4TO CONGRESO PANAMERICANO DE INGENIERIA NAVAL, INGENIERIA PORTUARIA Y TRANSPORTES MARITIMOS

TRABAJO TECNICO

TITULO LIQUEFIED GAS AND CHEMICAL SHIPS THEIR DESIGN, CONSTRUCTION AND REGULATION

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LIQUEFIED GAS AND CHEMICAL SHIPS

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ABSTRACT

The world LPG production-transportation-consumption situation is poised for a dramatic increase in volume of product in the late 1970's and the first half of the following decade. Large new production projects are well advanced in planning or are already in the construction phase. Many large new LPG ships are being constructed and the number of these ships to be delivered from 1976 through 1978 will double the size of the present fleet of such large carriers. These ships will handle part of the ocean trade between large major production and consumption terminals. Smaller ships will then distribute the product to localized storage terminals. A problem comes up at this point, however, since the existing fleet of smaller LPG tankers is not being expanded nor are the old ships being replaced in a timely way. This paper deals with the question of designing and building these new ships in light of new international rules (IMCO) and changed trade patterns. By way of background, a state-of-the-art description of the technology is given. It seems highly likely and desirable that these new small ships will be built in the shipyards of the countries served by their LPG trade. This means that the time is right for some South American builders to prepare themselves to handle the construction of these very specialized gas and chemical tankers.

The world LPG tanker fleet today amounts to over 400 vessels, three-quarters of which are less than 5,000M^3 capacity, and nearly one-third of which are suffering from some degree of old age. It is especially significant to note that this very large proportion of smaller or older vessels carry only about 5-10% of the present total world fleet's cargo capacity of about 3 million cubic meters. One-tenth the cargo capacity spread through three-quarters of the fleet! ....and of that three-quarters, almost half are in need of gradual replacement! What does this mean to the shipbuilder or the owner or charterer?

Before we try to answer, we should check further into the current makeup of the entire LPG fleet and its trade. (See Tables I and II). At the present time, the number of ships in the world LPG fleet, including those on firm order for future delivery, is increasing at an annual rate of much less than 5%, while the cargo capacity of the fleet is increasing at an annual rate of from 10-20%.

The significant factor is that the LPG fleet makeup, as shown in the present newbuilding tendency, is toward larger ships. The smaller, older ships are not being replaced quickly enough. By the end of 1975 there will be about 20 LPG ships in service ranging in size from 70,000M^3 to 100,000M^3. In 1976, 77 and 78, the number of ships in that size range will more than double. The largest LPG ships operated or being built today are 100,000M^3 (not including LNG ships capable of lifting LPG). Owners and shipbuilders are seriously pursuing studies and projects involving

TABLE I

APPROXIMATE SIZE AND AGE PROFILE OF PRE-1970 LPG FLEET
(Includes Tankers for LPG, Butane, Anhydrous Ammonia)

Year Built	CAPACITY Less than 5,000M^3	5,000-10,000M^3	10,000-20,000M^3
1960 & earlier	60 ships	5ships	2 ships
1961-65	80 "	2 "	4 "
1966-70	80 "	7 "	17 "

TABLE II

MAKE-UP OF WORLD LPG FLEET OPERATING AS OF FIRST 1975
(Includes LPG, Butane, Anhydrous Ammonia)

Method of Cargo Containment	Number of Ships*	Total Capacity
Pressurized, Non-Refrigerated	202	210,000M^3
Pressurized, Semi-Refrigerated	109	320,000M^3
Refrigerated, Non-Pressurized** and Pressurized Tanks	80	2,400,000M^3

* Of these numbers of ships, approximately 140 were of less than 1,000M^3 capacity each and about 200 were between 1,000M^3 and 5,000M^3 each.

** There are 43 LPG ships with capacity over 70,000M^3 each, including those operating and on order. These ships alone amount to about 3,200,000M^3 capacity. Only the ships already delivered and now operating are included in the 80 ships shown in the table.

ships of 200,000M^3 and above. These ships quite obviously are intended for primary ocean trades from gas-rich producing countries to gas-poor consumers. In most cases, the LPG carried in these ships will have to be further distributed by either ship or pipeline. This follow-on distribution by ship from large centralized terminals to smaller localized terminals will be handled by the next generation of small LPG tankers which must soon be planned, financed and built.

Let's look, for a moment, at the state of gas ship technology, at the cargo, and at the trade built up around it -- then we will come back to the question of how the replacements for today's smaller ships will be designed and where they may be built. For simplicity, we will talk in general terms only about LPG, which is a commercial mix of propane, butane, ethane and other hydrocarbons. LPG usually has a boiling temperature of -42° to -45°C, depending upon the mix, and a vapor pressure at 38°C of about 14.76 kg/cm^2 gage. In its liquid state at -42°C and atmospheric pressure, a given volume of product occupies 1/270 of the volume it would have occupied in its gaseous state at atmospheric pressure. For many of us, the most commonly encountered appearance of LPG is in rather small pressure vessel bottles capable of containing the liquefied gas at 17.6 kg/cm^2 gage and 46°C. Such bottles are seen on highway trucks, railway cars, and in industrial plants and homes. Until recently, most of the shoreside storage of LPG (local storage prior to distribution to final consumer) was similarly pressurized and liquefied but not refrigerated This, therefore, explains in part why most of the older smaller ships built for or converted to LPG service in the 1950's and early '60s were of the pressurized, non-refrigerated type. For their time these were versatile ships, having a number of tanks, frequently able to lift and segregate more than one cargo. The ships were small because the shore terminals were small and were rather isolated in shallow draft harbors. Trade routes were relatively short. LPG was produced mainly in refineries and the consumer was near the producer. Today's large volumes of LPG are coming more and more from natural gas production and shipping distances are often very great.

As LPG production and consumption increased during the 1960s and into the '70s, larger centralized storage facilities came on stream and these were commonly either partially or fully refrigerated. Thus, gradually, new LPG ships tended to increase slowly in size and to employ reliquefaction plants on board. The most modern LPG ships range in size up to 100,000M^3 and virtually every ship over about 20,000M^3 in size uses fully refrigerated low pressure cargo tanks. Even the new small ships are equipped with total reliquefaction capability though the tanks are of pressure vessel type, being able to sustain pressures of 2.8 to 4.2 kg/cm^2 gage normally.

LPG ships are built of two main types, distinguished by tank design, employing independent pressure vessel tanks or prismatic self-supporting gravity tanks. For operating and economic reasons, pressure vessel ships are normally built not larger than 15,000M^3 to 20,000M^3, while larger capacity vessels are practically always of the prismatic gravity tank designs.

Figures 1 through 4 and 4A show typical arrangements for both Pre- and Post-IMCO Gas Code pressure vessel tank ships. In the independent pressure vessel tank ships, the design pressures of the cargo tanks range from just over 1.4 kg/cm^2 gage up to full LPG atmospheric vapor pressure of 17.6 kg/cm^2 gage. These ships have cargo systems which may be non-refrigerated, semi-refrigerated or fully refrigerated. The capacity of the refrigeration plant and design pressure of the cargo tanks must be correlated to ensure that boiloff and uncontrolled release of cargo do not occur. Tank materials are selected for the required level of toughness to sustain minimum cargo operating temperatures. Because of the high degree of containment reliability which can be built into stress determinant body of revolution pressure vessel tanks, such containment systems do not normally require secondary barriers. If, however, the tanks become so large and/or the design pressure so low that stresses in the tank shell caused by internal pressure alone do not constitute the bulk of the stress field (i.e. gravity loads and bending and other stress components which may be less amenable to accurate analytical determination begin to take on significant magnitudes), then either a full or partial secondary barrier may be required. A full secondary barrier implies that means are provided around the cargo tank to safely hold all of the cargo from any tank in the event of a gross failure within that tank. The ship's hull may act as secondary barrier, provided hull steels are selected which may safely withstand the temperature of the

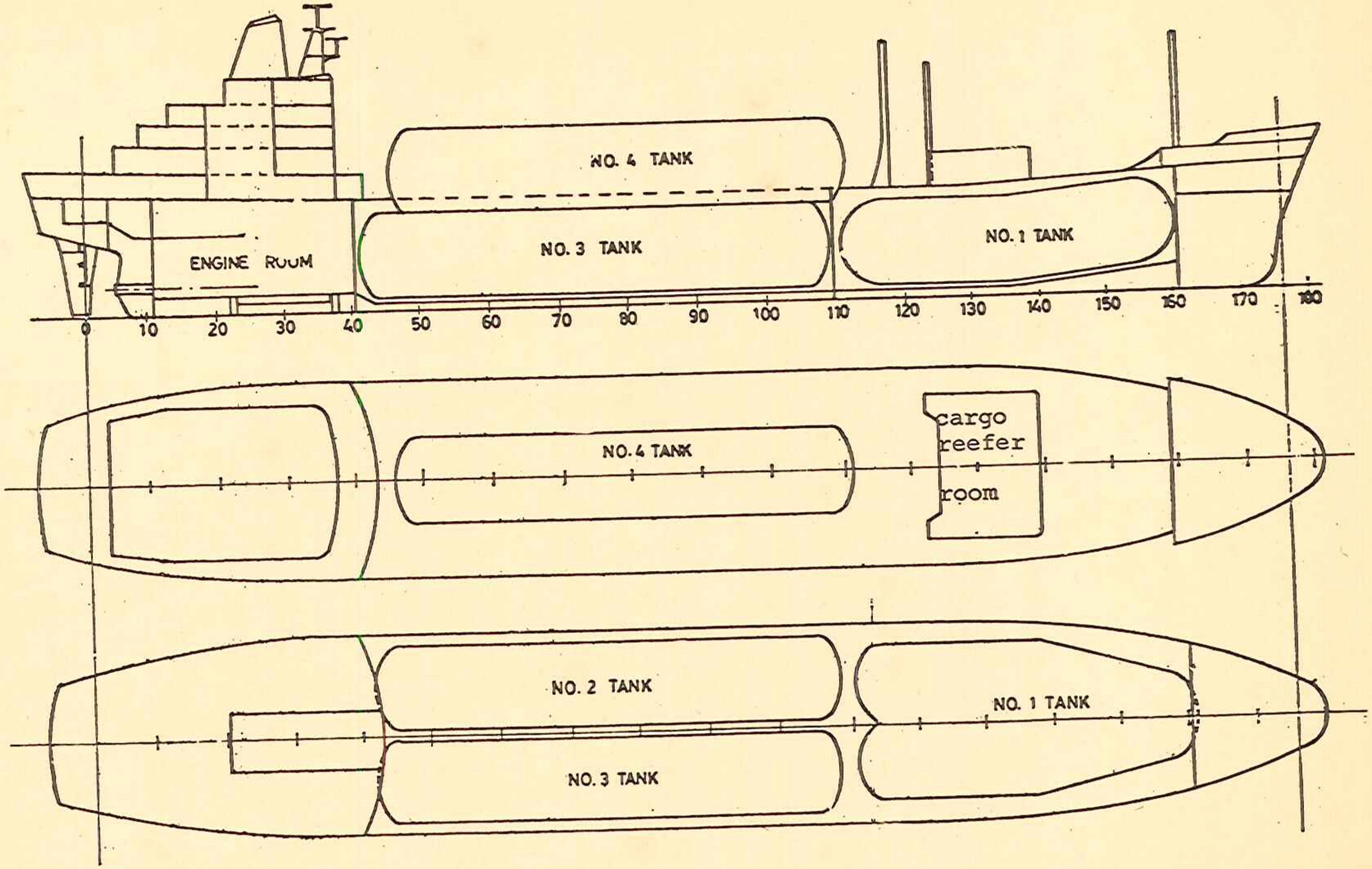
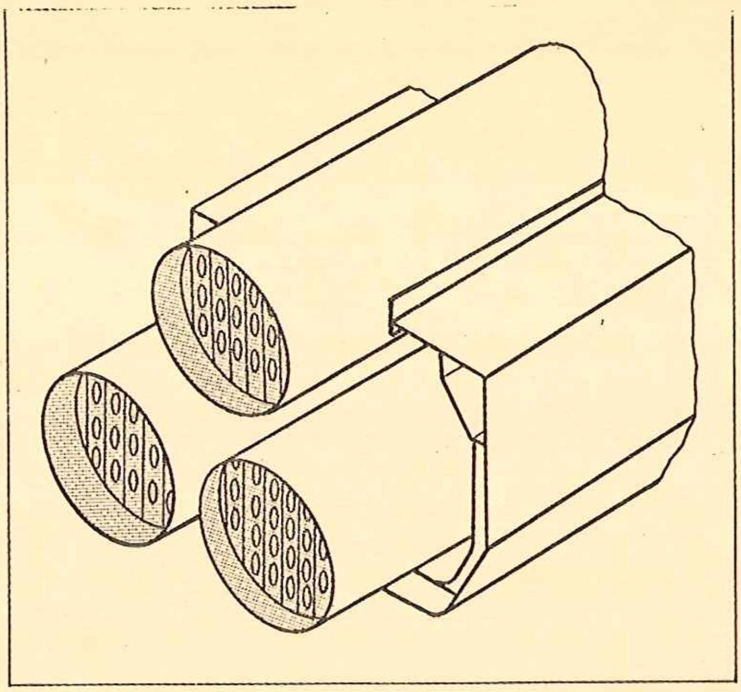
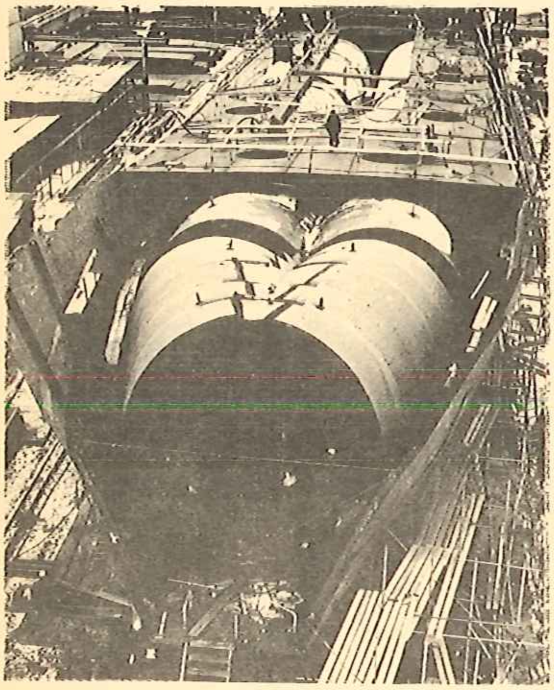
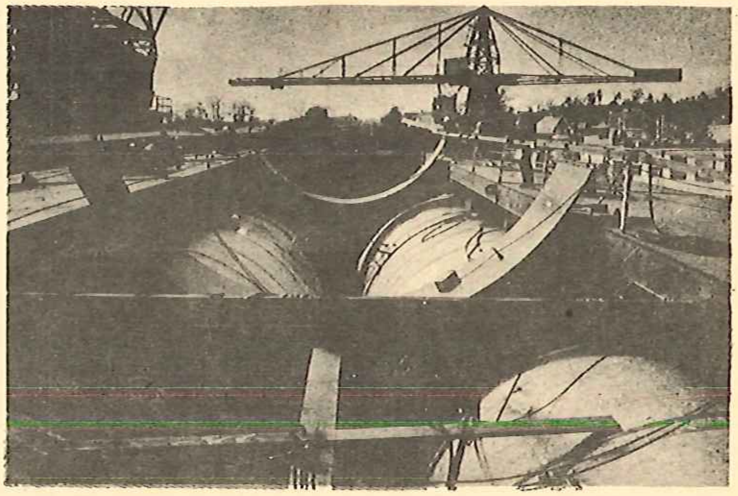


Figure 1

A representative arrangement for a Pre-IMCO Gas Code LPG tanker fitted with Independent Pressure Vessel Tanks. Ships of this type have been built in sizes up to about 15,000M^3.







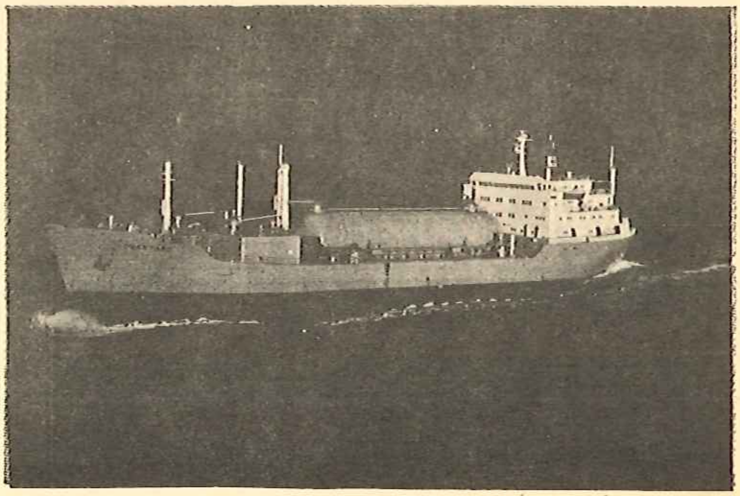
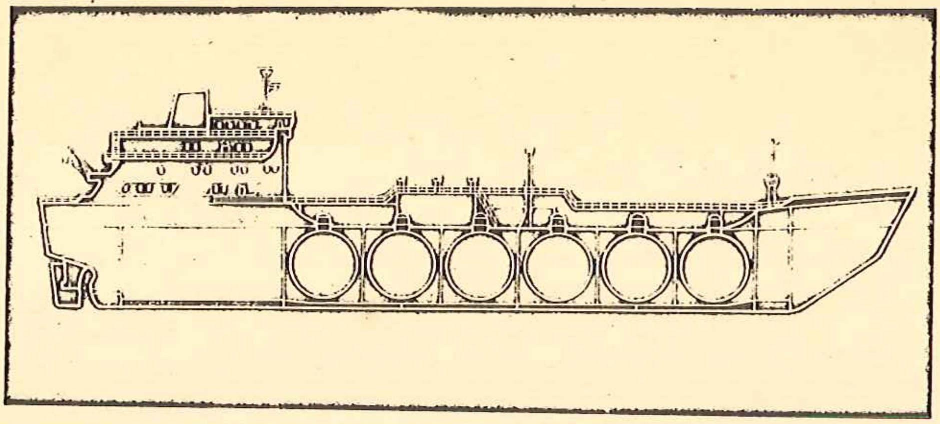
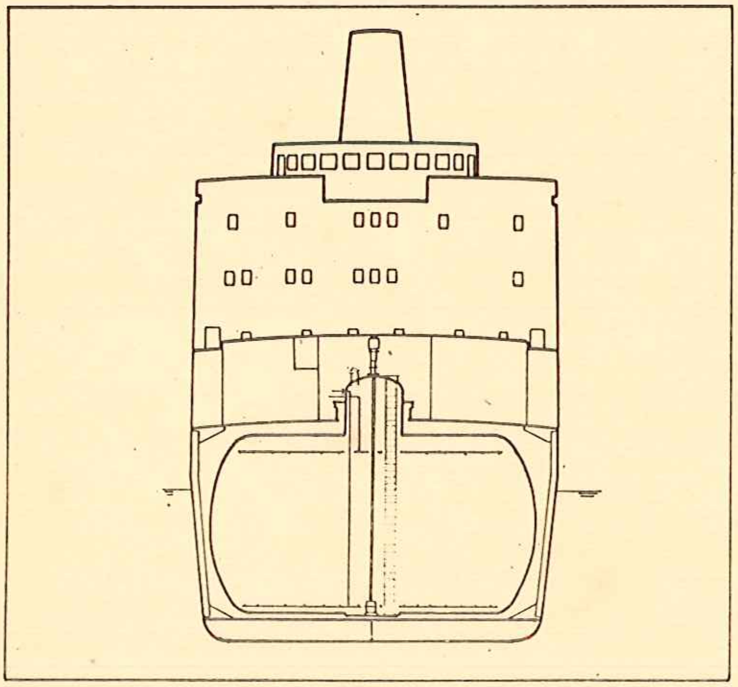
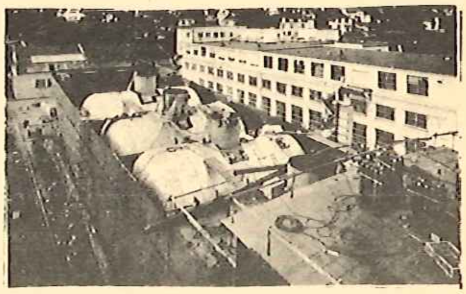


Figure 2

Construction details of LPG tankers fitted with Pressure Vessel Tanks. Tanks are partially built up outside the hull and lifted aboard in three or four sections. At right is a 12,000M^3 LPG/ NH_3 tanker of this type.







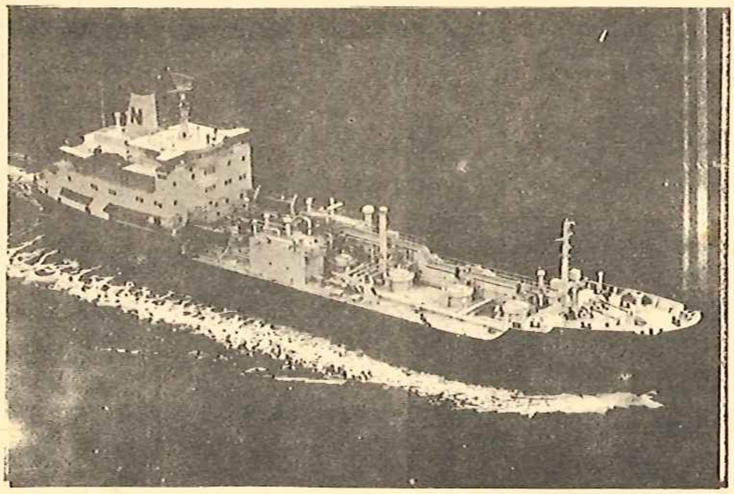
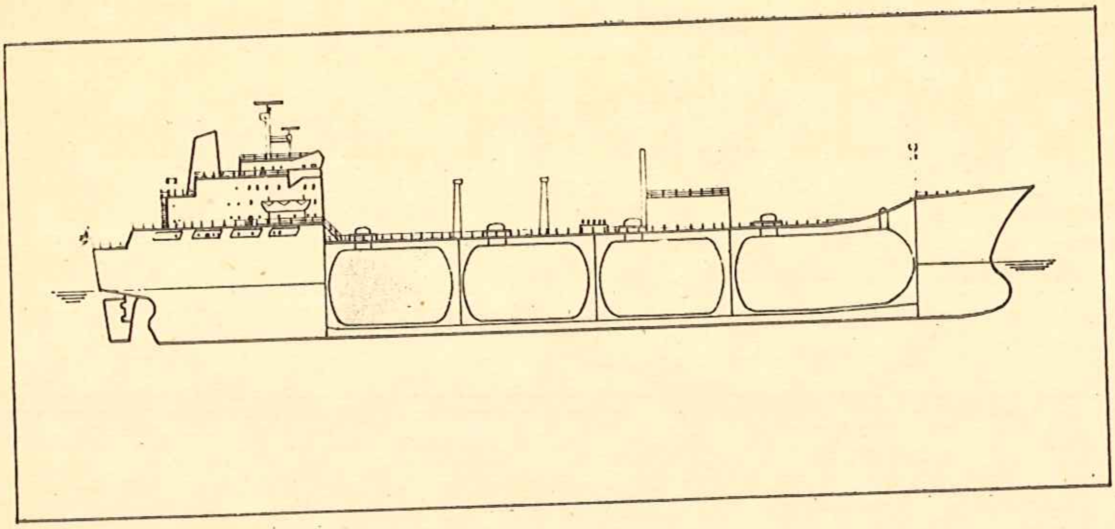


Figure 3

Typical arrangement of Post-IMCO Gas Code LPG tanker fitted with pressure vessel type tanks. Note increased subdivision, necessitating smaller athwartship tanks. At left is a 4100M^3 ethylene/LPG tanker of this type.



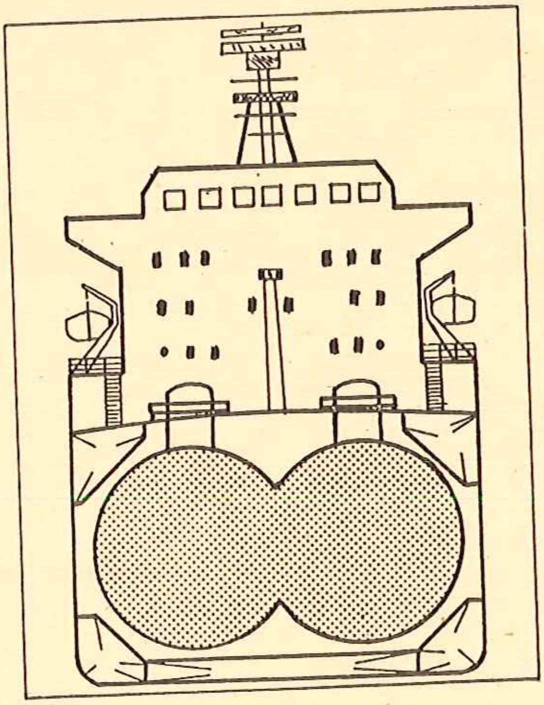


Figure 4

Another typical arrangement of a Post-IMCO Gas Code LPG tanker using Pressure Vessel type tanks. This arrangement is efficient in cubic and is especially applicable in the larger sized pressure vessel tank ships of 12-15,000M^3. (See also Figure 4-A)

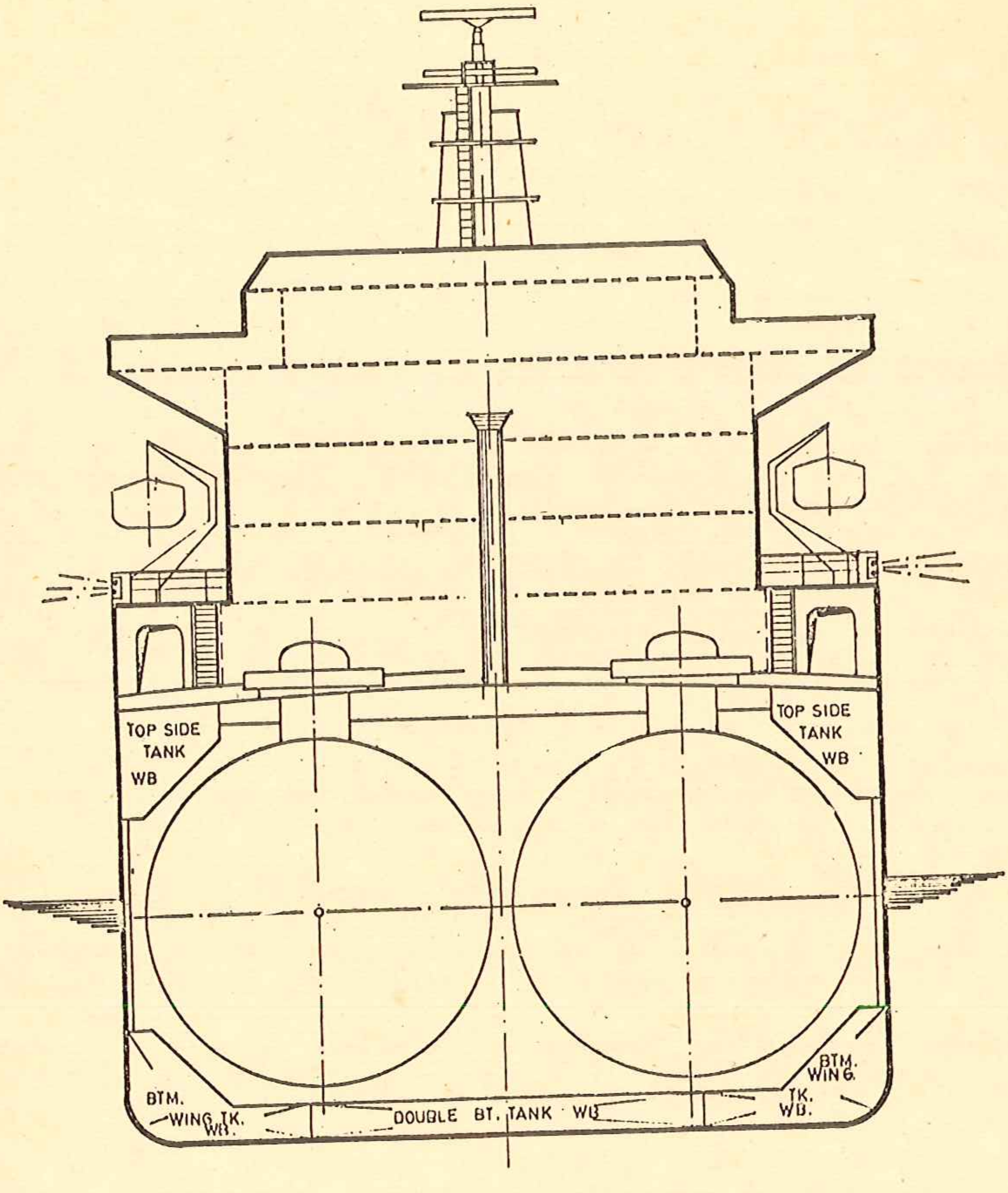


Figure 4A

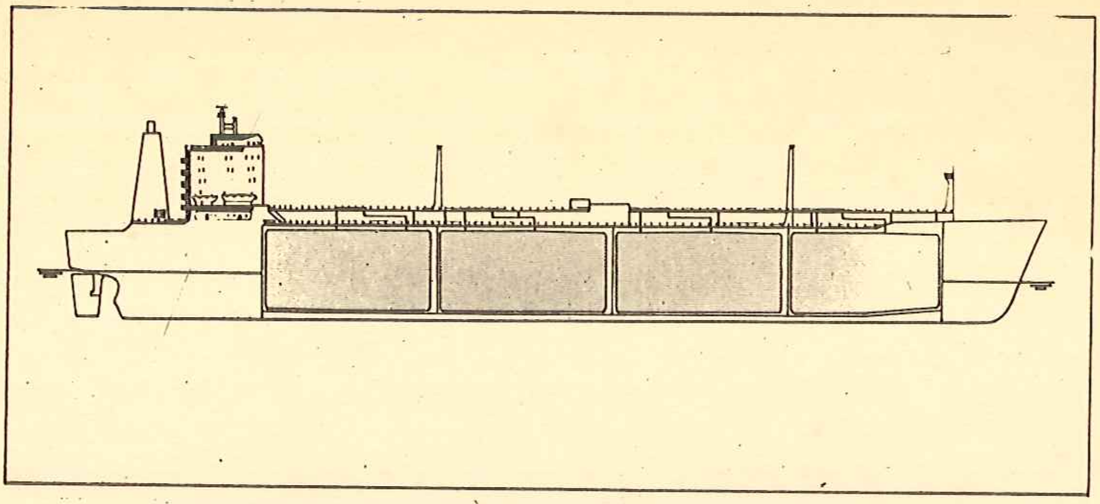
An improved, more economic and less complicated tank arrangement for a Post-IMCO Gas Code Pressure Vessel tanker of the same general type shown in Figure 4. A ship arranged as above would be ideally suited to ethylene as well as the full range of LPG's, Butane and Anhydrous Ammonia.

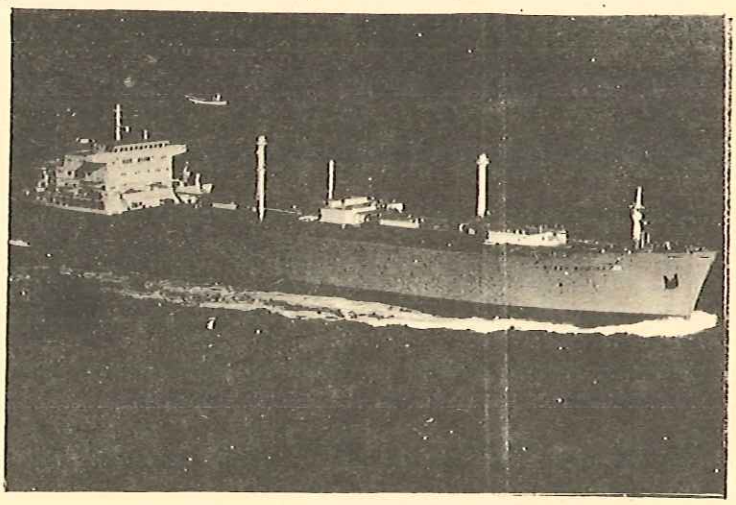
cargo at atmospheric pressure. A partial secondary barrier normally implies that the hull structure external to the cargo tank is protected from low temperatures in the event of cargo spray impingement from a small crack in the tank. The difference, therefore, between a full secondary barrier and a partial secondary barrier is that the former must be able to remain liquid tight to the cargo over relatively long periods of time, while the latter must only be able to withstand impingement of the cargo and protect the hull from unsafe low temperatures. The requirement for a partial secondary barrier may usually be met by installation of a hard surface insulation on the hull structure. Provision must also be made for safe drainage of leaked cargo into the inner bottom and discharge of that cargo either overboard or into adjacent intact cargo tanks.

Pressure vessel tanks themselves are supported in the hull on saddles which provide thermal isolation of tank from hull while permitting a certain amount of thermal movement (shrinkage) in the tank.

Prismatic gravity tank ships are normally built with double bottoms, lower side tanks (at the turn of the bilge) and under deck upper side tanks. Normally, full depth wing tanks are not needed for fuel or ballast reasons and, therefore, are not used. Figures 5 and 6 show the main characteristics of prismatic tank LPG ships.

These prismatic gravity tanks are designed for pressures of less than 0.7 kg/cm^2 gage, normally within the range 0.14 to





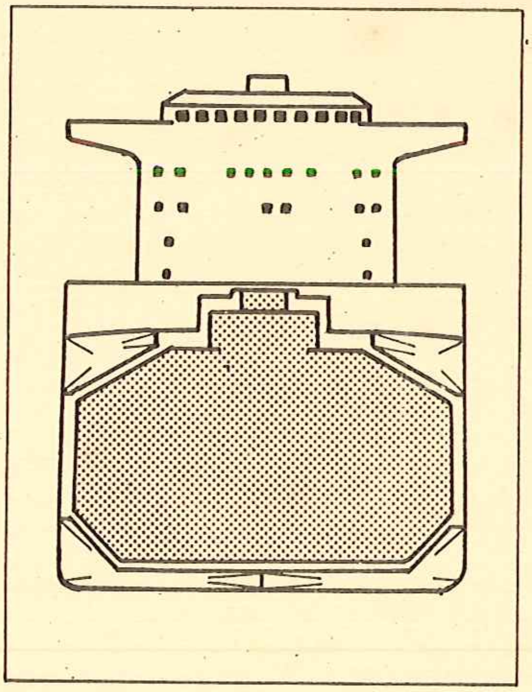
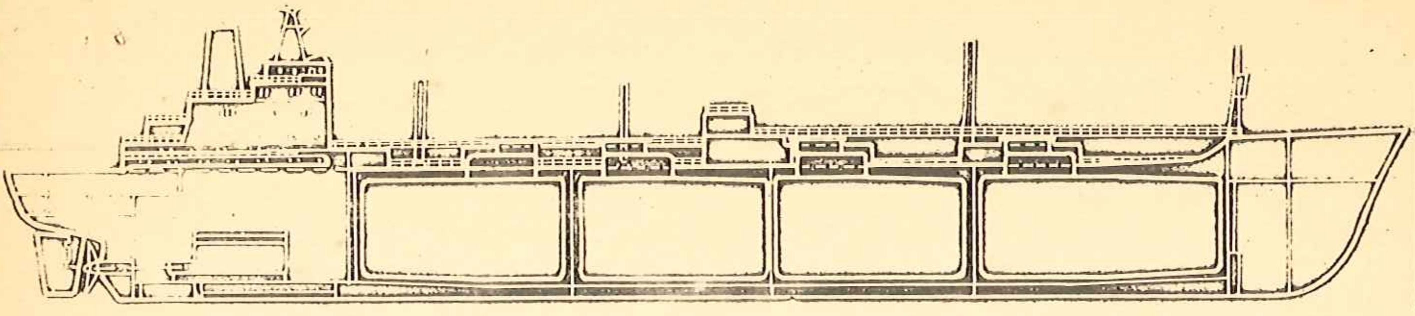


Figure 5

Typical arrangement of LPG/NH_3 tanker using independent prismatic self-supporting gravity type cargo tanks. Ships of this general configuration have been built in sizes from about 15,000M^3 to 100,000M^3. The concept is fully applicable as well to much larger ships of 200,000M^3 or more. In the center is a 52,000M^3 fully refrigerated ship of this type.



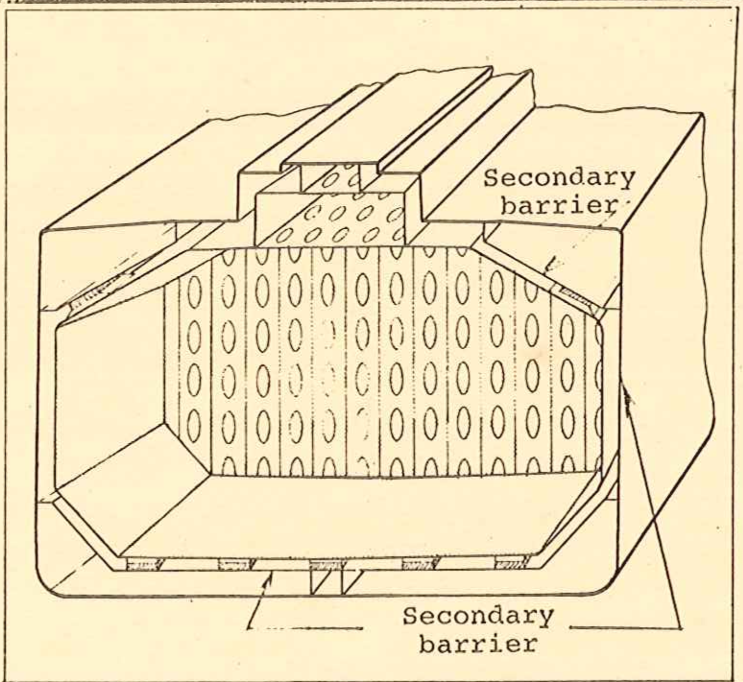
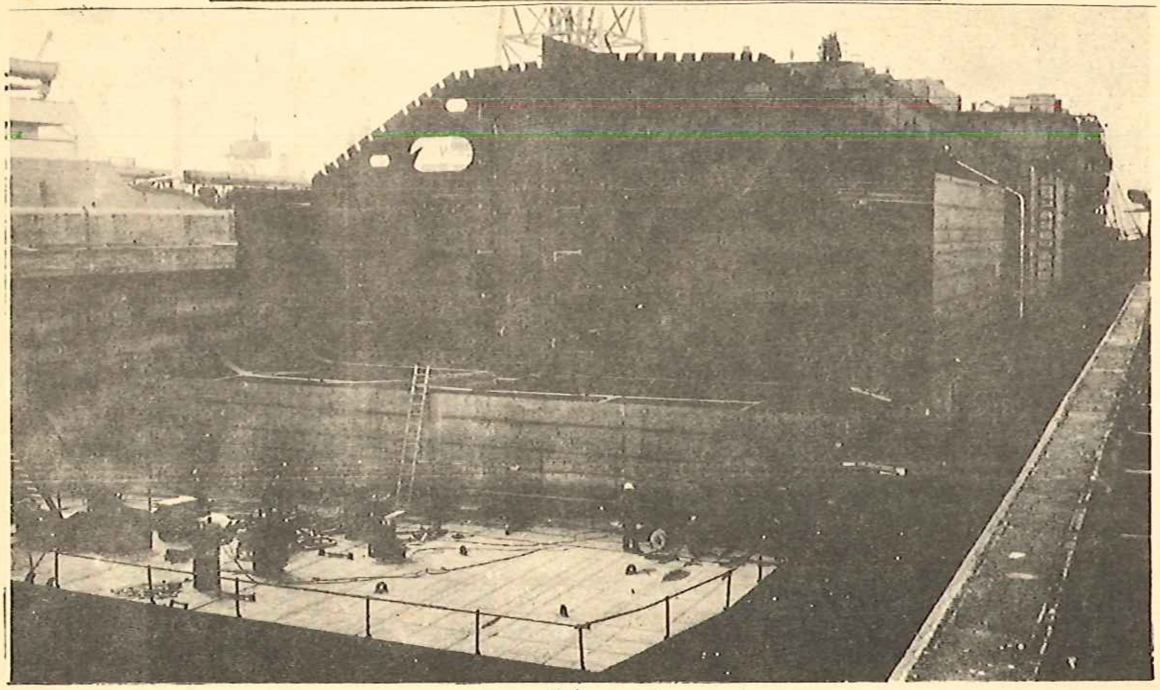


Figure 6

Construction and arrangement details of a fully refrigerated LPG tanker fitted with prismatic gravity type tanks. Note location of chocks and bottom blocks as well as extent of secondary barrier. Centerline longitudinal bulkhead appears in bottom picture. Tanks are built up in the ship as hull work proceeds.



0.28 kg/cm^2 gage, and are always of low temperature steel with allowable operating temperatures commonly down to -48°C in order to encompass as wide a range of cargoes as reasonably possible. The tanks are generally prismatic in shape, though built to conform to the gross shape of the hull, and are installed in independent holds. The tanks are supported on thermal insulating blocks from the inner bottom and are keyed or chocked to control motion longitudinally, transversely and vertically (against flotation). The system of support blocks and keys is such as to permit thermal contraction of the tanks inward and downward toward one point in each tank bottom. The cargo tanks are internally stiffened and usually divided by a longitudinal bulkhead, which is liquid tight up to the tank dome and open within the dome to equalize gas pressure on the bulkhead. Independent deep well pumps are installed in each tank half, while the longitudinal bulkhead is fitted with remote operated cross-flooding cargo valves near the pump sumps. Thus either pump may be used to discharge an entire tank. Athwartship non-tight swash bulkheads are common.

Not long ago, independent prismatic gravity tanks were designed according to ordinary classification society rules for deep tanks. With the advent of finite element and other analytical tools to improve the accuracy of stress determination in grillage structures, more rational stress analyses have been possible and these are sometimes used in establishing tank scantlings. Nevertheless, the methods are still rather rough and uncertain because boundary conditions (hull motions, tank fit-up and detail, thermal loads, etc.) are uncertain and for this reason classification societies and regulatory bodies normally require that full secondary barriers be installed outboard of the primary cargo tank. This requirement for secondary barriers around such tanks is also included in the new Recommendations of the IMCO Code for Gas Ships.

The secondary barrier must be fully capable of safely containing all of the leaked cargo from its adjacent tank over long periods of time (2 weeks or more) while, at the same time, protecting the basic integrity of the structural hull itself from too low temperatures. The secondary barrier requirement has in practice been satisfied in basically two ways:

1) with insulation on the inner hull, and
2) By using low temperature materials in those parts of the hull which could be cooled in the event of a major cargo tank internal failure.

The former method has been found difficult and expensive to adopt and today is not commonly used. In employing the latter method, large portions of both the inner and outer hulls are required to be fabricated of low temperature steels. This, of course, complicates the hull construction since these low temperature steels are more difficult to weld than ordinary hull steels and since production toughness tests are required on butt and seam welds.

Insulation on LPG tanks is extremely critical, not only from a cargo loss economic point of view but from a technical point of view, since the size and design of the cargo reliquefaction equipment are dependent on the efficiency of the insulation. The most prevalent insulation in this service today is high density closed cell polyurethane foam which is installed either in pre-cast slabs or is foamed (cast) in place directly onto the tank steel. The builder must be absolutely sure of the efficiency of the total insulation job. He must avoid convective heat leak paths as well as radiant heat leak voids throughout the system. The outside (warm side) of the insulation must be substantially moisture tight in order to avoid the possibility of water vapor in the hold space freezing out in the insulation and destroying it. In many cases, also, regulations require that the insulation be covered with a fire protective shell such as light aluminum or steel sheet, which will prevent ignition of the insulation in the event ship repair or other hot work is performed nearby.

The cargo piping system design will, of course, be determined to a large extent by the cargoes intended to be carried. Several general observations should, however, be made:

1) The system should allow for segregated carriage of at least two cargoes simultaneously. This is perhaps more important in the smaller ships than in the larger units since the smaller ships will be more likely to be called upon to meet the needs of more than one cargo terminal or shipper on a single voyage. Additionally, such segregation will allow these ships to handle small parcels of certain chemicals and chemical gases. Segregation must be complete and continuous from cargo tanks to trans-

fer piping, reliquefaction equipment, and relief valve vent masts.

2) The reliquefaction plant must have standby capacity and this requirement should be considered also in light of segregation needs. If the cargo tanks and piping are designed to be split into two independent systems, it should be possible to obtain both redundancy and segregation in the reliquefaction equipment by installing three independent refrigeration units: one for each half of the cargo system and the third for standby use in either half.

3) The cargo piping should be designed with a closed vapor system, so that on loading and discharging cargo gas may be displaced (compressed) either to shore or from shore. This will be especially important in the loading ports of the smaller ships where cargo gas discharge to the atmosphere can be expected to become more strongly regulated against.

The new IMCO Gas Code will have an effect on all LPG ships, causing design changes in newbuildings and, eventually, causing equipment and perhaps other changes even in older existing ships. Appendis I is the Table of Contents of the IMCO Gas Code, and from this we are quickly aware of the broad scope of that international recommendation. This Code is expected to be adopted by the IMCO Assembly in November of this year. The effect of the Code will probably be most pronounced on the smaller pressure vessel type ships, since according to the Code, all* new LPG ships must meet a two-compartment standard of subdivision. Appendix II is an excerpt from the Code listing the applicable damage conditions and subdivision requirements. Tables III through VII are a set of charts which summarize and compare the damage stability, survival capability and cargo tank location requirements for:

(1) International Load Line Convention, 1966.

(2) International Convention for the Prevention of Pollution from Ships, 1973.

(3) IMCO Chemical Code, 1971

(4) IMCO Gas Code, 1975.

As might be imagined, these stability requirements become more difficult to meet as ship size decreases. For this reason, pressure vessel ships, arranged as shown in Figures 1 and 2, which were extremely popular and, in fact, were the standard for many years, will gradually give way to ships with more and smaller tanks and greater compartmontation, Figures 3 and 4. Although this ad-

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*Exceptions: On vessels less than 150 meters in length, the assumed damage need not center on the engine room bulkheads. Also, for small pressure vessel ships less than 150 meters in length and with cargo tanks having design pressures of at least 7 kp/cm^2 and cargo temperature not lower than -55°C, the subdivision requirements are further relaxed. (See Appendix I, paragraph 2.5.2b)

TABLE III

EXTENT OF DAMAGE

			ILLC, 1966 (5)	ICPPS, 1973 (5)	IMCO CHEMICAL CODE	IMCO GAS CODE (5)
SIDE DAMAGE (1)	LONGITUDINAL		TWO-COMPARTMENT STANDARD (2)	1/3 $L^{2/3}$ OR 14.5m	1/3 $L^{2/3}$ OR 14.5m	1/3 $L^{2/3}$ OR 14.5m
	TRANSVERSE		B/5	B/5 OR 11.5m	B/5 OR 11.5m	B/5 OR 11.5m
	VERTICAL		FROM BASELINE UPWARD WITHOUT LIMIT	FROM BASELINE UPWARD WITHOUT LIMIT	FROM BASELINE UPWARD WITHOUT LIMIT	FROM BASELINE UPWARD WITHOUT LIMIT
	MINOR/LOCAL		NONE REQUIRED	NONE REQUIRED	760mm (3)	760mm (4)
BOTTOM DAMAGE (1)	LONGITUDINAL	FORWARD 0.3 L	NONE REQUIRED	1/3 $L^{2/3}$ OR 14.5m	L/10	1/3 $L^{2/3}$ OR 14.5m
		AFT 0.7 L	NONE REQUIRED	L/10 OR 5m	L/10 OR 5m	L/10 OR 5m
	TRANSVERSE	FORWARD 0.3 L	NONE REQUIRED	B/6 OR 10m	B/6 OR 10m	B/6 OR 10m
		AFT 0.7 L	NONE REQUIRED	5m	5m	B/6 OR 5m
	VERTICAL		NONE REQUIRED	B/15 OR 6m	B/15 OR 6m	B/15 OR 2m

(1) Where two values are given, the lesser extent applies for each specific case on a particular vessel.

(2) ILLC, 1966 does not specify a longitudinal extent of damage. However, for the assignment of a Type "A" freeboard, a two-compartment damage stability standard within the cargo length of the ship is required. The minimum bulkhead spacing is assumed to be (3.05 + 0.03L) or 10.7m, whichever is less.

(3) See tank location requirements in Table IV.

(4) See survival requirements in Table III and tank location requirements in Table IV.

(5) If a lesser extent of damage than the maximum specified would result in a more severe condition, such damage must be considered.

TABLE IV

DAMAGE LOCATIONS

ILLC, 1966

L < 225m:	TWO-COMPARTMENT DAMAGE WITHIN THE CARGO LENGTH; ENGINE ROOM NOT CONSIDERED
L > 225m:	TWO-COMPARTMENT DAMAGE WITHIN THE CARGO LENGTH AND ONE-COMPARTMENT DAMAGE FOR THE ENGINE ROOM (ENGINE ROOM CONSIDERED SEPARATELY AS A SINGLE FLOODED COMPARTMENT)

IMCO GAS CODE

TYPE IG:	DAMAGE ASSUMED ANYWHERE IN SHIP'S LENGTH, INCLUDING ENGINE ROOM. MINOR DAMAGE ASSUMED TO OCCUR ANYWHERE IN THE CARGO LENGTH.
TYPE IIG, L ≤ 150m:	DAMAGE ASSUMED ANYWHERE IN CARGO LENGTH; ENGINE ROOM CONSIDERED SEPARATELY AS A SINGLE FLOODED COMPARTMENT. MINOR DAMAGE ASSUMED TO OCCUR ANYWHERE IN THE CARGO LENGTH.
TYPE IIG, L > 150m:	DAMAGE ASSUMED ANYWHERE IN SHIP'S LENGTH, INCLUDING ENGINE ROOM. MINOR DAMAGE ASSUMED TO OCCUR ANYWHERE IN THE CARGO LENGTH.
TYPE IIPG, L ≤ 150m:	DAMAGE ASSUMED BETWEEN TRANSVERSE BULKHEADS[1/], INCLUDING ENGINE ROOM. MINOR DAMAGE ASSUMED TO OCCUR ANYWHERE IN THE CARGO LENGTH.
TYPE IIPG, L > 150m:	NO DEFINITION FOR A TYPE IIPG SHIP OVER 150m.
TYPE IIIG, L < 125m:	DAMAGE ASSUMED BETWEEN TRANSVERSE BULKHEADS[1/]; ENGINE ROOM NOT CONSIDERED. THE ABILITY TO SURVIVE FLOODING OF THE ENGINE ROOM SHOULD BE CONSIDERED BY THE ADMINISTRATION. MINOR DAMAGE ASSUMED TO OCCUR ANYWHERE IN THE CARGO LENGTH EXCEPT ON A TRANSVERSE BULKHEAD.
TYPE IIIG, L ≥ 125m:	DAMAGE ASSUMED BETWEEN TRANSVERSE BULKHEADS[1/], INCLUDING ENGINE ROOM. MINOR DAMAGE ASSUMED TO OCCUR ANYWHERE IN CARGO LENGTH EXCEPT ON A TRANSVERSE BULKHEAD.

1/SPACED GREATER THAN THE ASSUMED LONGITUDINAL EXTENT OF DAMAGE

TABLE IV (cont.)

DAMAGE LOCATIONS CONT.

ICPPS, 1973

$L \leqslant 100$	THE ADMINISTRATION MAY ALLOW RELAXATIONS FROM PARAGRAPH (3) OF REGULATION 25 (GENERAL DAMAGE STABILITY REQUIREMENTS)
$L \leqslant 150m$:	DAMAGE ASSUMED BETWEEN TRANSVERSE BULKHEADS;[1/] ENGINE ROOM NOT CONSIDERED
$150m < L \leqslant 225m$:	DAMAGE ASSUMED ANYWHERE IN THE SHIP'S LENGTH EXCEPT THE ENGINE ROOM; ENGINE ROOM CONSIDERED SEPARATELY AS A SINGLE FLOODED COMPARTMENT
$L > 225m$:	DAMAGED ASSUMED ANYWHERE IN THE SHIP'S LENGTH, INCLUDING THE ENGINE ROOM

IMCO CHEMICAL CODE

TYPE I:	DAMAGE ASSUMED ANYWHERE IN SHIP'S LENGTH, INCLUDING THE ENGINE ROOM
TYPE II, $L \leqslant 150m$:	DAMAGE ASSUMED ANYWHERE IN CARGO LENGTH; ENGINE ROOM CONSIDERED SEPARATELY AS A SINGLE FLOODED COMPARTMENT
TYPE II, $L \geqslant 150m$:	DAMAGE ASSUMED ANYWHERE IN SHIP'S LENGTH, INCLUDING THE ENGINE ROOM
TYPE III, $L < 125m$:	DAMAGE ASSUMED ANYWHERE IN CARGO LENGTH; ENGINE ROOM NOT CONSIDERED. THE ADMINISTRATION WILL DETERMINE THE SHIP'S ABILITY TO SURVIVE FLOODING OF THE ENGINE ROOM.
TYPE III, $L \geqslant 125m$:	DAMAGE ASSUMED ANYWHERE IN CARGO LENGTH; ENGINE ROOM CONSIDERED SEPARATELY AS A SINGLE FLOODED COMPARTMENT

[1/] SPACED GREATER THAN THE ASSUMED LONGITUDINAL EXTENT OF DAMAGE

TABLE V

SURVIVAL CAPABILITY REQUIREMENTS

	ILLC, 1966	ICPPS, 1973	IMCO CHEMICAL CODE	IMCO GAS CODE
MAXIMUM ANGLE OF HEEL AFTER DAMAGE	15°, OR 17° IF NO DECK EDGE IMMERSION	25°, OR 30° IF NO DECK EDGE IMMERSION	15°, OR 17° IF NO DECK EDGE IMMERSION (1)	30° (2)
RESIDUAL STABILITY AFTER DAMAGE	THE DAMAGED RIGHTING ARM CURVE MUST BE POSITIVE FOR 20° BEYOND THE FINAL EQUILIBRIUM ANGLE WITH A MAXIMUM RIGHTING ARM OF AT LEAST 100mm WITHIN THIS RANGE.			
STABILITY UPRIGHT AFTER FLOODING	GM $\geqslant$ 50mm	NONE	NONE	SEE NOTE (3)
MINOR/LOCAL DAMAGE	NONE	NONE	NONE	30° (4)

(1) L < 150m: The Administration can accept maximum angles of heel after damage up to 25°, provided it is positively shown that a lesser angle is not attainable.

L > 150m: 15°, or 17° if no deck edge immersion.

(2) At the final angle of heel, the emergency power supply must be capable of operating, and lifesaving appliances must be capable of operating from at least the low side.

(3) Equalization arrangements requiring mechanical aids are not to be considered for the purpose of reducing an angle of heel to meet S 2.4.1 and 2.4.2 (survival requirements); and if used, positive stability is to be maintained during all stages of equalization.

(4) Under local damage conditions of 760mm, the angle of heel must not reach that angle which would prohibit the restoration of propulsion and steering engine power at reduced speed and the use of the ballast system.

TABLE VI

TANK LOCATION REQUIREMENTS

ILLC, 1966

none

ICPPS, 1973

none

IMCO CHEMICAL CODE

TYPE I:	B/5 OR 11.5m, WHICHEVER IS LESS, FROM THE SIDE SHELL AT THE SUMMER LOAD LINE; AND B/15 OR 6m, WHICHEVER IS LESS, FROM BASELINE NOWHERE CLOSER THAN 760mm TO SHELL PLATING
TYPE II:	B/15 OR 6m, WHICHEVER IS LESS, FROM BASELINE; AND 760mm INBOARD FROM SHIP'S SIDE AT RIGHT ANGLES TO THE SUMMER LOAD LINE
TYPE III:	NONE

IMCO GAS CODE

TYPE IG:	B/5 OR 11.5, WHICHEVER IS LESS, FROM THE SIDE SHELL AT THE SUMMER LOAD LINE; AND B/15 OR 2m, WHICHEVER IS LESS, FROM BASELINE NOWHERE CLOSER THAN 760mm TO SHELL PLATING
TYPE IIG:	B/15 OR 2m, WHICHEVER IS LESS, FROM BASELINE; AND NOWHERE CLOSER THAN 760mm TO SHELL PLATING
TYPE IIPG:	SAME AS TYPE IIG
TYPE IIIG:	SAME AS TYPE IIG

TABLE VII

PERMEABILITY ASSUMPTIONS

ILLC, 1966

EMPTY COMPARTMENTS	0.95
MACHINERY SPACE	0.85
CARGO TANKS	0 TO 0.95*

*CONSISTENT WITH THE AMOUNT OF LIQUID CARRIED

ICPPS, 1973

APPROPRIATED TO STORES	0.60
OCCUPIED BY ACCOMMODATIONS	0.95
OCCUPIED BY MACHINERY	0.85
VOIDS	0.95
INTENDED FOR CONSUMABLE LIQUIDS	0 OR 0.95*
INTENDED FOR OTHER LIQUIDS	0 TO 0.95**

*WHICHEVER RESULTS IN THE MORE SEVERE REQUIREMENTS

**THE PERMEABILITY OF PARTIALLY-FILLED COMPARTMENTS SHALL BE CONSISTENT WITH THE AMOUNT OF LIQUID CARRIED.

IMCO CHEMICAL CODE

MACHINERY SPACE	0.85

THE PERMEABILITY OF OTHER SPACES SUBJECT TO FLOODING SHOULD BE DETERMINED AS TO REFLECT THE LIMITATIONS OF CARGO, FUEL, OR BALLAST LOADED.

IMCO GAS CODE

SAME AS ICPPS, 1973

ditional subdivision absolutely has an effect on ship capital cost, it is not an unmixed blessing. The owner can be rewarded with a highly versatile and flexible ship, provided great care and, above all, experience in this specialized field, are brought to bear on the questions of:

Tank size,

Tank design pressure and temperature,

Cargo system segregation,

Equipment of the cargo piping and cargo handling system.

In experienced design hands, the vessel need not be just another LPG tanker, but rather a mobile gas/chemical process plant.

Now where does this lead us concerning that segment of today's LPG fleet which is small (less than 5,000M^3 each ship), old and, at best, only partially refrigerated. These ships will have to be replaced gradually in the not too distant future -- but with what? In many cases, while the local distribution/storage (receiving) terminals may gradually have increased in size, they still use pressurized, non-refrigerated or semi-refrigerated tanks. At the same time, the production (shipping) terminals and main centralized marine terminals will almost all have converted to fully refrigerated, near ambient pressure storage. Therefore, the ships will have to load fully refrigerated cargo and either discharge at the same cargo conditions or discharge warmed-up product to semi or fully pressurized storage.

Based on this background, we can begin to forecast the characteristics of the replacement ships for the older LPG fleet segment:

1) They will probably be not a great deal larger in volume than their predecessors, the bulk being 4,000M^3 to 10,000M^3 capacity in order to fit the trade restraints of harbor draft and terminal size.

2) They will be fitted with fully refrigerated cargo plants, with tanks built to withstand some modest pressure up to, perhaps, the region of 2.8 kp/cm^2.

3) Cargo handling systems will be more sophisticated than previously seen in order to allow carriage of several cargoes simultaneously, including even incompatible cargoes simultaneously. Cargo plants will be designed to handle a wide range of gases, probably including chemicals.

4) They will be designed to satisfy the requirements of the new IMCO Gas Code. The IMCO Chemical Code, which was adopted by Resolution of the IMCO Assembly in 1971 will also play a part in the design of some ships, depending on the intended cargo list. These Codes will be especially influential in areas of subdivision and damage stability, cargo tank scantlings and materials, cargo piping system arrangement, and fire protection/fire fighting systems.

The new generation of small LPG ships will obviously cost very much more than their predecessors but they will be more versatile, more complex and sophisticated (perhaps even running with smaller crews) and certainly more safe.

Because of their size, these ships will be capable of being built in certain of the shipyards of South America. Highly production oriented (series production) shipyards are not especially well suited to the construction of this type tonnage, because the ships usually will not be contracted in series and the complexity of the cargo systems does not lend itself to the production scheduling needed in high capacity yards. A successful LPG tanker yard must be flexible in management, in engineering and in production. The depth and scope of engineering talent needed for both design and production in an LPG newbuilding yard is significantly greater than in most ordinary shipyards. It would be highly beneficial and prudent for any shipyard contemplating entering into this type production to align itself in a working relationship with an experienced, successful shipyard presently specializing in the field.

In light of the ever-increasing volumes of liquefied gases and ehcmicals which will flow through the ports of South America in the years soon ahead, and in view of the near term need for large numbers of small tankers to carry those cargoes, today is certainly the time to begin planning for domestic production of these ships.

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APPENDIX I

CODE FOR THE CONSTRUCTION AND EQUIPMENT OF SHIPS CARRYING LIQUEFIED GASES IN BULK

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APPENDIX II

SUBDIVISION AND DAMAGED STABILITY REQUIREMENTS FROM IMCO DRAFT CODE FOR THE CONSTRUCTION AND EQUIPMENT OF SHIPS CARRYING LIQUEFIED GASES IN BULK

(IMCO Document DE XIII/12 prepared in May 1975)

2.3 Damage and Flooding Assumptions

2.3.1 The following permeability factors should be applied to spaces assumed to be flooded:

Appropriated to stores	0.60
Occupied by accommodation	0.95
Occupied by machinery	0.85
Void	0.95
Intended for consumable liquids	0 or 0.95*
Intended for other liquids	0 or 0.95**

* Whichever results in the more severe requirements

** The permeability of partially filled compartments should be consistent with the amount of liquid carried.

Wherever damage penetrates a cargo tank, it should be assumed that the cargo is completely lost from that compartment and replaced by salt water up to the level of the final plane of equilibrium.

2.3.2 Assumed maximum extent of damage:

(a) Side damage:

(i) Longitudinal extent: $\frac{1}{3} L^{2/3}$ or 14.5m whichever is less.

(ii) Transverse extent: (inboard from the ship's side at right angles to the center line at the level of the summer load line) $\frac{B}{5}$ or 11.5m whichever is less.

(iii) Verticle extent: from the base line upwards without limit.

(b) Bottom damage:

	For 0.3L from the forward perpendicular of the ship	Any other part of the ship
(i) Longitudinal extent:	$\frac{1}{3}L^{2/3}$ or 14.5m whichever is less.	$\frac{L}{10}$ or 5m whichever is less.
(ii) Transverse extent:	$\frac{B}{6}$ or 10.0m whichever is less.	$\frac{B}{6}$ or 5m whichever is less.
(iii) Vertical extent:	$\frac{B}{15}$ or 2m whichever is less, measured from the moulded line of the shell at the center line.	$\frac{B}{15}$ or 2m whichever is less, measured from the moulded line of the shell at the center line.

(3) If any damage of a lesser extent than the maximum specified would result in a more severe condition, such damage should be considered.

2.4 Survival Requirements

2.4.1 Ships subject to the Code should be capable of surviving the damage assumed in 2.3 to the extent provided in 2.5 in a condition of stable equilibrium and should satisfy the following criteria.

(a) In any stage of flooding:

(i) The waterline taking into account sinkage, heel and trim should be below the lower edge of any opening through which progressive or down flooding may take place. Such openings should include air pipes and those which are closed by means of weathertight doors or hatch covers and may exclude those openings closed by means of watertight manhole covers and watertight flush scuttles, small watertight cargo tank hatch covers which maintain the high integrity of the deck, remotely operated watertight sliding doors, and side scuttles of the non-opening type. Credit may be given to any portion of the structure which remains watertight above or below the freeboard deck.

(ii) Where damage produces an angle of heel, the maximum angle at any stage of flooding should not exceed 30°.

(iii) The Administration should be satisfied that the residual stability is sufficient.

(b) In the final stage of flooding:

(i) The righting lever curve has a minimum range of 20° beyond the position of equilibrium in association with a maximum righting lever of at least 100 mm within this range. Unprotected openings should not be immersed with the minimum range of residual stability required unless the space concerned is included in damage stability calculations as a floodable space. Within this range the immersion of all openings listed in 2.4.1(a)(i) and others capable of being closed weathertight may be permitted.

(ii) The lifesaving devices should be capable of operating at the final angle of heel from the lower side of the vessel.

(iii) The emergency power supply should be capable of operating at the final angle of heel.

2.4.2 Under local damage conditions in the cargo area, extending in 760mm measured normal to the hull shell and which for a Type IG ship and a Type IIG/IIPG ship in accordance with 2.5.1 or 2.5.2(a) and (b) respectively, may occur on a transverse watertight bulkhead, the maximum angle of heel should in no case exceed that applicable under 2.4.1(a)(ii), and should not reach that angle which would prohibit the restoration of propulsion and steering engine power at reduced speed and the use of the ballast system.

2.4.3 The ship design should ensure that the possibility of hull damage causing asymmetrical flooding is kept to the minimum consistent with efficient arrangements. Equalization arrangements requiring mechanical aids such as valves or cross-leveling pipes, if fitted, should not be considered for the purpose of reducing an angle of heel or attaining the minimum range of stability to meet the requirements of 2.4.1 and 2.4.2, and if used sufficient residual stability should be maintained during all stages of equalization. Spaces which are linked by ducts of large cross-sectional area may be considered to be common.

2.5 Standard of damage to be applied

Ships subject to this Code should be designed and constructed so as to be capable of sustaining the damage indicated in 2.3 in the manner stated in 2.4 to the following standards:

2.5.1 All Type IG ships should be capable of sustaining damage anywhere in their lengths.

2.5.2(a) A Type IIG ship of more than 150m in length should be capable of sustaining damage anywhere in her length;

(b) A Type IIG ship of 150m or less in length should be capable of sustaining damage anywhere in her length except involving either of the bulkheads bounding a machinery space located aft;
alternatively, a Type IIG ship of 150m or less in length with independent tanks Type C designed for a MARVS of at least 7 kp/cm^2 and the design temperature of the cargo containment system is not below -55°C, need only be capable of sustaining damage anywhere in her length except involving transverse bulkheads spaced further apart than the longitudinal extent of damage as specified in 2.3.2(a)(i). Such a ship should be designated as a Type IIPG ship and so indicated on the Certificate of Fitness provided for in 1.6.

2.5.3(a) A Type IIIG ship of 125m in length and over should be capable of sustaining damage anywhere in her length except involving transverse bulkheads spaced further apart than the longitudinal extent of damage specified in 2.3.2(a)(i).

(b) A Type IIIG ship below 125m in length should be capable of sustaining damage anywhere in her length except involving transverse bulkheads spaced further apart than the longitudinal extent of damage specified in 2.3.2(a)(i) and except involving damage to the machinery space. However, the ability to survive flooding of the machinery space should be considered by the Administration.

2.5.4 Where the damage between adjacent transverse watertight bulkheads is envisaged as specified in 2.5.2(b) and 2.5.3, a main transverse bulkhead or a transverse bulkhead bounding side tanks or double bottom tanks should be assumed damaged if there is a step or a recess in a transverse bulkhead of more than 3.05m in length, located within the extent of penetration of assumed damage. The step formed by the after peak bulkhead and after peak tank top should not be regarded as a step for the purpose of this paragraph.

2.6 Location of Cargo Tanks

2.6.1 Cargo tanks should be located at the following minimum distances inboard:

(a) Type IG ships: from the side shell plating not less than the transverse extent of damage specified in 2.3.2 (a)(ii) and from the moulded line of the bottom shell plating at center line not less than the vertical extent of damage specified in 2.3.2(b)(iii), and nowhere less than 760mm from the shell plating.

(b) Types IIG/IIPG and IIIG ships: from the moulded line of the bottom shell plating at center line not less than the vertical extent of damage specified in 2.3.2(b)(iii) and nowhere less than 760mm from the shell plating.

2.6.2. For the purpose of tank location, the vertical extent of damage should be measured to the inner bottom when membrane or semi-membrane tanks are used, otherwise to the bottom of the cargo tanks. The transverse extent of damage should be measured to the longitudinal bulkhead when membrane or semi-membrane tanks are used, otherwise to the side of the cargo tanks.

2.6.3 Except for Type IG ships, suction wells installed in cargo tanks may protrude into the area of bottom damage provided that such wells are as small as practicable and the penetration does not exceed 25% of double bottom height or 350mm whichever is less.

2.6.4 Solid ballast should not normally be used in double bottom spaces in the cargo areas. Where, however, because of stability considerations, the fitting of solid ballast in such spaces becomes unavoidable, then the quantity and its disposition should be governed by the need to ensure that the impact loads resulting from bottom damage are not directly transmitted on to the cargo tank structure.

2.7 Special consideration for small ships

2.7.1 In the case of small ships intended for the carriage of products requiring Type IIG/IIPG ships and Type IIIG ships which do not comply in all respects with the appropriate requirements of 2.5.2 and 2.5.3, special dispensations may only be considered by the Administration where alternate measures can be taken which maintain the same degree of safety.

2.7.2 In the approval of the design of a ship for which a dispensation has been granted, the nature of the alternate measures prescribed should be clearly stated and be available to the Administration in the countries the ship will visit and any such dispensation should be duly noted on the Certificate of Fitness referred to in 1.6.

APPENDIX III

REPRESENTATIVE MAIN PARTICULARS FOR LPG/CHEMICAL/LNG TANKERS

Capacity & Cargo	LBP (m)	B (m)	D (m)	Full Load Draft (m)	Main Engine BHP (metric)	Trial Speed (kts)	Comments
				LPG			
2,570M^3 LPG/NH_3	79.5	14.7	7.05	4.80 LPG	2,480	13.7	Fitted with 4 pressure vessel tanks to meet new IMCO Gas Code. This tank configuration would also be useful for ethylene.
4,100M^3 LPG/NH_3/ Ethylene	93	16.5	9.45	5.79 Ethylene	4,000	14.8	Fitted with 6 pressure vessel tanks to satisfy new IMCO Gas Code. (See Fig. 3)
12,000M^3 LPG/NH_3/ Ethylene	127.4	20.5	11.9	7.8 LPG	9,900	17.8	A recent Pre-IMCO Gas Code ship fitted with 4 pressure vessel tanks, similar to the ship shown in Figs. 1 & 2.
15,000M^3 LPG/NH_3	140	25	14.25	7.2 LPG	10,000	17.3	Ship fitted with 7 pressure vessel tanks to satisfy the new IMCO Gas Code. Tanks arranged similar to those shown in Fig. 4, with midship section as in Fig. 4A. Arrangement well suited for ethylene.
22,000M^3 LPG/NH_3	155	23	15.5	9.4 LPG	14,600	17	Ship fitted with 4 each prismatic, self-supporting gravity tanks, similar to the arrangement shown in Figs. 5 & 6.
52,000M^3 LPG/NH_3	196	31.4	18.6	11.34 LPG	20,300	17.6	Fitted with 4 prismatic, self-supporting gravity tanks. This is the ship pictured in the center of Fig. 5.

APPENDIX III (cont.)

Capacity & Cargo	LBP (m)	B (m)	D (m)	Full Load Draft (m)	Main Engine BHP (metric)	Trial Speed (kts)	Comments
				LNG			
29,000M^3 LNG/Ethylene/ LPG	171	29	16.5	8.35 LNG	20,000	19.2	A combination liquefied gas carrier suitable for LNG, fitted with 4 spherical pressure vessel type tanks.
87,600M^3 LNG	237	40	23	10.45 LNG	30,000	19.2	An LNG tanker fitted with 5 spherical tanks.
125,000M^3 LNG	282	41.6	25	11.50 LNG	40,000	19.7	An LNG tanker fitted with 6 spherical tanks.
165,000M^3 LNG	290	48	27	11.6 LNG	60,000	22	An LNG tanker fitted with 5 spherical tanks.