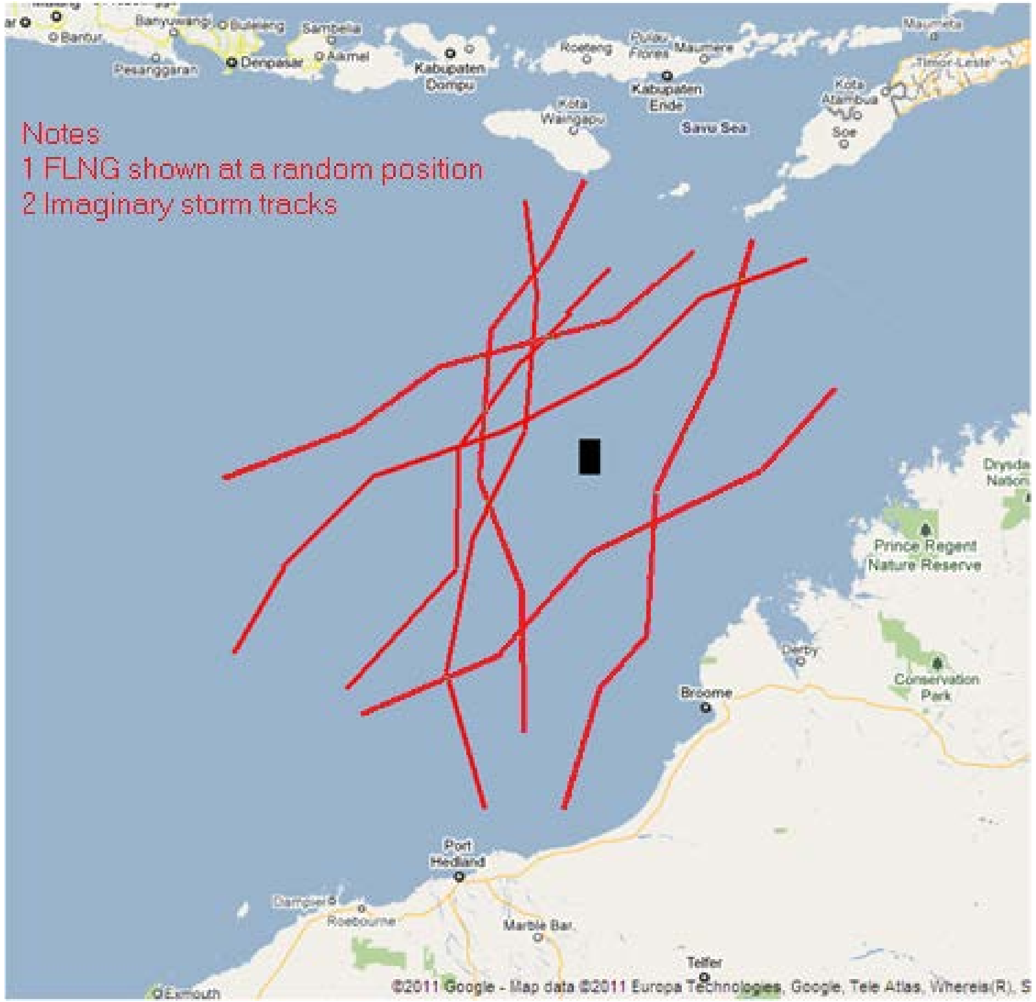
FLNG developments - Sloshing assessment of uni-directional seas

- Stage 1 Sloshing assessment - uni-directional seas
- For the portion of the environmental data that is predominantly uni-directional waves
  - For this example:
    - Uni-directional = 61% of the time
- Treat uni-directional waves as per normal ship sloshing assessment
  - This applies to the swell seas as well as the wind sea
  - Can use short term or long term assessment methods



FLNG developments - Validity of the multi directional sea states

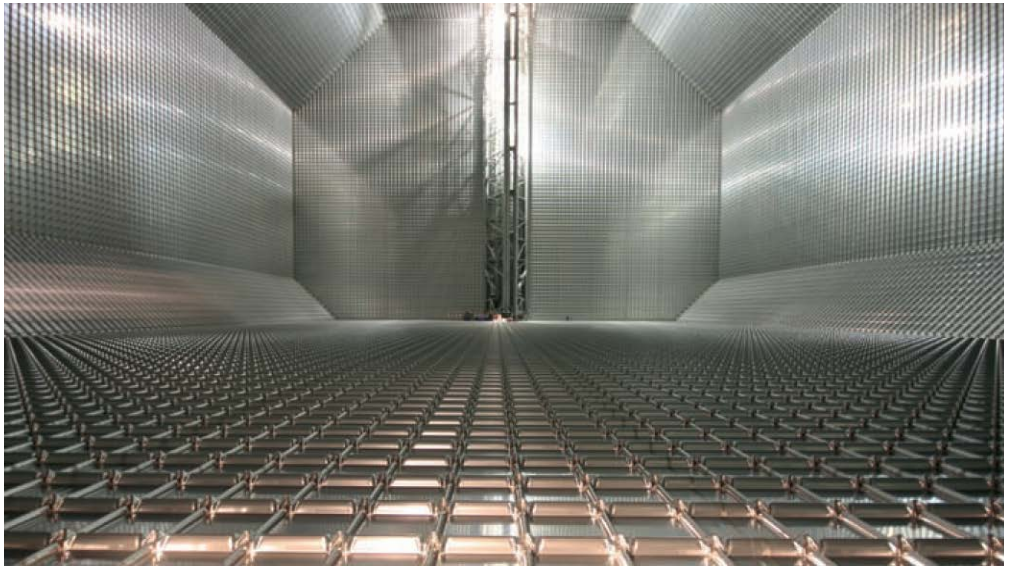
- Key events identified as Cyclone events
  - Cyclone tracks plotted
  - Taken from hindcast of say 40 years
- Issues
  - Hindcast is only a snapshot
  - Many other cyclone tracks are equally possible
  - Hence validity of multi directional sea state statistics may be suspect
- Need to derive means of enhancing the environmental data and the multi direction data in particular



Cyclone tracks from hindcast

FLNG developments – Storage tanks

- Membrane
  - Mk III
  - NO 96
  - GTT variant
- SPB
  - Stainless steel
  - Aluminium alloy
- Moss
- LPG
  - Independent
  - As per LNG



FLNG developments – Comparison of containment systems

Membrane

- No cool-down rate limit
- Large flat area of deck
- Tank shape suits hull structure
- Hull shape can be smaller
- Design company available for in-service advice

- Large single tanks results in deck not being supported
- Integrity of containment system depends on quality from many sub-contractors

Moss

- **Less chance of damage by mal-operation**
- **Primary barrier fully gas-tight**
- **Visible secondary barrier**
- **No barred fill ranges**
- **Easier access for repair**

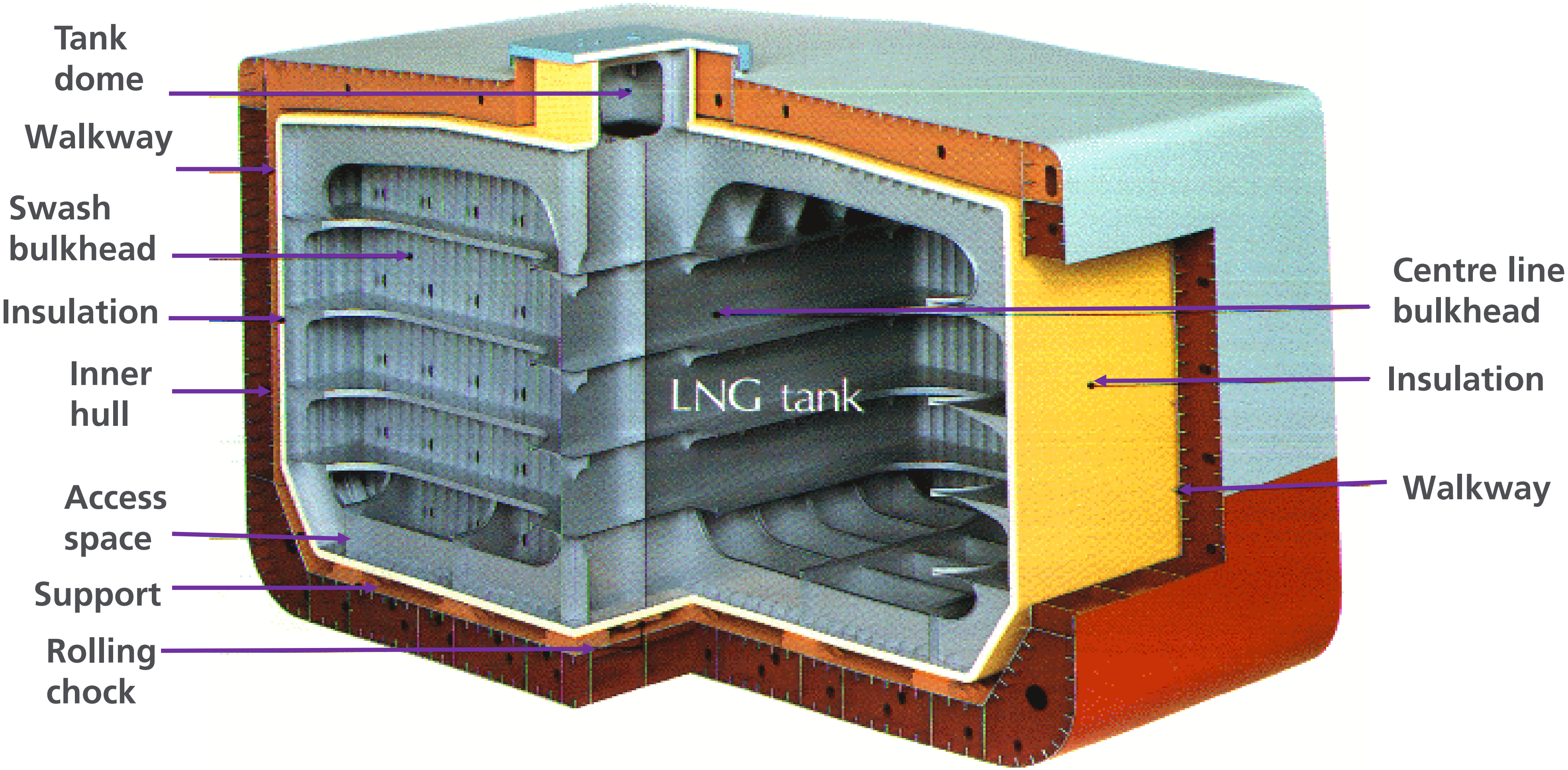
- **No flat deck area**
- **Expensive build facilities at shipyard**

SPB

- Same as Moss, plus
- Tanks have internal steelwork to support deck mounted structure
- Large flat area of deck potentially beneficial for floating LNG

- In-service experience limited to two smaller aluminium tank ships
- Limited shipyard experience

FLNG developments – IHI SPB system

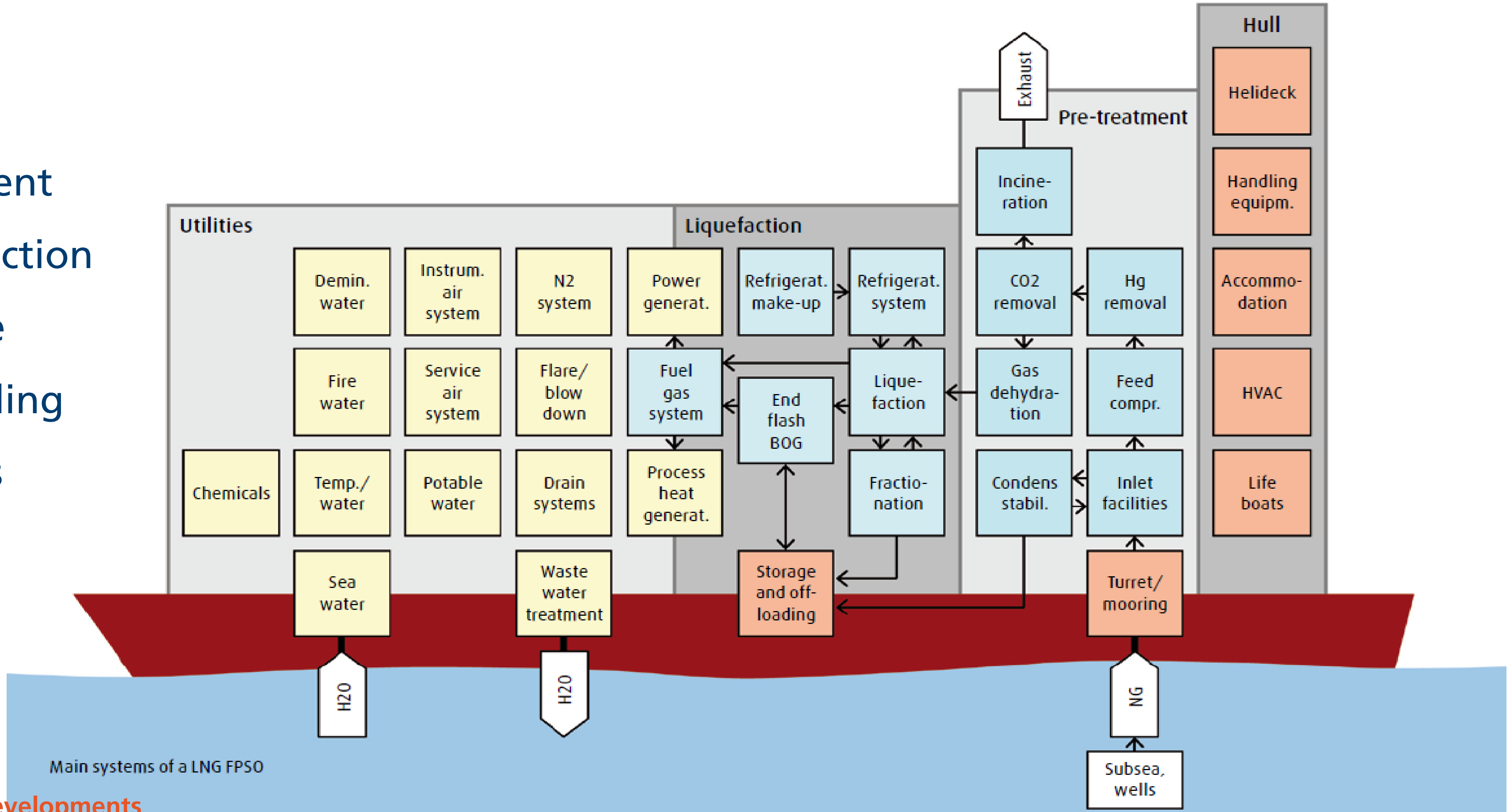


FLNG developments – Liquefaction time line

- 1914 – United States patent for gas liquefaction grant to Godfrey Cabot
- 1941 – First commercial LNG liquefaction plant in Cleveland (USA)
- 1959 – First LNG cargo carried by the '*Methane Pioneer*'
- 1964 - First base load LNG plant Arzew, Algeria used a cascade liquefaction plant
- 1970 – Marsa El Braga plant in Libia used a single mixed refrigerant cycle
- 1972 – Brunei LNG plant used a cascade system - propane and mixed refrigerant
- 1977 – First LNG in Middle East at Das Island (gas previously being flared)
- 1989 – Australian Northwest Shelf project - environmental impact effects
- 1997 – Ras Laffan, Qatar initial 3 trains constructed
- 2010 – Ras Laffan, Qatar 7 trains throughput increased 5 fold
- 2014 – First FLNG liquefaction plant utilising a propane and mixed refrigerant

FLNG developments – Topside plant and equipment

- Hull
- Import
- Treatment
- Liquefaction
- Storage
- Offloading
- Utilities



Main systems of a LNG FPSO

FLNG developments – Topside processes

The process equipment can be broken down into four specific plus one operational areas:

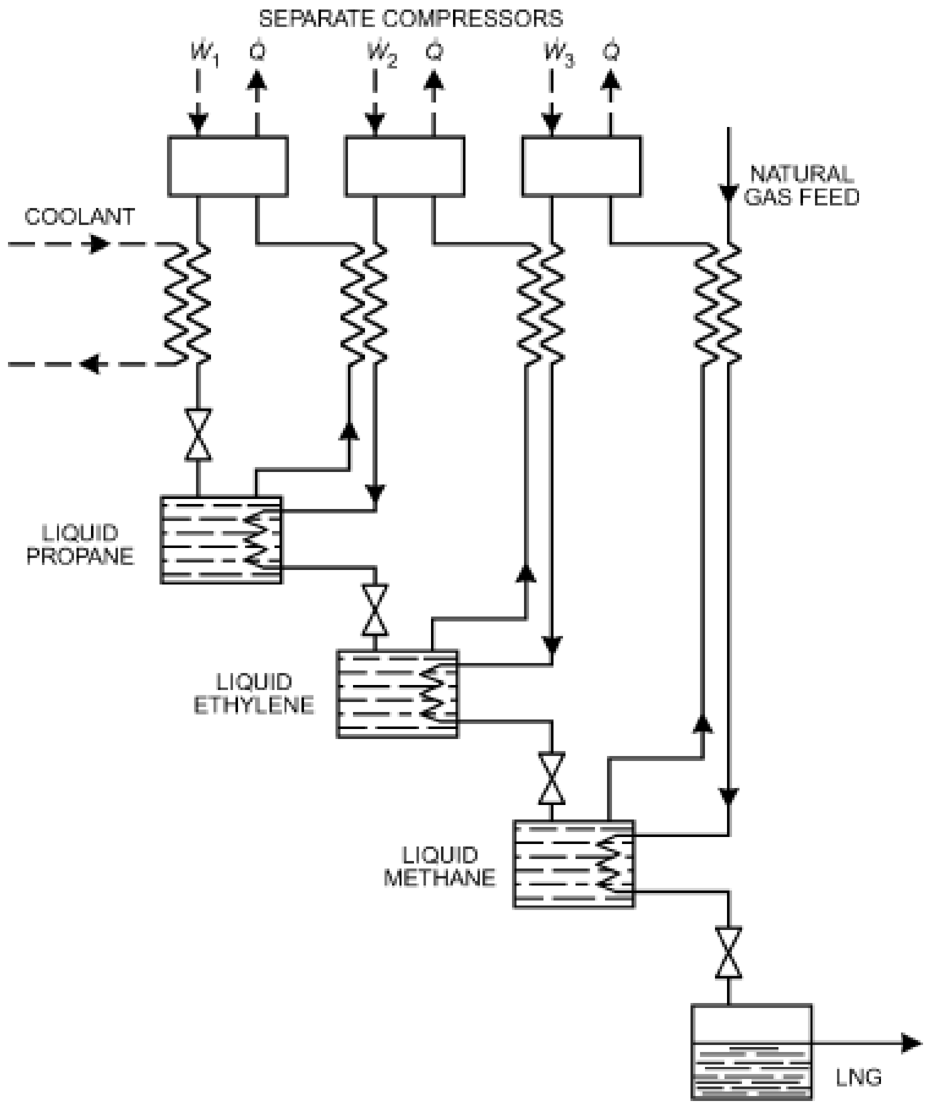
- Hull – accommodation HVAC, LNG, LPG & condensate storage, marine systems such as bilge, ballast and sea-water
- Pre-treatment/separation – turret, de-watering, de-sanding, hydrogen sulphide & carbon dioxide (sour gas) removal, Hg removal, heavy condensate removal
- Cryogenics – liquefaction module, refrigeration system, refrigerant make up, BOG control (end flash), light condensate removal
- Utilities – Power generation, fuel gas system, process sea water, waste water, fire water, blow down, flare, inert gas, nitrogen, air, chemicals, spill mitigation
- Operational – pigging, MEG system including tanks, pumps and filters

FLNG developments – Liquefaction cycles

- Cascade cycle
  - Three step cycle, propane (C_3) to minus 30°C, ethylene (C_2) down to minus 95°C and finally methane (C_1) to liquefy the LNG at around minus 160°C
- Mixed refrigeration cycle
  - Also know as the single mixed refrigeration cycle as all the refrigerants, propane, ethane and methane, forming a single fluid.
- Propane pre-cooling mixed refrigerant cycle
  - Better known under the term C_3-MR
  - Efficients now greater than 90% due to enhanced heat exchanger design
- FLNG liquefaction – Double C_3-MR system (also known as dual mixed refrigerant)
  - Steam turbine driven compressors may also be gas turbine driven

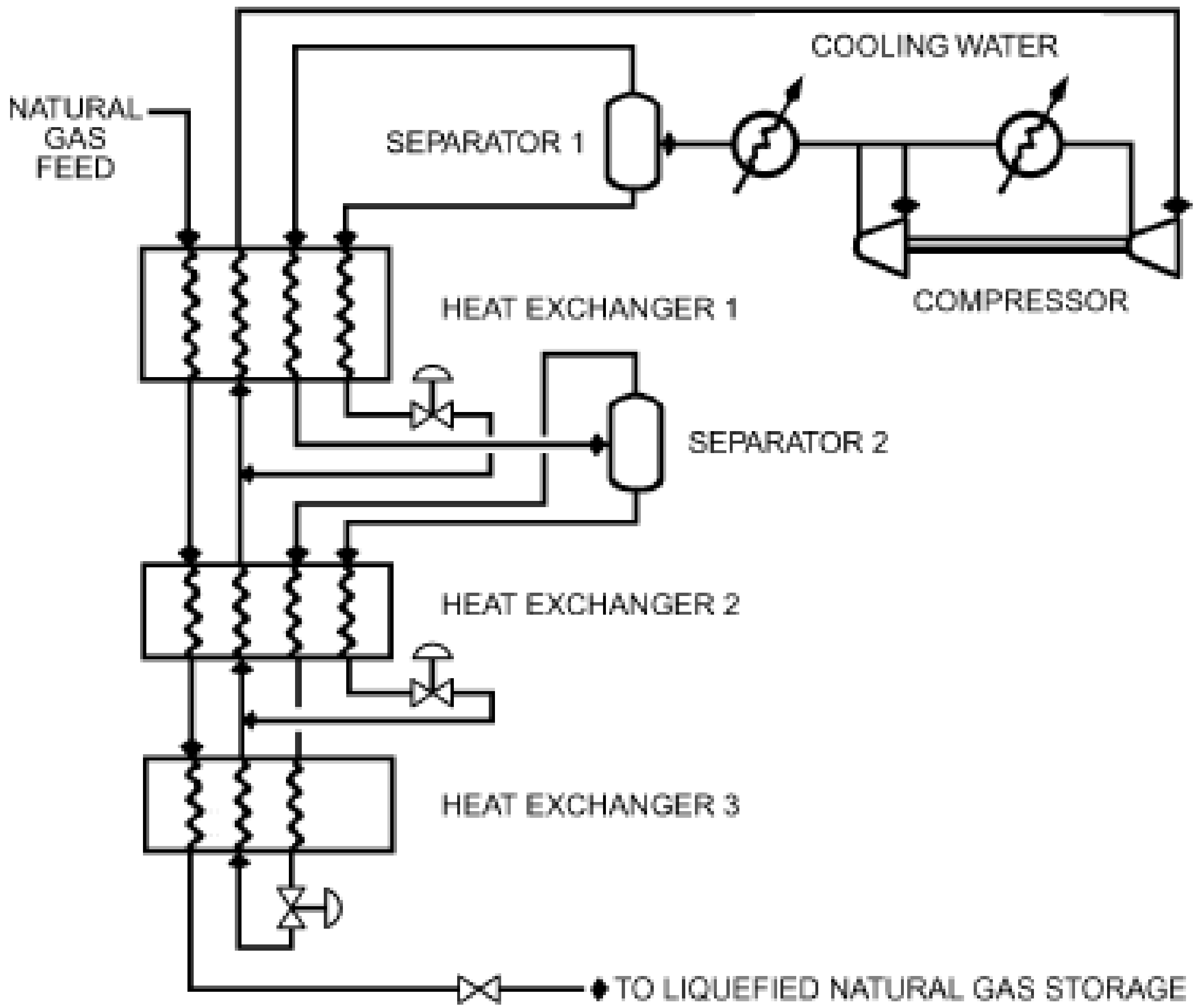
FLNG developments – Simple cascade liquefaction system

- First stage (propane)
  - Sea water cooled
  - Single or multi-stage compressor
- Second stage (ethylene)
  - Screw or centrifugal compressor
- Third stage (methane)
  - Normally refrigerant grade methane
  - Independent of feed gas



FLNG developments – Mixed refrigerant liquefaction system

- Sea water again used as medium to dissipate heat
- Multi-stage intercooled centrifugal compressor
- Circulation of a single mixed refrigerant
- Repeatedly condensed, vaporised, separated and expanded
- Reduced capital cost compared to cascade system



FLNG developments – Offloading

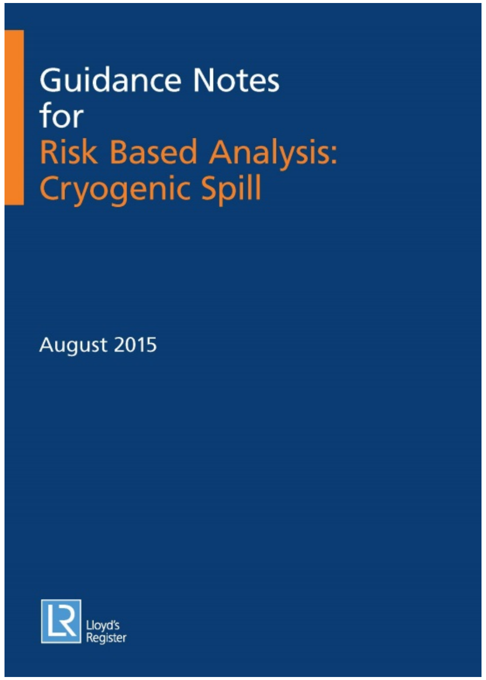
- LNG
  - Side by side
  - Tandem Over-the-stern
  - Remote
- LPG
  - As LNG
- Condensate
  - Hose reels
  - Floating hoses over-the-stern

FLNG developments – Safety aspects - Cryogenics

- For trading gas carriers it is only the manifold locations which needs to be considered:
  - Used periodically when the loading arms being connected, cargo transferred and disconnected when in port (benign) conditions
- For a FLNG
  - There will be constant LNG rundown into the storage tanks
  - The depropanizer, deethanizer and demethanizer process stages as well as the liquefaction modules will be constantly at or near cryogenic temperatures

FLNG developments – Cryogenic spill analysis

- The Lloyd's Register Guidance Note for Risk Bases Analysis: Cryogenic Spill has been developed to provide a consistent methodology to estimate probabilistic cryogenic loads for:
  - Assets - e.g. carbon steel embrittlement, hence potential escalation
  - Personnel - e.g. cryogenic burns, cold vapour inhalation, asphyxiation
- The guidance describes two different approaches, project phase based:
  - **Initial** Cryogenic Risk Analysis (High level)
  - **Advanced** Cryogenic Risk Analysis (Detailed)
- The August 2015 edition is currently available and complements the other Guidance Notes available for:
  - Fire Loading and Protection
  - Collision Analysis
  - Probabilistic Explosion Loads
  - Technology Qualification



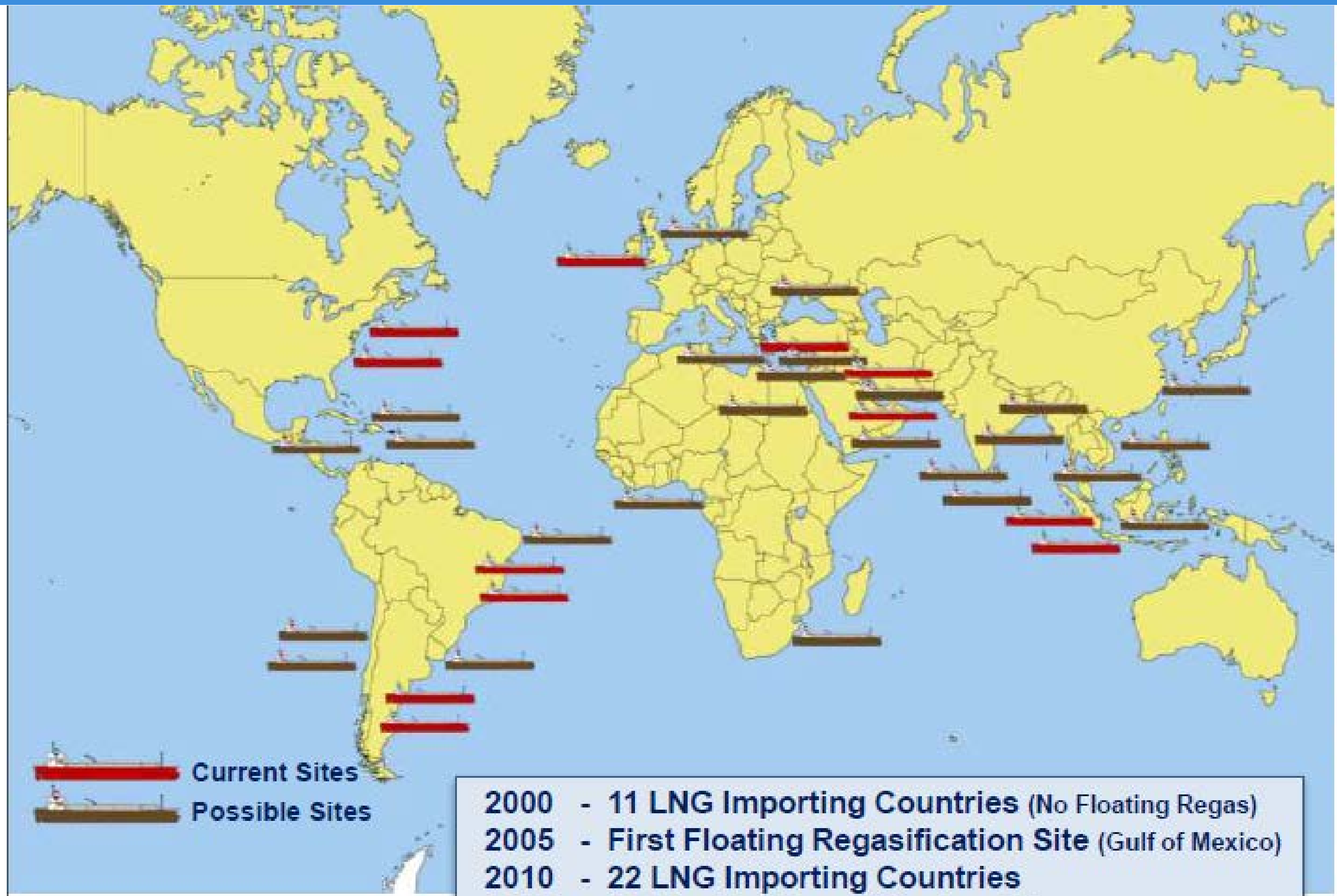
FLNG developments – Safety aspects – Process weighted

- Fire - inventory
- Explosion (blast)
- Smoke
- Fire water
- Flare location
- Radiation effect
- Topside escape
- Temporary refuge
- Lifeboat/liferaft location

FLNG developments – Further information on FLNGs

- http://www.shell.com/about-us/major-projects/prelude-flng.html

FSRU developments – Overview (SIGTTO)



2000 - 11 LNG Importing Countries (No Floating Regas)
2005 - First Floating Regasification Site (Gulf of Mexico)
2010 - 22 LNG Importing Countries
2013 - 12 Floating Regasification Sites
2015 - 40 or More Floating Regasification Sites (Projected)

CURRENT SITES

Argentina (2)
Brazil (2)
UAE (Dubai)
Israel
Indonesia (2)
Kuwait
United Kingdom
United States (2)

POSSIBLE SITES

Bangladesh
Bahrain
Brazil (#3)
Chile (2)
China
Dominican Republic
Egypt
Ghana
India
Indonesia (#3)
Italy
Jamaica
Jordan
Kuwait (#2)
Lebanon
Lithuania
Malaysia
Pakistan
Puerto Rico
South Africa
Sri Lanka
Ukraine
UAE (Abu Dhabi)
Uruguay
Vietnam

FSRU developments – Some existing and proposed new construction

Name of Vessel	Location	Capacity	Built	Storage
				m^3
BW SINGAPORE	Egypt	750 MMSCFD	2015-08	170,000
EXMAR-PM FSRU	India	4.5 mtpa	2016-05	26,320
FSRU TOSCANA	Italy	Peak shaving	2003-12	137,500
GdF Suez Cape Ann	China	750 MMSCFD	2009-09	145,000
GNL DEL PLATA	Uruguay	350 MMSCFD	2016-09	263,000
GOLAR ESKIMO	Jordan	720 MMSCFD	2014-12	160,000
GOLAR FREEZE	Dubai	470 MMSCFD	1977-02	125,000
GOLAR IGLOO	Kuwait	720 MMSCFD	2014-02	170,000
GOLAR SPIRIT	Brasil	240 MMSCFD	1981-09	129,000
GOLAR WINTER	Brasil	490 MMSCFD	2004-03	138,000
HOEGH GALLANT	Egypt	500 MMSCFD	2014-11	170,000
HOEGH GRACE	Colombia		2016-04	170,000
HYUNDAI ULSAN 2552	-	750 MMSCFD	2017-02	170,000
HYUNDAI ULSAN 2854	Russia	500 MMSCFD	2017-10	174,000
HYUNDAI ULSAN 2865	-	750 MMSCFD	2017-12	170,000
NUSANTARA REGAS SATU	Indonesia	480 MMSCFD	1977-07	125,000
PGN FSRU LAMPUNG	Indonesia	360 MMSCFD	2014-04	170,000
SAMSUNG 2118			2016-11	
SAMSUNG 2189			2017-11	

FSRU developments – Where new challenges are arising

- Locations – infrastructure may not be available – river, estuary or jetty based
- Use of existing ships
  - Age and suitability – Moss design very little usable deck area
  - Longevity study required to make conversion feasible
  - Deck loadings for major items of equipment
  - Fire and explosion aspects – jet fires outside normal Marine Rule set
- Regasification plants
  - High pressure liquid pumps
  - Normal heat exchanger type (shell and tube)
  - Submerged combustion vaporiser – peak loads
  - Open rack type vaporiser – base loads

FSRU developments – Existing ship verses dedicated unit

- Some of the major considerations include:
  - Inability to sail away or move easily out of severe weather
  - Reduced environmental loading associated with a fixed possible benign location
  - Service specific fatigue design
  - Constant partial filling and resultant sloshing loads
  - Need for continuous process operation if serving a town main
  - Availability of local dry docks thus access for inspection and repair
  - Additional loads such as; topside equipment, loading arms, helideck, etc.
  - Periodic ship to ship transfer operations using existing manifolds and hoses
  - Suitability of existing deluge and fire water systems

FSRU developments - Regasification system Rule sets

- Requirements included in Part 11, Chapter 20 of the 2015 edition of the Rules and Regulations for the Classification of Offshore Units
- In marine rule set, Provisional Rules for LNG Ships and Barges Equipped with Regasification Systems dated January 2014

FSRU developments – Operational concerns

- LNG loading arms – built to land-based standards
- Oderization (stenching)
- High pressure send-out gas ranging from 75 to 150 bar g
- Open and closed loop heating systems required dependant on location

FSRU developments – Operational concerns

- Use of spray pumps installed the gas carrier's cargo tank
- Use of large capacity cargo pumps
- High pressure liquid
- High pressure vapour
- Process shutdown
- Turndown limits
- Maintenance down time

FLNG & FSRU developments – Maintenance concerns

- Normal periodic dry docking and complete gas freeing not envisaged as an option:
  - Extensions to normal shut down periodicity
  - Sparing philosophies to take into consideration regarding maintenance requirements
  - Consideration to be given to the circulating fluid
  - Corrosion protection system to be enhanced
  - High cost due to send-out shutdown if extensive hot work required
  - Gas freeing of individual tanks under a local 'Permit to Work' system a possible option
  - Retractable cargo pumps so tank entry is not required
  - Method of ship to ship transfer – Loading arms maintenance or replacement hoses
  - RBI (Risk Based Inspection) – For entire unit either FLNG or FSRU

FLNG developments – Questions?

Questions

or

Six minute Shell video

or

Questions & Shell video?

presentation

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