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Research on safety supervision of Tianjin Nanjiang Port Liquefied Natural Gas floating storage and regasification unit

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Dalian, China

Research on Safety Supervision of Tianjin Nanjiang Port Liquefied Natural Gas Floating Storage and Regasification Unit

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Declaration

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

Signature:

Date: July 18, 2013

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Assessor:

Co-assessor:

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Title: **Research on Safety Supervision of Tianjin Nanjiang Port Liquefied Natural Gas Floating Storage and Regasification Unit**

Degree: **MSc**

Abstract

This research paper is a study of safety supervision of the first FSRU operated in Tianjin, China, which is similar to the safety supervision of LNG carrier but with some differences.

A brief look is taken at present LNG shortage of China that causes the increase of LNG demand and rise of LNG transportation. The flourishing LNG transportation market leads the vessels and receiving terminals greatly developed. Then, FSRU appeared and the configuration of FSRU developed gradually.

A detailed description is made on the Tianjin Nanjiang port FSRU, which includes not only the location, status of quays, vessel specifications, but also cargo handling process and cargo related system.

Relevant international conventions, codes and national regulations and technical specifications are listed to and the regulatory requirements of the United States, Japan and Australia are introduced to support the research.

Based on the properties of the LNG and the location of this project, risk of the FSRU is analyzed, and then some recommendations for safety supervision on this FSRU are proposed.

The concluding chapters examine the results of safety supervision of the FSRU, and discuss the potential use of this method on other LNG FSRUs in China in the future.

KEYWORDS: LNG, FSRU, Safety Supervision

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List of Abbreviations

ABS	American Bureau of Shipping
AMSA	Australia Maritime Safety Authority
BOG	Boil off gas
BTT	Boom to Tanker
BV	Bureau Veritas
China MSA	Maritime Safety Administration of China
CNOOC	China National Offshore Oil Corporation
DNV	Det Norske Veritas
EIA	Energy Information Agency
FRU	Floating Regasification Unit
FSRU	Floating Storage and Regasification Unit
GB	Guo Biao (Chinese) named National Standard
GBS	Gravity Based Structure
GTT	Gaztransport & Technigaz Company
HPU	Hydraulic Power Unit
ICS	International Chamber of Shipping
IEA	International Energy Agency
IGC Code	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
IMO	International Maritime Organization
LNG	Liquefied Natural Gas
LR	Lloyd's Register
MARPOL	International Convention for the Prevention of Pollution from Ships, 73 /78
NFPA	National Fire Protection Association
OCIMF	Oil Companies international Marine Forum
PBIT	Platform Based Import Terminal
PetroChina	PetroChina Company Limited
SIGTTO	Society of International Gas Tankers and Terminal Operators Limited

SRV	LNG Shuttle and Regas Vessel
SOLAS	International Convention for the Safety of Life at Sea, 1974
STCW Convention	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
U.S.	The United States
USA	the United States of America
USCG	United States Coast Guard
VTS	Vessel Traffic Service

Chapter 1 Introduction

1.1 Background

The world's energy demand is growing far more rapidly than the energy industry can supply, so alternative resources are being investigated by the energy industry to address the deficit in energy production. (Miller et al, 2004, p.5) LNG is one of the alternatives being explored. China's 12th Five Year Plan maps a path for the use of cleaner energy sources to mitigate the effects of rapidly rising energy demand. It is predicted that natural gas would reach an 8.3% share in the primary energy mix in 2015 from 4% in 2010. (Det Norske Veritas, 2011a). However, China is facing shortage of natural gas resources, as shown in Figure 1.

Figure 1-China Faces LNG Shortage
Source: Poten&Parteners, 2010

In 2010, for the purpose of getting a 20% increase in gas supply to avoid a repeated shortage as in 2009, Beijing's powerful National Development and Reform

Commission urged local companies to boost LNG spot purchases and bring forward new gas projects. CNOOC, PetroChina and Sinopec began to expand LNG deliveries. According to Poten LNGas 2.1, Chinese imports climbed 61% in 2009 and 75% during the first eight months of 2010. (Poten & Parteners, 2010) CNOOC LNG imports in 2012 amounted to 11 million tons. (CNOOC, 2013)

As a significant energy transportation port in north of China, Tianjin will play a key role in LNG imports. On February 29, 2012, CNOOC floating receiving terminal for LNG project in Tianjin was officially launched. This project consists of building two berths, one for docking FSRU, the other for docking LNG carriers which discharge cargoes. LNG-FSRU is functionally equivalent to a movable offshore LNG storage and regasification terminal. LNG delivered by LNG carriers would be stored and regasified on the FSRU. FSRU would be attached to the berth. The widely used approach now is regasified LNG in onshore receiving terminal, and then supply natural gas to the consumer. The main benefit of an FSRU is that it can be constructed within 36 months. Compared with the onshore receiving terminal, FSRU could shorten the construction period of about a year. FSRU can be attractive in that a low investment cost and short schedule is needed, and where there are land constraints.

1.2 Objectives of This Study

Energy market is becoming more competitive. For Tianjin, most of its energy supply relies on import from other provinces, thus it is increasingly urgent to establish a secure and stable energy supply system is increasingly urgent. In the future, Tianjin will expand natural gas imports to meet the requirements LNG consumption growth for economic development. Tianjin FSRU project will help Tianjin to get long-term and stable supply of high quality energy from the international energy market, and gradually establish a LNG reserve system to reduce the price fluctuations impact on

Tianjin energy market. Imported LNG will be used for power generation to ease the contradiction between power supply and consumption.

The present study, based on the relevant international conventions and national regulations and standards, and learning from foreign relevant regulatory experience and analysis the supervisory situation of Tianjin Nanjiang Port, aims to explore safety management strategy for Tianjin Nanjiang Port FSRU and propose measures and recommendations on FSRU management.

1.3 Main Contents of This Study

This thesis consists of six chapters. Chapter 2 introduces the LNG receiving terminals development, type of offshore terminal configurations as well as the development status of FSRU. Chapter 3 describes Tianjin FSRU project particularly on FSRU's profiles. Chapter 4 lists relevant conventions, codes, standards and technical specifications. Chapter 5 is focused on safety management and some recommendations are proposed. Chapter 6 is the conclusion.

Chapter 2 Introduction to FSRU

2.1 LNG Demand and Development of Receiving Terminals of the World

The long-term outlook for LNG is bright and the market fundamentals are strong. The global economic downturn has hit demand for energy of all types and from all quarters. At the same time, the world's capacity to produce LNG is surging. (Blackwell, 2009) According to the U.S. Energy Information Agency (EIA), worldwide natural gas demand grew by 57 Bcf/d from 2000 to 2007, nearly 25%. The EIA also predicts global natural gas demand to grow over 40 Bcf/d by the year 2015, and projects a further growth in demand of over 50 Bcf/d by 2025. (http://www.cheniere.com/lng_industry/Changing%20Outlook%20for%20LNG.pdf) Moreover, International Energy Agency (IEA) forecasts that world's liquefaction capacity will increase fivefold by 2030, as shown in Figure 2. (Kumar et al, 2011)

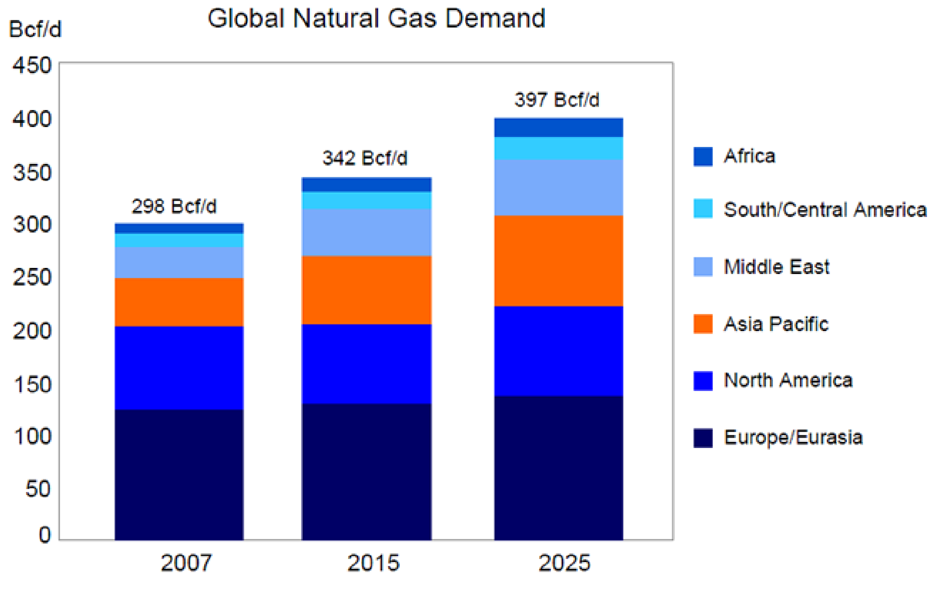

Figure 2-Global Natural Gas Demand
Source: Changing Outlook for LNG: *Global Natural Gas Demand*

For countries that lack indigenous natural gas resources and delivery infrastructure, LNG represents a rapid and cost-effective means of introducing natural gas into their local fuel mix. Currently there are 25 LNG-importing countries in Europe, Asia, South America, Central America, North America and the Middle East, up from 17 importing countries in 2007. Numerous developing countries, including Poland, Croatia, Bangladesh, Jamaica, Colombia, Panama, El Salvador, Costa Rica and Lebanon, among others, are considering plans to build new LNG terminals and enter the global LNG trade. (Changing Outlook for LNG: *Global Natural Gas Demand*) Most of the increase in liquefaction capacity is in the Middle East and Australia, where a large number of new liquefaction projects are expected to be developed, many of which will become operational within the next decade. Consumption of liquefaction capacity is expected to remain high during the entire projection period. All these activities underline that investors and developers have real confidence that the LNG market is going to grow continuously. (Kumar et al, 2011) The Major LNG exporting and importing countries are shown in Figure 3.

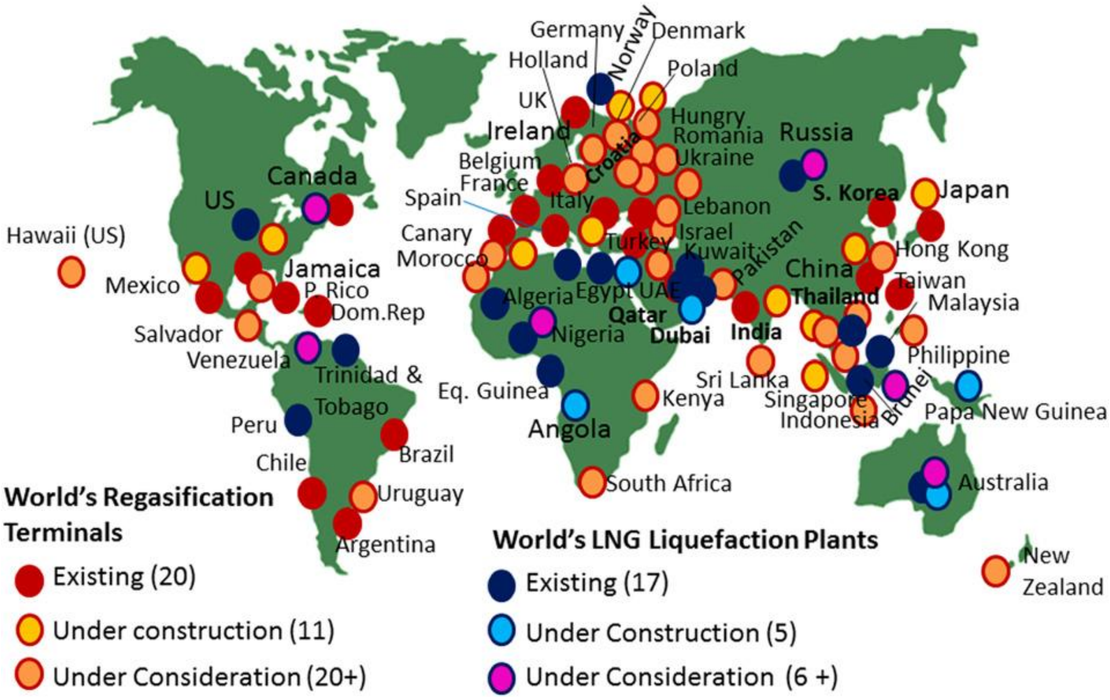

Figure 3-World's major LNG exporting and importing countries
Source: BG Group

In November 2000, the British magazine—*Offshore Engineer* reported that the Italian classification society conducted a study on FSRU and concluded that FSRU is economical and feasible. The study also indicated that there are many advantages on FSUR compared with conventional onshore terminals, especially for environmentally sensitive areas or densely populated areas. In April 2005, Excelerate announced that the world's first offshore LNG receiving gasification unit finished commissioning, and started commercial operations, which opened the prelude of FSRU development.

2.2 Type of Offshore LNG Receiving Terminals

In terms of the location of LNG receiving terminal, LNG receiving terminals can be divided into two categories. One is the onshore terminal, namely the traditional LNG terminal; the other is offshore LNG receiving terminal. Offshore terminals can be classified into the following categories:

- Floating Storage and Regasification Unit (FSRU);
- Floating Regasification Unit (FRU);
- LNG Shuttle and Regas Vessel (SRV);
- Gravity Based Structure (GBS);
- Platform Based Import Terminal (PBIT).

An FSRU is a semi-permanent floating offshore LNG-receiving terminal that allows offshore discharge of traditional LNG carriers, either through conversion of an existing LNG carrier or by using a new building. LNG is pumped from the tanks and sent to regasification units mounted on the deck of the FSRU.

FRU is a floating regasification unit, generally associated with underground gas storage. Compared with the FSRU, FRU has no function of storage. It is a LNG carrier with gasification facility, ant transfers LNG ashore through submarine pipelines. Currently, FSRU is the main mode of a floating terminal.

SRV is an alternative FSRU and similar to FRU. The SRV is an LNG vessel with on-board LNG vaporisers, and having the ability to connect to an underwater bouy system for discharging the vaporized LNG directly into a pipeline system.

A GBS is a concrete structure with various tanks inside. It not only contains the LNG storage but also acts as unloading berth, partial breakwater and the platform for the regas plant. (Sullivan & Maynard, 2005, p.3) It has been applied in the United Kingdom, Mexico, the United States, Canada, Australia, and other countries, but the cost is much higher than FSRU, FRU and SRV.

A PBIT uses platform structures which have been built or converted to receive LNG. The platform cannot withstand the load of LNG carrier and needs mooring with decentralized anchors or other flexible berths. It can be used in conjunction with large onshore underground gas storages.

2.3 Type of Offshore Terminal Configurations

For FSRU, there are two ways of construction. One is the newbuilding, and the other is conversion of existing LNG carriers. Major types of LNG containment systems utilized for LNG storage offshore are described in Figure 4.

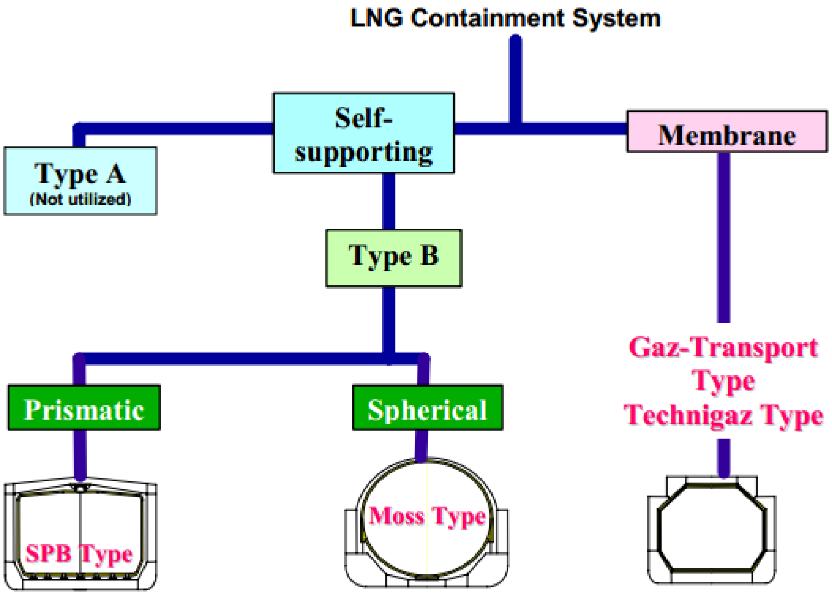

Figure 4-Types of LNG Containment Systems Utilized in Various Offshore Vessels
Source: Pepper & Shah, 2004

As Pepper and Shah (2004, p.3) stated:

> There are two main options for LNG containment systems, described in Lloyds Register energy and transportation, which are suitable for the LNG carriage. One is self-supporting Type B, and the other one is membrane tank system. Within option 1, there are two approved systems and they are Moss spherical tank system and IHI Self-supporting Prismatic Type B tank system (IHI-SPB). Option 2 is the Gas Transport & Technigaz membrane tank system. These configurations are generally considered for LNG storage in various offshore based terminal configurations.

Membrane tanks are non-self supported cargo tanks surrounded by a complete double hull ship structure. Membrane tank system is a breakthrough of LNG carrier technology, which draws a new concept of ship design and construction concept into ship industry. The membrane tanks consist of a cryogenic liner composed of primary and secondary membranes, as shown in Figure 5. The membrane is designed in such a way that thermal and other expansion or contraction is compensated for without undue stressing of the membrane.(DNV, 2011b) Membrane LNG Containment System based on membrane shield (thickness is 0.7~1.5mm) material. This material is adhered to the insulating layer, which is fixed within shell plating of the ship by bolt structures. The insulating layer of tanks is non-self-supporting, and the weight of liquid cargo acts on ship's structure through the insulating material.

Figure 5-Generic Membrane Tank
Source: DNV, 2011b

The Spherical cargo tanks ("Moss-type") consist of a primary barrier of aluminium. An insulation system outside the aluminium barrier is installed and a drip tray under the centre of the tank forms the reduced secondary barrier. (DNV, 2011b) A small amount of liquid cargo leakage can be collected in the drip tray, which to prevent structural damage to the ship. There is a cargo pump tower which is a cylindrical construction in the centre of the tank. The key elements of a MOSS spherical LNG tanks is shown in Figure 6.

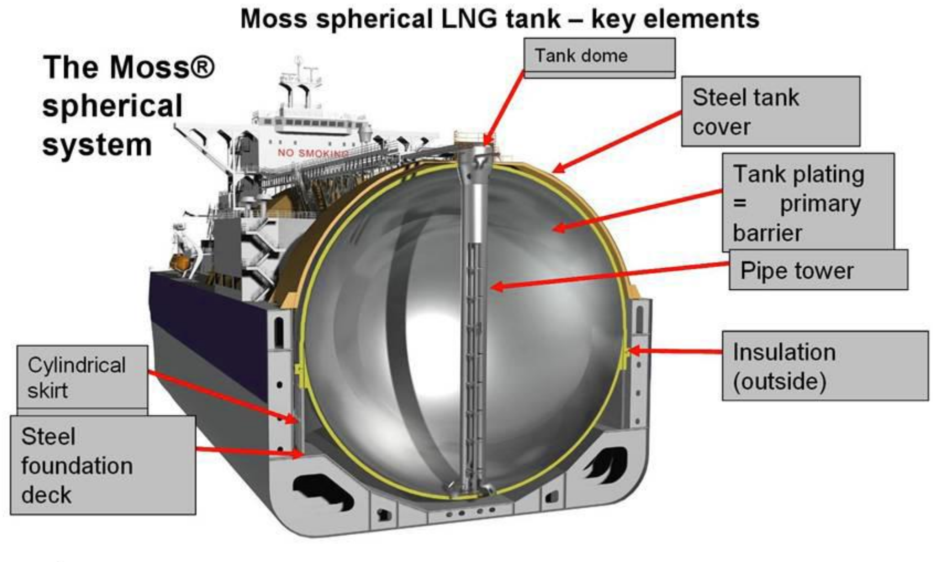

Figure 6-Spherical Tank – Courtesy Moss Maritime
Source: DNV, 2011b

IGC Code (1983) states that "Independent tanks are self supporting and they do not form part of the ship's hull and are not essential to the hull strength". This type of tanks is referred to as type B tanks. This type of tanks so far has a good safety record because of its good-design. Carriers have never been stopped operation due to deficiency and damage of tanks. The good shape of Moss spherical tanks is convenient for thermal analysis and calculation. Calculations results show that, in whatever state of the environment, it is unlikely to cause tank rupture resulting in disastrous consequences.

Prismatic tanks containment system is similar to the spherical tanks, but they differ in shape. The prismatic B-tank is built up of a single primary barrier, typically of aluminium or stainless steel or 9% nickel steel. The internal structure consists of typical ship hull structural elements in a plate—stiffener—girder system (DNV, 2011b), as shown in Figure 7.

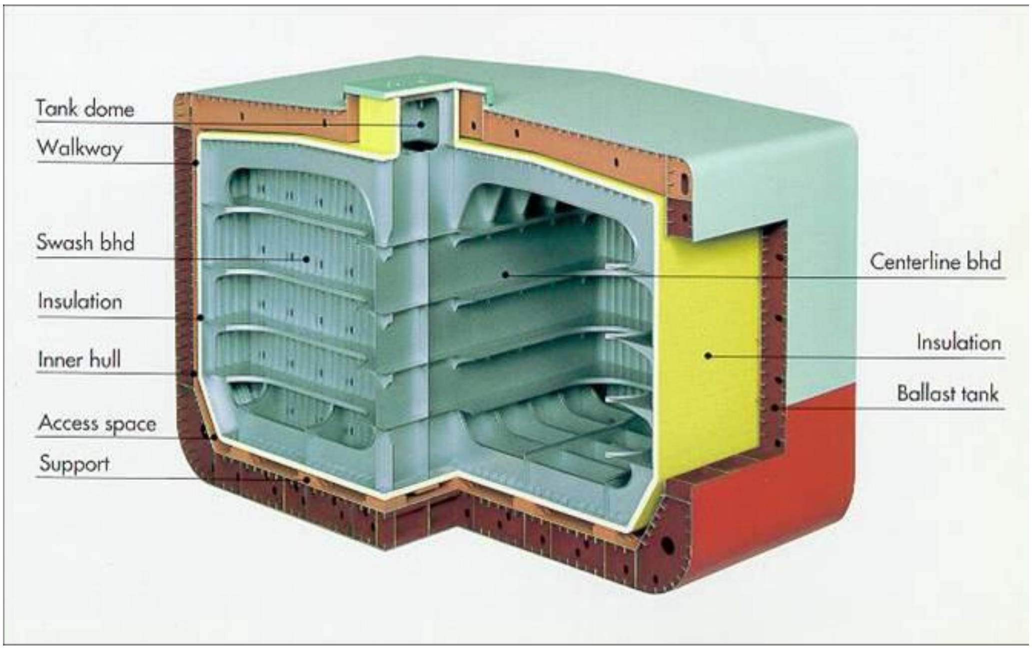

Figure 7-Prismatic Tank Construction – Courtesy of IHI Marine United Inc
Source: DNV, 2011b

The primary barrier is surrounded by an insulation system and drip trays (forming a partial secondary barrier) located near the cargo tank supports. (DNV, 2011b) Compared with the spherical tanks, the biggest advantage of prismatic tanks is the high space utilization of cargo hold. Using inner clapboards can prevent splashing liquid cargo from damaging the bulkhead. The prismatic tank has a cooling rate of -6℃/h, which is similar to spherical tanks.

Each configuration has its own advantages. However, Blackwell (2009) states that:

> There is no single overwhelming factor affecting which kind of LNG carrier makes the best FSRU. Indeed, availability and cost have to be prime considerations when seeking a candidate vessel. The technical community tends to favour older Moss tank vessels, especially if the intention is to moor the FSRU permanently. Moss tanks have a strong reputation for structural integrity and longevity. Additionally, an older vessel is likely to have been

more conservatively designed and hence will be more robust, so providing an easier foundation for major engineering modifications. A more modern membrane tank vessel, however, which will probably have a more efficient propulsion system, may be more attractive if the intention is to continue using the vessel to trade LNG.

2.4 Development of FSRU

FSRU provides a striking contrast with this traditional, complex LNG business model. From the research of Golar, interest in FSRU of LNG is being sustained even during the current economic downturn. The marked areas in the Figure 8 are where most of the potential enquiries to Golar. (Blackwell，2009)

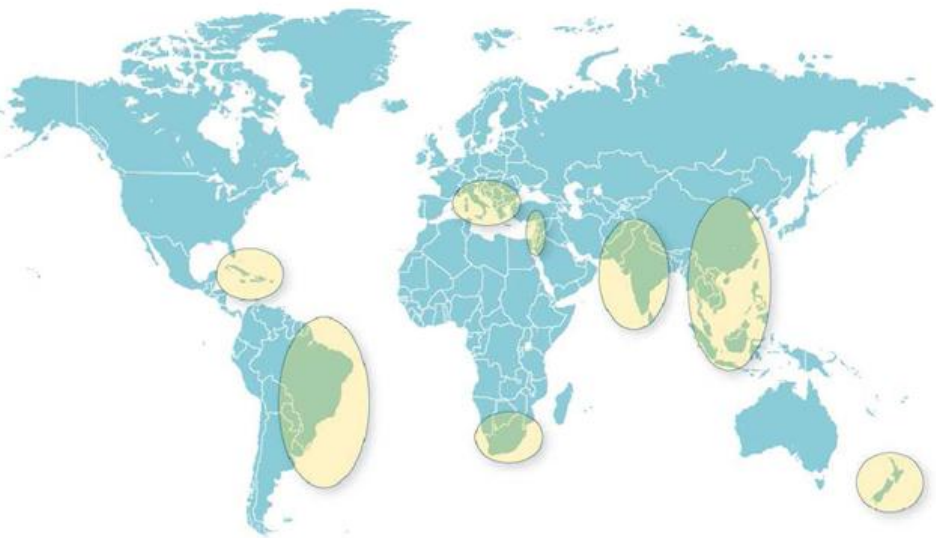

Figure 8-Interest in the Concept

Source: Blackwell, 2009

Since the first floating regas project delivered in 2004, the market has grown to 10 projects in operation and is expected to double by 2015. (Golar LNG, 2012) As can be seen from Figure 9, the green star denoted contracted and operational FSRU project, and the orange star denoted the committed and/or contracted.

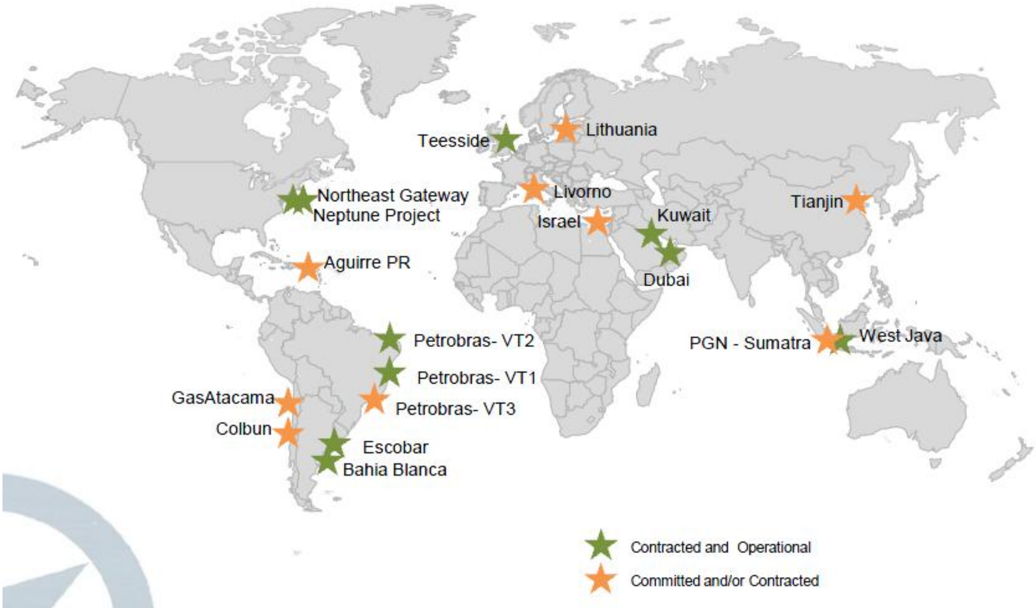

Figure 9-World FSRU Projects
Source: Golar LNG, 2012

As it can be seen from Figure 10, it is apparent that the number of floating regasification shows remarkable growth in the recent years. With the fast-growing of the LNG, the number of FSRU will increase gradually. Newbuilding FSRUs are now the preferred unit of choice over conversions of existing LNG carriers. FSRU Owner/Operators have responded to projected market growth with particular focus on FSRU newbuildings.

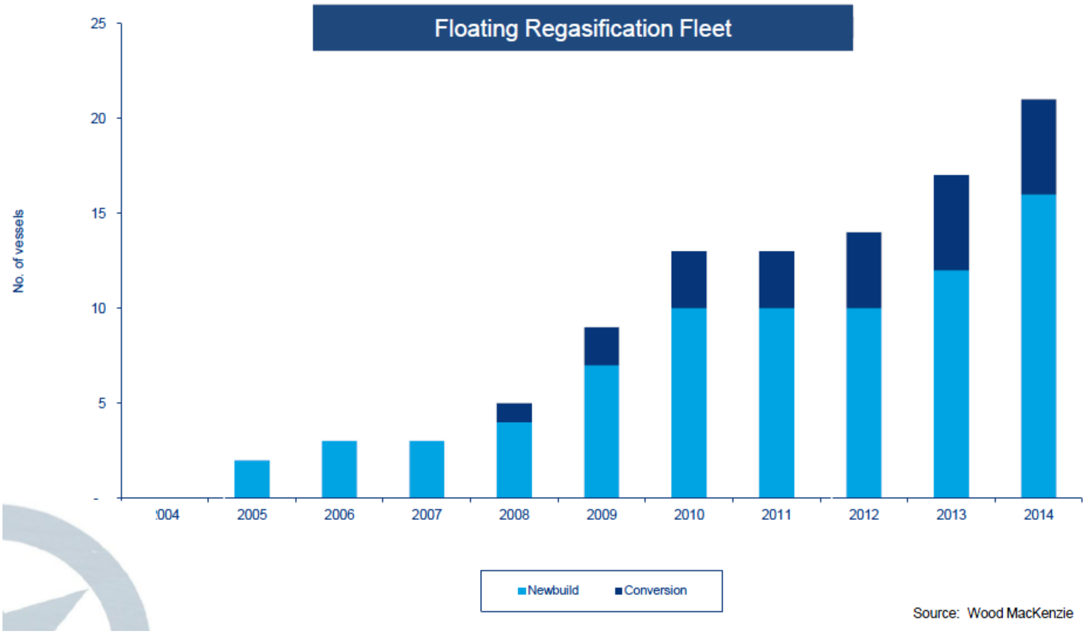

Figure 10-Floating Regasification Fleet
Source: Golar LNG, 2012

After 10 years of research and development, FSRU technology has become more mature. Currently, there are mainly three international companies which run FSRU business.

(1) Golar LNG Energy

This company formed in June 2009, who is headquartered in London. The controlling shareholder of this company is Golar LNG, which holds 68% of the shares. Golar LNG Energy was split from Golar LNG and established based on reserving all long-term Golar LNG contracts. It is committed to provide efficient and economical investment and operational programs for the LNG midstream industry. The company now has 3 conversion regasification vessels, serving for Brazil and Dubai floating LNG project respectively, and another one is under construction, which plans to serve for floating LNG project in Indonesia.

(2) Excelerate Energy

Excelerate Energy was established in July 2003 and headquartered in Woodlands, USA. It is a specialized provider in providing floating LNG regasification services, and has developed rapidly since the establishment. In recent years, as the global demand for LNG market expanded rapidly, it has become an authoritative company for providing floating regasification solutions. Particularly, it has extensive experience and industry-leading level in the LNG ship-to-ship discharging operations. This company operates eight LNG regasification vessels which are all newbuildings with vessel age less than 5 years.

(3) GDF Suez & Hoegh LNG

GDF Suez is an integrated energy company engaged in the field of natural gas development, power generation, energy trading and services, public facilities management, environmental protection, headquartered in Paris, France. Its LNG import volume is first in Europe and third in the world. Hoegh LNG is a professional private provider providing for floating offshore LNG transportation and regasification services, which was founded in the 1970s and headquartered in Oslo, Norway. It has over 30 years of operational management experience in the field of LNG transportation. GDF Suez operates two LNG regasification vessels through long-term leases. The two vessels are “GDF Suez Neptune” and “GDF Sue Cape Ann”. Both are newbuilding floating units, whose owner is the Hoegh LNG.

Chapter 3 Tianjin Nanjiang Port FSRU Project Descriptions

3.1 Basic conditions of Tianjin Nanjiang Port

3.1.1 Natural Conditions

Annual average temperature of Tianjin Nanjiang Port is 13.1℃, and the average annual precipitation is 363.7mm. Precipitation in this area shows a significant seasonal variation, the rainfall is concentrated in July and August. South wind is common in this area. Cold wind is more frequent, and the frequency of typhoon (including tropical storm) is small. Average wind speed over the years in this area is 4.5m/s, and the maximum wind speed is 26.5m/s. Fog usually occurs in autumn and winter of every year. Annual average relative humidity is 67%. Thunderstorms, lightning mostly occur in summer. Perennial glacial period of Bohai Bay is about 3 months. In early 2010, ice appeared in a large area, 45% of the waters are ice-covered, and the maximum ice thickness exceeding 30cm.

3.1.2 Status of Quay

The quay of this project is located at the southeast of Tianjin Nanjiang Port, north of Dagusha fairways. It is approximately 18km away from the Haihe River estuary lock. Location of this project is shown in Figure 11.

Figure 11-Location of This Project
Source: Retrieved May 24, 2013 from the World Wide Web: https://maps.google.com/ and marked by the author

The project consists of two newbuilding berths: one for FSRU docking, and the other for LNG carrier docking. Quay line is 70m away from the south breakwater axis; pier and the land are connection with bridge approach. The length of each berth is 400m. In addition, a new quay for 3000t bulk carriers will be built, with a quay length of 140m. The first stage of this project mainly uses FSRU for LNG loading and discharging, and the designed annual throughput is 2.2 million tons. The second stage of this project will use conventional large-scale onshore terminals, the annual throughput 600 million tons. Figure 12 describes the project renderings.

Figure 12-Project Renderings
Source: Provided by CNOOC

3.2 FSRU Profiles

3.2.1 Vessel Specifications

The target FSRU of the project is originally a LNG RV named "GDF SUEZ Cape Ann" which is a LNG carrier with self-propelled and offshore single point fixed mooring capacity. The vessel will serve the Tianjin project as the first FSRU in China under a sub-charter between GDF SUEZ and China National Offshore Oil Corporation Gas & Power Ltd. It is scheduled for commissioning in Tianjin in October 2013, followed by commercial operations thereafter. Figure 13 shows the GDF Suez Cape Ann.

Figure 13-GDF SUEZ Cape Ann
Source: Retrieved Aprial 24, 2013 from the World Wide Web:
http://www.hoeghlng.com/shipping/fleet/Pages/GDF-Suez-Cape-Ann.aspx

The SRV is the considered FSRU of this project, whose main characteristics are provided in Table 1, classified by Det Norske Veritas (DNV). The age of this vessel is 1 year.

Table 1-FSRU's Main Characteristics

Dimension	Length Overall (m)	283.06
	Breadth (m)	43.4
	Depth (m)	26.0
	Scantling Draught (m)	12.4
	Designed Draft (m)	11.4
	Displacement (t)	112,457
LNG Storage Capacity ($m^{3)}$	145, 146	
Regasification Rate (t/h)	630	
Transfer Pressure (MPa)	7.5	

Source: Compiled by the author based on the data provided by CNOOC

The FSRU is achieved by means of four tanks, through GTT's MK-III membrane containment system. Regasification plant located at No.1 cargo deck. This FSRU is equipped with mooring system, two bow thrusters, one stern thruster and positioning control system. It can position and connect mooring buoys automatically at sea. The unit was conceived with 145,146 m^3 LNG storage capacity with a filling ratio of 98.5%, and the storage temperature is -163℃.

3.2.2 Manifold Arrangement

The manifold of this FSRU has 5 interfaces, including four liquid-phases and a vapor-phase. The vapor-phase is arranged in the middle with two liquid-phases on the left and two on the right. Manifold arrangement confirms OCIMF standards. The centerline of manifold is 140.93m away from the bow, and the distance between the stern and the centerline of manifold is 142.13m. The spacing between the interface manifold is 3.0m. The spacing of discharging arms on dock should be consistent with the spacing of manifold interfaces. The height of manifold centerline to the main deck is 4.8m. Manifold arrangement is shown in Figure 14.

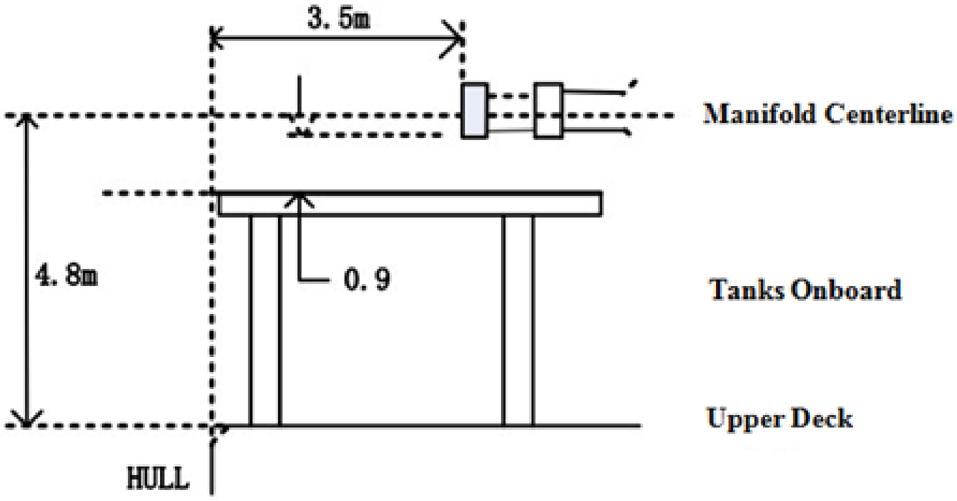

Figure 14-Manifold Arrangement
Source: Provided by CNOOC

3.2.3 Equipment Layout

This FSRU has a lower continuous rear upper deck, an inclined stem with bulbous bow, and a square stern as well as a semi-balanced rudder. Propulsion machinery and the accommodation are located at the rear of the vessel. There are channels at both port and starboard, which across the whole length of the cargo area. These channels are also used as pipes and cable channels. Cargo hold area and the engine room area is constructed double bottom. A cargo control room, a management office and a meeting room is located below the bridge in superstructure. Engines, boilers, generators and emergency diesel generators are in the aft engine compartment. Four LNG storage tanks are arranged in front of the engine compartment. Each tank is equipped with two low pressure pumps that are hydraulic submersible pumps, which are located in the pump wells at the bottom of the storage tanks. In addition, there are ballast tanks, fresh water storage tanks, diesel storage tanks and so on. Cranes equipped on deck is used for ship materials supply. Loading and unloading system is arranged amidships, and the interfaces of loading and unloading manifold are set in both port and starboard respectively. Regasification plant which can receive LNG and transport gas external located at the bow deck.

3.2.4 Safe Manning and Staff

According to information provided by the CNOOC, the FSRU as a vessel should be manned as shown in Table 2. There should be 25 crew members onboard. The ship manning meets the requirements of "minimum safe manning of ships rules of China". In order to manage and operate the FSRU efficiently and safely, Tianjin LNG FSRU preparatory group of CNOOC intends to set up positions as shown in Table 3. There should be 40 staff working for this project.

Table 2-Crew Manning of the FSRU

Captain	1
Chief Officer	1
Second Officer	2
Third Officer	2
Chief Engineer	1
Cargo Engineer	2
Second Engineer	1
Third Engineer	2
Electrical Engineer	1
Bosun	1
Able-bodied Seaman	3
Ordinary Seaman	2
Master Mechanic	2
Chief Cook	1
Assistant Cook	1
Waiter	2
Total	25

Source: Compiled by the author based on the data provided by CNOOC

Table 3-Positions of the FSRU

Positions	**Number of Positions**	**Number of the Staffs**
Manager	1	1
Deputy Manager	1	1
Mechanic	5	15
Technologist	4	12
Electrical and Instrument Control	4	4
Health Safety and Executive	2	5
Maintenance	2	2
Total	19	40

Source: Compiled by the author based on the data provided by CNOOC

3.3 Technical Process of FSRU

FSRU which moored offshore terminals need to be installed with necessary pressurized, gasification equipment and all necessary public system (including power system). LNG from the LNG carriers transported to FSRU storage unit through discharge arms, being taken into the LNG vaporizer after pumps in tank and high-pressure pump boosted. Gasification gas, after meeting the requirements of pressure and temperature and being metered, will be delivered to the gas pipelines on dock through high-pressure gas transmission arm. Boil off gas (BOG) generated in storage tank due to external heat will be pressurized the by BOG compressor, then preheated by the heater and transferred into the steam boiler burning as fuel. The steam produced by the boiler passes through the ethylene glycol solution/steam heat exchanger, transferring heat to the ethylene glycol solution, and then cooled to condense into water. Water will return to steam boiler tank, while the heated ethylene glycol solution will enter into the main LNG vaporizer as a heat medium for the LNG vaporization. General technical process of FSRU is shown in Figure 15.

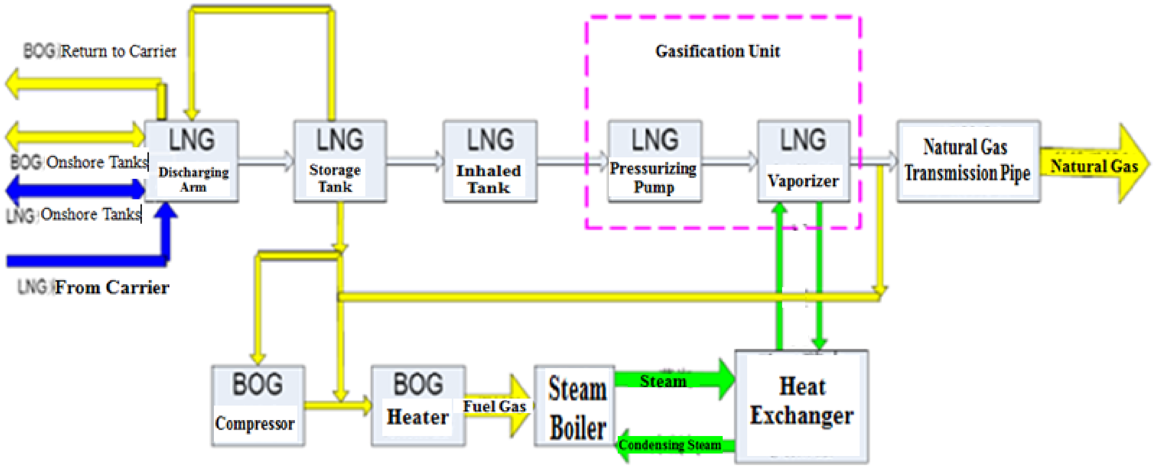

Figure 15-Technical Process of FSRU

Source: Provided by CNOOC and marked by the author

In addition, FSRU also provides liquid LNG for storage tanks onshore. In this case, LNG being pressurized will directly pass through the low pressure manifold, discharging arms and onshore LNG pipeline into storage tank onshore. During normal operation, tanks of FSRU maintain a lower pressure; as large amount of LNG is offloading, pressure in storage tanks may be negative. A high-pressure gas return line should be led from the gasification plant, and through a pressure regulator, the high pressure gas enter into the LNG storage tanks to maintain a positive pressure. If BOG from storage tanks is insufficient to supply the boiler, force vaporizer shall be started, which would gasify LNG in tanks. After being heated, this gas will supply for the boiler to meet the power demand of the FSRU.

3.4 Cargo Handling Process

After the LNG carrier berthed and connected with the discharging arms, LNG will be transferred by pumps in carrier to discharging arm, and then pass through branch pipes to the mains. A major part of the LNG is delivered to the FSRU through the loading arms; another small portion of LNG is delivered to the tanks of receiving station. Loading and unloading process is shown in Figure 16.

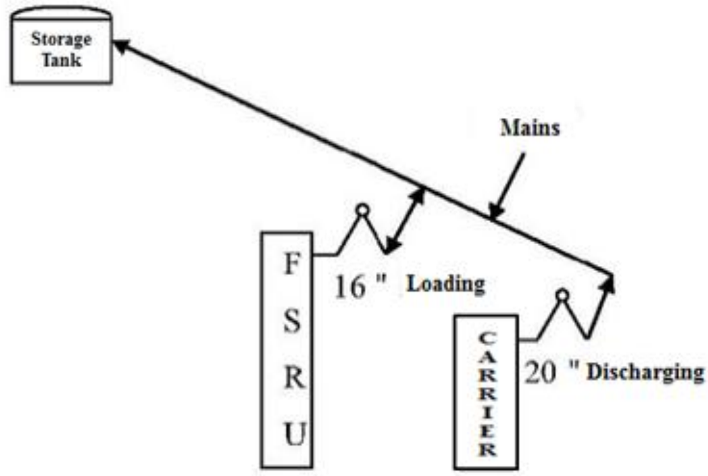

Figure 16-Cargo Handling Process
Source: Provided by CNOOC and marked by the author

Specific unloading steps are as follows:

- Pre-cooling the connecting lines before unloading;
- Connecting the LNG unloading arms, vapor return arms with terminal transmission pipes, and connecting FSRU loading arms with terminal transmission pipes;
- Opening the discharging valve and the FSRU loading valve, cooling FSRU loading arms and LNG carrier unloading arms gradually;
- LNG carrier discharges cargoes to the FSRU and onshore storage tanks simultaneously;
- After finishing unloading, close the discharge valve and the FSRU loading valve, then start cold circulation pumps in onshore tanks, and LNG into the discharge mains start cold cycle;
- Purge remnants of LNG in unloading arms to LNG carriers and remnants of LNG in FSRU loading arms to FSRU with nitrogen;
- Disconnect the discharging arms and vapor return arms with LNG carrier.

There are four FSRU's loading arms with 16" diameter, three of which for liquid transmission and one for vapor return. Four discharging arms with 20" diameter, three of them for liquid transmission and one for vapor return, transmission capacity are 6600m^3/h, 19800m^3/h. For conventional LNG carriers with loading capacity of 130000~145000m^3, discharging time will be within 16 hours at normal conditions. Even if one discharging arm fails to work, two unloading arms will be used and unloading operations will be finished within 20 hours. If the vapor return arm fails to use, one liquid discharging arm will be used for vapor return.

It is essential to mentioned that LNG is loaded from LNG shuttle tankers into FSRU via the BTT (Boom to Tanker) LNG transfer system. The fundamental requirements for BTT system are to work in cryogenic operative conditions and to compensate the relative motions between the FSRU and the LNG shuttle tanker. The BBT is mainly composed of the boom, the double pantograph system and the automatic control system. The boom is able to slew around the king compost to compensate for relative angular motions in the horizontal plane (±70°) of the two floaters. The function of the double pantograph system is to compensate for relative wave frequency motions. The automatic control system monitors the relative position of the two vessels and controls the emergency procedures. (Dogliani, 2002)

3.5 Cargo Related Systems of Tianjin Nanjiang Port FSRU

3.5.1 Unloading System

LNG in the mains onshore enters FSRU tanks through loading arms, and each tank connects corresponding loading arms by a cryogenic pipeline. Meanwhile, the outlet of low-pressure pumps in FSRU tanks is connected with the mains onshore to transport LNG to onshore storage tanks. LNG carrier unloading and FSRU LNG offloading cannot work simultaneously, which need to be controlled by the valve switch. Loading and discharging arms onshore are all rigid. Unloading arms with safe break away couplings make the unloading arms to be detached in emergency when it is beyond its work scope due to ship motion. The emergency detachment process of unloading arms is automatically controlled. Position monitor signal is transmitted to unloading arms control panel in control room through a hard-wire, which triggers the corresponding shutdown action. Remote manual disconnection can be carried out by control system. Connection between unloading arms and LNG carrier can be achieved by remote control unloading arms. Power of unloading arms operation is supplied by a hydraulic power unit (HPU) on the dock.

3.5.2 Storage System

Tanks of the FSRU are MK-III membrane tanks. Their maximum daily evaporation rate is about 0.16%, and their designed life span is 40 years. According to the requirements of Gaztransport & Technigaz (GTT) Company which is specialized in the field of LNG membrane containment systems, in addition to the tank bottom, the remainder of the tank is strengthened structure, which improves pressure resistance level of tanks at a large degree. But when the FSRU is in operation at sea, there are level and capacity limitations. The liquid level cannot be at 10% to 70% of tank height. Tanks maximum design pressure is 25KPa and minimum design pressure is -1KPa. Designed cargo loading density is not greater than 500kg/m^3 to ensure daily evaporation rate is not higher than 0.16%.

FSRU is equipped with four emergency cargo pumps/high pressure supply pumps. Each has a flow rate of 550m^3/h, and pump head is 145mLC. The pumps have two purposes. One is used as emergency alternatives when the tube low-pressure pumps fail; the other is used to provide LNG for gasification facility. The main purpose of these pumps in this FSRU is the latter.

Each tank is installed with one LNG supply pump. In order to meet the requirements of flow rate for gasification, when the vaporization facility running at full capacity, three supply pumps should be started; when the vaporization system is running at a minimum load, one supply pump should be started.

In addition, No. 3 and No. 4 tanks each are equipped with a fuel gas supply pump. When BOG is insufficient for combustion, this pump will pressurize and transport LNG to the fuel gas vaporizer, and then supply for the internal combustion engine or gas fuel boilers. Each fuel supply pump's flow rate is $40m^3/h$ and pump head 215mLC.

3.5.3 Vaporization System

The vaporization system is located at the bow deck, which consists of three gasification units. These three vaporization units are each independently and can be disassembled for transportation when it is maintained or overhauled. Each vaporization unit is composed by LNG high-pressure pumps, a vaporizer, high-pressure pump suction buffer tanks, heating water circulation pumps, sea water heater and associated valves, piping and instruments. Six high pressure pumps are used for normal vaporization and export. Each high-pressure pump has a capacity of 105t/h, the inlet pressure is 5bar and the outlet pressure is up to 120bar. LNG is injected to suction pump buffer tank by the high-pressure pump of gasification facility, and then pressurized by the high pressure pumps and enter the vaporizer. The high pressure pump is installed in the pump cylinder, which is mounted on steel supports along with the vaporizer. The modular design of the gasification skid should meet the requirements of stress on deck structure. Specific arrangement should meet the requirements of explosion levels and safety analysis.

The high-pressure suction buffer tank, as gas liquid separation tank, receives BOG generated by the following procedure:

● BOG generated by the buffer tank absorbing ambient heat;

● BOG generated when the high pressure pump standby;

● BOG generated during reflow process when high-pressure pump is started.

During receiving the BOG, pressure of the buffer tank is controlled by the pressure control valve. When the pressure increases, the relief valve is opened and BOG will return to the BOG main of FSRU.

The FSRU in this project can only regasify LNG through a system of closed-loop mode. The vaporizers would use glycol/water solution as a medium to warm the LNG and convert it to natural gas. Boil-off gas heats glycol/water solution and then returns to the steam boiler after circulation, while the heated glycol/water solution as a heat medium is used for LNG vaporization. This method can avoid the danger of hydrocarbon gases entering the boiler water system due to LNG vaporizer internal leakage. It is generally used when the seawater quality is poor or seawater temperature is low. Tianjin FSRU project is located in Bohai Sea, the sea water quality is poor, and the seawater temperature in winter is about 0℃, which cannot meet the temperature requirements of the vaporizer inlet. Therefore, the closed-loop mode should be chosen. Specific gasification process is shown in Figure 17.

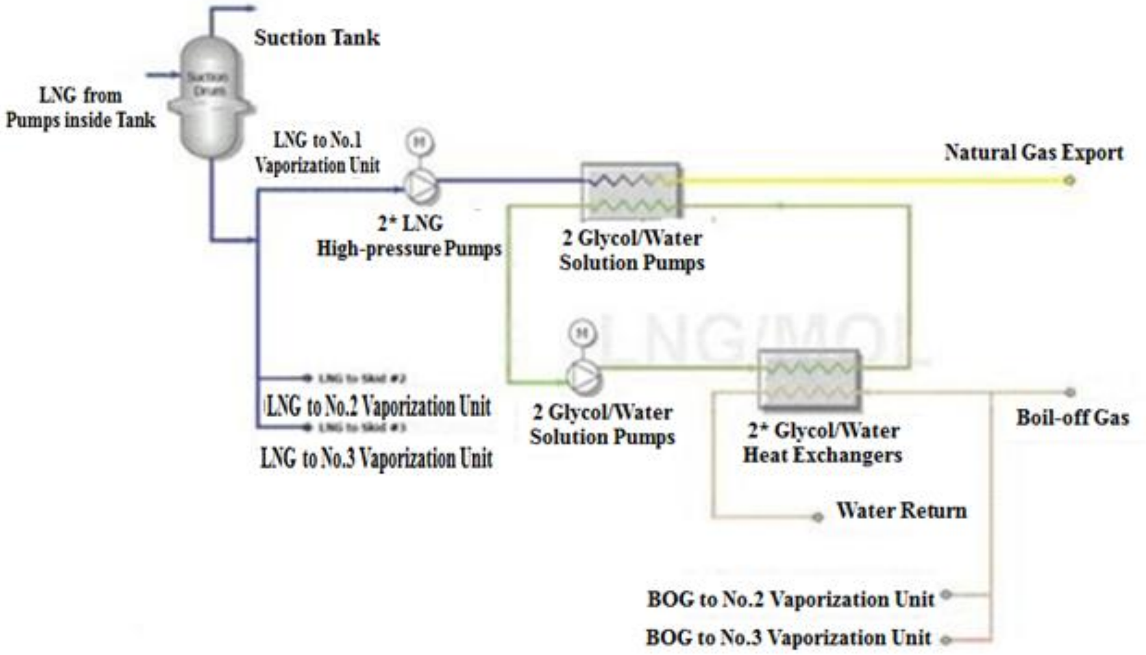

Figure 17- Flowchart of Gasification Unit

Source: Provided by CNOOC and marked by the author

Vaporizer is skid mounted with high pressure pumps, two high-pressure pumps corresponding to a vaporizer. There are totally 3 vaporizers, each of which with gasification capacity of 42~210t/h. Vaporizer outlet gas pressure is adjustable between 46~114bar, and temperature is 10~20℃. Vaporizer is arranged as shown in Figure 18, and working parameters are described in Table 4.

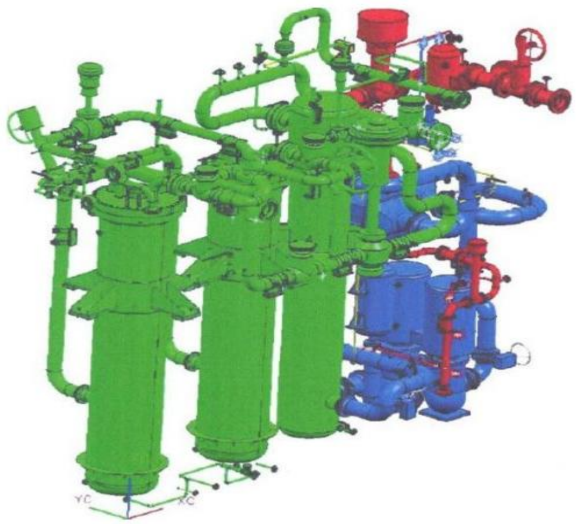

Figure 18-Vaporizer Layout
Source: Provided by CNOOC

Table 4-Vaporizer Working Parameters

Gasification Rate(mmscf/day)	120	250	450	500	600	712.5	750
Gasification Speed(t/h)	101	210	378	420	504	599	630
Gasification Continuing Days(day)	26.0	12.5	7.0	6.3	5.2	4.4	4.2

Source: Compiled by the author based on the data provided by CNOOC

3.5.4 Transferring System

There are three cases of transfer liquid phase with FSRU:

Firstly, LNG carrier discharges cargoes. LNG is transferred from LNG carrier to the LNG mains on dock through unloading arms, and then the unloaded LNG is transferred to FSRU through loading arms on dock.

Secondly, transport LNG from storage tanks onshore to the FSRU. Onshore storage tank project has no gasification plants, so it can only support the liquid transportation, and gaseous natural gas products are provided by the FSRU. In the annual average export volume conditions, LNG capacity of storage tanks is 60,000m^3, which can ensure export liquid 16.4 days, while the capacity of gasification vessel can only guarantee gasification supply 11.6 days. Hence, in the carrier late or non-operating days, the amount of remaining LNG in storage tanks onshore is relatively larger. In order to ensure the gas supply for users, it is needed to transport LNG from the storage tanks onshore to the FSRU. When the storage tanks supplement LNG to FSRU, the amount of supplementation is determined by the gasification and export volume of the FSRU. When the export volume is 1,230m^3/h (in maximum gasification capacity condition), it is needed to start seven pumps (each with a capacity of 180m^3/h) inside the onshore tanks to supplement LNG for the FSRU.

Thirdly, the FSRU discharges LNG to storage tanks onshore. When in operation, start two low-pressure pumps FSRU and connect a LNG loading / unloading arm. LNG being pressurized by low-pressure pumps passes through loading arms and LNG cryogenic pipeline, and is transported to storage tanks onshore. Discharging manifold of the FSRU and LNG gasification supply mains are arranged independently, so the loading and unloading process does not affect the gasification operation of the FSRU.

3.5.5 Pressure Relief System

Where the working pressure of a pressure vessel is likely to exceed the design pressure, pressure relief system should be set up. Internal high pressure may be caused by the connected high pressure equipment, and also may be due to external causes like fire.

(1) Pressure Relief of Cargo Tanks

In each tank's gas phase space, two pilots should be set to operate the relief valve (each with 50% of flow rate) in accordance with the provisions of IMO. The relief valve is designed for the safety in failure. This could ensure that the pressure in tanks is maintained within a designed safe range.

(2) Pressure Relief of Pipelines

There are purge interfaces between liquid phase pipelines and safe return pipelines. Also, there are liquid phase filling interfaces between spray pipelines and liquid phase pipelines. For these lines and interfaces, as long as the space between two adjacent valves has the possibility of liquid accumulation, it is needed to set up a spring-loaded pressure relief valve. At least two relief valves should be set up in tandem to protect onboard liquid phase spray pipelines. Setting pressure of the relief valve should be consistent with the system designed pressure. Relief valve should relieve gas to tanks. In order to allow for isolating any deactivated tank, relief valve outlet lines should be connected to at least two independent tanks. Relief valve is isolated from the deactivated tank by exhaust casing with blind flange. A check valve should be set at the connection of relief valve and deactivated tank.

3.5.6 Ballast System

FSRU is equipped with seawater ballast system. Usually, there are four seawater intakes on the bottom of the hull. Among them, there are two main intakes. One is on the port side, and the other on the starboard side, which would serve the ballast water and utility seawater needs. Entering seawater should be filtered, and whole seawater used for this receiving terminal enters from these inlets.

3.5.7 Primary Auxiliary Facilities and Systems

The primary auxiliary facilities and systems on the FSRU include power generation facilities and the associated selective catalytic reduction systems, metering facilities, recondensers and boil off gas compressors, an emergency flare stack, a seawater system, crew quarters, waste and water treatment systems, command control system as well as fire protection system. The water/glycol system, in addition to being used in the vaporization system, would be used for cooling down the FSRU’s machinery and equipment.

Chapter 4 Relevant Conventions, Codes, Standards and Technical Specifications

LNG FSRU is a new concept. Although there are no specific requirements for the safety of FSRU, a number of codes, standards and regulations concerning LNG carriers, dangerous goods, offshore floating facilities and the handling operations can be applicable. For example, The IGC code is not directly applicable for offshore units, but it provides requirements related to the safety of liquefied gas containment systems. (Gourdet & Toderan) In addition, since the FSRU is operated in the Bohai Sea in China, requirements from China should be considered.

4.1 Relevant International Conventions and Guidelines

IMO, as a specialized organization to develop maritime safety and security through international rules for the United Nations, has so far developed a number of ship safety conventions and rules, covering vessels and equipment, crew, ship management navigation environment and other aspects. There is no specific provision for FSRU, but we can learn from the relevant provisions for LNG carriers. The major conventions and rules about LNG carriers are as follows.

4.1.1 Relevant International Conventions

International conventions are mainly developed for trading ships, but may be extended to offshore units as well. The most important IMO conventions are the following:

- International Convention for the Safety of Life at Sea(SOLAS), 1974;
- International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978(STCW 78);
- International Convention for the Prevention of Pollution from Ships, 73 /78 (MARPOL 73/78).

4.1.2 Relevant International Codes

There are some international codes related to the safety supervision of LNG carriers or receiving units.

- International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC code);
- International Maritime Dangerous Goods Code (IMDG Code);
- Recommendations on the Transport of Dangerous Goods, United Nations;
- International Management Code for the Safe Operation of Ships and for Pollution Prevention(ISM Code);
- International Regulations for Preventing Collisions at Sea (COLREGS);
- The Code for the Construction and Equipment of Mobile Offshore Drilling Units, 1989 (MODU, 1989).

4.2 Relevant International Technical Specifications, Guidelines

Some technical specifications and guidelines are more specialized on management of LNG transportation.

- Liquefied Gas Handling Principle on Ships and in Terminals, which is formulated by Society of International Gas Tankers and Terminal Operators Limited (SIGTTO), aiming to regulate handling operations and personnel protection of ships carrying liquefied gases;

- Tanker Safety Guide, Liquefied Gas, which is formulated by International Chamber of Shipping(ICS), aiming to provide safe operating instructions, properties of liquefied gas, as well as knowledge about liquefied gas carriers and their equipment for the crew on liquefied gas carriers;
- Ship to Ship Transfer Guide, Liquefied Gas, a supplement for “Tanker Safety Guide, Liquefied Gas” and also formulated by ICS, aiming to make the captain, ship and barge operators as well as others familiar with ship-to-ship lighterage operations of liquefied gas, and providing a reference for lighterage operations among LNG carriers, LNG RV and FSOs;
- Safety guide for terminals handling ships carrying Liquefied Gases in bulk, which is formulated by Oil Companies international Marine Forum (OCIMF), designed to ensure the safe handling of Liquefied gas carriers in bulk and provide safe methods of operation for operating personnel on terminal;
- Contingency Planning and Crew Response Guide for Gas Carrier Damage at Sea and in Port Approaches, which is formulated by ICS,OCIMF and SIGTTO;
- Crew safety standards and training of large LNG carries, which is formulated by SIGTTO, designed to provide operating guidelines for shipowners and new operating personnel, and mainly used for the training of new crew on LNG carriers, so as to meet the requirements of the STCW Convention;
- LNG Operations in Port Area: Essential best practices for the industry, which is formulated by SIGTTO;
- Ship Inspection Report (SIRE) Programme –Ship Inspection Guidelines for Crude Oil Carriers, Chemical Tankers and Liquefied Gas Carriers, which is formulated by OCIMF;
- Classification and Certification of Offshore LNG Terminals, which is formulated by Bureau Veritas (BV), designed for providing applicable guidelines on classification and certification of offshore LNG terminals;
- Classification of Offshore Floating Gas Units, which is also formulated by BV,

aiming to provide applicable guidelines on classification and certification of offshore floating gas units;

- National Fire Protection Association (NFPA) 59A: Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG).

4.3 Relevant Domestic Laws, Regulations and Technical Standards

4.3.1 Relevant National Laws and Regulations

National laws and regulations must be referred to research on the safety management of LNG transportation.

- Production Safety Law of the People's Republic of China;
- Port Law of the People's Republic of China;
- Maritime Traffic Safety Law of the People's Republic of China;
- Emergency Response Law of the People's Republic of China;
- Regulations on Safety Administration of Hazardous Chemicals;
- People's Republic of China Regulations on Inspection of Ships and Offshore Facilities;
- People's Republic of China Rules on Ships Safety Inspection;
- Safety Supervision and Management Regulations on Ships Carrying Dangerous Goods;
- Rules on Waterway Transportation of Dangerous Goods;
- Port Dangerous Goods Management Regulations.

4.3.2 Relevant National Technical Standards

National technical standards set the requirements of LNG industry, and can guide the management of LNG FSRU.

- Requirements for Safety Operation of Ships Carrying Liquefied Gases (GB18180-2000), which specifies the requirements related to the safe operation, cargo handling, lighting of LNG carrier, aiming to unify safety technical requirements for Ships Carrying Liquefied Gases;
- Safety standard of ship to ship transfer operations of liquefied gas carriers on waters (GB17422-1998);
- Safety Technical Requirements for Liquefied Gas Terminal, which entry into force on September 1, 2000, aiming to regulate the requirements for LNG terminal facilities, equipment and safety technology that apply to all liquefied gas terminals as a mandatory standard;
- Code for Design of Liquefied Natural Gas Port and Jetty;
- General Properties of Liquefied Natural Gas;
- Statutory Inspection Rules on Ships and Offshore Installations (Technical Regulation for Statutory Survey of Domestic Seagoing Ships, 2001), which is developed by China Maritime Safety Administration and entered into force in 1 September, 2011;
- Construction and Equipment Specifications on Ships Carrying Liquefied Gases in Bulk, 2006.

4.4 Regulatory Requirements of Some Developed Countries

It is also worth learning from regulatory experience of some developed countries.

4.4.1 U.S.A

U.S. Act 33 Code of Federal Regulation-165.20 states that “A Safety Zone is a water area, shore area, or water and shore area to which, for safety or environmental purposes, access is limited to authorized persons, vehicles, or vessels. It may be stationary and described by fixed limits or it may be described as a zone around a vessel in motion.” (http://www.law.cornell.edu/cfr/text/33/165.20) USCG is responsible for the safety of ship in domestic navigable waters. Its responsibility covers not only the crew and cargo facilities, but also the dock personnel.

In the United States, LNG carriers and the equipment onboard must be inspected and approved by well-known classification societies like ABS, LR and BV. For a LNG carrier flying a foreign flag, USCG requires the shipowner to provide detailed information and instructions to be recognized, the drawings of newbuilding LNG carrier must be approved by USCG, and the construction of the LNG carrier must be supervised by surveyors from well-known classification societies. When the LNG carrier arrives at an American port, inspection will be performed by the USCG. If it does not comply with related codes, operations of the LNG carrier can be conducted only after correction and checking out the "Letter of Compliance". Working time of LNG carrier crew is limited to prevent fatigue operation. In order to improve response capabilities, simulator training and exercises are performed on LNG carrier crew. USCG also provides requirements for LNG carrier navigation area and restricted access area. Moreover, USCG takes strict security and safety measures for the arriving LNG carrier, including annual terminal facilities safety and security inspection system, pilot and tug staff special training, LNG carrier not anchoring system, reporting and pre-licensing system, security area and escort system. For example, Boston Harbor limits the arrival and departure time and maximum draft of the LNG carrier. It also specifies that there must be a qualified gas engineer on board to supervise cargo handling operation.

4.4.2 Japan

Japan's LNG import capacity is large and its transportation network is well-developed. Many LNG carriers navigate in Tokyo Bay waters. Currently, Japan imports LNG from all over the world through 22 LNG terminals. In Japan, LNG carrier navigation, anchoring, berthing and loading and unloading actions are governed by Japanese Harbor Regulation Act and performed by the Port Authority and the

Japanese Coast Guard separately according to their respective responsibilities. Japanese Coast Guard implements 24-hour custody on LNG carriers entering or leaving port. The guard boat provides escort for LNG carriers when the ship berthing and unberthing, and patrols in the vicinity waters to ward off other ships in order to reduce the incidence of collisions. Safety speed is set in the import fairway and harbor area, and mandatory pilotage must be implemented. There should be escort ships equipped with firefighting equipments. Japan's Tokyo Bay safety rules on LNG carrier include prohibiting LNG carriers import at night; prohibiting discharge LNG vapor in Tokyo Bay, prohibiting use LNG as fuel in the dock, speed limits with12knots in Tokyo Bay and 3.5 knots in harbor as well as mandatory pilotage and firefighting boat escort.

4.4.3 Australia

Functions of Australia Maritime Safety Authority (AMSA) and Maritime Safety Administration of China (China MSA) are different in maritime business. Compared with the management mechanism of China MSA, AMSA does not have the responsibilities of navigable management, emergency incident response handling, search and rescue as well as pollution incident handling. These responsibilities are performed by the port authorities and local government departments. Australian Port Authority is responsible for the navigable management of ships arriving and departure. To reduce the LNG carrier ship operational risk in port waters, the port authorities take strict precautions. These measures are as follows. Firstly, following relevant circumstances including cargo tank pressure, temperature, pre-cooling and other basic data should be reported before entering port. After getting permission from the port authorities, the LNG carrier could enter the port for loading. Secondly, each step of LNG carrier import and export operations, berthing operations, loading and unloading operations, and pilotage are subject to strict control and monitoring by port authorities.

Chapter 5 Safety Supervision of Tianjin Nanjiang Port FSRU

5.1 Risks of FSRU

Accidental hazards for FSRU include collisions with other ships, spills during LNG transfers, natural phenomena, and accidents associated with the storage and regasification of LNG. These events could cause consequences that include the puncture of LNG cargo tanks from a ship collision and a subsequent fire or combustion-related explosion caused by an LNG leak or spill on board the FSRU. (Cabrillo Port Liquefied Natural Gas Deepwater Port Final EIS/EIR, 2007) The FSRU is subject to regular wave forces that can build up and cause damage to tanks. (Chan et al, 2004) Intentional threats can range from an insider threat to intentional external attacks using weapons or delivery modes such as airplanes, ships, or boats. Thus, the FSRU mainly faces the threats as follows.

Leakage may be caused by an operational failure or tank rupture. The usually operational failure happens in the cargo handling process. For this FSRU, leakage may take place in two stages. One is LNG carrier discharging LNG through unloading arms; the other is the FSRU loading LNG through loading arms. During the cargo handling operation, the handling arms failures are likely to occur and cause LNG leakage. As the installation of emergency shutdown system, even if leakage occurs, the amount is not too large. Tank rupture may be caused by ship collision which damages the hull or tanks of the FSRU. Since LNG is a clear cryogenic liquid which boils at -162.3℃, it causes cryogenic hazards. If LNG spills on the deck, the low temperatures of LNG can be the cause of structural impairment in the event of leakage and contact with normal steel. This is a well-known phenomenon and recommendations have been made for the appropriate structural protection to be put in place where necessary. Also, the LNG could cause cryogenic burns to FSRU personnel in the event that the LNG is spilled and come into contact with unprotected skin. If LNG spills to the sea, a pool of LNG will form on the water's surface. The liquid will vaporize into a cloud which will likely encounter an ignition source and resulting in a poor fire. Asphyxiation of the FSRU, LNG vessel, tug or pilot boat crews is possible although not considered a major issue.

The accidental breaching events include the possibility of collisions of the FSRU from another vessel. (Sandia Report, 2006) Collision is most likely to occur when the LNG shuttle carrier berths the adjacent berth. Operational failures of the pilot or the captain, or improper operation of the tugboat all may cause collision. Other vessels passing through near area are also probable to collide with the FSRU. Collision may cause damages on the hull and/or tanks. This would not only cause the LNG spills but also damages of vessel structure which threats the safety the FSRU and crew onboard. If the wind is extremely strong or the wave is too high, the floating unit may contact with the quay. It is harmful for the FSRU and the quay.

Besides these two major risks, there are some other risks of the FSRU. One is LNG storage fires. Since the event of tank rupture is unlikely to occur, a LNG fire may be impossible to extinguish. Moreover, the LNG tanks are equipped with secondary barriers and multiple levels of over pressure protection. Note that the benefit of a location mooring to the berth would play a part in such an incident, with onshore firefighting support easily. If necessary, firefighting support vessels can arrive on the scene rapidly. Another risk of the FSRU is sloshing in LNG tanks. The membrane design of LNG tanks requires the transfer of structural loading from the membrane to the hull structure. The loading on the membrane due to LNG sloshing has been studied extensively and shown to be acceptable for a known design of membrane tank, but nonetheless, this remains an issue to be proven for the specific design of membrane proposed for the FSRU. One more risk is the hydrocarbon releases. The connection and disconnection of LNG unloading couplings is considered to increase the risk of hydrocarbon releases local to the FSRU. However, with the new BTT system, any such release would occur at some distance downwind from the FSRU, so that this should not significantly impact the individual risk for personnel on the unit. (Dogliani, 2002)

5.2 Particular Requirements for Safety Supervision on LNG Carrier and FRSU

The LNG carrier has characteristics of large-scale, shallow draft, large wind resistance, big blind area, high speed and poor course stability, as well as the unique cargo containment systems. FSRU that is equipped with the necessary pressurized and gasification equipments as well as all necessary auxiliary systems (including power system) not only has the general function of LNG carriers, but also has capabilities of LNG storage and regasification. The FSRU is moored at the pier or to the offshore. In addition, LNG loading and unloading operation is a complex process. During the period of LNG delivered to the tanks of LNG carrier or FSRU, LNG vapor will be continuously produced in the tanks. When the carrier is not equipped with reliquefier, the LNG vapor must be diverted to the engine room as powered fuel or be released to the atmosphere through the exhaust pipe system. When the ship is discharging at the port, in order to fill vacuum caused by the LNG cargo unloading, LNG vapor must be continuously supplemented to the tanks. Therefore, LNG carrier or FSRU cargo system all has the gas phase and liquid phase piping and equipment to support the LNG and its vapor transfer operations at the same time, and forms a closed system to prevent it from mixing with the surrounding air to form explosive gases. Meanwhile, LNG loading and unloading piping and equipment shall also meet the requirements of working at a low temperature of -163℃. By analysis on the historical accidents statistics, LNG carrier accidents are mainly caused by cargo system failure, collision, improper operation, running aground, ship equipment failure, mooring loose, tank sloshing, and so on.

Based on the characteristics above, in the actual process of safety supervision, following requirements should be met to respond to LNG carriers and FSRU.

5.2.1 Requirements for LNG Carriers or FSRU Entering into Port and Berthing

Under normal circumstances, LNG carriers are limited to enter into port in daytime and a good climate. According to the estimated time of arrival, it should be adjusted to arrive at appropriate time as far as possible to avoid anchoring, and directly enter into port. While the LNG carrier reaches the pilot embarkation area, unrelated vessels are not allowed to enter this area. When FSRU or LNG carriers sail in fairways, traffic control should be implemented and escort vessels should be served. Tugs, fireboats and patrol boats of MSA should escort the FSRU or LNG carrier through the whole process. There should not be other ships in the range of 1 n mile front and rear. MSA is responsible for implementation of traffic control for the LNG carrier or FSRU and should publish navigational notices or warnings in advance. In addition, safety speed should be set within the port area and the entering fairways, and compulsory pilotage must be implemented. Berthing and unberthing operations of FSRU or LNG carrier should also be in the daytime and with adequate assistance from tugs. Tugs must be sufficient and with excellent performance.

5.2.2 Requirements for Cargo Handling Operation

Before loading and unloading operations, both sides should work on cargo operations, ballasting operations, emergency response as well as other matters and reach a written agreement to establish and implement a ship to shore or ship to ship safety checklist system. Berthing safety zone shall eliminate all sources of ignition; any electrical device used shall conform to the requirements on prevention of fire and explosion.

In the process of loading and unloading operations, servicing or maintenance operations that impact the ship power and manipulation, test and use of radar and radio transmitters, oil (water) supply operations as well as other operations which influence the safety of cargo handling operation should be prohibited. A patrol boat should guard on duty near the LNG carrier or FSRU in cargo handling operation, and at least a fireboat or a tug with the function of firefighting should watch nearby. In general, the bow of FSRU or LNG carrier should be directed to the departing waterway during berthing and make available emergency towing. The engine of the FSRU and LNG shuttle should keep the state of standby. Cargo operations should be stopped immediately under the following circumstances: tankers onboard or onshore being abnormal; cargo system leaking, thunder and lightning and other inclement weather or sea conditions as well as other conditions which endanger the safety of cargo operations. Appropriate safety measures should be taken by both the vessels and the shore.

5.2.3 Other Requirements

Emergency anchorages shall be provided for FSRU and LNG carrier. Its anchor position should keep proper safety clearances with other anchorages. Vessels at anchor should be kept safe watch and smooth communications. Operations of berthing and unberthing, loading and unloading as well as arriving and departing should be reported to and permitted by the MSA. Emergency conditions and security incidents should also be reported. Personnel protective equipment and emergency medical facilities should be set on the quay.

5.3 Recommendations on Safety Supervision of Tianjin Nanjiang Port FSRU

In addition to following the requirements above, safety supervision on Tianjin Nanjiang Port FSRU project should be combined with its own characteristics of

Tianjin Port, with emphasis on marine navigation environment, ship operating procedures and personnel training and other aspects. It is necessary to develop a practical and practicable system which is consistent with regional characteristics and implement it in practice. Based on the actual situation of Tianjin Port and learning from regulatory experience of developed countries, following recommendations are made on the safety supervision of Tianjin Nanjiang port FSRU project.

- FSRU and LNG carriers of this project arrive and depart through Tianjin Dagusha fairway. In recent years, the number of ships passing through Dagusha fairway has increased year by year, and arriving ships are mainly cargo vessels and tankers. In addition, Tianjin port is continuously expanded through reclamations. There is a large number of ships for harbor construction and most of them pass through the Dagusha fairway. Also, there are many fishing boats passing through the waters. The ship conditions, technical capability and maneuverability of the vessels passing through the waters vary greatly. Therefore, the navigable environment of this fairway is complex. In addition, the radar system of VTS cannot cover the anchorages and fairway waters completely. To this end, when LNG carriers or FSRU arriving and departure, they should be mandatory escorted and safe speed must be specified.

- Berthing and unberthing operations should be carried out in the daytime and it must be assisted by tugs. Since LNG carriers with shallow draft and large windage area, their steerage in drip voyage is poor, and it is needed to get the tug assistance as soon as possible in the process of berthing and unberthing. It should use portside U-turn mode to berth and then it could depart directly. When the LNG carriers or FSRU berth, traffic control should be implemented. Emergency towing with sufficient strength and appropriate length should be prepared for the moored LNG carrier or FSUR. If an emergency arises, they can be towed to the emergency anchorage quickly.

- Before the cargo handling operations of FSRU and LNG carriers, communication channels should be established between the ship and shore. Emergency plan between ship and shore should be developed and emergency preparedness for the plan should be completed. Cargo operation plan and ballast plan should be developed. Operation personnel onboard and onshore should be familiar with these plans and carry out operations in accordance with these plans. Maritime administration should practice a licensing system for loading and unloading operations. The plans above and other related materials should be submitted to maritime administration to apply for carrying out loading and unloading operations. Maritime administration would examine these materials and check the emergency preparedness. If the material is complete and emergency preparedness is sufficient, maritime administration could allow the cargo handling operations. If necessary, maritime administration can carry out on-site supervision during the period of cargo loading and unloading operations.

- LNG tanks, whether on ships, on land, or offshore, require exceptionally large amounts of force to cause damage. Because the amount of energy required to breach containment is so large, in almost all causes the major hazard presented by terrorists is a fire, not explosion. (Foss,2006) Therefore, emergency fire detection and protection must be used in this project. In addition, operations of open fire must be agreed by firefighting department and firefighting preparedness must be ready.

- The Code for Design of Liquefied Natural Gas Port and Jetty Section 5.3.7 states that "When LNG carriers moored in harbor, spacing between other passing ships and the LNG carrier shall not be less than 200m". (China Ministry of Transport, 2009) According to the specific circumstances of Tianjin port, it is proposed that a static safe area should be set at the LNG terminal forefront waters. Other ships are not allowed to enter this area to prevent other ships colliding with the LNG carrier or FSRU. Safety code for LNG terminals should determine restricted zones onshore to control the access by unauthorized persons. Restricted area means the area related to LNG transfer operations and should be clearly expressed. After this project being put into operation, it is posed that the speed of vessels passing through the waters nearby should be re-limited. On the one hand, it is to ensure the safety of ships. On the other hand, once a navigable ship which loses control collides with the mooring LNG carrier or FSRU, lower speed could reduce the consequences of the accident.

- Minor hazardous events such as LNG leaks on the FSRU or the LNG carrier, are likely to occur from time to time. Tugs and the FSRU should be equipped with firefighting equipment, and the FSRU and LNG carrier crew should be well trained to handle such emergencies. Nevertheless, cryogenic damage to crew or equipment could take place. Minor hazards would escalate under extremely sudden and difficult weather conditions. In this case, the emergency shutdown system is useful and this type of emergency response training is necessary. (*Safety Review*)

- In the event of a spill on deck, cold temperature, which is one of LNG's properties, could cause cryogenic damage to the FSRU or LNG carrier. Additionally, it could cause cryogenic burns to personnel on either vessel if it comes into contact with unprotected skin. Asphyxiation of the FSRU crew and the tug/pilot boat crews is also possible during a large spill. (*Safety Review*) Therefore, personal protective equipments, protective clothing, emergency respiratory masks should be provided for the personnel work onboard and onshore.

- A safety zone should be set for the FSRU. In the event of an accidental release of LNG around a facility, the safety zone can protect neighboring communities from personal injury, property damage or fire.

- Emergency anchorage should be set. If any emergency arises, the LNG carrier or

FSRU could be towed to the anchorage to avoid endangering the safety of terminals and people onshore. Emergency anchorage can be the existing anchorage of Tianjin port or be set specifically.

- Training of supervision officers should be strengthened. This FSRU is the first in China, and it is fresh for all supervision officers. Therefore, there is no existing management experience and practice available for reference. Officers should be trained on how to supervise the FSRU.

- This FSRU will be moored to terminal for a long period. The safe manning and watchkeeping during this period should be considered.

- China Classification Society should do more research on FSRU and its safety. Current FSRU are mostly constructed by developed countries and were surveyed by famous classification societies. China Classification Society should develop China's FSRU construction standards and make more efforts to make China have the ability to build FSRU.

- Although the FSRU is more than 18 km away from the populated area. It is also likely an attractive terrorist target because an incident might cause casualties and may be very accessible for extensive media coverage. However, the safety of crew members on board and management staff onshore should be guarded. Port security must be strengthened, and unrelated person should not be allowed to enter the area near the FSRU. People who want to enter the area must be checked.

- In winter, wind is usually strong, and the water may be ice covered. It is needed to strengthen the mooring capacity to avoid the FSRU colliding with terminal.

Chapter 6 Conclusion

This dissertation analyzed the necessity FSRU for China and introduced the worldwide FSRU and the development of FSRU all around the world. It also gave a detailed description of the Tianjin Nanjiang port FSRU about its location, technical parameters, specifications, technical process and relevant systems. Then, relevant conventions, codes and regulations concerning the supervision of LNG Carrier and terminals are listed. Some regulatory requirements of the United States, Japan and Australia for supervision on LNG carriers are cited as well. It also defined the risks of the FSRU and enumerated particular requirements for safety supervision on LNG carrier and FRSU. Finally, it proposed some recommendations on how to improve the safety management of the FSRU.

Admittedly, safety supervision on this FSRU is a new and complex issue. There is no experience on the management of FSRU. Not only the safety supervision authority, but also the management department of the company is not very familiar with the FSRU. The cargo handling process and LNG regasification process are fresh for them. Officers of the supervision department and staff of CNOOC should study on the LNG FSRU management. They should improve their skills on survey or supervision of FSRU. It is believed that, with the best efforts of all parties, this FSRU project will operate safely.

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