LOW TEMPERATURE DATA BASE OF 9%NI STEEL FOR Type-B LNG FUEL TANK THROUGH FCGR TEST

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Introduction

■ IMO's Sulphur Limit for ships' fuel oil

○ IMO regulations to reduce Sulphur oxides (SOx) emissions from ships.

- Crude Oil contains sulphur which, following combustion in the engine, ends up in ship emissions.
- Sulphur oxides (SOx) are known to be harmful to human health, causing respiratory symptoms and lung disease.
- In the atmosphere, SOx can lead to acid rain, which can harm crops, forests and aquatic species, and contributes to the acidification of oceans.

→ Limiting SOx emissions from ships.

○ IMO 2020 – Cleaner shipping for cleaner air

- From 1 January 2020, the limit for Sulphur in fuel oil used on board ships is reduced to 0.5% from 3.5%.

○ The LNG fueled ship and carrier market is expected to grow due to the conservative experimental rule.

■ Five beneficial changes from IMO's Sulphur limit for ships' fuel oil

Sulphur 2020

Cleaner air

77% drop in overall Sulphur oxide (SOx) emissions from ships - annual reduction of approximately 8.5 million metric tonnes of SOx

Positive impacts on human health

Premature deaths, cardiovascular, respiratory and pulmonary diseases will all be reduced.

Higher quality fuels

The majority of ships will switch to higher quality, low Sulphur fuel oil to meet the limit.

Ship operators, owners + refineries have adapted

Guidance issued by IMO and other stakeholders to enhance preparedness ahead of the entry into force of Sulphur 2020

Changes for enforcement authorities

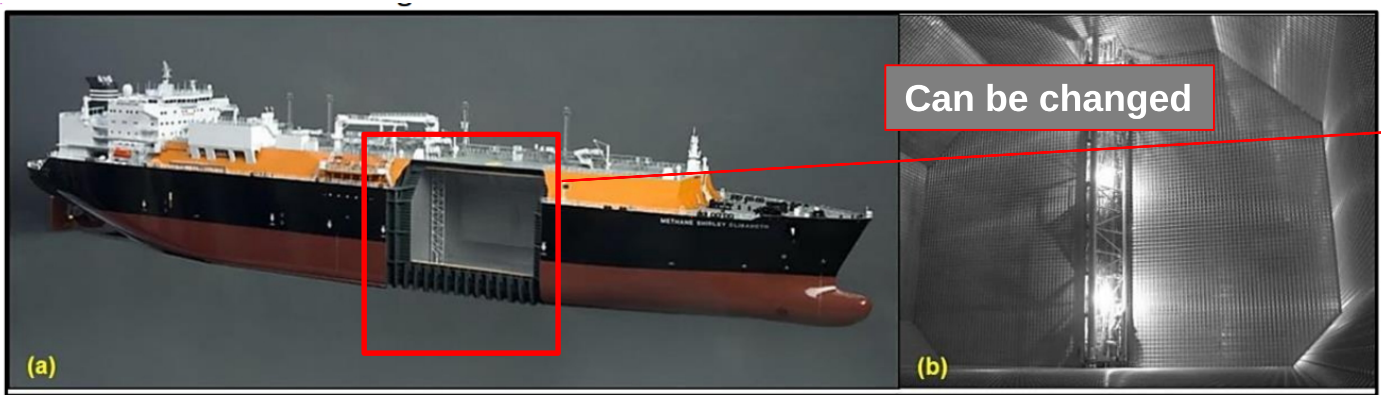
Flag and port state control will be making sure ships are compliant.

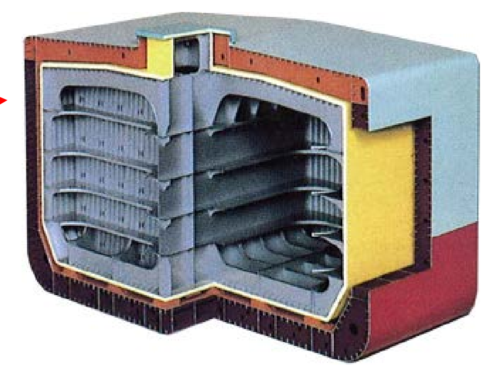
LNG Carriers

○ The LNG fueled ship and carrier market is expected to grow due to IMO 2020.

- LNG carriers are the tank ships designed to carry Liquefied Natural Gas (LNG) at a cryogenic temperature of -162℃.
- Global consumption of LNG is expected to grow at a significant rate driven by supportive government regulations and increasing demand.

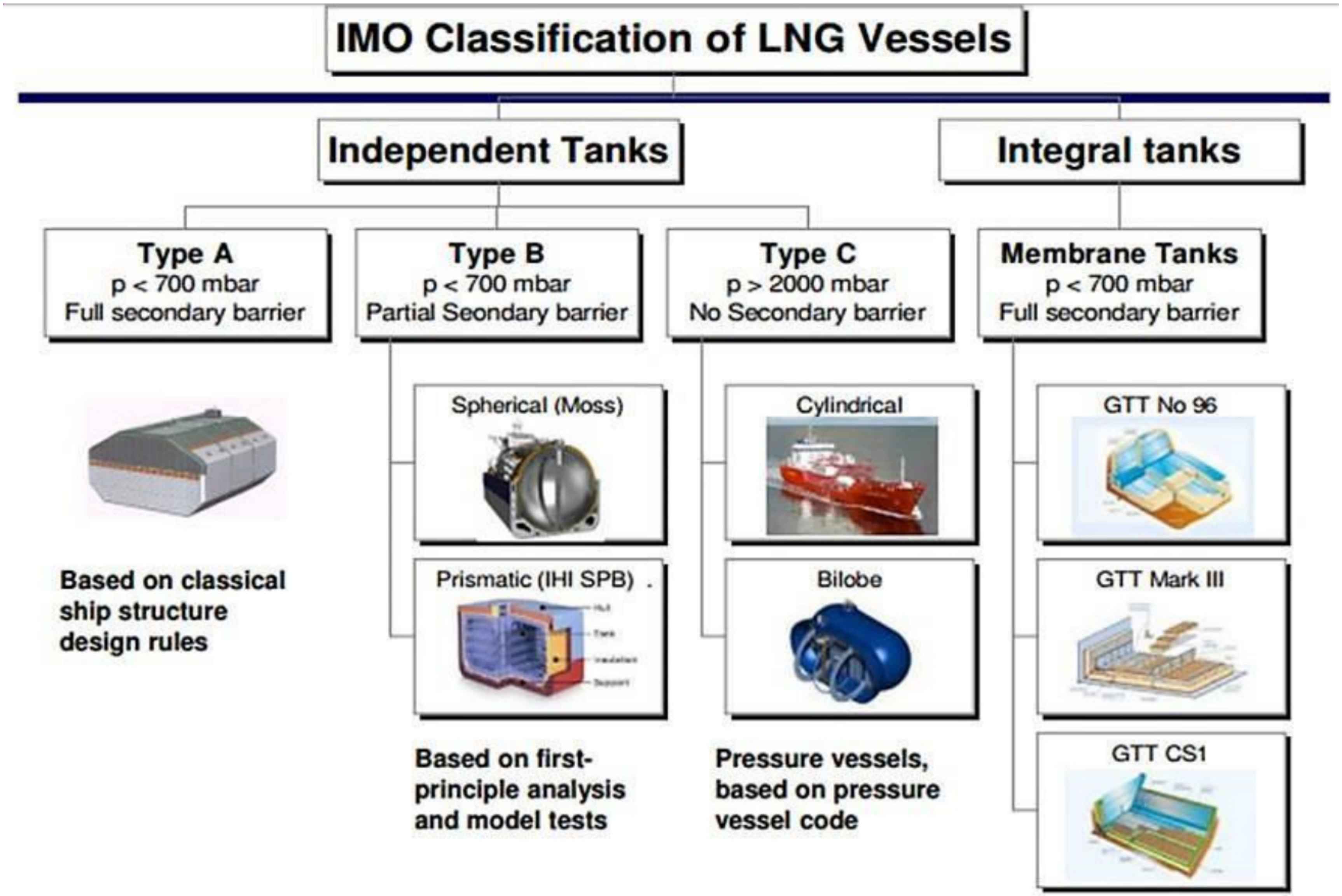
LNG carrier with Spherical (MOSS) tank **LNG carrier with Type-C tank** **LNG carrier with Membrane tank**





LNG carrier with Membrane tank **Type-B tank**

Tank Type of LNG Vessels



Tank Design Principle

■ Tank design principle : Prevent LNG spill from fuel tanks

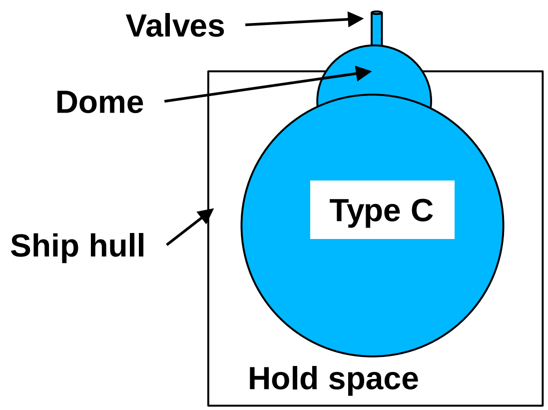
○ What to do with the gas from a tank leak?

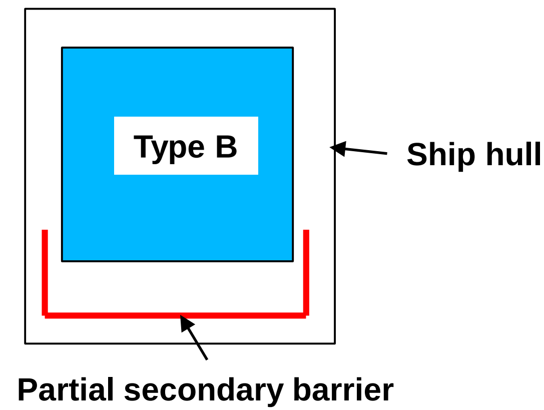
- Type C → Leaks possible only from valves
- Type A and Membrane Tank → Gas release has to be handled in case of large leaks
- Type B tank → Limited gas release from leaks has to be handled

■ Tanks types and their safety principles

○ Type C (min. pressure > 2 bar g)

- Leakage free tank
- Leaks possible only from valves



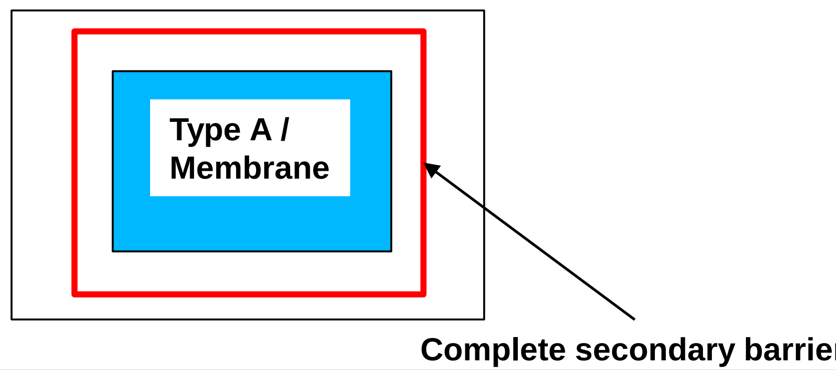


○ Type B tank (max pressure ≤ 0.7 bar g)

- Only minor leaks of the tank structure possible
- Limited liquefied gas release has to be handled

○ Type A and Membrane tank (max pressure ≤ 0.7 bar g)

- Complete first barrier failure not excluded.
- Liquefied gas release has to be handled.



Summary – Prevent Gas

■ Prevent gas from entering safe spaces

○ Gas tight secondary barrier or hold space: Type A > Membrane and Type B

○ Thermal insulation: Type A and Membrane > Type B

→ Consideration of low temperatures needed (from gas of the drip tray)

○ Type C tanks without pipes into the hold space:

- No low temperature protection because no leaks in the shell assumed. Nevertheless small amounts of gas should be able to be handled.
- Watertight hold space with differential pressure between adjacent spaces.

  → Pressure in hold space lowest
- Gas detection in the hold space

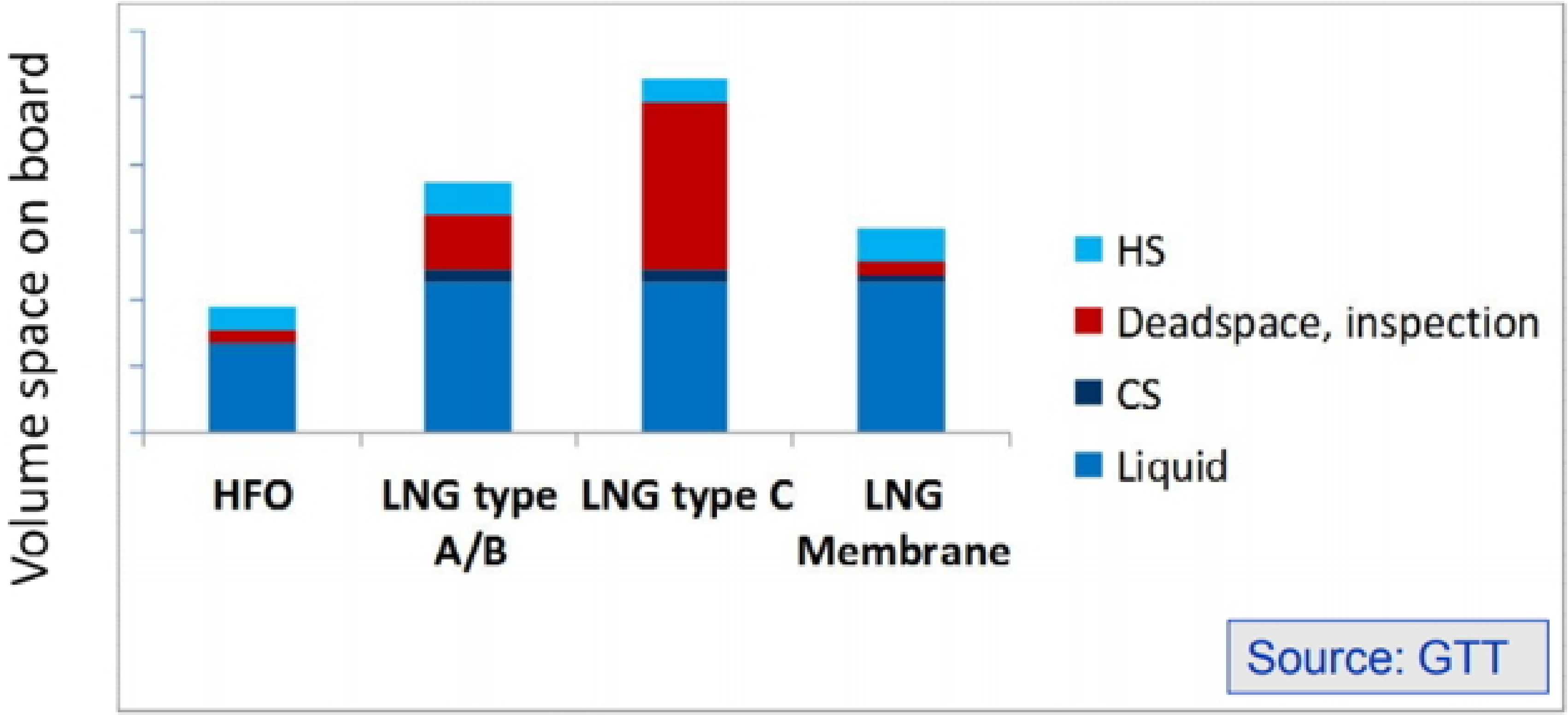
○ Type C tanks with pipes into the hold space

- Leaks from pipes assumed → gas tight, low temperature resistant secondary barrier.

  (existing vacuum tank design for ships)

Safe release of gas in case of tank failure must be considered.

Space needed for different tank types



CS=Containment System,
HS=Handling System

Characteristic of Tank type

	Membrane	Type B	Type C Single-lobe	Type C Bi-lobe	Type C Multi-lobe
Volume ratio - Inspection space and adjacent surfaces	🟢	🟢	🔴	🟡	🟢
Weight	🟢	🟡	🟢	🟢	🟢
Cost of installation	🟡	🔴	🟢	🟢	🟢
Time of installation - Build ship hull and tank at once	🔴	🟡	🟢	🟢	🟢
New building or retrofit	🟢 🟡	🟢	🟢	🟢	🟢
Design pressure & gas consumers	🔴	🔴	🟢	🟢	🟢
Secondary barrier need & arrangement	🟡	🟡	🟢	🟢	🟢
Manage logistics	🟡	🟡	🟢	🟢	🟡

※ The tank size should be different up to the tank type.
> 10,000 CBM : Membrane and Type B tank
≤ 10,000 CBM : Type C tank

Why? - Type B Tank

■ Require the DB of the low temperature steel for the type B tank

○ Type C and Membrane type tank are conventional type.

→ A lot of data and improved design concepts of tank

- Applied steel

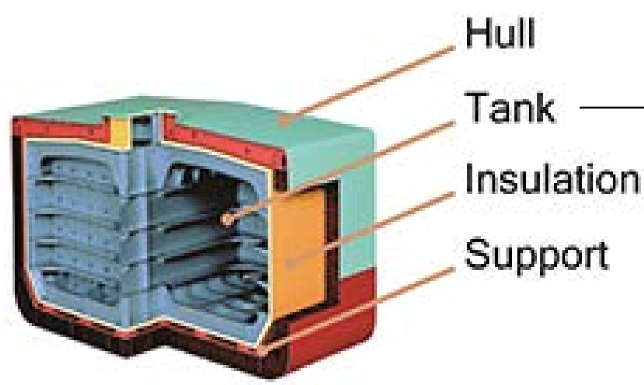
.Type C : 9% Ni steel or High Mn Steel

. Membrane : SUS 304L

○ Type B has been considered for a long time with Al.

→ Type B tank design is reconsidered with 9% Ni or High Mn steel by trend and growth of technology and business policy.

: IMO 2020, Delivery time of tank, Cost of materials etc.



Applied Material : 9%Nickel steel
Hign Manganess steel

Low Temperature Steel

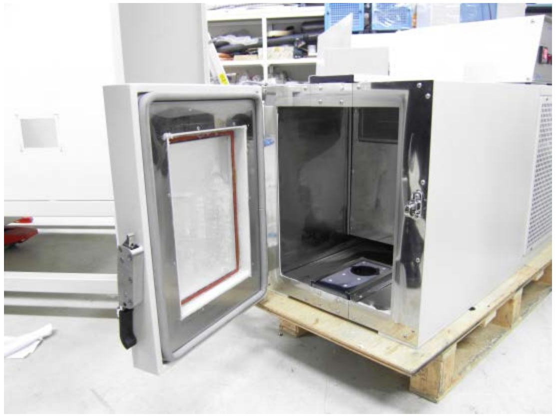
■ Applied Steel Grade for Gas Carrier

	LEG Carrier		LPG Carrier	LNG Carrier	
Type of material	Liquefied Ethylene Gas	Liquefied Ethane Gas	Liquefied Petroleum Gas	Liquefied Natural Gas	
Liquefied Temp.[℃]	-104	-89	-42	-162	-162
Grade	5% Ni Steel	3.5% Ni Steel	FH Grade	9% Ni Steel	High Mn Steel
Min design temp.[℃]	-105	-90	-60	-165	-165
Supply Con.	QT	QT	TM	QT	QT
Thickness [mm]	Max 50	Max 40	Max 50	Max 50	Max 40
YP [MPa]	390 ~	355 ~	275 ~	490 ~	400 ~
TS [MPa]	570 ~ 710	540 ~ 690	470 ~ 640	640 ~ 840	800 ~
EL (%)	Min 21	Min 22	Min 22	Min 19	Min 22
CVN Temp (℃)	-110 ~ -125	-95 ~ -110	-65 ~ -80	-196	-196
CVN (Avg. J)	27	27	27	27	27

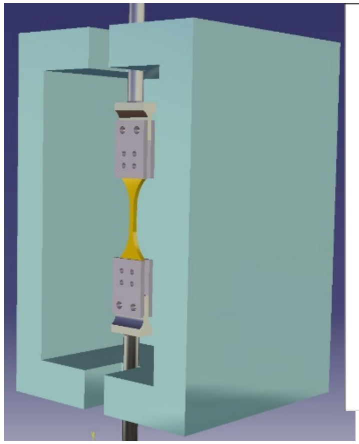
Experiment and Analysis

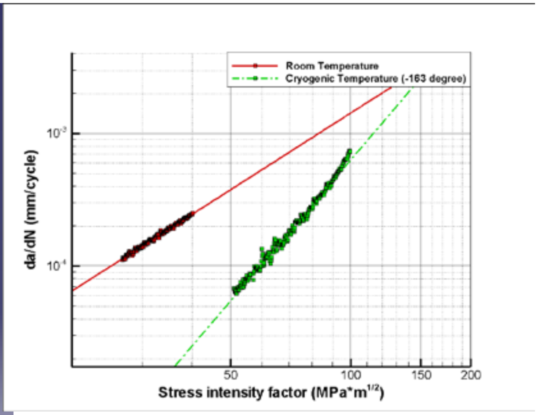
Experimental Equipment

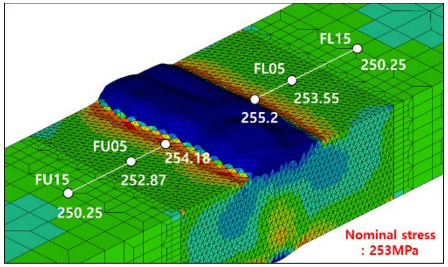
50Mton Fatigue Test (MTS)

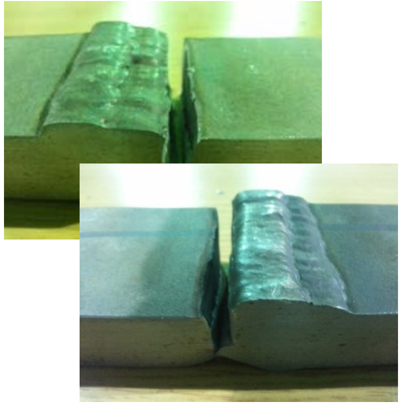


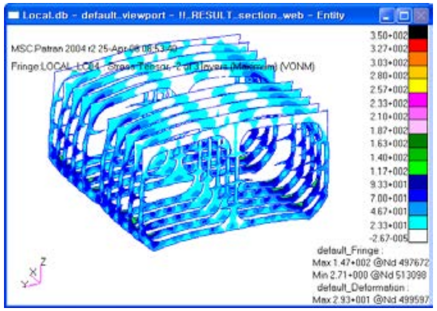
Low Temperature Chamber

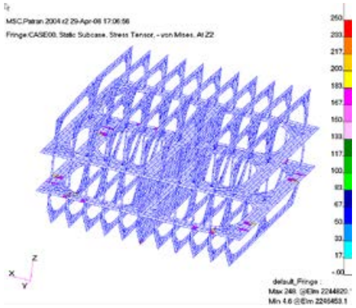












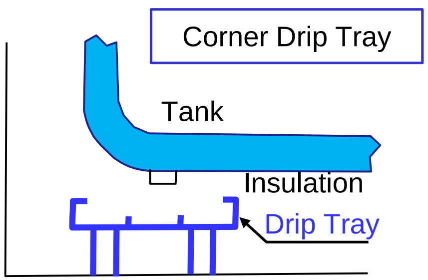
Design Concept

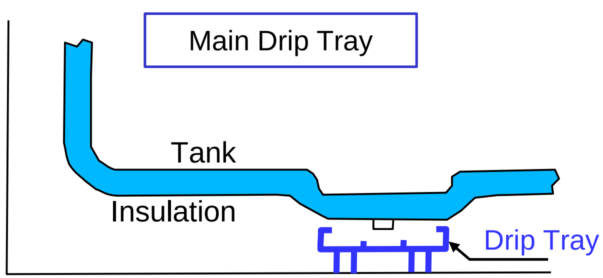
1. Design considering fatigue crack propagation rate and fracture toughness

- Require the analysis for the approval of design
- Leak before-failure condition check
- When the leakage arise, the crack size should be small and LNG evaporate immediately before the gas contact drip tray
- The size of Drip tray should be enough to take the gas for 15 days.
- Comparing with the fracture toughness between the welding line and HAZ

2. Apply the fatigue crack propagation rate for design

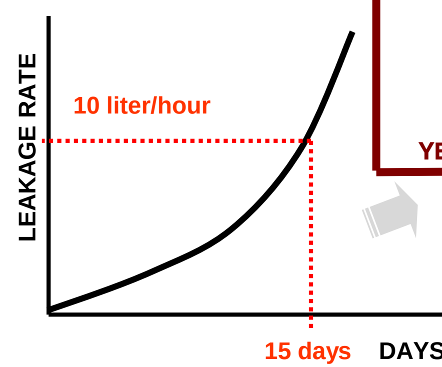
- For the fatigue analysis on the sloshing load
- Improve the fatigue strength at the low temperature
- Decrease the weight of tank

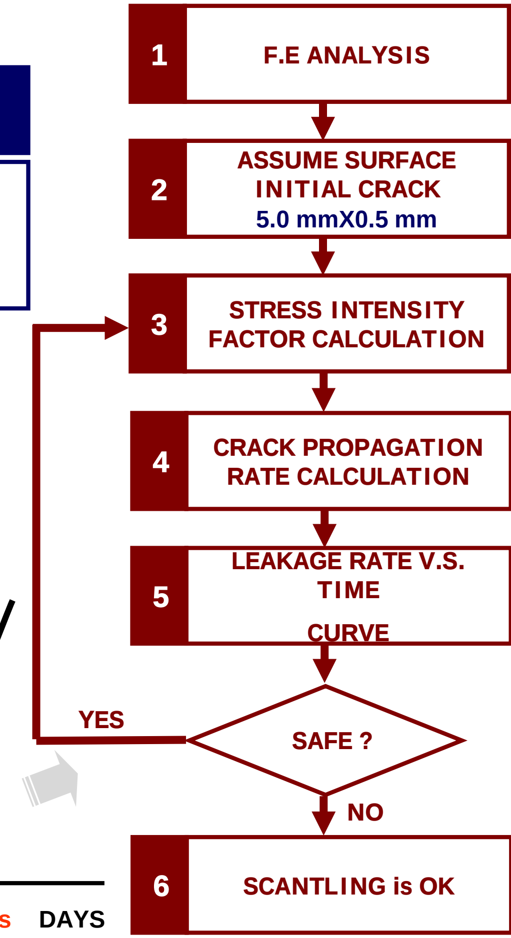




WHERE TO CHECK

- TANK BOUNDARY
- RECTANGULAR PANEL
- LONG EDGE
- TOE OF FILLET





■ K-Decreasing Procedure

○ This procedure is started by cycling at a ΔK and Kmax level equal to or greater than the terminal pre-cracking values.

○ The K-decreasing procedure is not recommended at fatigue crack growth rates above 10^{-8} m/cycle.

○ Determine the best-fit straight between growth rates of 10^{-9} and 10^{-10} m/cycle.

○ Normalized K-gradient,

$$C = \left(\frac{1}{K}\right) \cdot \left(\frac{dK}{da}\right) > -0.08\ \mathrm{mm}^{-1}$$

○ $K = K_o \exp[C(a - a_o)]$

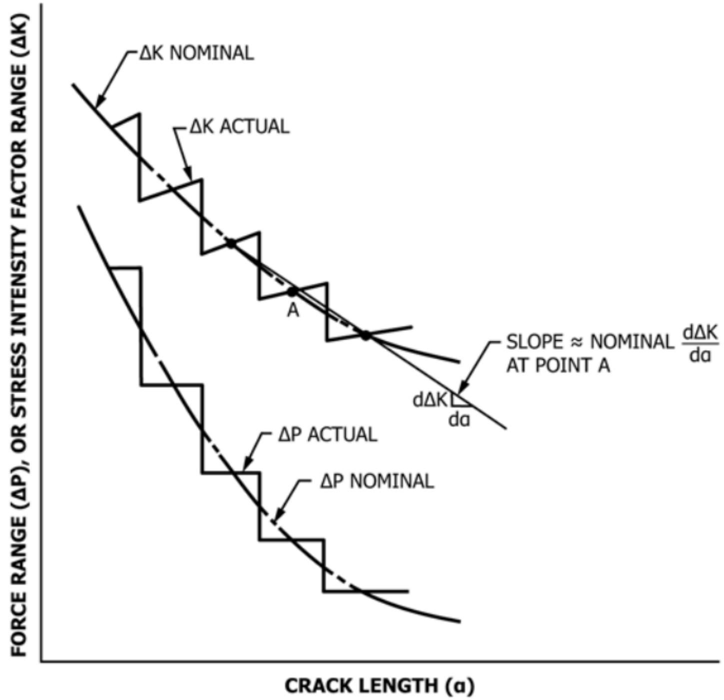


FIG. 2 Typical *K* Decreasing Test by Stepped Force Shedding

FCGR Test

■ FCGR Experiment

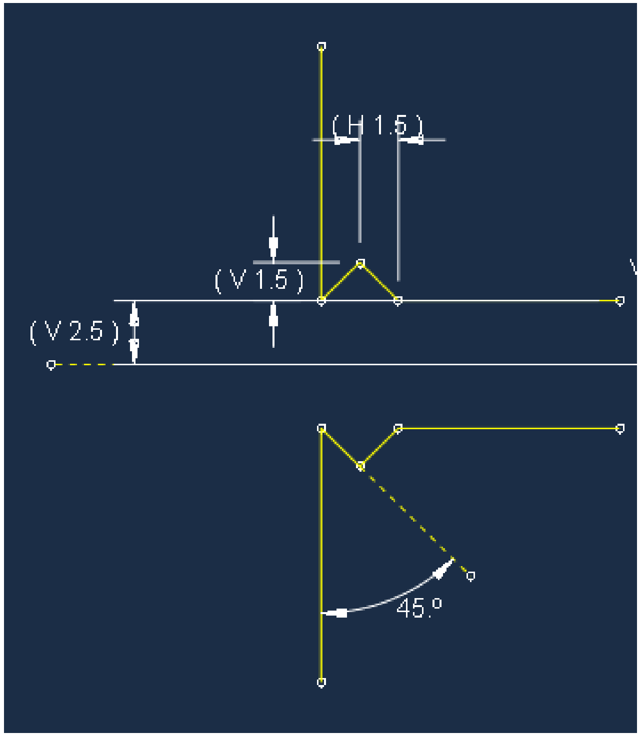
◯ The machined notch plus the pre-crack must lie within the envelope

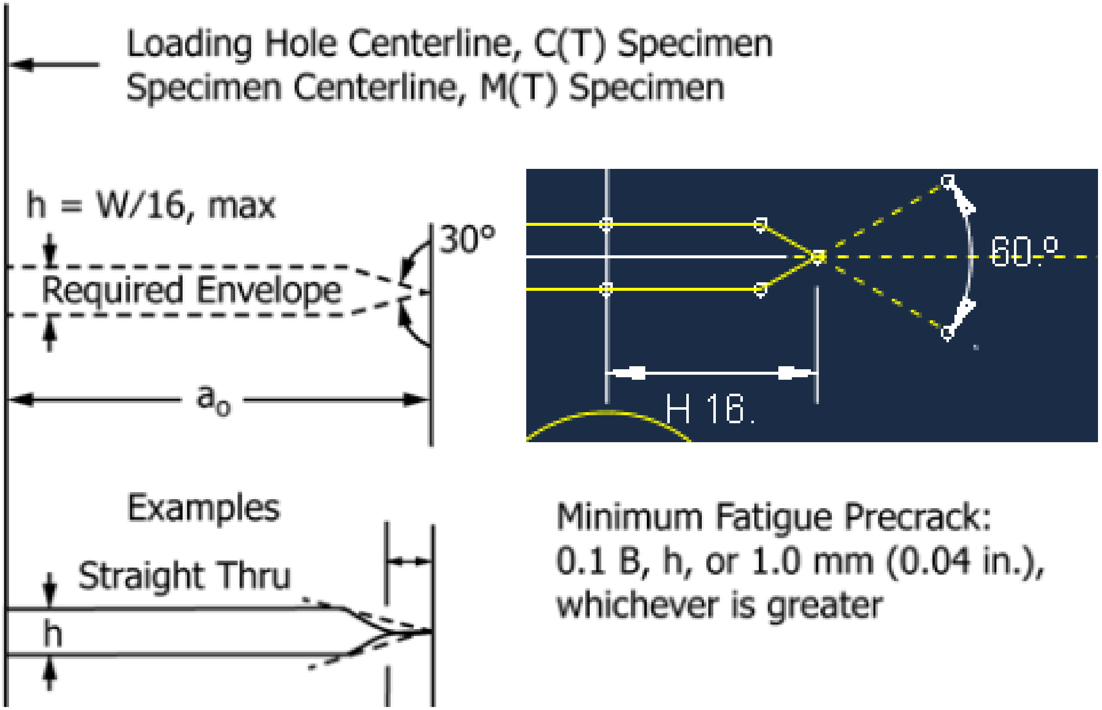
◯ The fatigue pre-crack shall not be less than 0.1B, h(5mm), or 1.0mm.

◯ Gage = 2.5 x 2 = 5mm

Notch Crack = 16mm

Fatigue Crack = 5mm





■ CTOD Test

○ E1290

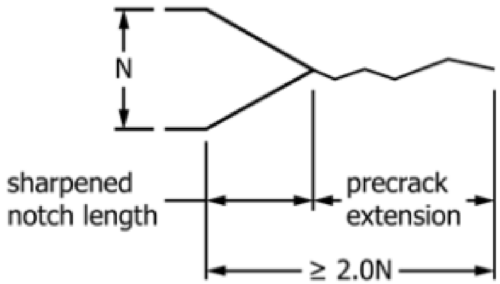
1. The length of the fatigue pre-crack shall not be less than 1.3mm.
2. Force should not exceed Pm from E1820.

$$P_m = \frac{0.4 B b_o^2 \sigma_Y}{2W + a_o}$$

3. For the first step the K_max shall be limited by 25MPa√m.
4. For the second step the K_max shall be limited by 25MPa√m.
5. The second pre-cracking step shall include at least the final 50% of the fatigue pre-crack growth or 1.3mm

○ E1280

1. For the first step the K_max shall be limited by 0.063σ_ys MPa √m.
2. Sum of sharpened notch length (1.73mm) and pre-crack larger than
   2N (2x2mm = 4mm). Pre-crack > (4 – 1.73 = 2.27mm)



Experimental Item – Type B LNG Fuel Tank FCGR and Fracture Toughness

Description	Welding Method	Check Position	Temp.
K-gradient	SAW	HAZ (3mm)	Real Temp. / Low Temp.
	FCAW	HAZ (3mm)	Real Temp. / Low Temp.
Fatigue Crack Growth Rate (da/dN)	SAW	HAZ (3mm)	Real Temp. / Low Temp.
	FCAW	HAZ (3mm)	Real Temp. / Low Temp.
CTOD	SAW	CG-HAZ	Real Temp. / Low Temp.
		FG-HAZ	Real Temp. / Low Temp.
	FCAW	CG-HAZ	Real Temp. / Low Temp.
		FG-HAZ	Real Temp. / Low Temp.

Appendix - Tank Type of LNG Vessels

■ Introduction

- For transferring LNG as a cargo IMO type B (Moss Maritime spherical tanks) and membrane tanks (Gaz Transport and Technigaz) mainly are used. New developments use IMO type A tanks and IMO type C tanks. For LNG propulsion on ship other than LNG carriers, IMO type C tank are preferable.

a) Integral tank

Integral tanks form a structural part of the ship's hull and are influenced by the same loads which stress the hull structure. Integral tanks are not normally allowed for the carriage of liquefied gas if the cargo temperature is below -10 degree C. Certain tanks on a limited number of Japanese-built LPG carriers are of the integral type for the dedicated carriage of full refrigerated butane.

b) Membrane tank (Thick. 0.7mmt ~ 1.5 mmt)

The concept of the membrane containment system is based on a very thin primary barrier (membrane – 0.7 to 1.5 mm thick) which is supported through the insulation. Such tanks are not self-supporting like the independent tanks. An inner hull forms the load bearing structure. Membrane containment systems must always be provided with a secondary barrier to ensure the integrity of the total system in the event of primary barrier leakage.

The membrane is designed in such a way that thermal expansion or contraction is compensated without over-stressing the membrane itself. There are two principal types of membrane system in common use – both named after the companies who developed them and both designed primarily for the carriage of LNG. These two companies have now combined into one.

Appendix - Tank Type of LNG Vessels

C) Independent tank

Independent tanks are completely self-supporting and do not form part of the ship's hull structure. Moreover, they do not contribute to the hull strength of a ship. As defined in the IGC Code, and depending mainly on the design pressure, there are three different types of independent tanks for gas carriers: these are known as Type 'A', "B' and 'C'.

Type 'A' tanks are constructed primarily of flat surfaces. The maximum allowable tank design pressure in the vapour space of for this type of system is 0.7 barg; this means cargoes must be carried in a fully refrigerated condition at or near atmospheric pressure (normally below 0.25 barg).

This type of tank as found on a fully refrigerated LPG carrier. This is a self-supporting prismatic tank which requires conventional internal stiffening. In this example the tanks is surrounded by a skin of foam insulation. Where perlite insulation is used, it would be found filling the whole of the hold space.

The material used for Type 'A' tanks is not crack propagation resistant. Therefore, in order to ensure safety, in the unlikely event of cargo tank leakage, a secondary containment system is required. This secondary containment system is known as a secondary barrier and is a feature of all ships with Type 'A' tanks capable of carrying cargoes below -10 degree C.
For a fully refrigerated LPG carrier (which will not carry cargoes below –55 degree C) the secondary barrier must be a complete barrier capable of containing the whole tank volume at a defined angle of heel and may form part of the ship's full, as shown in the figure.

In general, it is this design approach which is adopted. By this means appropriate parts of the ship's hull are constructed of special steel capable of withstanding low temperatures. The alternative is to build a separate secondary barrier around each cargo tank.

C) Independent tank

The IGC Code stipulates that a secondary barrier must be able to contain tank leakage for a period of 15 days.

On such ships, the space between the cargo tank (sometimes referred to as the primary barrier) and the secondary barrier is known as the hold space. When flammable cargoes are being carried, these spaces must be filled with inert gas to prevent a flammable atmosphere being created in the event of primary barrier leakage.

C-1) Type ‘B’

Type ‘B’ tanks can be constructed of flat surfaces or they may be of the spherical type. This type of containment system is the subject of much more detailed stress analysis compared to Type ‘A’ systems. These controls must include an investigation of fatigue life and a crack propagation analysis. The most common arrangement of Type ‘B’ tank is a spherical tank. This tank is of the Kvaerner Moss design.

Because of the enhanced design factors, a Type ‘B’ tank requires only a partial secondary barrier in the form of a drip tray. The Type ‘B’ spherical tank is almost exclusively applied to LNG ships; seldom featuring in the LPG trade. A type ‘B’ tank, however, need not be spherical.

There are Type ‘B’ tanks of prismatic shape in LNG service. The prismatic Type ‘B’ tank has the benefit of maximizing ship-deck. Where the prismatic shape is used, the maximum design vapour space pressure is, as for Type ‘A’ tanks, limited to 0.7 barg.

C) Independent tank

C-1) Type ‘B’

Most Moss type vessels have 4 or 5 tanks. The insulation in these tanks is provided by thick layer of foam insulation around the tank. The tanks are checked for any leakages by nitrogen atmosphere in special thin layer called “tinfoil”. This layer also allow the insulation to remain dry.

These tanks are susceptible to contraction and expansion during cool down and warm up, so that can reach even 2 foots(0,6098m) . For these reason all piping come into the tanks through the top part and are connected to the ships lines via flexible bellows. The skit is also constructed to endure changes in tank diameters, as well as it has enough to transfer successfully tanks weight to ships hull. The pressure in this tanks usually don't exceed 55kPa (0.55bar) but in emergency cases it can reach the 1 bar pressure.

C-2) Type ‘C’

Type ‘C’ tanks are normally spherical or cylindrical pressure vessels having design pressures higher than 2 barg. The cylindrical vessels may be vertically or horizontally mounted. This type of containment system is always used for semi-pressurized and fully pressurized gas carriers.

In the case of the semi-pressurized ships it can also be used for fully refrigerated carriage, provided appropriate low temperature steels are used in tank construction. Type ‘C’ tanks are designed and built to conventional pressure vessel codes and, as a result, can be subjected to accurate stress analysis. Furthermore, design stresses are kept low. Accordingly, no secondary barrier is required for Type ‘C’ tanks and the hold space can be filled with either inert gas or dry air.

C) Independent tank

C-2) Type ‘C’

In the case of a typical fully pressurized ship (where the cargo is carried at ambient temperature), the tanks may be designed for a maximum working pressure of about 18 barg. For a semi-pressurized ship the cargo tanks and associated equipment are designed for a working pressure of approximately 5 to 7 barg and a vacuum of 0.5 barg. Typically, the tank steels for the semi-pressurized ships are capable of withstanding carriage temperatures of -48 degree C for LPG or -104 degree C for ethylene. (Of course, an ethylene carrier may also be used to transport LPG.)

Type ‘C’ tanks as fitted in a typical fully pressurized gas carrier. With such an arrangement there is comparatively poor utilization of the hull volume; however, this can be improved by using intersecting pressure vessels or bi-lobe type tanks which may be designed with a taper at the forward end of the ship. This is a common arrangement in semi-pressurized ships.