

程》第十五條第二款及第三款、第十六條及第二十五條第一款至第三款的規定，作出本批示。

一、續任下列人士為澳門樂團有限公司董事會成員，任期一年：

（一）梁惠敏，並由其擔任董事長；

（二）許健華。

二、續任陳家耀為澳門樂團有限公司董事會成員，任期至二零二六年七月十八日止。

三、續任下列人士為澳門樂團有限公司監事會成員，任期一年：

（一）杜慧芳，並由其擔任主席；

（二）麥詠珠。

四、委任林興隆為澳門樂團有限公司監事會成員，任期一年。

五、本批示第一款（一）項、第二款，以及第三款（二）項所指成員以兼任方式擔任有關職務。

六、本批示自二零二六年一月二十四日起產生效力。

二零二五年十二月三十一日

行政長官 岑浩輝

artigo 16.º e dos n.ºs 1 a 3 do artigo 25.º dos Estatutos da Sociedade Orquestra de Macau, Limitada, o Chefe do Executivo manda:

1. São renovadas as nomeações dos seguintes, como membros do Conselho de Administração da Sociedade Orquestra de Macau, Limitada, pelo período de um ano:

1) Leong Wai Man, que preside;

2) Hoi Kin Wa.

2. É renovada a nomeação de Chan Ka Io, como membro do Conselho de Administração da Sociedade Orquestra de Macau, Limitada, até 18 de Julho de 2026.

3. São renovadas as nomeações dos seguintes, como membros do Conselho Fiscal da Sociedade Orquestra de Macau, Limitada, pelo período de um ano:

1) Tou Wai Fong, que preside;

2) Mak Weng Chu.

4. É nomeado Lam Heng Long, como membro do Conselho Fiscal da Sociedade Orquestra de Macau, Limitada, pelo período de um ano.

5. Os membros referidos na alínea 1) do n.º 1, no n.º 2 e na alínea 2) do n.º 3 do presente despacho exercem as suas funções em regime de acumulação de funções.

6. O presente despacho produz efeitos a partir de 24 de Janeiro de 2026.

31 de Dezembro de 2025.

O Chefe do Executivo, *Sam Hou Fai*.

第 23/2025 號行政長官公告

國際海事組織海上安全委員會於二零一五年六月十一日透過第MSC.391 (95) 號決議通過了《國際使用氣體或其他低閃點燃料船舶安全規則》（《國際氣體燃料規則》），該規則已於二零一七年一月一日在國際法律秩序上生效，包括對澳門特別行政區生效；

基於此，行政長官根據第3/1999號法律《法規的公佈與格式》第五條（一）項和第六條第一款的規定，命令公佈國際海

Aviso do Chefe do Executivo n.º 23/2025

Considerando que, em 11 de Junho de 2015, o Comité de Segurança Marítima da Organização Marítima Internacional (OMI), através da resolução MSC.391(95), adoptou o Código Internacional para a Segurança dos Navios que utilizam Gases ou outros Combustíveis com Baixo Ponto de Inflamação (Código IGF), e que tal Código entrou em vigor na ordem jurídica internacional, incluindo a Região Administrativa Especial de Macau, em 1 de Janeiro de 2017;

O Chefe do Executivo manda publicar, nos termos da alínea 1) do artigo 5.º e do n.º 1 do artigo 6.º da Lei n.º 3/1999 (Publicação e formulário dos diplomas), o referido Código IGF adoptado pelo Comité de Segurança Marítima da OMI através da resolução

事組織海上安全委員會透過第MSC.391（95）號決議通過的上
指《國際氣體燃料規則》的中文和英文正式文本。

MSC.391(95), nos seus textos autênticos em línguas chinesa e
inglesa.

二零二五年十二月二十六日發佈。

Promulgado em 26 de Dezembro de 2025.

行政長官 岑浩輝

O Chefe do Executivo, *Sam Hou Fai*.

第 MSC.391 (95) 號決議

(2015 年 6 月 11 日通過)

通過《國際氣體或其他低閃點燃料動力船舶安全規則》 (《氣體燃料規則》)

海上安全委員會，

憶及《國際海事組織公約》關於本委員會職能的第二十八條第(二)款，

認識到對使用氣體或其他低閃點燃料船舶的強制性規則的必要性，

注意到第 MSC.392 (95) 號決議，經該決議，委員會特別地通過了對《1974 年國際海上人命安全公約》(公約)第 II-1、II-2 章及附件附錄的修正案，以使《國際氣體或其他低閃點燃料動力船舶安全規則》(《氣體燃料規則》)的規定根據公約具有強制性，

在其第九十五屆會議上，審議了《國際氣體或其他低閃點燃料動力船舶安全規則》草案，

- 1 通過《氣體燃料規則》，其文本載於本決議附件之中；
- 2 請各公約締約政府注意，《氣體燃料規則》將自 2017 年 1 月 1 日，在公約第 II-1、II-2 章和附件附錄修正案生效時具有效力；
- 3 還請各締約政府考慮，儘實際可行地對不足 500 總噸的使用氣體或其他低閃點燃料的貨船自願地應用《氣體燃料規則》；

- 4 認識到，對增加的低閃點燃料的要求，將在本組織予以制定後加入《氣體燃料規則》；
- 5 要求本組織秘書長將本決議和附件中所含《氣體燃料規則》文本的核證無誤副本，散發給所有公約締約國政府；
- 6 還要求本組織秘書長將本決議和附件中所含《氣體燃料規則》文本的副本散發給本組織所有非《安全公約》締約國政府的會員國。

附件

國際氣體或其他低閃點燃料動力船舶安全規則》

（《氣體燃料規則》）

目 錄

1	前言
A 部分	
2	通則
2.1	適用範圍
2.2	定義
2.3	替代設計
3	目標和功能要求
3.1	目標
3.2	功能要求
4	一般要求
4.1	目標
4.2	風險評估
4.3	爆炸後果限制
A-1 部分	對使用天然氣燃料船舶的特殊要求
5	船舶的設計和佈置

- 5.1 目標
- 5.2 功能要求
- 5.3 一般規定
- 5.4 機器處所的概念
- 5.5 燃氣安全機器處所規定
- 5.6 應急切斷（ESD）保護機器處所規定
- 5.7 燃料管系的位置和保護規定
- 5.8 燃料準備艙設計規定
- 5.9 艙底系統規定
- 5.10 滴盤規定
- 5.11 圍閉處所入口和其他開口佈置規定
- 5.12 空氣閘規定
- 6 燃料圍護系統
- 6.1 目標
- 6.2 功能要求
- 6.3 一般規定
- 6.4 液化氣燃料圍護系統規定
- 6.5 可移動液化氣體燃料艙規定
- 6.6 壓縮氣體燃料圍護規定
- 6.7 壓力釋放系統規定
- 6.8 液化氣燃料艙充裝極限規定
- 6.9 燃料儲存條件的維護規定
- 6.10 燃料儲存系統內大氣控制規定
- 6.11 燃料儲存艙處所（除 C 型獨立液艙外的燃料圍護系統）內大氣

控制規定

- 6.12 C 型獨立液艙周圍處所的大氣控制規定
- 6.13 惰化規定
- 6.14 船上惰性氣體的製造和儲存規定
- 7 材料和總管路設計
 - 7.1 目標
 - 7.2 功能要求
 - 7.3 總管路設計規定
 - 7.4 材料規定
- 8 加注燃料
 - 8.1 目標
 - 8.2 功能要求
 - 8.3 燃料加注站規定
 - 8.4 集管規定
 - 8.5 燃料加注系統規定
- 9 設備燃料供應
 - 9.1 目標
 - 9.2 功能要求
 - 9.3 燃料供應冗餘規定
 - 9.4 燃氣供應系統安全功能規定
 - 9.5 機器處所外燃料分佈規定
 - 9.6 燃氣安全機器處所內設備燃料供應規定
 - 9.7 應急切斷（ESD）保護機器處所內設備氣體燃料供應規定
 - 9.8 通風管道和防止內部管路燃氣泄漏的外部管路設計規定

- 9.9 壓縮機和泵規定
- 10 包括推進和其他燃氣設備的動力產生
 - 10.1 目標
 - 10.2 功能要求
 - 10.3 活塞式內燃機規定
 - 10.4 主輔鍋爐規定
 - 10.5 燃氣輪機規定
- 11 消防安全
 - 11.1 目標
 - 11.2 功能要求
 - 11.3 防火規定
 - 11.4 消防總管規定
 - 11.5 噴水系統規定
 - 11.6 化學乾粉滅火系統規定
 - 11.7 火災探測和報警系統規定
- 12 防爆
 - 12.1 目標
 - 12.2 功能要求
 - 12.3 一般規定
 - 12.4 區域分級規定
 - 12.5 危險區域範圍
- 13 通風
 - 13.1 目標
 - 13.2 功能要求

13.3 一般規定

13.4 液艙連接處所規定

13.5 機器處所規定

13.6 燃料準備艙規定

13.7 燃料加注站規定

13.8 管道和雙套管規定

14 電氣裝置

14.1 目標

14.2 功能要求

14.3 一般規定

15 控制、監測和安全系統

15.1 目標

15.2 功能要求

15.3 一般規定

15.4 加注和液化氣體燃料艙監測規定

15.5 加注控制規定

15.6 燃氣壓縮機的監測規定

15.7 燃氣發動機的監測規定

15.8 燃氣探測規定

15.9 失火探測規定

15.10 通風規定

15.11 燃料供應系統安全功能規定

附件 新穎構成燃料圍護系統設計中極限狀態方法使用標準

B-1 部分

16 製造、工藝和試驗

16.1 通則

16.2 一般試驗規定和規範

16.3 燃料圍護系統金屬材料的焊接和無損探傷

16.4 金屬材料構造的其他規定

16.5 試驗

16.6 焊接、焊後熱處理和無損傷試驗

16.7 試驗要求

C-1 部分

17 演習和應急演練

18 操作

18.1 目標

18.2 功能要求

18.3 維護規定

18.4 加注燃料操作規定

18.5 圍閉處所進入規定

18.6 燃料系統的惰化和驅氣規定

18.7 燃料系統上或附近的熱工規定

附件 液化天然氣裝艙單

D 部分

19 培訓

19.1 目標

19.2 功能要求

1 前言

本規則的目的是為《國際氣體船規則》沒有涵蓋的、使用低閃點燃料的船舶提供一個國際標準。

本規則的基本原則是針對所涉及燃料的性質，對使用低閃點燃料的機器、設備和系統的佈置、安裝、控制和監控提供強制規定，以儘力減少對船舶、船員和環境的風險。

在制定本規則的整個過程中，認識到本規則必須基於完善的造船和工程原理，以及對當前操作經驗、現場數據和研發的充分了解。由於新燃料技術的迅速發展，本組織將考慮到經驗和技術的發展，定期地對本規則進行審核。

本規則論及使用低閃點燃料需要特殊考慮的所有方面。氣體燃料規則以目標型方法制定（第 MSC.1/Circ.1394 號通函），因此為每章規定有了目標和功能要求，以構成設計、建造和操作的基礎。

本規則的當前版本包括滿足天然氣燃料功能要求的規定。對其他低閃點燃料的規定將在本組織制定後納入本規則。

同時，對於其他低閃點燃料，必須通過替代設計證明其符合本規則的功能要求。

A 部分

2 總則

2.1 適用範圍

除另有明文規定外，本規則適用於《安全公約》第 II-1 章 G 部分所適用的船舶。

2.2 定義

除以下另有說明外，定義與《安全公約》第 II-2 章相同。

2.2.1 事故係指可能造成死亡、人身傷害、環境破壞或財產和經濟利益損失的失控事件。

2.2.2 船寬 (B) 係指在最深吃水處 (夏季載重線吃水) 或以下的船舶最大寬度 (參閱《安全公約》第 II-1/2.8 條)。

2.2.3 加注燃料係指將液體或氣體燃料從陸上或浮動設備轉移到船舶永久艙或將可移動艙與燃料供應系統連接。

2.2.4 認證安全類型係指由經主管機關認可的有關當局或代其行事的經認可組織根據認可標準所認證的在易燃氣體環境中操作為安全的電氣設備。

2.2.5 CNG 係指壓縮天然氣 (另見 2.2.26)

2.2.6 控制站係指《安全公約》第 II-2 章中定義的處所，以及在本規則中，指機艙控制室。

2.2.7 材料選擇的設計溫度係指可在液化氣燃料艙中裝載或運輸液化氣燃料的最低溫度。

2.2.8 設計蒸汽壓力 “ P_0 ” 是船艙設計中使用的船艙頂部的最大測量壓力。

2.2.9 雙隔斷和放氣閥係指管路中一套串聯的兩個閥門和第三個，使壓力能夠從這兩個閥門之間的管路中釋放的閥門。此佈置也可由一個兩通閥和一個截止閥組成，而不是三個單獨的閥門。

2.2.10 雙燃料發動機係指使用本規則所涵蓋燃料（和引燃燃料）和油類燃料的發動機。油類燃料可包括餾分油和渣油。

2.2.11 圍閉處所係指在沒有人工通風時，通風將受到限制及任何爆炸氣體將不會自然消散的任何處所。

2.2.12 ESD 係指應急切斷。

2.2.13 爆炸係指無控制燃燒引發的爆燃事件。

2.2.14 爆炸壓力釋放係指通過從指定的開口釋放過壓，防止容器或圍閉處所內的爆炸壓力超過容器或處所的最大設計過壓的措施。

2.2.15 燃料圍護系統係指含液艙連接的燃料儲存佈置，包括所設主屏壁和次屏壁以及附屬絕熱層和任何間隔處所，還包括必要時用於支持這些構件的鄰接結構。如果次屏壁是船體結構的一部分，則其可以是燃料儲存艙處所的邊界。

燃料艙周圍處所定義如下：

- .1 燃料儲存艙處所係指由船舶結構所圍閉、其內部設有燃料圍護系統的處所。如果燃料儲存艙處所內設有液艙連接，則將也是液艙連接處所；
- .2 屏壁間處所係指不論是其全部還是部分由絕熱材料或其他

材料所填充的主屏壁和次屏壁之間的處所；和

- .3 液艙連接處所係指圍閉處所內，設有此類連接管的液艙要求的所有液艙連接管和液艙閥周圍的處所。

2.2.16 灌裝限度 (FL) 係指當液體燃料達到參照溫度時燃料艙中相對於總倉容的最大液體容量。

2.2.17 燃料準備艙係指設有燃料準備目的的泵、壓縮機和/或氣化器的任何處所。

2.2.18 燃氣係指當溫度為 37.8°C 時其蒸氣壓力超過 2.8bar (絕對壓力) 的一種液體。

2.2.19 用氣設備係指船上使用燃氣為燃料的任何裝置。

2.2.20 僅用燃氣的發動機係指只能靠燃氣運作，不能轉換成靠任何其他種類燃料運作的發動機。

2.2.21 危險區域係指具有或可預期具有爆炸性燃氣的大氣、其燃氣量達到足以要求對設備的構造、安裝和使用採取特殊預防措施的區域。

2.2.22 高壓係指超過 10bar 的最大工作壓力。

2.2.23 獨立艙是自身支持的，不構成船體結構的一部分，對船體強度也並非必至關重要。

2.2.24 LEL 係指最低爆炸極限。

2.2.25 船長 (L) 係指現行國際載重線公約中定義的船長。

2.2.26 LNG 係指液化天然氣。

2.2.27 裝載限度 (LL) 係指相對於艙的可裝載倉容的最大允許液體容

量。

2.2.28 低閃點燃料係指具有低於《安全公約》第 II-2/4 條 2.1.1 段下所允許閃點的氣態或液態燃料。

2.2.29 *MARVS* 係指釋放閥的最大允許調定值。

2.2.30 *MAWP* 係指系統組件或艙的最大允許工作壓力。

2.2.31 膜式艙係指非自身支持的液艙，由鄰接的船體結構通過絕熱層支持的一層水密和氣密薄膜組成。

2.2.32 多燃料發動機係指可以使用相互分離的兩種或多種不同燃料的發動機。

2.2.33 非危險區域係指所具有的爆炸性燃氣大氣的燃氣量預期不足以達到要求對設備構造、安裝和使用採取特殊預防措施的區域。

2.2.34 露天甲板係指沒有重大火災風險，至少兩端/兩邊開口或一端開口並有足夠的自然通風，通過舷側外板或甲板上分佈的永久性開口有效地覆蓋甲板全長的甲板。

2.2.35 風險是後果的可能性和嚴重性的綜合表述。

2.2.36 參照溫度係指與燃料艙中的燃料在壓力釋放閥的設定壓力下的蒸汽壓力相應的溫度。

2.2.37 次屏壁係指燃料圍護系統中設計成能暫時容納可能從主屏壁泄漏的液態燃料，並防止船體結構的溫度下降至不安全的程度的液密外層構件。

2.2.38 半圍閉處所係指由於諸如屋頂、風障和艙壁結構的存在且其佈置

使燃氣消散不會發生，其自然通風條件明顯不同於露天甲板條件的處所。

2.2.39 釋放源係指設備中的燃氣、蒸汽、水霧或液體可能釋放到大氣中並會形成爆炸性大氣的點或位置。

2.2.40 不可接受的動力喪失係指按照《安全公約》第 II-1/26.3 條，在必需的輔助設備之一失靈時，不可能保持或恢復推進機器的正常操作。

2.2.41 蒸氣壓力係指在規定溫度下以絕對兆帕（MPa）表示的液體上方飽和蒸氣的平衡壓力。

2.3 替代設計

2.3.1 本規則包括與低閃點燃料使用有關的所有設備和裝置的功能要求。

2.3.2 低閃點燃料系統的燃料、設備和裝置可能：

- .1 偏離本規則所載的要求，或
- .2 設計成使用本規則未明確述及的燃料。

此類燃料、設備和裝置可以使用，但要符合有關目標和功能要求的意圖，並能提供與相關章節同等的安全水平。

2.3.3 等效替代設計須如《安全公約》第 II-1/55 條的規定予以證明，並由主管機關認可。然而，主管機關不能允許用操作方法或程序替代本規則規定的特定安裝、材料、器具、儀器、設備的部件或其類型。

3 目標和功能要求

3.1 目標

本規則的目標是為船舶的安全和環保的設計、建造和操作並特別是使用天然氣或其他低閃點燃料作為燃料的推進機械、輔助發電機械和/或其他目的機械系統的安裝作出規定。

3.2 功能要求

3.2.1 系統的安全、可靠性和可依賴性須與新的並可比較的常規油類燃料的主輔助機械所達到的相當。

3.2.2 燃料相關危害的可能性和後果須通過諸如通風、探測和安全行動的佈置和系統設計限制到最低。在發生燃氣泄漏或降低風險措施失效時，需啟動必要的安全行動。

3.2.3 設計原理須確保氣體燃料裝置的降低風險措施和安全行動不會導致不可接受的動力喪失。

3.2.4 須限制危險區域，以儘力減少會影響船舶、船上人員和設備安全的潛在風險。

3.2.5 危險區域中安裝的設備須減少至操作目的所要求的最低限度，並須得到適宜和適當發證。

3.2.6 須防止爆炸、易燃和有毒氣體濃度的非有意積聚。

3.2.7 須保護系統部件不受外部損害。

3.2.8 須儘力減少危險區域內的着火源，以減少爆炸可能性。

3.2.9 須為能夠無泄漏地接收和容納所要求狀態的燃料對安全和合適的燃料供應、存儲和加注做出佈置。除因安全理由所必須者外，系統須設計成能防止在包括空閒時段的正常操作條件下排泄。

3.2.10 須提供為其預定用途而適當設計、建造和安裝的管系、圍護和過壓釋放裝置。

3.2.11 須為確保安全可靠的操作而設計、建造、安裝、操作、維護和保護機械、系統和組件。

3.2.12 燃料圍護系統以及含有可向處所內排放燃氣的來源的機器處所，其佈置和位置須使兩者內的失火或爆炸均將不會導致不可接受的動力喪失，或使艙室內其他設備無法運行。

3.2.13 須提供適合的控制、警報、監測和關閉系統，以確保安全可靠的操作。

3.2.14 須設有適合所有處所和區域的固定燃氣探測。

3.2.15 須提供適合於相關危險的失火探測、保護和滅火措施。

3.2.16 燃料系統和用氣機械的啟用、試驗和維護須滿足安全性、可用性和可靠性的目標。

3.2.17 技術文件須允許對系統和其組件是否符合適用的規則、導則、所用的設計標準和與安全性、可用性、維護性和可靠性相關的原則進行評估。

3.2.18 技術系統或組件的單項故障不得導致不安全或不可靠狀況。

4 一般要求

4.1 目標

本章的目標是確保對所涉及的風險實施必要的評估，以消除或減輕對船上人員、環境或船舶的任何不利影響。

4.2 風險評估

4.2.1 須進行風險評估，以確保解決使用低閃點燃料對船上人員、環境、結構強度或船舶完整性帶來的風險。須考慮到在任何可合理預見的故障後，與實體佈局、操作和維護相關的危險。

4.2.2 對於 A-1 部分所適用的船舶，4.2.1 中所要求的風險評估僅需要在第 5.10.5、5.12.3、6.4.1.1、6.4.15.4.7.2、8.3.1.1、13.4.1、13.7 和 15.8.1.10 段以及附件第 4.4 或 6.8 段明確要求時進行。

4.2.3 對風險須使用可接受和經認可的風險分析技術進行分析，並須至少考慮到功能喪失、組件損壞、失火、爆炸和電擊。分析須確保儘可能消除風險。不能被消除的風險須得到必要的減輕。須記錄風險的詳情和減輕方法，並使主管機關滿意。

4.3 爆炸後果限制

包含任何潛在釋放源和潛在着火源的任何處所內的爆炸不得：

- .1 造成除事故發生處所外的任何處所的設備/系統損壞或擾亂其正常功能；
- .2 損壞船舶，導致主甲板下浸水或任何連續浸水發生；
- .3 損壞工作區域或起居區域，導致在正常操作條件下停留在此區域的人員受傷；
- .4 擾亂控制站和配電所需配電室的正常運行；
- .5 損壞救生設備或相關降放裝置；
- .6 擾亂位於爆炸損壞處所外的消防設備的正常運行；

- .7 影響船上其他區域，導致涉及到特別是貨物、燃氣和燃油的連鎖反應可能發生；或
- .8 阻礙人員進入救生設備或阻礙脫險通道。

A-1 部分

對使用天然氣燃料船舶的特殊要求

就本部分中的規定而言，燃料係指液化或氣態的天然氣。

應認識到天然氣的構成會因天然氣來源和加工過程而不同。

5 船舶的設計和佈置

5.1 目標

本章的目標是為發電設備、燃料儲存系統、燃料供應設備和燃料加注系統的安全位置、處所佈置和機械保護作出規定。

5.2 功能要求

5.2.1 本章與 3.2.1 至 3.2.3、3.2.5、3.2.6、3.2.8、3.2.12 至 3.2.15 和 3.2.17 中的功能要求有關。尤其是以下所列適用：

- .1 考慮到船舶安全操作和船舶其他有關危險，燃料艙的位置須使碰撞或擱淺後液艙破損的可能性降到最低；
- .2 燃料圍護系統、燃料管系和其他燃料釋放源的位置和佈置須使被釋放的燃氣通向戶外安全位置；
- .3 含燃料釋放源處所的入口和其他開口，其佈置須防止易燃、窒息或有毒氣體逸至未為此類氣體的存在所設計的處所；
- .4 燃料管系須受到保護，以防止機械損傷；

- .5 推進和燃料供應系統須設計成任何燃氣泄漏後的安全行動不會導致不可接受的動力喪失；及
- .6 須將具有燃氣或低閃點燃料機械的處所內氣體爆炸的可能性降到最低。

5.3 一般規定

5.3.1 燃料儲存容器須受到保護，以防止機械損傷。

5.3.2 露天甲板上的燃料儲存倉和/或設備的位置，須確保自然通風充足，以防止逸出燃氣積聚。

5.3.3 燃料艙須以下列方式受到保護，以防止碰撞或擱淺造成外部損壞：

- .1 燃料艙與船舷的最短距離為 $B/5$ 或 11.5 米，以較小值為準，在夏季載重線吃水平面上，從船內側沿垂直於船體中心線方向量取；

其中：

B 為在最深吃水線（夏季載重線吃水）或以下的船舶最大型寬（參見《安全公約》第 II-1/2.8 條）。

- .2 各燃料艙的邊界須為包括其倉閥門的倉結構的縱向、橫向和垂向限界。
- .3 對於獨立艙，保護性距離須從艙殼板（艙維護系統的主屏蔽）量起。對於膜式艙，該距離須從環繞該艙絕熱層的隔艙壁量起。

.4 燃料艙界限的位置不得比以下所列更靠近舷側外板或艏端：

.1 對於客船： $B/10$ 但不得小於 0.8 米。但是，當舷側外板位於 5.3.3.1 所要求的 $B/5$ 或 11.5 米以內，此距離無需大於 $B/15$ 或 2 米，以小者為準。

.2 對於貨船：

.1 如果 $V_c \leq 1,000\text{m}^3$ ，0.8m；

.2 如果 $1,000\text{m}^3 < V_c < 5,000\text{m}^3$ ， $0.75 + V_c \times 0.2 / 4,000\text{m}$ ；

.3 如果 $5,000\text{m}^3 \leq V_c < 30,000\text{m}^3$ ， $0.8 + V_c / 25,000\text{m}$ ；和

.4 如果 $V_c \geq 30,000\text{m}^3$ ，2m，

式中：

V_c 相當於 20℃ 時單個燃料艙總設計容積的 100%，包括氣室和附屬物。

.5 燃料艙最低界限須位於最小距離 $B/15$ 或 2m 以上，取小者，從中心線的船底外板型線量起。

.6 對於多體船， B 值可特別考慮。

.7 對於客船，燃料艙須在按照《安全公約》第 II-1/8.1 條從船艏垂線量起的 $0.08L$ 處的橫截面之後，對於貨船在防撞艙壁之後。

式中：

船長 (L) 係指《國際載重線公約》中定義的船長

(參見《安全公約》第 II-1/2.5 條)。

- .8 對於具有提供更高碰撞和/或擱淺抗力的船殼結構的船舶，
燃料艙位置的規定可按照 2.3 節予以特殊考慮。

5.3.4 作為以上 5.3.3.1 的替代，可使用以下計算方法來確定燃料艙的可接受位置：

- .1 如以下所述計算的 f_{CN} 值，對於客船須小 0.02 對於貨船須小於 0.04。
- .2 f_{CN} 由此公式計算得出：

$$f_{CN} = f_l \times f_t \times f_v$$

式中：

f_l 按《安全公約》第 II-1/7-1.1.1.1 條系數 P 公式計算得出。 x_1 的值須符合從艏端到燃料艙最後界限的距離， x_2 的值須符合從艏端到燃料艙最前界限的距離。

f_t 按《安全公約》第 II-1/7-1.1.2 條系數 r 公式計算得出，並反映破損穿透越過燃料艙外界限的可能性。公式為：

$$f_t = 1 - r(x_1, x_2, b)$$

f_v 按《安全公約》第 II-1/7-2.6.1.1 條系數 v 公式計算得出，並反映破損不垂直延伸到燃料艙最低界限以上的可能性。公式為：

$$f_v = 1.0 - 0.8 \cdot ((H - d)/7.8), \text{如果 } (H - d) \text{ 小於或}$$

等於 7.8m. f_v 不得大於 1。

$f_v = 0.2 - (0.2 \cdot ((H - d) - 7.8)/4.7)$ 在其他情況下， f_v 不得小於 0。

式中：

H 是從基線，到燃料艙最低界限的距離，以 m 計；和

d 是最深吃水（夏季載重線吃水）。

- .3 每一燃料艙的界限須取為包括液艙閥門的液艙結構最外層的縱向、橫向和垂直限界。
- .4 對於獨立艙，保護距離須測量至液艙殼板（液艙圍護系統主屏蔽）。對於膜式艙，該距離須測量至液艙絕熱周圍的艙壁。
- .5 燃料艙界限的位置不得比以下所列更靠近舷側外板或船舶艏端：
 - .1 對於客船：B/10 但不得小於 0.8 米。但是，當舷側外板位於 5.3.3.1 所要求的以小者為準的 B/5 或 11.5 米的舷內，此距離無需大於 B/15 或 2 米，以小者為準。
 - .2 對於貨船：
 - .1 如果 $V_c \leq 1,000 \text{m}^3$ ，0.8m；
 - .2 如果 $1,000 \text{m}^3 < V_c < 5,000 \text{m}^3$ ， $0.75 + V_c \times 0.2 / 4,000 \text{m}$ ；
 - .3 如果 $5,000 \text{m}^3 \leq V_c < 30,000 \text{m}^3$ ， $0.8 + V_c / 25,000 \text{m}$ ；和

.4 如果 $V_c \geq 30,000\text{m}^3$ ，2m，

式中：

V_c 相當於 20 °C 時單個液艙的總設計容積的 100%，包括氣室和附屬物。

- .6 如果不止一個非重疊燃料艙位於縱向方向，每個燃料艙的 f_{CN} 按照第 5.3.4.2 段分別計算得出。用於完整燃料艙佈置的值是每個單獨液艙得出的所有 f_{CN} 值的總和。
- .7 如果燃料艙佈置不以船舶中心線對稱，要對左舷和右舷 f_{CN} 分別進行計算，並且用其平均值進行評估。兩舷均須滿足第 5.3.4.5 條規定的最短距離。
- .8 對於具有提供更高碰撞和/或擱淺抗力的船殼結構的船舶，燃料艙位置的規定可按照第 2.3 節予以特殊考慮。

5.3.5 當燃料載於需要完整或部分次屏壁的燃料圍護系統內時：

- .1 燃料儲存艙處所須以雙層底與海水分隔；和
- .2 燃料儲存艙處所還須設置構成邊艙的縱艙壁。

5.4 機器處所的概念

5.4.1 為了將設有氣體燃料機械的機器處所內氣體爆炸可能性降到最低，以下兩個替代概念之一可以適用：

- .1 燃氣安全機器處所：機器處所的裝置使該處所在所有正常和非正常情況下被視為燃氣安全，即固有燃氣安全。

燃氣安全機器處所內的單項故障不能導致燃料氣體釋放到

機器處所中。

- .2 應急切斷保護機器處所：機器處所的裝置使該處所被視為在正常情況下不危險，但在某些非正常情況下有可能變成危險。當發生涉及燃氣危險的非正常情況時，不安全設備（着火源）和機器械的應急切斷（ESD）須自動執行，在此種情況下使用或工作的設備或機器須為經認證的安全類型。

應急切斷保護機器處所內的單項故障可能造成燃氣釋放至該處所中。通風設計成能容納由於技術故障可能出現的最大泄漏情景。

導致危險燃氣濃度的故障，如燃氣管破裂或氣密襯墊爆裂，涵蓋於爆炸壓力釋放裝置和應急切斷裝置之下。

5.5 燃氣安全機器處所規定

- 5.5.1 燃料系統內的單項故障不得導致燃氣釋放到機器處所中。
- 5.5.2 機器處所界限內所有燃料管系須按照 9.6 圍閉在氣密圍阱內。

5.6 應急切斷保護的機器處所規定

- 5.6.1 應急切斷保護須限於經認證的定期無人操作的機器處所。
- 5.6.2 須採取措施防護機器處所外部區域的爆炸、損壞，並確保冗餘供電。須提供但可能不限於以下裝置：

- .1 燃氣探測器；
- .2 截止閥；

.3 冗餘；和

.4 有效通風。

5.6.3 在下列條件下，可接受機器處所內無外部氣密圍阱的燃氣供應管系：

.1 推進動力發動機和電力發動機須位於兩個或以上沒有任何共同限界面的機器處所內，除非能夠有文件證明一次事故不會同時影響兩個處所。

.2 燃氣機器處所須僅含確保燃氣機械設備保持其功能所需的最少的必要設備、組件和系統。

.3 須安裝固定式燃氣探測系統，其佈置能自動切斷燃氣供應，並斷開所有不屬於經認證安全型的電氣設備或裝置。

5.6.4 不同機器處所之間的發動機分佈須使任一機器處所燃料供應的切斷不得導致不可接受的動力喪失。

5.6.5 由單一艙壁隔開的應急切斷保護機器處所須有足夠的強度，來承受任一處所內局部燃氣爆炸的影響，而不影響相鄰處所和該處所內設備的完整性。

5.6.6 應急切斷保護機器處所須設計成能減少燃氣積聚和氣窩形成的幾何形狀。

5.6.7 應急切斷保護機器處所的通風系統須按照第 13.5 條進行佈置。

5.7 燃料管系的位置和保護規定

5.7.1 燃料管距離舷側不得小於 800mm。

5.7.2 燃料管系不得直接通過《安全公約》中定義的起居處所、服務處所、電氣設備艙或控制站。

5.7.3 通過滾裝處所、特殊類別處所和露天甲板上的燃料管須受到保護，以防止機械損壞。

5.7.4 應急切斷保護機器處所內的氣體燃料管系須儘可能遠離電氣裝置和含有易燃液體的液艙。

5.7.5 應急切斷保護機器處所內的氣體燃料管系須受到保護，以防止機械損傷。

5.8 燃料準備艙設計規定

燃料準備艙，除非其佈置和安裝符合本規則對液艙連接處所的規定，須設於露天甲板上。

5.9 艙底系統規定

5.9.1 在本規則所涵蓋燃料可以存在的區域內安裝的艙底水系統須與與燃料不能存在的處所中的艙底水系統隔開。

5.9.2 如燃料載於需要次屏壁的燃料圍護系統中，則須配備適當的排放裝置，用於處理通過相鄰船體結構漏入貨艙處所或絕熱處所的任何泄漏。艙底系統不得連至安全處所內的泵。須設有能探測此類泄漏的裝置。

5.9.3 A 型獨立液化氣艙的液艙處所或保護層處所，須設有燃料艙泄漏或破裂時適於處理液態燃料的排放系統。

5.10 滴盤規定

5.10.1 在可能發生泄漏而造成船舶結構破損處或需要對受泄漏影響的區域加以限制之處，須裝設滴盤。

5.10.2 滴盤須用適合的材料製成。

5.10.3 滴盤須與船舶結構絕熱，使周圍的船體或甲板結構在液態燃料泄漏時不會暴露於不可接受的冷卻環境。

5.10.4 每個滴盤須安裝一個排放閥，使雨水向舷外排出。

5.10.5 每個滴盤須有足夠的容量，使風險評估的最大泄漏量得以處理。

5.11 圍閉處所入口和其他開口佈置規定

5.11.1 不得設置從非危險處所通往危險處所的直接通道。如果此類開口因操作原因是必要的，須提供符合 5.12 要求的空氣閘。

5.11.2 如果批准在甲板下設置燃料準備艙，須儘可能設有從露天甲板直接通往該艙的獨立通道。如果不能設有來自甲板的獨立通道，須提供符合 5.12 規定的空氣閘。

5.11.3 如果通往液艙連接管處所的通道為非直接來自露天甲板的獨立通道，須佈置為栓閉艙門。具有栓閉艙門的處所將是危險處所。

5.11.4 如果通往應急切斷保護機器處所的通道來自船上另一圍閉處所，則入口需佈置為符合 5.12 的空氣閘。

5.11.5 對於惰化處所，其通道佈置須能防止人員意外進入。如果此處所的通道不是來自露天甲板，密封裝置須確保防止惰化氣體泄漏到相鄰處所。

5.12 空氣閘規定

5.12.1 空氣閘是一個氣密艙壁圍閉的處所，具有兩個氣密門，其間距至少為 1.5m，但不大於 2.5m。除非《國際載重線公約》另有要求，空氣閘的門檻高度不得小於 300mm。門須為自閉式，且無任何門擋裝置。

5.12.2 空氣閘須在相對於相鄰危險區域或處所的過壓狀態下進行機械通風。

5.12.3 空氣閘須設計成在空氣閘所分隔的氣體危險處所發生最嚴重事件時，氣體不能被釋放到安全處所。事件須按照 4.2 進行風險分析評估。

5.12.4 空氣閘須為簡單形狀。它們須提供自由方便通道，並有不小於 1.5m² 的甲板面積。空氣閘不得用於其他目的，例如儲藏室。

5.12.5 空氣閘處所的兩側均須配備聲光報警系統，當一門以上移離關閉位置時，發出報警。

5.12.6 對於其來自危險處所的通道受空氣閘保護的甲板下非危險處所，在危險處所中失去負壓時，該處所的通道須受限直至通風恢復。失壓時，須在一處有人處所發出聲光警報表明失壓和空氣閘門開啟。

5.12.7 安全所需重要設備不得斷電，且須為防爆型。這可包括照明、探火、廣播和通用警報系統。

6 燃料圍護系統

6.1 目標

本章的目標是對氣體儲存作出適當規定，將其對人員、船舶和環境的風險儘力降低至等同於常規油類燃料船舶的水平。

6.2 功能要求

本章與 3.2.1、3.2.2、3.2.5、3.2.8 至 3.2.17 中的功能要求有關，
以下尤其適用：

- .1 燃料圍護系統須設計成液艙或與液艙連接部分的泄漏不致危及船舶、船上人員或環境。要避免的潛在危險包括：
 - .1 使船舶材料觸及允許限度以下的溫度；
 - .2 易燃燃料進入有點火源的位置；
 - .3 燃料和惰性氣體導致的潛在毒性和缺氧風險；
 - .4 至集合站、逃生路線和救生設備的通道受阻；
 - .5 救生設備的可用性降低。
- .2 燃料艙的壓力和溫度須控制在圍護系統的設計限制和可能的燃料運輸要求之內；
- .3 燃料圍護系統須設計成任何氣體泄漏後的安全行動不會導致不可接受的動力喪失；和
- .4 如果用可移動罐儲存燃料，燃料圍護系統的設計須與本章所述永久安裝的艙等效。

6.3 一般規定

6.3.1 液態天然氣可在最大允許釋放閥設定值（MARVS）最高為 1.0 兆帕下儲存。

6.3.2 燃氣艙最高允許工作壓力（MAWP）不得超過最大允許釋放閥設定值（MARVS）的 90%。

6.3.3 置於甲板下的燃料圍護系統對於相鄰處所須為氣密；

6.3.4 所有液艙連接、配件、法蘭和液艙閥門，除非液艙連接位於露天甲板上，必須圍閉在氣密的艙連接處所內。一旦液艙連接處發生泄漏，該氣密艙連接處所須能安全容納液艙的泄漏。

6.3.5 除 C 型燃料儲存艙外，燃料儲存艙管路接頭的位置須高於液艙最高液面。但經主管機關特殊考慮後，對於其他類型的液艙，低於最高液面的接頭也可予以接受。

6.3.6 液艙和管道故障後釋放液體的第一個閥門之間的管系，須具備與 C 型液艙相同的安全性，其動態應力不得超過 6.4.15.3.1.2 中規定的限值。

6.3.7 液艙連接處所的艙壁材料的設計溫度須與可能的最大泄漏狀態下可能承受的最低溫度相一致。液艙連接處所須設計成能承受此等泄漏期間產生的最大壓力。或者，可提供通往安全位置（桅杆）的釋壓排放。

6.3.8 至液艙連接處所的可能的最大泄漏須根據細節設計、探測和關閉系統確定。

6.3.9 管系連接如果在液艙液面下，須受次屏壁保護直至第一個閥門。

6.3.10 如果液化燃氣儲存艙位於露天甲板上，則對船舶鋼材須使用滴盤對艙連接的潛在泄漏和其他泄漏源予以防護。材料的設計溫度與所載燃料在正常大氣壓力下的溫度一致。保護船舶的鋼制結構須考慮到液艙的正常操作壓力。

6.3.11 須提供方法將存儲艙內的液化氣安全排淨。

6.3.12 須有可能使用燃料管系對燃料儲存艙進行排空、除氣和通風。船上須備有實施上述程序的說明。在使用乾燥空氣通風之前，須使用惰性

氣體實施惰化，以避免液艙和燃料管道內的爆炸危險大氣。具體規定見 6.10。

6.4 液化氣燃料圍護系統規定

6.4.1 通則

6.4.1.1 4.2 中要求的風險評估須包括對船舶液化氣燃料圍護系統的評估，並可能會導致融入船舶整體設計的附加安全措施。

6.4.1.2 固定液化氣燃料圍護系統的設計壽命須不少於船舶的設計壽命或者不少於 20 年，以較大者為準。

6.4.1.3 可移動罐櫃的設計壽命不得少於 20 年。

6.4.1.4 液化氣燃料圍護系統應根據北大西洋環境條件和相關無限航行長期海況分佈圖設計。對於專門用於有限航行的液化氣燃料圍護系統，主管機關可以接受與預期使用相一致的寬鬆環境條件。對於在比北大西洋環境更惡劣的條件下運營的液化氣燃料圍護系統，可要求應更為嚴格的环境條件。

6.4.1.5 液化氣燃料圍護系統須設計成具有適當的安全裕度，從而：

- .1 在完整條件下，承受液化氣燃料圍護系統設計壽命預期的環境條件及其相應裝載工況，包括滿載均勻和部分裝載工況和任何中間層級的部分充裝；和
- .2 適於載荷、結構建模、疲勞、腐蝕、熱效應、材料可變性、老化和建造公差的不確定性。

6.4.1.6 液化氣燃料圍護系統的結構強度須按失效模式評定，包括但不限於塑性變形、屈曲和疲勞。每個液化氣燃料圍護系統設計時須考慮的具

體設計條件見 6.4.15。有 3 類主要的設計條件：

- .1 極限設計條件—液化氣燃料圍護系統結構及其結構件須承受建造、試驗和預期投入使用期間可能發生的載荷，而不失結構完整性。設計須考慮下列載荷的適當組合：
 - .1 內部壓力；
 - .2 外部壓力；
 - .3 在所有裝載工況下船舶運動引起的動載荷；
 - .4 熱載荷；
 - .5 晃蕩載荷；
 - .6 船舶變形引起的載荷；
 - .7 液艙和液化氣燃料重量及在支持構件部位的相應的反作用力；
 - .8 絕熱層重量；
 - .9 作用在塔架和其他附件處的載荷；和
 - .10 試驗載荷。
- .2 疲勞設計條件—液化氣燃料圍護系統結構及其結構件不得在累積循環載荷下失效。
- .3 事故設計條件——液化氣燃料圍護系統須滿足本規則所述下列各項事故設計條件（事故或異常事件）：
 - .1 碰撞—液化氣燃料圍護系統須承受 6.4.9.5.1 中規定的

碰撞載荷，且支持結構或艙結構不會有危及艙及其支持結構的變形。

.2 失火—液化氣燃料圍護系統須在 6.7.3.1 中預期的失火情況下承受該段中所規定的內部壓力的增加，且無破裂。

.3 浸水艙室造成的液艙上浮力—止浮裝置須承受 6.4.9.5.2 中規定的向上的力，且不會有危及船體的塑性變形。液化氣燃料圍護系統可以發生塑性變形，但不能危及安全撤離船舶。

6.4.1.7 須採取措施確保所要求的尺寸滿足結構強度規定並在整個設計壽命期間得到保持。措施可包括但不限於材料選擇、塗層、腐蝕增量、陰極保護和惰化。

6.4.1.8 須制定液化氣燃料圍護系統的檢查/檢驗計劃並由主管機關認可。檢查/檢驗計劃須確定在液化氣燃料圍護系統整個壽命的檢驗期間要檢查和（或）驗證的各個方面，特別是選擇液化氣燃料圍護系統設計參數時假定的任何必需的營運中檢驗、維護和試驗。檢查（檢驗）計劃可包括 6.4.12.2.8 或 6.4.12.2.9 中規定的具體關鍵位置。

6.4.1.9 液化氣燃料圍護系統的設計、建造和配備須提供進入檢查（檢驗）計劃中規定的需要檢查區域的適當的通道。液化氣燃料圍護系統（包括所有相關內部設備）的設計和建造須確保操作、檢查和維護期間的安全。

6.4.2 液化氣燃料圍護安全原則

6.4.2.1 圍護系統需具備能安全維護透過主屏壁的所有潛在泄漏的完整

液密次屏壁，並且該次屏壁能與絕熱系統一起防止船舶結構的溫度下降至不安全的程度。

6.4.2.2 如果酌情按照 6.4.2.3 至 6.4.2.5 能夠證明同等的安全水平，次屏壁的尺寸和形狀或佈置可以減小或忽略。

6.4.2.3 已確定結構失效導致臨界狀態的可能性極低但不能排除透過主屏壁泄漏可能性的液化氣燃料圍護系統，須具備部分次屏壁和能夠安全處理和處置泄漏的小量泄漏保護系統（臨界狀態係指開裂發展至不穩定狀態）。

裝置須符合下列要求：

- .1 達到臨界狀態前能可靠探測到的失效形成（例如通過氣體探測或檢查）須有足夠長的形成時間以採取補救措施；和
- .2 達到臨界狀態前不能安全探測到的失效形成須有比液艙預計壽命長得多的預計形成時間。

6.4.2.4 對於主屏壁結構失效和泄漏的可能性極低且可忽略不計的液化氣燃料圍護系統，例如 C 型獨立液艙，不要求次屏壁。

6.4.2.5 對於需要完全或部分次屏壁的獨立液艙，須設置安全處理液艙泄漏的裝置。

6.4.3 與液艙類型相關的次屏壁

6.4.15 中界定的與液艙類型相關的次屏壁須按下表設置。

基本液艙類型	次屏壁要求
膜式液艙	完整的次屏壁
獨立液艙	
— A 型獨立液艙	完整的次屏壁
— B 型獨立液艙	部分的次屏壁
— C 型獨立液艙	不要求次屏壁

6.4.4 次屏壁的設計

次屏壁（包括安裝防濺屏的情況）須設計成：

- .1 能在 15 天的時限內容納任何預計液化氣燃料泄漏，除非慮及 6.4.12.2.6 中所述的載荷譜，具體航次適用不同衡準；
- .2 液化氣燃料艙內能導致主屏壁失效的物理、機械或操作事件不得損害次屏壁的應有功能，反之亦然；
- .3 船體結構支持構件或附件的失效不會導致主屏壁和次屏壁液密的喪失；
- .4 能以外觀檢查或以主管機關可接受的其他合適方式定期檢查其有效性；
- .5 6.4.4.4.中所要求的方法須經主管機關認可，並須至少包括：
 - .1 在液密有效性受損之前，可接受的缺陷尺寸和次屏壁內位置的詳細情況；
 - .2 探測以上.1 中缺陷的建議方法的各項數值的精度和範圍；

.3 如不進行全尺度模型試驗，在確定接受衡準中使用的比例因數；和

.4 熱和機械循環載荷對建議試驗有效性的影響。

.6 次屏壁在靜橫傾角為 30° 時須滿足其功能要求。

6.4.5 部分次屏壁和主屏壁小量泄漏保護系統

6.4.5.1 6.4.2.3 中允許的部分次屏壁須與小量泄漏保護系統一起使用並滿足 6.4.4 中的所有規定。

小量泄漏保護系統須包括探測主屏壁泄漏的裝置，諸如防濺屏等使任何液化氣燃料向下進入部分次屏壁的設置以及可包括自然蒸發的處置液體的手段。

6.4.5.2 須根據相當於在最初探測到主屏壁泄漏後，從 6.4.12.2.6 所述的載荷譜中得到的破損範圍所泄漏的液化氣燃料量確定部分次屏壁的容量。可適當考慮液體蒸發、泄漏率、泵的排量以及其他有關因素。

6.4.5.3 所要求的液體泄漏探測可通過液體傳感器或有效使用壓力、溫度或氣體探測系統或任何組合進行。

6.4.5.4 獨立液艙無法根據幾何學的算法計算出泄漏收集的具體位置時，部分次屏壁須在標準靜態角時滿足其功能要求。

6.4.6 支持裝置

6.4.6.1 液化氣體燃料艙須由船體以在液艙受到 6.4.9.2 至 6.4.9.5 中界定的適用靜、動載荷作用時防止液艙本體移動的方式予以支撐，同時允許液艙在溫度變化和船體變形時收縮和膨脹，且無對船體和液艙的不當應力。

6.4.6.2 須為獨立液艙設置止浮裝置，並能承受 6.4.9.5.2 中界定的載荷，且無會危及船體結構的塑性變形。

6.4.6.3 支持構件和支持裝置須承受 6.4.9.3.3.8 和 6.4.9.5 中界定的載荷，但這些載荷無需相互組合，或與波浪引起的載荷組合。

6.4.7 相關結構和設備

6.4.7.1 液化氣燃料圍護系統須設計成能承受相關結構和設備施加的載荷。這包括泵塔、液化氣燃料氣室、液化氣燃料泵和管系、清艙泵和管系、氮氣管系、通道艙口、梯子、管系貫穿件、液位錶、獨立液位報警錶、噴嘴和儀錶系統（例如壓力、溫度和應力錶）。

6.4.8 絕熱

6.4.8.1 須按要求設置絕熱層以防止船體溫度降至許用值以下（見 6.4.13.1.1）並將進入液艙的熱流限制在 6.9 中適用的壓力和溫度圍護系統能維持的水平。

6.4.9 設計載荷

6.4.9.1 一般要求

6.4.9.1.1 本節界定了須就 6.4.10 至 6.4.12 中的規定予以考慮的設計載荷。這包括載荷類別（永久、功能、環境和意外）以及對載荷的描述。

6.4.9.1.2 這些載荷須考慮的範圍取決於液艙類型，並在下文中更全面地予以詳細描述。

6.4.9.1.3 液艙連同其支持結構和其他固定裝置，須慮及下述載荷的相關組合予以設計。

6.4.9.2 永久載荷

6.4.9.2.1 重力載荷

液艙重量、絕熱層、塔架和其他附件產生的載荷須予以考慮。

6.4.9.2.2 永久外部載荷

外部作用在液艙上的結構和設備的重力載荷須予以考慮。

6.4.9.3 功能載荷

6.4.9.3.1 液艙系統操作使用產生的載荷須歸類為功能載荷。

6.4.9.3.2 在所有設計條件下確保液艙系統完整性的所有關鍵功能載荷須予以考慮。

6.4.9.3.3 在確定功能載荷時，至少須考慮下列適用衡準的影響：

- (a) 內部壓力；
- (b) 外部壓力；
- (c) 熱載荷；
- (d) 振動；
- (e) 相互作用載荷；
- (f) 與結構和安裝相關的載荷；
- (g) 試驗載荷；
- (h) 靜橫傾載荷；
- (i) 液化氣燃料重量

(j) 晃蕩

(k) 風擊、浪擊和綠海效應對安裝在露天甲板上的液艙的影響。

6.4.9.3.3.1 內部壓力

- .1 在任何情況下，包括 6.4.9.3.3.1.2， P_0 均不得小於釋放閥的最大調定值（MARVS）。
- .2 對於無溫度控制和液化天然氣燃料壓力僅由環境溫度支配的液艙， P_0 不得低於在溫度為 45°C 時的液化氣燃料蒸氣錶壓，但下列除外：
 - .1 對於在限制區域內航行的船舶，主管機關可接受較低的環境溫度值。反之，可要求較高的環境溫度值。
 - .2 對於在限制時段內航行的船舶， P_0 可基於航行期間的實際壓力上升進行計算，並可慮及任何液艙絕熱。
- .3 經主管機關特別考慮，並符合 6.4.15 中給出的對各類液艙的限制條件，在動載荷降低的特定場所條件下（港口或其他場所），可接受高於 P_0 的蒸氣壓力 P_h 。
- .4 用於決定內部壓力的壓力數值須為：
 - .1 $(P_{gd})_{\max}$ 是使用最大設計加速度確定的相關液體壓力。
 - .2 $(P_{gd \text{ site}})_{\max}$ 是使用場所特定加速度確定的相關液體壓力。

.3 P_{eq} 應為如下計算得出的 P_{eq1} 和 P_{eq2} 的大者：

$$P_{eq1} = P_0 + (P_{gd}) \max (\text{MPa}) ,$$

$$P_{eq2} = P_h + (P_{gd \text{ site}}) \max (\text{MPa}) .$$

.5 內部液壓是指因發生 6.4.9.4.1.1 中所指船舶運動所導致的液化氣燃料重心加速度產生的壓力。由重力和動力加速度的聯合作用所引起的內部液體壓力 P_{gd} 須如下計算：

$$P_{gd} = \alpha_{\beta} z_{\beta} (p / (1.02 \times 10^5)) (MPa)$$

式中：

α_{β} = 在任意的 β 方向上由重力和動載荷引起的無因次加速度（即相對於重力加速度）（見圖 6.4.1）。

對於大型液艙，應使用考慮到橫向、垂向和縱向加速度的加速度橢球。

z_{β} = 壓力確定點以上從液艙殼板沿 β 方向測量的最大液體高度（見圖 6.4.2）。

在確定 Z_{β} 時，除非液艙氣室的總容積 V_d 不超過按下列公式所得值，否則被視為獲接受總倉容一部分的液艙氣室應予以考慮：

$$V_d = V_t \left(\frac{100 - FL}{FL} \right)$$

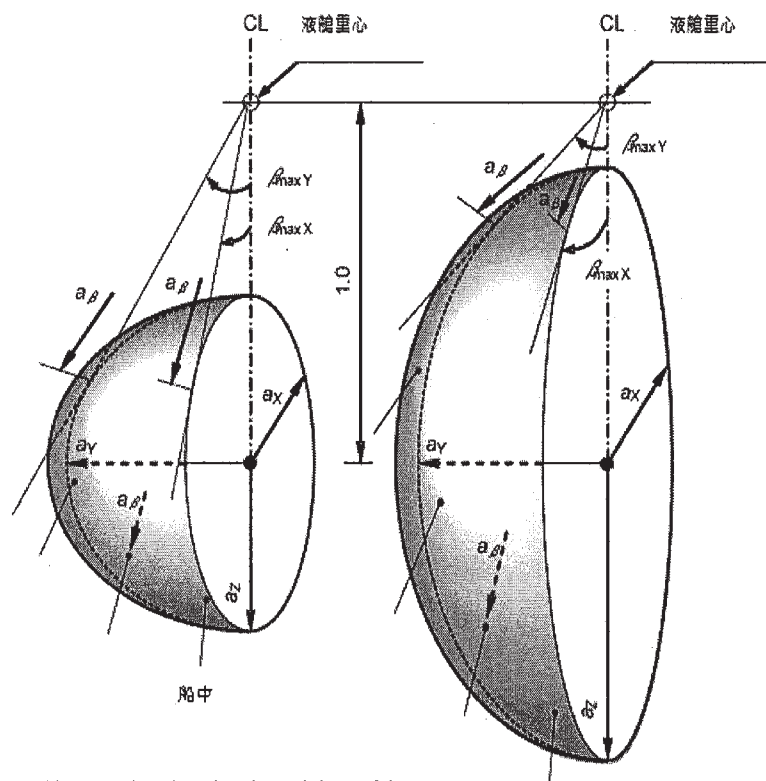
式中：

V_l = 無任何氣室的液艙容積；和

FL = 按 6.8 規定的充裝極限

P = 設計溫度下的最大液化氣燃料密度
(kg/m^3)。

須考慮給出最大值 $(P_{gd})_{max}$ 或 $(P_{gd\ site})_{max}$ 的方向。在需要考慮三個方向的加速度分量時，須適用橢球取代圖 6.4.1 中的橢圓。上述公式僅適用於注滿的液艙。



a_β = 在任意 β 方向上的加速度（靜態和動態） 距首垂線 $0.05L$ 處

a_x = 加速度縱向分量

a_y = 加速度橫向分量

a_z = 加速度垂向分量

圖 6.4.1—加速度橢球

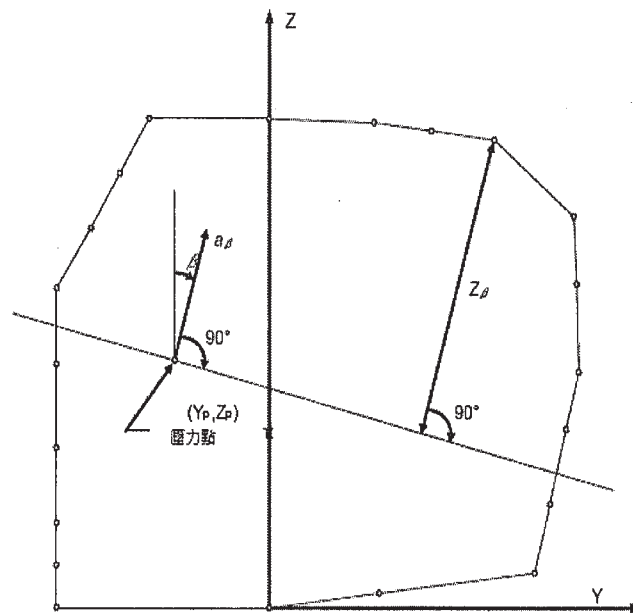


圖 6.4.2—內部壓頭的確定

6.4.9.3.3.2 外部壓力

外部設計壓力載荷須基於液艙任何部分會同時承受的較小內部壓力與較大外部壓力之差。

6.4.9.3.3.3 熱載荷

6.4.9.3.3.3.1 對於擬用於載運溫度低於 -55°C 的液化氣體燃料的液艙，須考慮冷卻期間的瞬態熱載荷。

6.4.9.3.3.3.2 當所設計的支持裝置或附件和營運溫度可能會引起較大的熱應力時，對於這類液化氣燃料圍護系統，須考慮穩態熱載荷（見 6.9.2）。

6.4.9.3.3.4 振動

6.4.9.3.3.4.1 須考慮振動對液化氣燃料圍護系統的潛在破壞影響。

6.4.9.3.3.5 相互作用載荷

須考慮液化氣燃料維護系統和船體結構之間相互作用產生的靜載荷分量以及相關結構和設備產生的載荷。

6.4.9.3.3.6 與結構和安裝相關的載荷

須考慮與結構和安裝相關的載荷或條件，例如起重。

6.4.9.3.3.7 試驗載荷

須考慮 16.5 中所述液化氣燃料圍護系統實驗的相應載荷。

6.4.9.3.3.8 靜橫傾載荷

須考慮在 0°到 30°範圍內最不利靜橫傾角的相應載荷。

6.4.9.3.3.9 其他載荷

須考慮未特別提及但對液化氣燃料圍護系統有影響的任何其他載荷。

6.4.9.4 環境載荷

6.4.9.4.1 環境載荷係定義為液化氣燃料圍護系統上由周圍環境產生且未歸類為永久、功能或意外載荷的載荷。

6.4.9.4.1.1 船舶運動產生的載荷

確定動載荷須考慮船舶在其使用壽命期間將經歷的在不規則海浪中船舶運動的長期分佈。對由於必要的減速和改變航向導致的動載荷降低，可以予以考慮。船舶運動將包括縱蕩、橫蕩、垂蕩、橫搖、縱搖和首搖。作用於液艙的加速度，需在液艙的重心予以估算並包括下列分量：

- .1 垂向加速度：垂蕩、縱搖以及可能還有橫搖（垂直於船舶

基線) 的運動加速度；

- .2 橫向加速度：橫蕩、首搖和橫搖的運動加速度；以及橫搖的重力分量；和
- .3 縱向加速度：縱蕩和縱搖的運動加速度；以及縱搖的重力分量。

預測船舶運動引起的加速度的方法須由主管機關提議並認可。

對於限定航區營運的船舶，可予以特別考慮。

6.4.9.4.1.2 動態相互作用載荷

須考慮液化氣燃料圍護系統和船體結構之間相互作用產生的動載荷分量，包括相關結構和設備產生的載荷。

6.4.9.4.1.3 晃蕩載荷

液化氣燃料系統和內部構件上的晃蕩載荷須對預定充裝水平的整個範圍予以估算。

6.4.9.4.1.4 雪和冰載荷

雪和結冰，如相關，須予考慮。

6.4.9.4.1.5 冰中航行產生的載荷

對於擬在冰中航行的船舶，須考慮冰中區航行產生的載荷。

6.4.9.4.1.6 艙面巨浪積水載荷

須考慮甲板積水的載荷。

6.4.9.4.1.7 風載荷

須考慮相關的風產生的載荷。

6.4.9.5 意外載荷

意外載荷定義為在異常和意外情況下施加在液化氣燃料圍護系統及其支持裝置上的載荷。

6.4.9.5.1 碰撞載荷

確定碰撞載荷須基於滿載工況下的液化氣燃料圍護系統，及向前慣性力相應於下表中的 a ，向後慣性力相應於 $a/2$ ，其中 g 為重力加速度。

船長 (L)	設計加速度 (a)
$L > 100\text{m}$	$0,5g$
$60 < L \leq 100\text{m}$	$\left(2 - \frac{3(L - 60)}{80}\right)g$
$L \leq 60\text{m}$	$2g$

對於弗勞德數 (Fn) > 0.4 的船舶須予以特殊考慮。

6.4.9.5.2 船舶浸水產生的載荷

對於獨立液艙，在設計止浮墊塊和相鄰船體和艙結構的支持結構中，須考慮空液艙完全浸入水中所產生的浮力。

6.4.10 結構完整性

6.4.10.1 一般要求

6.4.10.1.1 結構設計須確保液艙具有足夠的承受所有相關載荷的能力和足夠的安全裕量。須考慮塑性變形、屈曲、疲勞和喪失液密和氣密的可能性。

6.4.10.1.2 液化氣燃料圍護系統的結構完整性可由符合有關液化氣燃料圍護系統類型的 6.4.15 予以證明。

6.4.10.1.3 對於那些設計新穎或者與 6.4.15 規定所涵蓋者有顯著不同的液化氣燃料圍護系統類型，其結構完整性須由符合 6.4.16 予以證明。

6.4.11 結構分析

6.4.11.1 分析

6.4.11.1.1 設計分析須基於獲接受的靜力學、動力學和材料強度原則。

6.4.11.1.2 簡化方法或簡化分析，但凡是保守的，可用於計算載荷影響。模型試驗可與理論計算共用或代替理論計算。如果理論方法不適當，可要求模型或全尺度試驗。

6.4.11.1.3 確定對動載荷的響應時，須考慮會影響結構完整性的動力影響。

6.4.11.2 載荷情景

6.4.11.2.1 對於要考慮的液化氣燃料圍護系統的每個位置或部分和要分析的每個可能的失效模式，須考慮可能同時作用的所有相關載荷組合。

6.4.11.2.2 須考慮建造、裝卸、試驗和營運條件下的所有相關階段最不利的情景。

6.4.11.2.3 當分別計算靜應力和動應力時，除有正當理由的其他計算方法外，總應力須按下式計算：

$$\begin{aligned}\sigma_x &= \sigma_{x.st} \pm \sqrt{\sum (\sigma_{x.dyn})^2} \\ \sigma_y &= \sigma_{y.st} \pm \sqrt{\sum (\sigma_{y.dyn})^2} \\ \sigma_z &= \sigma_{z.st} \pm \sqrt{\sum (\sigma_{z.dyn})^2} \\ \tau_{xy} &= \tau_{xy.st} \pm \sqrt{\sum (\tau_{xy.dyn})^2} \\ \tau_{xz} &= \tau_{xz.st} \pm \sqrt{\sum (\tau_{xz.dyn})^2} \\ \tau_{yz} &= \tau_{yz.st} \pm \sqrt{\sum (\tau_{yz.dyn})^2}\end{aligned}$$

式中：

$\sigma_{x.st}$, $\sigma_{y.st}$, $\sigma_{z.st}$, $\tau_{xy.st}$, $\tau_{xz.st}$ 和 $\tau_{yz.st}$ 為靜應力；和

$\sigma_{x.dyn}$, $\sigma_{y.dyn}$, $\sigma_{z.dyn}$, $\tau_{xy.dyn}$, $\tau_{xz.dyn}$ 和 $\tau_{yz.dyn}$ 為動應力，

上述各值須從加速度分量和因撓曲和扭轉引起的船體應變分量中分別予以確定。

6.4.12 設計條件

對於所有相關載荷情景和設計條件，設計中須考慮所有相關失效模式。設計條件見本章前面部分，載荷情景見 6.4.11.2。

6.4.12.1 極限設計條件

6.4.12.1.1 結構能力可通過試驗、或慮及材料彈性和塑性特性的分析、簡化線性彈性分析或本規則的規定予以確定：

- 1 須考慮塑性變形和屈曲。
- 2 分析須基於如下特徵載荷值：

永久載荷： 預期值

功能載荷： 規定值

環境載荷： 對於波浪載荷： 10^8 波浪遭遇時遇到的
最可能的最大載荷

.3 下列材料參數適用於極限強度評估：

.1 R_e = 室溫下特定材料最低屈服應力 (N/mm^2)。如在應力—應變曲線上未顯示出明確的屈服應力，則 0.2% 的驗證應力適用。

.2 R_m = 室溫下特定材料最低抗拉強度 (N/mm^2)。

對於諸如一些鋁合金中的無法避免低匹配焊接（即焊接金屬的抗拉強度低於母材的抗拉強度）的焊接，須採用熱處理後的相應 R_e 或 R_m 值。在這種情況下，橫向焊接抗拉強度不得小於母材的實際屈服強度。如無法做到，這類材料製成的焊接結構不得用於液化氣燃料圍護系統中。

上述性能應與材料標定的機械性能的下限值相一致，包括製成狀態的焊縫金屬。經主管機關特別考慮後，可考慮低溫下經提高的屈服應力和抗拉強度。

.4 等效應力 σ_c (Von Mises, Huber) 須按下式確定：

$$\sigma_c = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - \sigma_x \sigma_y - \sigma_x \sigma_z - \sigma_y \sigma_z + 3(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2)}$$

式中：

σ_x = x 方向的總正應力；

σ_y = y 方向的總正應力；

σ_z = z 方向的總正應力；

τ_{xy} = x-y 平面的總剪應力；

τ_{xz} = x-z 平面的總剪應力；和

τ_{yz} = y-z 平面的總剪應力。

以上數值須按 6.4.11.2.3 中的規定計算。

- .5 7.4 所涵蓋者之外的其他材料的允許應力須在各情況下經主管機關認可。
- .6 各應力可由疲勞分析、裂紋擴展分析和屈曲標準進一步予以限制。

6.4.12.2 疲勞設計條件

- .1 疲勞設計條件是有關累積循環裝載的設計條件。
- .2 如要求疲勞分析，疲勞載荷的累積效應須符合：

$$\sum \frac{n_i}{N_i} + \frac{n_{Loading}}{N_{Loading}} \leq C_w$$

式中：

n_i = 液艙的使用壽命期間每一應力水平的應力循環次數；

N_i = 按照韋勒（S-N）曲線，相應的應力水平導致斷裂的循環次數；

$n_{裝載}$ = 液艙的使用壽命期間裝卸循環次數，不少於

1,000。裝卸循環包括完整的壓力和熱循環；

$N_{\text{裝載}}$ = 由於裝卸產生的疲勞載荷導致斷裂的循環次數；和

C_W = 許用最大疲勞累積損傷比。

疲勞損傷須基於液艙的設計壽命，但不小於 10^8 波浪遭遇。

- .3 如要求，須考慮到液化氣燃料圍護系統預期壽命期間所有疲勞載荷及其適當的組合，對液化氣燃料圍護系統進行疲勞分析。須考慮各種充裝工況。
- .4 分析中使用的設計 S-N 曲線須適用於材料和焊接件、結構細節、製作程序和預期的適用應力狀況。

S-N 曲線須基於對應於至終失效的相關實驗數據的平均值減去兩倍的標準差曲線的 97.6% 的殘存概率。使用通過不同方式得到的 S-N 曲線要求調整 6.4.12.2.7 至 6.4.12.2.9 中規定的可接受 C_W 值。

- .5 分析須基於以下特徵載荷值：

永久載荷： 預期值

功能載荷： 規定值或規定的過去值

環境載荷： 預期載荷過去值，但不小於 10^8 循環。

如使用簡化動力裝載譜評估疲勞壽命，該譜須經主管機關特別審議。

.6 如按 6.4.2.3 的規定減小次屏壁的尺寸，須進行疲勞裂紋擴大的斷裂力學分析以確定：

- .1 6.4.12.2.7 至 6.4.12.2.9 中酌情要求的，結構中的裂紋擴展路徑；
- .2 裂紋擴大速度；
- .3 裂紋擴展至導致液艙泄漏所需時間；
- .4 全厚度裂紋的尺寸和形狀；和
- .5 可探測到的裂紋穿透全厚度後達到臨界狀態所需時間。

斷裂力學通常基於作為試驗數據平均值加上兩倍的標準差得出的裂紋擴大數據。疲勞裂紋擴大分析和斷裂力學的方法須基於公認的標準。

分析裂紋擴展時，須酌情慮及許用無損試驗和目力檢查標準，假定所用檢查方法不能探測到的最大初始裂紋。

6.4.12.2.7 中規定的裂紋擴展分析可採用為期 15 天內的簡化載荷分佈和順序。該分佈可參圖 6.4.3 所示獲得。諸如 6.4.12.2.8 和 6.4.12.2.9 中的更長時間的載荷分佈和順序須經主管機關認可。

安排須酌情符合 6.4.12.2.7 至 6.4.12.2.9。

.7 對於能通過泄漏探測可靠探測到的失效：

C_w 須小於或等於 0.5。

從發現泄漏至達到臨界狀態，除對從事特殊航行的船舶適用不同規定，預計失效發展剩餘時間不得少於 15 天。

- .8 不能通過泄漏探測到但能在營運中檢查時可靠探測到的失效：

C_w 須小於或等於 0.5。

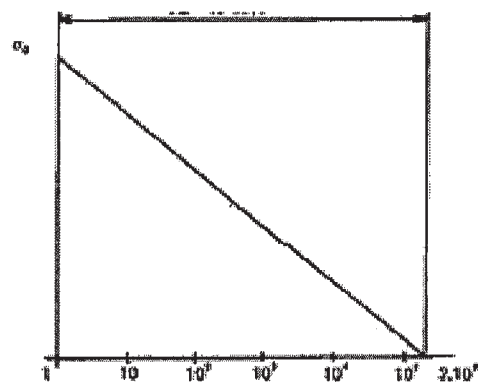
從營運檢查方法不能探測到的最大裂紋至達到臨界狀態，預計失效發展剩餘時間不得少於檢查間隔的 3 倍。

- .9 在液艙中有效的缺陷探測或裂紋擴大探測無法保證的特定位置，須至少使用下列更嚴格的疲勞驗收衡準：

C_w 須小於或等於 0.1。

從假定的初始缺陷至達到臨界狀態，預計失效發展時間不得少於液艙使用壽命的 3 倍。

~15 天



響應循環

σ_o = 船舶使用壽命中最可能的最大應力

響應循環比例為對數的；數值 2.10^5 係作為估算算例給出。

圖 6.4.3—簡化載荷分佈

6.4.12.3 意外設計條件

6.4.12.3.1 意外設計條件是發生概率極低的意外載荷的設計條件。

6.4.12.3.2 分析須基於以下特徵值：

永久載荷：	預期值
功能載荷：	規定值
環境載荷：	規定值
意外載荷：	規定值或預期值

6.4.9.3.3.8 和 6.4.9.5 中所述載荷無需進行相互或與波浪引起的載荷合成。

6.4.13 材料和構造

6.4.13.1 材料

6.4.13.1.1 構成船舶結構的材料

6.4.13.1.1.1 為確定船體結構中使用的板和型材的等級，需對所有類型的液艙進行溫度計算。計算中須做出下列假定：

- .1 須假定所有液艙的主屏壁處於液化氣燃料溫度。
- .2 除以上.1 外，如要求設置完整的或部分的次屏壁，須對任一艙假定其處於大氣壓力下的液化氣燃料溫度。
- .3 對環球航行，環境溫度須取空氣為 5°C 和海水為 0°C。主管機關，對航行於限制區域的船舶可接受較高的溫度值，反之，對在冬季月份預期會有較低溫度的區域航行的船舶可規定較低的溫度值。

- .4 須假定空氣和海水為靜止狀態，即無強制對流調節。
- .5 須假定船舶整個壽命期間由於諸如 6.4.13.3.6 和 6.4.13.3.7 中規定的熱和機械老化、壓縮、船舶運動和液艙振動等因素造成的絕熱性能降低。
- .6 須考慮泄漏的液化氣燃料蒸發所產生的冷卻效應，如適用。
- .7 可按照 6.4.13.1.1.3 對船體加熱予以認定但加熱佈置要符合 6.4.13.1.1.4。
- .8 除 6.4.13.1.1.4 中所述者外，對於任何加熱方式，均不予認定。
- .9 對於連接內外層殼體的構件，在確定其鋼材級別時可取平均溫度。

6.4.13.1.1.2 由於液化氣燃料溫度的影響使設計條件下的計算溫度在 0℃ 以下的所有船體結構材料須符合表 7.5。這包括支持液化氣體燃料液艙的船體結構、內底板、縱艙壁板、橫艙壁板、肋板、強肋骨、桁材以及所有相連的扶強構件。

6.4.13.1.1.3 可採用對船體結構材料進行加熱的方法，以確保這些材料的溫度不會降到低於表 7.5 規定的材料等級的最低允許值。在進行 6.4.13.1.1.1 要求的計算時，可按照下列原則對加熱予以計入：

- .1 對於任何橫向船體結構；
- .2 在規定了較低的環境溫度時，對於 6.4.13.1.1.2 中所述的縱向船體結構，但這些材料在加熱計算中不予計入時要仍適

於空氣為 5°C 和海水為 0°C 的環境條件；和

- .3 作為 6.4.13.1.1.4.2 的替代，對於液艙之間的縱向艙壁，可對加熱予以計入，但這些材料要仍適於 -30°C 的最低設計溫度，或在慮及加熱時，比按 6.4.13.1.1.1 確定的溫度低 30°C，取較小者。在這種情況下，無論這些艙壁被視為有效與否，船舶總縱強度須符合《安全公約》第 II-1/3-1 條。

6.4.13.1.1.4 6.4.13.1.1.3 中所述的加熱措施須符合下列要求：

- .1 加熱系統須佈置成當該系統的任一部分失效時，備用加熱設備仍能保持不低於 100% 的理論熱要求；
- .2 加熱系統須被視為關鍵輔助。至少一個按照 6.4.13.1.3.1 設置的系統的所有電氣部件須由應急電源供電；和
- .3 主管機關對圍護系統認可須包括加熱系統的設計和構造。

6.4.13.2 主屏壁和次屏壁的材料

6.4.13.2.1 用於建造不構成船體的主屏壁和次屏壁的金屬材料須適於其可能經受的設計載荷並符合表 7.1、7.2 或 7.3 的規定。

6.4.13.2.2 主屏壁和次屏壁中使用的、但表 7.1、7.2 和 7.3 中未涵蓋的非金屬或金屬材料可由主管機關慮及其可能承受的設計載荷、性能和預定的用途，予以認可。

6.4.13.2.3 如果主屏壁或次屏壁使用或包含了非金屬材料（包括複合材料），須對其酌情進行下列性能試驗，以確保其適合於預定用途：

- .1 與液化氣燃料的相容性；

- .2 抗老化性；
- .3 力學性能；
- .4 熱膨脹和收縮；
- .5 耐磨性；
- .6 凝聚性；
- .7 抗振性能；
- .8 防火和阻止火焰傳播性能；和
- .9 耐疲勞破壞和裂紋擴展性能。

6.4.13.2.4 對上述性能，如適用，須在營運中預計最高溫度和低於最低設計溫度 5℃，但不低於-196℃之間的範圍內進行試驗。

6.4.13.2.5 如主屏壁和次屏壁使用了非金屬材料（包括複合材料），連接過程也須如上述進行試驗。

6.4.13.2.6 可考慮在主屏壁和次屏壁中使用非防火和阻止火焰傳播的材料，但要受到適當系統（諸如永久惰性氣體環境）的保護或設有阻火屏壁。

6.4.13.3 液化氣燃料圍護系統中使用的絕熱和其他材料

6.4.13.3.1 液化氣燃料圍護系統中使用的承載絕熱和其他材料須適於設計載荷。

6.4.13.3.2 液化氣燃料圍護系統中使用的絕熱和其他材料須酌情具有下列性能，以確保適於其預定的用途：

- .1 與液化氣燃料的相容性；
- .2 在液化氣燃料中的可溶性；
- .3 對液化氣燃料的吸收；
- .4 收縮性；
- .5 抗老化性；
- .6 封閉氣泡含量；
- .7 密度；
- .8 力學性能，能承受液化氣燃料和其他載荷影響，熱膨脹和收縮；
- .9 耐磨性；
- .10 凝聚性；
- .11 熱傳導性；
- .12 抗振性能；
- .13 防火和阻止火焰傳播性能；和
- .14 耐疲勞破壞和裂紋擴展性能。

6.4.13.3.3 對上述性能，如適用，須在營運中預計最高溫度和低於最低設計溫度 5°C，但不低於-196°C 之間的範圍內進行試驗。

6.4.13.3.4 由於所處位置或環境條件，絕熱材料須具有適當的防火和阻止火焰傳播的性能，並須得到充分的防止水蒸汽滲透和機械損傷保護。絕熱層如位於露天甲板或以上並在液艙罩貫穿處，須具有符合公認標準

的適當耐火性能或由具有低播焰性並形成有效經認可蒸氣密封的材料所覆蓋。

6.4.13.3.5 不滿足公認耐火標準的絕熱層，只要其表面由具有低播焰性並形成有效經認可蒸氣密封的材料所覆蓋，可在不保持永久惰化的貨艙處所中使用。

6.4.13.3.6 須在適當老化的樣品上進行絕熱層的熱傳導性試驗。

6.4.13.3.7 當採用粉末或顆粒狀絕熱層時，須採取措施減少營運中的材料壓實，保持要求的熱傳導性，同時防止對液化氣燃料圍護系統增加任何不適當的壓力。

6.4.14 建造過程

6.4.14.1 焊縫設計

6.4.14.1.1 對獨立液艙殼體的所有焊接接頭，均須採用全焊透型的平面內對接焊。僅對於氣室和殼體的連接，可根據焊接工藝認可試驗的結果採用全焊透型 T 型焊接。除氣室上的小型貫穿件外，噴管焊縫也要設計成全焊透型。

6.4.14.1.2 C 型獨立液艙和主要以曲面構成的 B 型獨立液艙液密主屏壁的焊接接頭的細節須滿足以下要求：

- .1 所有縱向和環形接頭均應為對接、全焊透、雙面 V 型坡口或單面 V 型坡口形式。須採用雙面焊或使用襯墊環獲得全焊透的對接焊縫。如使用襯墊環，則除很小的處理用壓力容器外，焊後須予以去除。根據對焊接工藝認可試驗的結果，可允許其他邊緣制備。液艙殼與 C 型雙瓣液艙縱向艙

壁的連接，可接受全焊透型 T 型焊接。

- .2 對於液艙本體和氣室之間以及氣室和有關的附件之間的連接坡口制備，須按主管機關可接受的標準設計。容器上連接噴管、氣室或其他貫通件的焊縫以及法蘭與容器或噴管連接的所有焊縫均須為全焊透型焊縫。

6.4.14.2 黏合和其他連接過程的設計

6.4.14.2.1 黏合（或用除焊接外的一些其他過程連接）接頭的設計須考慮連接過程的強度特徵。

6.4.15 艙的類型

6.4.15.1 A 型獨立液艙

6.4.15.1.1 設計依據

6.4.15.1.1.1 A 型獨立液艙係指按照主管機關的要求，主要應用傳統的船舶結構分析程序設計的液艙。如果這種液艙主要是由平面構成，則其設計蒸氣壓力 P_0 須小於 0.07MPa。

6.4.15.1.1.2 要求有 6.4.3 中界定的完整次屏壁。次屏壁須按照 6.4.4 設計。

6.4.15.1.2 結構分析

6.4.15.1.2.1 須慮及 6.4.9.3.3.1 中所述的內部壓力和與支持和關鍵系統以及船體的適當部分相互作用的載荷，進行結構分析。

6.4.15.1.2.2 對於在本規則要求中沒有包括的部件，如支持結構，在儘可能計及 6.4.9.2 至 6.4.9.5 中所述載荷和支持結構處的船舶變形後，須採用

直接計算法確定其應力。

6.4.15.1.2.3 具有支持構件的液艙須為 6.4.9.5 中規定的意外載荷予以設計。這些載荷無需相互合成或與環境載荷合成。

6.4.15.1.3 極限設計條件

6.4.15.1.3.1 對於主要由平面構成的液艙，主要構件和次要構件（扶強材、強肋骨、縱桁、桁材）的公稱薄膜應力，如按傳統的分析方法進行計算，採用鎳鋼、碳錳鋼、奧氏體鋼和鋁合金時，不得超過 $R_m/2.66$ 或 $R_e/1.33$ 值的較小者， R_m 和 R_e 的定義在 6.4.12.1.1.3 中。但是，如對主要構件進行了詳細計算，6.4.12.1.1.4 中界定的等效應力 σ_c 可超過上述數值，增加到主管機關可接受的應力值。計算須慮及彎曲、剪切、軸向和扭轉變形，以及由於船殼結構和液化氣體燃料液艙底的變形而引起的船體和液化氣燃料液艙的相互作用力的影響。

6.4.15.1.3.2 液艙界限的結構尺寸至少須滿足主管機關對深艙的要求，並考慮到 6.4.9.3.3.1 中規定的內部壓力和 6.4.1.7 所要求的任何腐蝕裕量。

6.4.15.1.3.3 須審查液化氣燃料液艙結構是否有潛在的屈曲。

6.4.15.1.4 意外設計條件

6.4.15.1.4.1 液艙和液艙支持構件須為 6.4.9.5 和 6.4.1.6.3 中規定的相關意外載荷和設計條件予以設計。

6.4.15.1.4.2 在承受 6.4.9.5 中規定的意外載荷時，應力須符合酌情計及其較低的發生概率加以修正的 6.4.15.1.3 中規定的驗收衡準。

6.4.15.2 B 型獨立液艙

6.4.15.2.1 設計依據

6.4.15.2.1.1 B 型獨立液艙係指採用模型試驗、精確分析手段和分析方法確定應力水平、疲勞壽命和裂紋擴展特性所設計的液艙。如果這類液艙主要由平面構成（棱形液艙），則其設計蒸氣壓力 P_0 須小於 0.07MPa。

6.4.15.2.1.2 要求有 6.4.3 中界定的帶有保護系統的部分次屏壁。小量泄漏保護系統須按照 6.4.5 設計。

6.4.15.2.2 結構分析

6.4.15.2.2.1 在確定結構對下列情況的適應性時，須考慮所有動、靜載荷的影響：

- .1 塑性變形；
- .2 屈曲；
- .3 疲勞破壞；和
- .4 裂紋擴展。

須進行有限元分析或類似方法的分析和斷裂力學分析或其他等效的分析。

6.4.15.2.2.2 須進行三維分析對應力水平，包括與船體的相互作用進行評估。該分析模型須包括液化氣燃料液艙及其支持和關鍵系統以及船體的適當部分。

6.4.15.2.2.3 對在不規則波浪中特定的船舶加速度和運動以及船舶及其液化氣燃料液艙對這些力和運動的響應須進行完整的分析，除非這些數據可得自類似船舶。

6.4.15.2.3 極限設計條件

6.4.15.2.3.1 塑性變形

對於主要由回轉體構成的 B 型獨立液艙，其許用應力不得超過：

$$\begin{aligned}\sigma_m &\leq f \\ \sigma_L &\leq 1.5f \\ \sigma_b &\leq 1.5F \\ \sigma_L + \sigma_b &\leq 1.5F \\ \sigma_m + \sigma_b &\leq 1.5F \\ \sigma_m + \sigma_b + \sigma_g &\leq 3.0F \\ \sigma_L + \sigma_b + \sigma_g &\leq 3.0F\end{aligned}$$

式中：

$$\begin{aligned}\sigma_m &= \text{等效總體主膜應力；} \\ \sigma_L &= \text{等效局部主膜應力；} \\ \sigma_b &= \text{等效主彎曲應力；} \\ \sigma_g &= \text{等效二階應力；} \\ f &= R_m/A \text{ 或 } R_e/B, \text{ 取其較小者；和} \\ F &= R_m/C \text{ 或 } R_e/D, \text{ 取其較小者。}\end{aligned}$$

R_m 和 R_e 見 6.4.12.1.1.3 中的定義。對於應力 σ_m 、 σ_L 和 σ_b ，另見 6.4.15.2.3.6 中的應力類別定義。

A 和 B 的數值須至少為下列最小值：

	鎳鋼和碳錳鋼	奧氏體鋼	鋁合金
A	3	3.5	4
B	2	1.6	1.5
C	3	3	3
D	1.5	1.5	1.5

上述數字可慮及主管機關接受中所審議的設計條件予以更改。對於由主要平面構成的 B 型獨立液艙，用於有限元分析的許用膜等效應力不得超過：

- .1 對於鎳鋼和碳錳鋼， $R_m/2$ 或 $R_e/1.2$ ，取其較小者；
- .2 對於奧氏體鋼， $R_m/2.5$ 或 $R_e/1.2$ ，取其較小者；和
- .3 對於鋁合金， $R_m/2.5$ 或 $R_e/1.2$ ，取其較小者。

上述數字可慮及主管機關接受中所審議的應力位置、應力分析方法和設計條件予以修正。

殼板的厚度和扶強材的尺寸不得小於對 A 型獨立液艙所要求者。

6.4.15.2.3.2 屈曲

對承受外部壓力和引起壓縮應力的其他載荷的液化氣燃料液艙的屈曲強度分析須按照公認標準進行。方法須充分考慮到理論和實際屈曲應力值之間因板邊不對中、缺乏平直、橢圓度以及在規定弧長或弦長範圍內存在的失圓度而引起的差別。

6.4.15.2.3.3 疲勞設計條件

6.4.15.2.3.3.1 須按照 6.4.12.2 的規定進行疲勞和裂紋擴展評估。根據缺陷的可探測性，驗收標準須符合 6.4.12.2.7、6.4.12.2.8 或 6.4.12.2.9。

6.4.15.2.3.3.2 疲勞分析須考慮建造公差。

6.4.15.2.3.3.3 主管機關認為必要時，可要求做模型試驗，以確定應力集中系數和結構單元的疲勞壽命。

6.4.15.2.3.4 意外設計條件

6.4.15.2.3.4.1 液艙和液艙支持構件須為 6.4.9.5 和 6.4.1.6.3 中規定的相關意外載荷和設計條件而設計。

6.4.15.2.3.4.2 在經受 6.4.9.5 中規定的意外載荷時，應力須符合在慮及其較低的發生概率而經酌情修正的 6.4.15.2.3 中規定的驗收衡準。

6.4.15.2.3.5 標記

壓力容器的任何標記，須以不致產生不可接受的局部應力升高的方法做出。

6.4.15.2.3.6 應力類別

對於應力評估，應力類別在本節中界定如下：

- .1 正應力係指對參照平面的正交應力的分量。
- .2 膜應力係指平均分佈的及等於所審議部件全厚度應力平均值的正應力分量。
- .3 彎曲應力係指所審議部件全厚度的可變應力減去膜應力。
- .4 剪應力係指作用於參照平面的應力分量。
- .5 初應力係指平衡外力和力矩所需的外加載荷產生的應力。初應力的基本特點是非自限制性。顯著超出屈服強度的初應力將導致失穩或至少嚴重變形。

- .6 總體主膜應力係指這樣的主膜應力，其在構件中的分佈，使載荷不會因屈服而導致重新分佈。
- .7 局部主膜應力發生在壓力或其他力學載荷產生的、並與主要或不連續影響相關的一種膜應力造成結構中其他部分載荷轉移過渡變形時。此應力分類為局部主膜應力，雖然具有一些次應力的特點。應力區域可被視為是局部的，如果：

$$S_1 \leq 0.5\sqrt{Rt} ; \text{ 和}$$

$$S_1 \geq 2.5\sqrt{Rt}$$

式中：

S_1 = 子午線方向之上等效應力超過 $1.1f$ 上的距離；

S_2 = 子午線方向上至初總膜應力限值被超出區域的距離；

R = 容器的平均半徑；

t = 總體主膜應力限值被超出處的容器壁厚度；

和

f = 允許總體主膜應力。

- .8 次應力係指相鄰構件限制或結構自我限制所產生的正應力或剪應力。次應力的基本特點是其自限制性。局部屈服和小的變形可滿足造成應力產生的條件。

6.4.15.3 C 型獨立液艙

6.4.15.3.1 設計依據

6.4.15.3.1.1 C 型獨立液艙的設計依據為經修訂納入斷裂力學和裂紋擴展衡準的壓力容器衡準。6.4.15.3.1.2 中規定的最小設計壓力旨在確保動應力足夠低，從而在液艙使用壽命期間，初始表面裂紋不會擴展超過外殼厚度的一半。

6.4.15.3.1.2 設計蒸氣壓力不得小於：

$$P_0 = 0.2 + AC (\rho_r)^{1.5} \text{ (MPa)}$$

式中：

$$A = 0.00185 \left(\frac{\sigma_m}{\Delta\sigma_A} \right)^2,$$

其中：

σ_m = 設計主膜應力；

$\Delta\sigma_A$ = 許用動態膜應力（雙振幅，當概率水平為 $Q=10^{-8}$ ）並等於：

- 對於鐵素體（珠光體）/馬氏體和奧氏體鋼， 55N/mm^2 ；
- 對於鋁合金（5083-0）， 25N/mm^2 ；

C = 液艙的特性尺度，取下列各值中的最大者：

$$h, 0.75b \text{ 或 } 0.45\ell,$$

其中：

H = 液艙高度（沿船舶的垂向量取），m；

B = 液艙寬度（沿船舶的橫向量取），m；

ℓ = 液艙長度（沿船舶的縱向量取），m；

ρ_r = 設計溫度下貨物的相對密度（淡水： $\rho_r = 1$ ）。

6.4.15.3.2 殼體厚度

6.4.15.3.2.1 在考慮殼體厚度時，以下所列適用：

- .1 對於壓力容器，按 6.4.15.3.2.4 計算出的厚度須被視為加工成形後沒有任何負公差的最小厚度；
- .2 對於壓力容器，加工成形後殼體和封頭的最小厚度（包括腐蝕裕量）須為：對於碳錳鋼和鎳鋼，不小於 5mm；對於奧氏體鋼不小於 3mm；對於鋁合金，不小於 7mm。
- .3 當進行 6.4.15.3.2.4 所述的檢驗和無損探傷時，按 16.3.6.4 計算中所用的焊接有效系數須為 0.95。如慮及其他因素，諸如所使用的材料、接頭型式、焊接方法以及載荷類型等，則焊接有效系數可以增大到 1.0。對於處理用壓力容器，主管機關在考慮了諸如所使用的材料、設計溫度、材料製造時的零韌性轉變溫度、接頭型式和焊接方法等因素，可以接受不小於 16.3.6.4 中的局部無損探傷，但在這種情況下，所採用的焊接有效系數不得大於 0.85。對於特殊材料，上述系數須根據焊接接頭的標定機械性能減小。

6.4.15.3.2.2 在內部壓力計算中須考慮 6.4.9.3.3.1 中界定的設計液體壓力。

6.4.15.3.2.3 用於驗證壓力容器屈曲的設計外部壓力 P_e 不得小於按下式計算所得值：

$$P_e = P_1 + P_2 + P_3 + P_4 \quad (\text{MPa})$$

式中：

P_1 = 真空釋放閥的調定壓力。對未配備真空釋放閥的容器，須作特別考慮，但一般須取為不小於 0.025MPa。

P_2 = 安放壓力容器或壓力容器部件的全封閉處所的壓力釋放閥（PRV）的調定壓力；對其他處所， $P_2 = 0$ 。

P_3 = 由於絕熱層的重量和收縮、殼體重量（包括腐蝕裕量）以及壓力容器可能承受的其他外部載荷所引起的作用在殼體中或殼體上的壓力。這些壓力包括但不限於：氣室、塔架和管路的重量、部分充裝工況下的貨品、加速度和船體變形的影響。此外，還須考慮外部壓力或內部壓力或兩者的局部作用。

P_4 = 由水壓頭引起的作用於露天甲板上的壓力容器或壓力容器一部分的外部壓力；對其他處所， $P_4 = 0$ 。

6.4.15.3.2.4 基於內部壓力的結構尺寸，須如下計算：

須確定承受 6.4.9.3.3.1 中界定的內部壓力的壓力容器承壓部件，包括法蘭，的厚度和形狀。在所有情況下，須根據獲接受的壓力容器設計原理進行這些計算。壓力容器承壓部件的開口，須按主管機關可接受的公認標準予以加強。

6.4.15.3.2.5 對於靜、動載荷的應力分析，須如下進行：

- .1 壓力容器的結構尺寸，須按 6.4.15.3.2.1 至 6.4.15.3.2.4 和 6.4.15.3.3 予以確定；
- .2 須對支持構件及其殼體連接件處的載荷和應力進行計算。如適用，須採用 6.4.9.2 至 6.4.9.5 中所述載荷。支持結構處的應力須符合主管機關可接受的公認標準。在特殊情況下，主管機關可要求作疲勞分析；和
- .3 如主管機關要求，須對二階應力和熱應力予以特別考慮。

6.4.15.3.3 極限設計條件

6.4.15.3.3.1 塑性變形

對於 C 型獨立液艙，許用應力不得超過：

$$\begin{aligned}
 \sigma_m &\leq f \\
 \sigma_L &\leq 1.5f \\
 \sigma_b &\leq 1.5f \\
 \sigma_L + \sigma_b &\leq 1.5f \\
 \sigma_m + \sigma_b &\leq 1.5f \\
 \sigma_m + \sigma_b + \sigma_g &\leq 3.0f \\
 \sigma_L + \sigma_b + \sigma_g &\leq 3.0f
 \end{aligned}$$

式中：

$$\begin{aligned}
 \sigma_m &= \text{等效總體主膜應力；} \\
 \sigma_L &= \text{等效局部主膜應力；} \\
 \sigma_b &= \text{等效主彎曲應力；} \\
 \sigma_g &= \text{等效二階應力；和} \\
 f &= R_m/A \text{ 或 } R_e/B, \text{ 的小者；}
 \end{aligned}$$

R_m 和 R_e 見 6.4.12.1.1.3 中的定義。對於應力 σ_m , σ_L , σ_g 和 σ_b , 另見 6.4.15.2.3.6 中的應力類別定義。A 和 B 值須至少具有下列最小值：

	鎳鋼和碳錳鋼	奧氏體鋼	鋁合金
A	3	3.5	4
B	1.5	1.5	1.5

6.4.15.3.3.2 屈曲衡準須如以下所列：

對於承受外部壓力和引起壓縮應力的其他載荷的壓力容器，其厚度和形狀須基於使用獲接受的壓力容器屈曲理論的計算，並須充分考慮到理論和實際屈曲應力值之間因板邊不對中、橢圓度以及在規定弧長（或弦長）範圍內存在的失圓度而引起的差別。

6.4.15.3.4 疲勞設計條件

6.4.15.3.4.1 對於 C 型獨立液艙，如在大氣壓力下液化氣燃料溫度低於 -55℃，主管機關可要求附加驗證以依據同液艙的尺寸、形狀、支持結構和連接件，核查其是否符合 6.4.15.3.1.1 對靜應力和動應力的要求。

6.4.15.3.4.2 真空絕緣液艙支持構件的疲勞強度設計須特別注意，對液艙內外壁之間的有限檢查可能性也須特殊考慮。

6.4.15.3.5 意外設計條件

6.4.15.3.5.1 液艙和液艙支持構件須為 6.4.9.5 和 6.4.1.6.3 中規定的相關意外載荷和設計條件而設計。

6.4.15.3.5.2 在承受 6.4.9.5 中規定的意外載荷時，應力須符合酌情慮及其較低的發生概率而經修訂的 6.4.15.3.3.1 中規定的驗收衡準。

6.4.15.3.6 標記

壓力容器的任何標記，須以不致產生不可接受的局部應力升高的方法做出。

6.4.15.4 膜式液艙

6.4.15.4.1 設計依據

6.4.15.4.1.1 膜式圍護系統的設計依據為使熱和其他的膨脹或收縮得到補償，且無喪失薄膜密性的不當風險。

6.4.15.4.1.2 在考慮 6.4.15.4.2.1 中列明的營運事件中，須使用基於分析和試驗的系統方法證明該系統將提供其預期功能。

6.4.15.4.1.3 要求具備 6.4.3 中界定的完整次屏壁。次屏壁須按照 6.4.4 進行設計。

6.4.15.4.1.4 設計蒸氣壓力 P_0 通常不得超過 0.025MPa。如果船體構材尺寸相應加大並適當考慮支持絕熱層的強度， P_0 可增加到一較高、但小於 0.07MPa 的數值。

6.4.15.4.1.5 膜式液艙的定義並不排除使用非金屬薄膜或將薄膜包括或合併在絕熱層內的設計。

6.4.15.4.1.6 薄膜厚度一般不得超過 10mm。

6.4.15.4.1.7 按照 6.11.1，惰性氣體在主要絕熱處所和次要絕熱處所中的循環須足以允許有效的氣體探測。

6.4.15.4.2 設計考慮

6.4.15.4.2.1 須評估在薄膜壽命期間可能導致液密喪失的潛在事件。這包

括但不限於：

.1 極限設計事件：

- .1 薄膜拉力失效；
- .2 絕熱層的壓縮破壞；
- .3 熱老化；
- .4 絕熱層和船體結構之間喪失連接；
- .5 薄膜與絕熱系統喪失連接；
- .6 內部結構及其支持結構的結構完整性；和
- .7 支持船體結構的破損。

.2 疲勞設計事件：

- .1 薄膜，包括與船體結構的接頭和附件，疲勞；
- .2 絕熱層的疲勞裂紋；
- .3 內部結構及其支持結構的疲勞；和
- .4 導致壓載水進入的內殼疲勞裂紋。

.3 意外設計事件：

- .1 意外機械破損（例如營運時液艙內掉落的物體）；
- .2 絕熱處所的意外過壓；
- .3 液艙的意外真空；和
- .4 內殼結構進水。

單個內部事件會導致 2 個薄膜同時或級聯失效的設計不可接受。

6.4.15.4.2.2 按照 6.4.15.4.1.2 進行設計時，須確定建造液化氣燃料圍護系統時使用的材料的物理性能（機械的、熱的、化學的等）。

6.4.15.4.3 載荷和載荷組合

對於因屏壁間處所的超壓、液化氣體燃料液艙中可能出現的真空、液體晃蕩的影響、船體振動的影響或這些事件的組合而可能造成的液艙完整性喪失，須予以特別注意。

6.4.15.4.4 結構分析

6.4.15.4.4.1 須進行旨在確定極限強度的結構分析和/或試驗和液化氣燃料圍護和相關結構（例如 6.4.7 中界定的泵及其支持結構）的疲勞評估。結構分析須提供對已確定的對液化氣燃料圍護系統為關鍵性的各失效模式進行評估所需的數據。

6.4.15.4.4.2 船體結構分析序計及 6.4.9.3.3.1 中所述的內部壓力。須特別注意船體的變形及其與薄膜和相關絕熱層的相容性。

6.4.15.4.4.3 6.4.15.4.4.1 和 6.4.15.4.4.2 中所述的分析須基於船舶和液化氣燃料圍護系統特有的運動、加速度和響應。

6.4.15.4.5 極限設計條件

6.4.15.4.5.1 須按照 6.4.15.4.1.2 確定在營運條件下各關鍵部件、子系統或組件的結構抗力。

6.4.15.4.5.2 液化氣燃料圍護系統、其與船體結構的連接件和內部液艙結構失效模式強度驗收衡準的選擇須反映與所考慮的失效模式相關的後

果。

6.4.15.4.5.3 內殼用材尺寸須滿足對深艙的要求，並慮及 6.4.9.3.3.1 中所述的內部壓力和 6.4.9.4.1.3 中界定的對晃蕩載荷的適當規定。

6.4.15.4.6 疲勞設計條件

6.4.15.4.6.1 對液艙內無法通過連續監測可靠探測到失效發展的結構（即泵塔）以及部分薄膜和泵塔附件，須進行疲勞分析。

6.4.15.4.6.2 須按照 6.4.12.2 及依據以下所列的相關規定進行疲勞計算：

- .1 結構部件對於結構完整性的重要性；和
- .2 檢查的有效性。

6.4.15.4.6.3 對於可經試驗和/或分析證明裂紋將不會發展至造成 2 個薄膜同時或級聯失效的結構單元， C_w 須小於或等於 0.5。

6.4.15.4.6.4 要定期檢查的結構單元，若未處理的疲勞裂紋會發展至造成 2 個薄膜同時或級聯失效，須滿足 6.4.12.2.8 中所述的疲勞和斷裂力學規定。

6.4.15.4.6.5 無法靠近進行營運中檢查的結構單元，若疲勞裂紋會無預兆地發展至造成 2 個薄膜同時或級聯失效，須滿足 6.4.12.2.9 中所述的疲勞和斷裂力學規定。

6.4.15.4.7 意外設計條件

6.4.15.4.7.1 圍護系統和支持船體結構須為 6.4.9.5 中規定的意外載荷而設計。這些載荷無需相互或與環境載荷合成。

6.4.15.4.7.2 附加相關意外情景須基於風險評估予以確定。須特別考慮液

艙內的繫固設備。

6.4.16 新穎概念的極限狀態設計

6.4.16.1 不能使用 6.4.15 進行設計的新穎構造的燃料圍護系統須酌情使用本節以及 6.4.1 至 6.4.14 進行設計。按照本節進行的燃料圍護系統設計須基於極限狀態設計的原則，該極限狀態設計是一種可適用於已確定設計方案又適用於新穎設計的設計途徑。此更通用的方法所保持的安全水平與使用 6.4.15 設計的已知圍護系統所達到的安全水平類似。

6.4.16.2.1 極限狀態設計是系統性方法，對每個結構單元就與 4.3.4 中確定的設計條件相關的可能失效模式進行評估。極限狀態可定義為超出後結構或部分結構不再滿足規定的狀態。

6.4.16.2.2 對於每個失效模式，一個或多個極限狀態可能相關。考慮到所有相關極限狀態，結構單元的極限載荷為從所有相關極限狀態中得出的最小極限載荷。極限狀態分為以下 3 類：

- .1 終極極限狀態（ULS），在完整（無破損）條件下，對應於最大承載能力或在某些情況下，對應於最大適用應變或變形。
- .2 疲勞極限狀態（FLS），對應於由於隨時間變化（循環）裝載的影響造成的降級；和
- .3 意外極限狀態（ALS），與結構的抗意外狀況能力有關。

6.4.16.3 極限狀態設計的程序和相關設計參數須符合第 A-1 部分附錄中所載的《新穎構造燃料圍護系統設計中極限狀態方法使用標準》（LSD 標準）。

6.5 可移動液化氣燃料液艙的規定

6.5.1 液艙的設計須符合 6.4.15.3。液艙支持（集裝箱框架或卡車底盤）須為預定用途而設計。

6.5.2 可移動燃料液艙須置於設有以下所列的專門區域：

- .1 取決於所在位置和貨物操作的液艙機械保護；
- .2 若處於開放甲板：泄漏保護和水噴霧冷卻系統；和
- .3 若處於圍閉處所：要將該處所視為液艙連接處所。

6.5.3 可移動燃料艙在與船舶系統相連時，須固定在甲板上。設計液艙的支撐和固定佈置，須慮及船舶特性和液艙位置，為最大預期靜態和動態傾斜、最大預期加速度值而設計。

6.5.4 須考慮到可移動燃料艙的強度及其對船舶穩性的影響。

6.5.5 須使用經認可的軟管或其他為提供足夠靈活性而設計的適當方法與船舶燃料管道系統連接。

6.5.6 須為非永久性連接意外斷開或斷裂情況提供限制燃料泄漏量的佈置。

6.5.7 可移動燃料艙減壓系統須連接至固定排氣系統。

6.5.8 可移動燃料艙控制和監測系統須與船舶控制和檢測系統融合。可移動燃料艙安全系統須與船舶安全系統融合（如液艙閥門關閉系統，泄漏/氣體探測系統）。

6.5.9 須確保檢查和維護液艙連接的安全通道。

6.5.10 與船舶燃油管道系統連接後，

- .1 除 6.5.6 所述的減壓系統，須確保能隨時隔離每一個可移動液艙；
- .2 對一個可移動液艙的隔離不得妨礙其餘可移動液艙的可用性；和
- .3 液艙不得超過 6.8 中給出的灌裝極限。

6.6 壓縮天然氣燃料圍護的規定

6.6.1 用於壓縮天然氣的儲存液艙須經主管機關認證並批准。

6.6.2 壓縮天然氣艙須裝有設定點低於艙設計壓力的壓力釋放閥，且排放口的位置須符合 6.7.2.7 與 6.7.2.8 中的要求。

6.6.3 須提供在發生可能影響到液艙的失火時釋放液艙壓力的適當手段。

6.6.4 通常不允許在圍閉處所內存儲壓縮天然氣，但經特殊考慮並經主管機關認可，可以允許，但除滿足 6.3.4 至 6.3.6 外，還要滿足以下所列：

- .1 須提供在發生可能影響到液艙的失火時釋放液艙壓力並使液艙惰化的適當手段；
- .2 包含壓縮天然氣存儲的圍閉處所內的所有表面須具有防止任何高壓氣體損失及所導致的凝結的隔熱保護，除非艙壁係為氣體碰撞滲漏會產生的最低溫度而設計；及可隨氣體膨脹泄漏而上升；
- .3 包含壓縮天然氣存儲的圍閉處所內設有固定滅火系統。對撲滅噴射狀火焰應特別予以考慮。

6.7 壓力釋放系統規定

6.7.1 通則

6.7.1.1 所有燃料儲存艙均須具有與燃料圍護系統的設計及其所裝載的燃料相適應的壓力釋放系統。所承受的壓力可能超過其設計承受能力的燃料儲存艙處所，屏壁間處所，液艙連接處所和液艙圍堰，也須具備合適的壓力釋放系統。6.9 中規定的壓力控制系統須獨立於壓力釋放系統。

6.7.1.2 可能承受超過其設計壓力的燃料儲存液艙須配備真空保護系統。

6.7.2 液化氣燃料艙的壓力釋放系統

6.7.2.1 如果不能排除向真空絕緣液艙的真空處所中釋放燃料，在液艙位於甲板之下時，真空處所須由連接到通風系統的減壓裝置予以保護。在露天甲板上，對於尺寸不超過 40 英尺集裝箱的液艙，若所釋放的氣體不會進入安全區域，主管機關可接受直接向大氣中釋放。

6.7.2.2 液化氣燃料艙須設有最少 2 個壓力釋放閥（PRV），以允許在出現故障或泄漏時斷開一個壓力釋放閥。

6.7.2.3 屏壁間處所須設有壓力釋放裝置。對於薄膜系統，設計方須證明屏壁間處所壓力釋放閥具有足夠的尺寸。

6.7.2.4 壓力釋放閥的調定壓力須不高於設計該液艙時所採用的蒸氣壓力。具有不超過總釋放能力 50% 的閥可調至 MARVS 以上 5% 的壓力以允許按順序開啟，儘量減少不必要的蒸氣釋放。

6.7.2.5 下列溫度要求適用於安裝至壓力釋放系統的壓力釋放閥：

- .1 設計溫度低於 0°C 的液化氣燃料艙上的壓力釋放閥的設計和佈置須能防止由於結冰而造成閥失靈；

- .2 壓力釋放閥的結構和佈置，須慮及因環境溫度結冰的影響；
- .3 壓力釋放閥須由熔點高於 925℃ 的材料構成。可接受內部結構和密封使用低熔點材料，只要不損害壓力釋放閥的故障保險運作；和
- .4 先導式壓力釋放閥上的感應導管和排氣管須足夠堅固以防止破損。

6.7.2.6 須有燃料艙的壓力釋放閥發生故障時的緊急隔離安全裝置：

- .1 須提供程序並納入操作手冊（見第 18 章）；
- .2 程序須只允許隔離一個液化天然氣燃料液艙所安裝的減壓閥，為此須包含物理連鎖；和
- .3 壓力釋放閥的隔離須在船長的監督下進行。該行動須在船舶航行日誌內，及在壓力釋放閥處記錄。

6.7.2.7 安裝在液化氣燃料液艙上的每個壓力釋放閥須與透氣系統相連接，該系統須為：

- .1 其建造使氣體將不受阻礙且通常在出口處直接垂直向上排放；
- .2 其佈置使水或雪進入透氣系統的可能性減至最低；和
- .3 其佈置須使透氣管出口的高度通常高出露天甲板不小於 B/3 或 6m，取其大者，並高出工作區域和步橋 6m。然而，通風杆高度可依據主管機關的特殊考慮限制至較低高度。

6.7.2.8 壓力釋放閥的出口與最近的以下設備通常須至少間隔 10 米：

- .1 進氣口、排氣口或居住區、服務和控制區，或其他氣體安全區的開口；和
- .2 機械裝置排氣口。

6.7.2.9 所有其他燃氣透氣管出口均須按照 6.7.2.7 和 6.7.2.8 佈置。須設有措施，防止液體因與其相連處所的靜液壓力而從透氣管桅出口溢出。

6.7.2.10 在透氣管系中，須設有能從可積聚液體的地方排放液體的措施。須將壓力釋放閥和管路佈置成在任何情況下液體不會積聚在壓力釋放閥內或其附近。

6.7.2.11 在透氣管出口端，須裝設網孔不大於 13mm^2 的適當的防護網以防異物進入，且不會對流量造成不利影響。

6.7.2.12 所有透氣管路須設計和佈置成不會因承受外界溫度的變化、流動產生的力或船體的運動而受損。

6.7.2.13 須將壓力釋放閥連接至液艙最高部分。壓力釋放閥在液艙上的位置須使其在船舶處於橫傾 15° 和縱傾 $0.015L$ (L 界定於 2.2.25 中) 的情況下，在 6.8 中給出的充裝極限 (FL) 下仍保持在氣相中。

6.7.3 壓力釋放系統的尺寸確定

6.7.3.1 壓力釋放閥的尺寸確定

6.7.3.1.1 每個液化氣燃料艙的各壓力釋放閥的綜合釋放能力須在使液化氣燃料艙中的壓力升高不超過釋放閥的最大允許調定值 (MARVS) 的 20% 時，釋放以下所列之大者：

- .1 如果液化氣燃料艙惰化系統的最大可達到的工作壓力超過液化氣燃料艙的 MARVS，則取液化氣燃料艙惰化系統的最大能力；或
- .2 用下式算得的火災波及時的蒸氣生成量：

$$Q = FGA^{0.82} \text{ (m}^3\text{/s)}$$

式中：

Q = 在 273.15K 和 0.1013MPa 的標準狀態下所需的最小空氣排放率；

F = 用於不同類型液化氣燃料艙的火災波及系數：

F = 1.0，對於甲板上無絕熱層的液艙；

F = 0.5，對於甲板以上其絕熱層係經主管機關認可的液艙。（認可將基於所使用的防火材料、絕熱層的熱傳導性能及其在火災波及時的穩定性）；

F = 0.5，對於安裝在貨艙處所內的無絕熱獨立液艙；

F = 0.2，對於貨物處所內有絕熱的獨立液艙（或絕熱貨艙處所內的非絕熱獨立液艙）；

F = 0.1，對於惰化貨艙處所內的絕熱獨立液艙（或惰化、絕熱貨艙處所內的非絕熱獨立液艙）；和

$F = 0.1$ ，對於膜式液艙。

對於部分突出於露天甲板上的獨立液艙，其火災波及系數，須根據甲板上、下方的表面面積予以確定。

$G =$ 按照以下公式的氣體系數：

$$G = \frac{12.4}{LD} \sqrt{\frac{ZT}{M}}$$

其中：

$T =$ 在釋放狀態下，即在 120% 的釋放閥調定壓力下的的絕對溫度 (K) ；

$L =$ 在釋放狀態下，物質被氣化時的潛熱，kJ/kg ；

$D =$ 根據比熱 k 確定的常數，用下列公式計算：

$$D = \sqrt{k \left(\frac{2}{k+1} \right)^{\frac{k+1}{k-1}}}$$

式中：

$k =$ 釋放狀態下的比熱率，其值在 1.0 和 2.2 之間。如果 k 為未知數時，須取 $D = 0.606$ ；

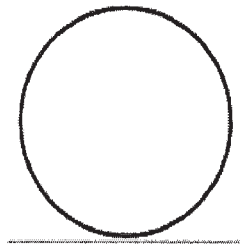
Z = 在釋放狀態下，氣體的壓縮系數；

如此系數為未知數，須取 $Z = 1.0$ ；

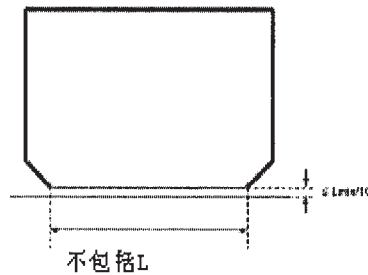
M = 產品分子量。

須確定擬載運的每一液化氣燃料的氣體系數，其最高值須用於 PRV 尺寸確定。

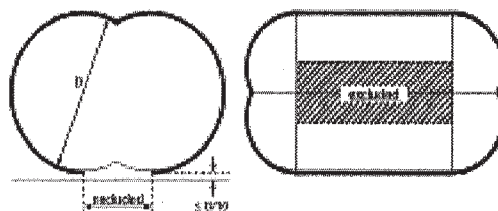
A = 不同艙型的液艙外表面面積 (m^2)，如圖 6.7.1 所示。



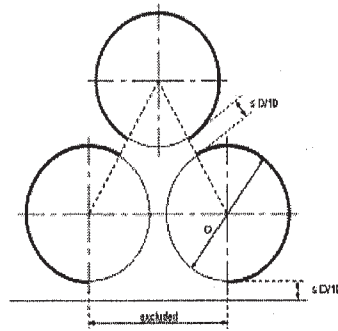
具有球形、半球或半橢圓形封頭的圓柱形液艙或球形液艙



棱形液艙



雙耳式液艙



水平圓柱形液艙佈置

圖 6.7.1

6.7.3.1.2 對於燃料存儲貨艙處所內的真空絕緣液艙和燃料存儲貨艙處所內由空倉與潛在火災荷載隔離或被無火災荷載的船舶處所圍繞的液艙，以下所列適用：

如須為火災載荷確定減壓閥尺寸，相應的火災因數可簡化為以下值：

$$F = 0.5 \text{ 至 } F = 0.25$$

$$F = 0.2 \text{ 至 } F = 0.1$$

最小火災因數 $F = 0.1$

6.7.3.1.3 釋放狀態下要求的空氣質量流由下列公式得出：

$$M_{\text{空氣}} = Q^* \rho_{\text{空氣}} \text{ (kg/s)}$$

式中：空氣密度 ($\rho_{\text{空氣}}$) = 1.293 kg/m³ (在 273.15K，0.1013MPa 時的空氣)。

6.7.3.2 通風管道系統尺寸測定

6.7.3.2.1 確定壓力釋放閥的尺寸時，須考慮壓力釋放閥上游和下游的壓

力損失以確保 6.7.3.1 要求的流量。

6.7.3.2.2 上游壓力損失

- .1 透氣管路中從液艙到壓力釋放閥入口處的壓降，須不超過按照 6.7.3.1 計算的流率下該釋放閥調定壓力的 3%；
- .2 先導式壓力釋放閥感應導管直接引自液艙氣室時，該壓力釋放閥須不受進入管壓力損失的影響；和
- .3 對於流量式導管，須考慮遠程感應導管中的壓力損失。

6.7.3.2.3 下游壓力損失

- .1 如設有共用透氣總管和透氣管桅，計算須包括所有關聯壓力釋放閥的流量。
- .2 透氣管中從壓力釋放閥出口至通往大氣的排放位置的背壓，包括任何與其他液艙相連的透氣管連接，須不超過下列值：
 - .1 非平衡壓力釋放閥： MARVS 的 10%；
 - .2 平衡壓力釋放閥： MARVS 的 30%；和
 - .3 先導式壓力釋放閥： MARVS 的 50%。

可接受壓力釋放閥製造商提供的替代值。

6.7.3.2.4 為確保壓力釋放閥的穩定運作，泄放須不少於進口壓力損失和額定排量時 0.02 倍 MARVS 的總和。

6.8 液化氣燃料艙的充裝極限的規定

6.8.1 液化氣存儲液艙在 2.2.36 中界定的參照溫度下不得充裝超過液艙容量的 98%。

實際燃料填充溫度的填充極限曲線須由以下公式得出：

$$LL = FL\rho_R/\rho_L$$

式中：

LL = 2.2.27 中界定的裝載極限，以百分數表達；

FL = 2.2.16 中界定的以百分數表示的充裝極限，此處為 98%；

ρ_R = 參照溫度下燃料的相對密度；和

ρ_L = 裝載溫度下燃料的相對密度。

6.8.2 在液艙的絕熱和液艙位置使艙中內容因外部失火而加熱的概率非常小時，可做出特殊考慮，允許高於使用參照溫度計算出的充裝極限，但不得超過 95%。這也適用於安裝了第二個壓力維護系統的情況（見 6.9）。但是，如壓力僅由燃料使用設備維持/控制，則須使用 6.8.1 中計算出的充裝極限。

6.9 維護燃料儲存狀態的規定

6.9.1 液艙壓力和溫度控制

6.9.1.1 除設計成在最高設計環境溫度條件下能承受燃料的最大蒸氣錶壓力的液化氣燃料艙外，液化氣燃料液艙的壓力和溫度須通過主管機關可接受的方法，諸如下列方法之一，始終保持在設計範圍內：

.1 蒸氣的再液化；

- .2 蒸氣的熱氧化；
- .3 壓力積聚；和
- .4 液化氣燃料冷卻。

所選擇的方法，假設液艙處於滿艙正常工作壓力以及船舶處在空閒狀態，即只產生生活用電，須能將液艙壓力保持在液艙壓力釋放閥的設定壓力以下達 15 天。

6.9.1.2 除緊急情況外，為控制液艙壓力而排放燃料蒸汽是不可接受的。

6.9.2 系統設計

6.9.2.1 對於全球營運，其最高的環境設計溫度須為海水 32℃，空氣 45℃。對於在特熱或特冷區域中的營運，這些設計溫度須令主管機關滿意地予以增減。

6.9.2.2 系統的總體能力須使其在不向大氣排放的情況下將壓力控制在設計條件內。

6.9.3 再液化系統

6.9.3.1 再液化系統須按照 6.9.3.2 設計與計算。該系統還要為無或低消耗的情況充分確定其大小。

6.9.3.2 須按下列方式之一佈置再液化系統：

- .1 直接系統：對氣化的燃料進行壓縮、冷凝並輪回燃料艙；
- .2 間接系統：用製冷劑對燃料或氣化的燃料進行冷卻或冷凝，而不壓縮；

- .3 混合系統：將氣化的燃料壓縮並在燃料/制冷劑的熱交換器中加以冷凝，及輪回燃料艙；或
- .4 如果在設計條件內的壓力控制操作期間，再液化系統產生包含甲烷的廢氣流，這些廢氣須儘實際可行地在不向大氣排放的情況下予以處置。

6.9.4 熱氧化系統

6.9.4.1 熱氧化可按照本規則中所述對用氣設備的規定對蒸氣予以消耗或在專用的氣體燃燒器（GCU）中對蒸氣予以消耗而實現。必須證明氧化系統的能力足以消耗所需數量的蒸汽。對此，需考慮推進或其他服務的慢速運行和/或無耗時段。

6.9.5 相容性

6.9.5.1 用於燃料製冷或冷卻的製冷劑或輔助介質須與其可能接觸的燃料相容（不能產生任何危險反應或過度腐蝕性產品）。此外，在使用多種製冷劑或介質時，須相互相容。

6.9.6 系統的可用性

6.9.6.1 系統及其支持輔助服務的可用性須為：在（機械非靜止部件或控制系統部件）發生單項故障時，可由另一個服務/系統保持燃料艙的壓力和溫度；

6.9.6.2 使燃料艙的壓力和溫度保持在其設計範圍內所必需的熱交換器須設有備用熱交換器，除非其所具備的能力超過保持壓力所需最大要求能力的 25%並能在無外部幫助的條件下在船上進行修理。

6.10 燃料儲存系統內大氣控制的規定

6.10.1 須設有一個管路系統，使各燃料艙能夠安全除氣，並從除氣狀態安全充裝燃料。該系統的佈置須儘力減少大氣變換後氣體或空氣穴留存的可能性。

6.10.2 須將系統設計成利用惰性介質作為中間步驟消除大氣變換作業任何部分期間燃料艙內易燃混合物存在的可能性。

6.10.3 須為每個燃料艙提供氣體採樣點以監測大氣變換進程。

6.10.4 用於液艙除氣的惰性氣體可由船舶外部供給。

6.11 燃料存儲貨艙處所（除 C 型獨立液艙外的燃料圍護系統）內大氣控制的規定

6.11.1 要求全部或部分次屏壁的燃料圍護系統的相關屏壁間處所和燃料存儲艙處所貨艙處所，須使用適當的乾燥惰性氣體惰化，並用船上惰性氣體發生系統或用船上儲存提供補充惰性氣體以保持惰化。船上儲存的惰性氣體須足以滿足至少 30 天的正常消耗。主管機關可依據船舶的運營考慮較短時間。

6.11.2 或者，6.11.1 中所述的、只要求部分次屏壁的處所可用乾燥空氣充填，但船上要保持惰性氣體存儲或設有足以惰化上述處所中最大處所的惰性氣體發生系統，以及上述處所和相關蒸氣探測系統的構成以及惰化裝置的能力，要確保能迅速探測到燃料艙的任何泄漏並在可能發展成危險狀態之前完成惰化。須設有提供足夠的適當質量乾燥空氣的設備，以滿足預期之需。

6.12 C 型獨立液艙周圍處所環境控制的規定

6.12.1 燃料艙周圍處所，須充填適當的乾燥空氣，並用合適的乾燥空氣

設備提供的乾燥空氣，保持該狀態。這只適用於因低溫表面有冷凝和結冰問題的燃料艙。

6.13 惰化規定

6.13.1 須設有如下規定的用以防止燃料蒸氣倒流至惰性氣體系統的佈置。

6.13.2 為防止可燃氣體回流至任何非危險處所，惰性氣體供應管線須串聯配備兩個關閉閥並在兩關閉閥門之間安裝一個通風閥（雙阻斷和排放閥）。另外，須在雙阻斷和排放閥佈置與燃料系統之間安裝一個可關閉的止回閥。這些閥門須位於非危險處所之外。

6.13.3 當至燃料管路系統的連接為非永久性時，可用兩個止回閥代替 6.13.2 中要求的閥門組。

6.13.4 所採用的佈置須使每個被惰化的處所都能被隔離，並為控制這些處所中的壓力設置必要的控制和釋放閥等。

6.13.5 如果絕熱處所持續獲得惰性氣體作為泄漏檢查系統的一部分，須設有裝置監測各處所獲得的氣體量。

6.14 船上惰性氣體生產和儲存的規定

6.14.1 產生惰性氣體的設備須能產生在任何時間含氧量都不超過容積的 5% 的惰性氣體。惰性氣體製造設備的惰性氣體供應管路上須安裝一個連續讀取含氧量計和一個調定在最高含氧量為容積的 5% 的報警裝置。

6.14.2 惰性氣體系統須具有適合於燃料圍護系統的壓力控制和監測裝置。

6.14.3 如氮氣發生器或氮儲存設施安裝在機艙外的單獨隔間中，該單獨

隔間須配備每小時能至少提供 6 次換氣的獨立機械抽排通風系統。須安裝低氧警報。

6.14.4 氮氣管道須只能通過通風良好的處所。圍閉處所內的氮氣管道須：

- 完全焊接；
- 只在需要安裝閥門處使用儘少數量的法蘭連接；和
- 儘可能短。

7 材料和總管路設計

7.1 目標

7.1.1 本章的目標是確保燃料在所有營運狀態下的安全裝卸，針對所涉及產品的性質，儘量減少對船舶、船員和環境的風險。

7.2 功能要求

7.2.1 本章與 3.2.1、3.2.5、3.2.6、3.2.8、3.2.9 以及 3.2.10 中的功能要求相關，特別是以下所列適用：

7.2.1.1 燃料管道須能夠吸收燃料極端溫度造成的熱膨脹或收縮而不產生重大應力。

7.2.1.2 須採取措施保護管路、管系和部件和燃料艙免受因熱變形及燃料艙和船體構件的移動而引起的過大應力的影響。

7.2.1.3 若燃氣包含可能在系統裏凝結的較重成分，則須安裝安全移除液體的設備。

7.2.1.4 必要時，須對低溫管路與其鄰接的船體構件進行熱隔離，以防止

船體溫度降至船體材料設計溫度之下。

7.3 總管路設計的規定

7.3.1 總則

7.3.1.1 安全且可靠營運及維護所需的燃料管道和所有其他管道須按照至少與國際海事組織可接受標準等效的標準用顏色標記。

7.3.1.2 當液艙或管路與船體結構熱隔離時，須為管路和液艙與船體的電氣接地作出安排。所有具有密封墊片的管接頭和軟管接頭均須電氣接地連接。

7.3.1.3 所有可在充滿液體的情況下被隔絕的管線或部件，均須設有釋放閥。

7.3.1.4 須對可能包含低溫燃料的管路進行熱絕緣以儘可能減少濕氣凝結。

7.3.1.5 除燃料供給管道外的管線和電纜，若不產生點火源或有損於雙層壁管或導管的完整性，可佈置在雙層壁管或導管內。雙層壁管或導管須只包含營運目的所必須的管線或電纜。

7.3.2 壁厚

7.3.2.1 最小壁厚須按照下列公式計算：

$$t = (t_0 + b + c) / (1 - a/100) \text{ (mm)}$$

式中：

$$t_0 = \text{理論厚度}$$

$$t_0 = PD / (20Ke + P) \text{ (mm)}$$

其中：

P = 7.3.3 中所述設計壓力 (MPa) ；

D = 外徑 (mm) ；

K = 7.3.4 中所述許用應力 (N/mm²) ；和

e = 有效系數。對於無縫鋼管以及由經認可的焊接管製造廠供應的，按經認可標準進行無損探傷後認為等效於無縫鋼管的縱向焊或螺旋焊焊接管，取 1.0。在其他情況下，按經認可標準，可根據製造工藝要求有效系數小於 1.0 ；

b = 彎曲餘量 (mm) 。對 b 值的選取，須使僅受內壓的彎曲部分的計算應力不超過許用應力。如未做出此種證明，則 b 值須為：

$b = Dt_0/2.5r$ (mm)

其中：

r = 平均彎曲半徑 (mm) ；

c = 腐蝕餘量 (mm) 。如果預計受到腐蝕或浸蝕，則管系的壁厚須比其他設計規定所要求的值有所增加。此餘量須與管道的預期壽命相一致；和

a = 壁厚製造負公差 (%) 。

7.3.2.2 絕對最小壁厚須符合主管機關可接受的標準。

7.3.3 設計條件

7.3.3.1 對於管路、管系和部件，須取下列設計條件中的較大者：

- .1 對於可能與其釋放閥隔離並在任何時候僅含有蒸氣的管系或部件，45°C 的蒸氣壓力，假定系統中處於該系統的工作壓力和工作溫度下的飽和蒸氣初始狀態；或
- .2 燃料艙和燃料處理系統的 MARVS；或
- .3 相關泵或壓縮機的釋放閥的調定壓力；或
- .4 燃料管系的最大裝卸總壓頭；或
- .5 管路系統的釋放閥調定壓力。

7.3.3.2 管道、管系和部件須設定最小設計壓力為 1.0MPa，但管端敞開的管路則不少於 0.5MPa。

7.3.4 許用應力

7.3.4.1 對於包括不鏽鋼的鋼製管道，7.3.2.1 中的強度厚度公式中要考慮的許用應力須是下列值中較小者：

$$R_m/2.7 \text{ 或 } R_e/1.8$$

式中：

R_m = 室溫下材料最低抗張強度 (N/mm²)；和

R_e = 室溫下材料最低屈服應力 (N/mm²)。如在應力應變曲線上未顯示出確定的屈服應力，則 0.2% 的驗證應力適用。

7.3.4.2 為防止附加載荷造成管子的損壞、破斷和過度下垂或失穩，而需要一定的機械強度時，管壁厚度須比 7.3.2 要求的值有所增加。如增加管

壁厚度不現實或反而會使管子產生過大的局部應力，則須採用其他的設計方法，以減小、防止或消除上述載荷。此類附加載荷會因支撐、船舶變形、轉輸作業時的液壓喘振、懸掛閥的重量、對充裝臂連接的反作用力或其他原因而產生。

7.3.4.3 非鋼制管道的許用應力須由主管機關考慮。

7.3.4.4 高壓燃料管系須有足夠的建造強度。須通過應力分析予以確認並慮及：

- .1 管系重量引起的應力；
- .2 有意義時的加速度荷載；和
- .3 船舶中拱和中垂引起的內壓和載荷。

7.3.4.5 當設計溫度為-110℃或更低時，須考慮到由於管子的重量，包括加速度載荷（如較大）、內部壓力、熱收縮以及船舶中拱和中垂引起的載荷等所產生的所有應力，對管系的每一分支進行完整應力分析。

7.3.5 管路的柔性

7.3.5.1 燃料管道的佈置和安裝須提供必要的靈活性以保持管道系統在實際運營狀態下的完整性，並考慮到疲勞損壞的可能性。

7.3.6 管路裝配和連接細節

7.3.6.1 法蘭、閥件和其他附件，須符合主管機關可接受的標準並要慮及

7.3.3.1 中界定的設計壓力。對於蒸氣管路中使用的波紋管和膨脹接頭，可接受低於 7.3.3.1 中界定的最小設計壓力。

7.3.6.2 用於高壓燃料管系中的所有閥門和膨脹接頭須按照主管機關可接

受的標準予以認可。

7.3.6.3 管道系統須焊接並使用最少的法蘭接頭連接。須防止密封墊片爆裂。

7.3.6.4 管路製造與連接細節須符合以下所列：

7.3.6.4.1 直接連接

- .1 根部完全焊透的對接焊連接可用於各種用途。當設計溫度低於 -10°C 時，對接焊須為雙面焊或與雙面焊等效的對接焊，這可以通過採用在第一焊道上加襯墊、自耗嵌補或惰性氣體封底等方法予以實現，當設計壓力超過 1.0MPa 及設計溫度為 -10°C 或更低時，須除去襯墊。
- .2 具有符合公認標準尺寸的套筒焊接接頭和相關焊接，須僅用於外徑小於或等於 50mm 和設計溫度不低於 -55°C 的設備管路和端部開敞管路。
- .3 符合公認標準的螺紋連接須僅用於外徑小於或等於 25mm 的次要管路和儀錶管路。

7.3.6.4.2 法蘭接頭

- .1 法蘭接頭中的法蘭，須為頸焊、套焊或插入焊等類型；及
- .2 對於除端部敞開管路以外的所有管路，下列限制適用：
 - .1 設計溫度低於 -55°C 時，須僅採用頸焊法蘭；及
 - .2 設計溫度低於 -10°C 時，對於公稱尺寸大於 100mm 者，不得採用套焊法蘭，而對於公稱尺寸大於 50mm

者，不得採用插入焊法蘭。

7.3.6.4.3 膨脹接頭

如按 7.3.6.1 設置波紋管和膨脹接頭，下列要求適用：

- .1 如果需要，須保護波紋管防止結冰；
- .2 除液化氣燃料存儲艙內，不得採用套筒接頭；和
- .3 波紋管通常不得佈置在圍閉處所內。

7.3.6.4.4 其他接頭

管路接頭須按 7.3.6.4.1 至 7.3.6.4.3 連接，但對於其他特殊情況，主管機關可考慮替代佈置。

7.4 材料規定

7.4.1 金屬材料

7.4.1.1 燃料圍護和管道系統的材料須符合以下列表中給出的最低規定：

表 7.1：適用於設計溫度不低於 0℃ 的燃料艙和處理用壓力容器的板材、管材（無縫管和焊接管）、型材和鍛件。

表 7.2：適用於設計溫度低於 0℃ 和低至-55℃ 的燃料艙、次屏壁和處理用壓力容器的板材、型材和鍛件。

表 7.3：適用於設計溫度低於-55℃ 和低至-165℃ 的燃料艙、次屏壁和處理用壓力容器的板材、型材和鍛件。

表 7.4：適用於設計溫度低於 0℃ 和低至-165℃ 的燃料管系和處理用管系的管材（無縫管和焊接管）、鍛件和鑄件。

表 7.5：適用於 6.4.13.1.1.2 要求的船體結構的板材和型材。

表 7.1

設計溫度不低於 0℃ 的燃料艙和處理用壓力容器的板材、 管材（無縫管和焊接管） ^{1,2} 、型材和鍛件		
化學成分和熱處理		
◆ 碳錳鋼		
◆ 全鎮靜細晶粒鋼		
◆ 經主管機關同意的少量合金元素添加		
◆ 構成極限由主管機關認可		
◆ 正火或淬火和回火的 ⁴		
張力和韌性（衝擊）試驗規定		
取樣頻率		
◆ 板材	按“件”試驗	
◆ 型材和鍛件	按批試驗	
力學性能		
◆ 張力性能	規定最低屈服應力不超過 410N/mm ^{2,5}	
韌性（夏比 V 型缺口衝擊試驗）		
◆ 板材	橫向試樣，最小平均能量值（KV）27J	
◆ 型材和鍛件	縱向試樣，最小平均能量值（KV）41J	
◆ 試驗溫度	厚度 t（mm）	試驗溫度（℃）
	T ≤ 20	0
	20 < t ≤40 ³	-20
註：		
1. 對於無縫管和附件，常規做法適用。使用縱向焊接和螺旋焊接的管材，須經主管機關特別認可。		
2. 管道不要求進行夏比 V 型缺口衝擊試驗。		
3. 本表一般適用於厚度不超過 40mm 的材料。更大厚度的建議須經主管機關認可。		
4. 可使用控制軋製工藝或熱-力控制工藝（TMCP）作為替代。		
5. 規定的最低屈服應力超過 410N/mm ² 的材料可由主管機關認可。這些材料的焊縫和熱影響區的硬度應予以特別注意。		

表 7.2

設計溫度低於 0℃和低至-55℃的燃料艙，次屏壁和處理用 壓力容器的板材、型材和鍛件 ¹ 最大厚度為 25mm ²						
化學成分和熱處理						
◆ 碳錳鋼						
◆ 全鎮靜、鋁處理的細晶粒鋼						
◆ 化學成分（爐罐分析）						
	C	Mn	Si	S	P	
	最大 0.16% ³	0.70~1.60%	0.10~0.50%	最大 0.025%	最大 0.025%	
可選添加元素：合金化和晶粒細化元素一般可與下列相符：						
	Ni	Cr	Mo	Cu	Nb	V
	最大 0.80%	最大 0.25%	最大 0.08%	最大 0.35%	最大 0.05%	最大 0.10%
Al 總含量最少 0.020%（酸溶性最少 0.015%）						
◆ 正火或淬火和回火 ⁴						
張力和韌性（衝擊）試驗規定						
取樣頻率						
◆ 板材			按“件”試驗			
◆ 型材和鍛件			按批試驗			
力學性能						
◆ 張力性能			規定最低屈服應力不超過 410N/mm ^{2,5}			
韌性（夏比 V 型缺口衝擊試驗）						
◆ 板材			橫向試樣，最小平均能量值（KV）27J			
◆ 型材和鍛件			縱向試樣，最小平均能量值（KV）41J			
◆ 試驗溫度			比設計溫度低 5℃，或-20℃，取其低者			
註：						
1. 對鍛件的夏比 V 型缺口衝擊試驗和化學成分規定，可由主管機關特別考慮。						
2. 對厚度超過 25mm 的材料，夏比 V 型缺口衝擊試驗須如下進行：						
材料厚度（mm）		試驗溫度（℃）				
25 < t ≤ 30		比設計溫度低 10℃，或-20℃，取其低者				
30 < t ≤ 35		比設計溫度低 15℃，或-20℃，取其低者				
35 < t ≤ 40		比設計溫度低 20℃				
40 < t		經主管機關認可的溫度				
衝擊能量值須按所用試樣種類符合表列的要求。						
用於燃料艙和燃料艙部件的材料，如焊後熱應力完全消除，可在比設計溫度低 5℃或-20℃（取其低者）的溫度進行試驗。						

對於已消除熱應力的加強構件和其他構件，其試驗溫度須與鄰接燃料艙殼體厚度所要求的試驗溫度相同。

3. 如設計溫度不低於 -40°C ，經主管機關特別同意，材料的含碳量最大可增至 0.18%。
4. 可使用控制軋製工藝或熱-力控制工藝（TMCP）作為替代。
5. 規定的最低屈服應力超過 410N/mm^2 的材料可由主管機關認可。這些材料的焊縫和熱影響區的硬度應予以特別注意。

指導：

厚度超過 25mm 的材料，如其試驗溫度為 -60°C 或更低，可能需要採用符合本章表 7.3 規定的鋼材或經特殊處理的鋼材。

表 7.3

設計溫度低於-55℃和低至-165℃ ² 的燃料艙，次屏壁和處理用受壓容器的板材、型材和鍛件 ¹										
最大厚度 25mm ^{3,4}										
最低設計溫度（℃）	化學成分 ⁵ 和熱處理	衝擊試驗溫度（℃）								
-60	1.5% 鎳鋼—正火或正火和回火或淬火和回火或 TMCP ^{見註釋 6}	-65								
-65	2.25% 鎳鋼—正火或正火和回火或淬火和回火或 TMCP ^{6,7}	-70								
-90	3.5% 鎳鋼—正火或正火和回火或淬火和回火或 TMCP ^{6,7}	-95								
-105	5% 鎳鋼—正火或正火和回火或淬火和回火 ^{6,7,8}	-110								
-165	9% 鎳鋼—二次正火和回火或淬火和回火 ⁶	-196								
-165	奧氏體鋼，如 304，304L，316，316L，321 和 347 等，固溶處理 ⁹	-196								
-165	鋁合金，如 5083，退火	不要求								
-165	奧氏體鐵—鎳合金（含 36%Ni），按經同意的熱處理方法	不要求								
張力和韌性（衝擊）試驗要求										
取樣頻率										
◆ 板材	按“件”試驗									
◆ 型材和鍛件	按批試驗									
韌性（夏比 V 型缺口衝擊試驗）										
◆ 板材	橫向試樣，最小平均能量值（KV）27J									
◆ 型材和鍛件	縱向試樣，最小平均能量值（KV）41J									
註：										
1. 對用於臨界條件的鍛件所要求的衝擊試驗，須提交主管機關特別考慮。										
2. 設計溫度低於-165℃時的規定，須經主管機關特別同意。										
3. 對於含 1.5%Ni、2.25%Ni、3.5%Ni 和 5%Ni 且厚度超過 25mm 的材料，衝擊試驗須如下進行：										
<table><tr><td>材料厚度（mm）</td><td>試驗溫度（℃）</td></tr><tr><td>25 < t ≤ 30</td><td>比設計溫度低 10℃</td></tr><tr><td>30 < t ≤ 35</td><td>比設計溫度低 15℃</td></tr><tr><td>35 < t ≤ 40</td><td>比設計溫度低 20℃</td></tr></table>			材料厚度（mm）	試驗溫度（℃）	25 < t ≤ 30	比設計溫度低 10℃	30 < t ≤ 35	比設計溫度低 15℃	35 < t ≤ 40	比設計溫度低 20℃
材料厚度（mm）	試驗溫度（℃）									
25 < t ≤ 30	比設計溫度低 10℃									
30 < t ≤ 35	比設計溫度低 15℃									
35 < t ≤ 40	比設計溫度低 20℃									
衝擊能量值須按所用試樣種類符合表列的要求。對與厚度超過 40mm 的材料，夏比 V 型缺口衝擊能量值須予以特別考慮。										

4. 可採用厚度超過 25mm 的 9%Ni 鋼、奧氏體不鏽鋼和鋁合金。
5. 化學成分限制須符合公認標準。
6. TMCP 鎳鋼需要經主管機關接受。
7. 淬火和回火的鋼材，可與主管機關商定較低的最低設計溫度。
8. 經特殊熱處理的 5%鎳鋼，例如經三級熱處理的 5%鎳鋼，可用於低至-165℃，但要在-196℃下進行衝擊試驗。
9. 經主管機關同意，可免除衝擊試驗。

表 7.4

設計溫度低於 0°C 和低至 -165°C ³ 的燃料管系和 處理用管系的管材（無縫管和焊接管） ¹ 鍛件 ² 和鑄件 ² 最大厚度為 25mm			
最低設計 溫度 (°C)	化學成分 ⁵ 和熱處理	衝擊試驗	
		試驗溫度 (°C)	最小平均能量 (KV)
-55	碳錳鋼。為全鎮靜細晶粒，正火或經同意的熱處理方法 ⁶	見註 4	27
-65	2.25% 鎳鋼。正火，正火和回火或淬火和回火 ⁶	-70	34
-90	3.5% 鎳鋼。正火，正火和回火或淬火和回火 ⁶	-95	34
-165	9% 鎳鋼 ⁷ 。二次正火加和火或淬火和回火	-196	41
	奧氏體鋼，如 304，304L，316，316L，321 和 347。固溶處理 ⁸	-196	41
	鋁合金，如 5083，退火		不要求
張力和韌性（衝擊）試驗要求			
取樣頻率			
◆ 按批試驗。			
韌性（夏比 V 型缺口衝擊試驗）			
◆ 衝擊試驗：縱向試樣			
註：			
1. 使用縱向焊接和螺旋焊接管，須經主管機關特別認可。			
2. 對鍛件和鑄件的規定可能要經主管機關特別考慮。			
3. 對設計溫度低於 -165°C 的規定須經主管機關特別同意。			
4. 試驗溫度須比設計溫度低 5°C，或為 -20°C，取其低者。			
5. 化學成分的限度須符合公認標準。			
6. 對於經淬火和回火的材料，可與主管機關商定採用較低的設計溫度。			
7. 此化學成分不適用於鑄件。			
8. 經主管機關同意，可免除衝擊試驗。			

表 7.5

6.4.13.1.1.2 所要求的船體結構板材和型材								
船體結構最低 設計溫度（℃）	各鋼級的最大厚度（mm）							
	A	B	D	E	AH	DH	EH	FH
0℃及以上	公認標準							
低至-5℃	15	25	30	50	25	45	50	50
低至-10℃	×	20	25	50	20	40	50	50
低至-20℃	×	×	20	50	×	30	50	50
低至-30℃	×	×	×	40	×	20	40	50
低於-30℃	按表 7.2，但表 7.2 及該表腳註 2 中給出的厚度限度不適用。							
註：								
“x”係指不使用鋼級。								

- 7.4.1.2 氣體燃料艙之外的管路不得使用熔點低於 925°C 的材料。
- 7.4.1.3 對於壓縮天然氣液艙，以上未做規定的材料的使用可能要經主管機關特別考慮。
- 7.4.1.4 內有高壓氣體的內管，所要求的外管道或導管須至少滿足表 7.4 中對設計溫度低至零下 55°C 的管材的材料規定。
- 7.4.1.5 液化氣體燃料管道的外管道或導管，須至少滿足表 7.4 中對設計溫度低至零下 165°C 的管材的材料規定。

8 加注燃料

8.1 目標

8.1.1 本章的目標是為船上提供適合的系統，以確保加注燃料不對人員，環境以及船舶造成任何危險。

8.2 功能要求

8.2.1 本章與 3.2.1 至 3.2.11 以及 3.2.13 至 3.2.17 中的功能要求有關。

特別是以下所列適用：

8.2.1.1 將燃料輸送至存儲艙的管路系統須設計成，管路系統的任何泄露不會對人員、環境或船舶造成任何危險。

8.3 燃料加注站規定

8.3.1 通則

8.3.1.1 加注站須位於開敞甲板上以獲得充足的自然通風。圍閉或半圍閉式加注站須在風險評估內得到特別考慮。

8.3.1.3 對於任何溢漏燃料的安全管理須作出佈置。

8.3.1.4 須有適當措施，從泵吸口及加注管線中釋放壓力並清除液體內含。液體要排入液化氣燃料艙或其他適當的位置。

8.3.1.5 在發生燃料泄漏時，周圍船體或甲板結構不得受到不可接受的冷卻。

8.3.1.6 對於壓縮天然氣加注站，須考慮低溫鋼質防護層，以確定逃逸冷射流衝擊周圍船體結構的可能性。

8.3.2 船舶燃料軟管

8.3.2.1 用於燃料駁運的液體和蒸氣軟管，須與燃料相容並適於燃料的溫度。

8.3.2.2 承受燃料艙壓力或泵或蒸氣壓縮機排放壓力的軟管，須按照不小於軟管在燃料加注期間承受的最大壓力五倍的爆破壓力進行設計。

8.4 集管規定

8.4.1 加注集管須設計成能經受加注時的外部載荷。加注站的連接須為

配備有附加安全幹脫離耦合/自封的幹斷開式連接。連接器須為標準類型。

8.5 燃料加注系統規定

8.5.1 須提供有加注管道惰性氣體驅氣佈置。

8.5.2 加注系統的佈置須在充裝存儲艙期間不讓任何氣體排入大氣。

8.5.3 任何加注管路連接處附近均須串聯設置一個手動截止閥和一個遙控截止閥或一個手動遙控結合截止閥。遙控截止閥須能夠在加注操作控制處及/或其他安全地點操作。

8.5.4 須提供操作完成後將燃料從加注管路中排空的措施。

8.5.5 加注管路須為惰化和除氣做出佈置。加注管路在未加注時，除不除氣後果業經評估並經認可，須處於除氣狀態。

8.5.6 若加注管路有交叉佈置，須由適當的隔離裝置確保不將燃料意外地轉輸至船舶未用於加注燃料的一側。

8.5.7 船-岸連接或等效的自動或手動的緊急切斷（應急切斷）通訊手段，須予以設置。

8.5.8 如未證明因壓力喘振的考慮需要一個更高值，8.5.3 所要求的按照 16.7.3.7 計算的由觸發報警器到遙控操作閥完全閉合的默認時間須經調整。

9 設備燃料供應

9.1 目標

本章的目標是確保向各燃料使用設備安全有效地分配燃料。

9.2 功能要求

本章與 3.2.1 至 3.2.6，3.2.8 至 3.2.11 以及 3.2.13 至 3.2.17 中的功能要求有關，特別是，以下所列適用：

- .1 在提供有安全通道進行操作和檢查時，燃料供應系統須佈置成將任何燃料釋放的後果降至最低，同時為操作和檢查提供安全通道。
- .2 將燃料駁運至燃料使用設備的管路須設計成一個屏壁的失效不會導致管系至周圍區域的泄漏而對船上人員，環境或船舶造成危險；和
- .3 機器處所外燃料管線的安裝與保護須將泄漏造成的對人員的傷害和對船舶的損壞降至最低。

9.3 燃料供應冗餘規定

9.3.1 對於單燃料裝置，由燃料艙到燃料使用設備的燃料供應系統須全部冗餘和分隔佈置，使一個系統的泄漏不致導致不可接受的動力損失。

9.3.2 對於單燃料裝置，燃料儲存須分置在兩個或更多的液艙中。這些液艙須位於不同的艙室中。

9.3.3 僅對於 C 類艙，如為一個液艙裝設兩個完全獨立的液艙連接處所，可接受單一液艙。

9.4 供氣系統安全功能的規定

9.4.1 燃料存儲艙的入口和出口須在儘可能靠近燃料存儲艙的位置設置閥門。需要在常規作業期間操作的閥門，若無法觸及，須遙控操作。當觸發 15.2.2 中要求的安全系統時，液艙閥門無論可觸及與否，均須自動

操作。

9.4.2 至各用氣設備或各組用氣設備的主供氣管線須串聯配置一個手動截止閥和一個自動操作的主氣體燃料閥或手動自動結合操作閥。這些閥門須位於含用氣設備的機器處之外的管路部分中，且儘可能靠近氣體加熱裝置（如裝有）之處。當觸發 15.2.2 中要求的安全系統後，主燃氣閥們須自動切斷燃氣供應。

9.4.3 自動主燃氣閥們須能夠從含用氣設備的機器處所內脫險通道上、機艙集控室（如適用）、機器處所外的安全位置及駕駛室進行操作。

9.4.4 各用氣設備須配備“雙截斷和排放”閥門佈置。這些閥門須按.1或.2 中所述予以佈置，以在觸發 15.2.2 中要求的安全系統時，將自動關閉串聯的截止閥門並自動開啟排放閥，和：

- .1 至用氣設備的燃氣管中的兩個截止閥須串聯。排放閥須位於燃氣管路兩個串聯的閥門之間的向安全的露天環境排氣的管路上；或
- .2 可將串聯截止閥之一和排放閥的功能集中在一個閥體上，佈置成將阻斷至用氣設備的流動並打開排放。

9.4.5 兩截止閥須為故障關閉型，排放閥須為故障開啟型。

9.4.6 雙截斷和排放閥門組須同樣用於發動機正常停機。

9.4.7 如果氣體燃料總閥自動關閉，雙截斷和排放閥門組下游的整個供氣分支須假定發動機至管系的反流而自動通風。

9.4.8 至各發動機燃氣供應管線上，在雙截斷和排放閥門組的上游須配有一個手動操作的截止閥，以確保發動機維護期間的安全隔離。

9.4.9 對單發動機設備和多發動機設備，在為各發動機各設有主閥時，主燃氣閥和雙截斷和排放閥們組的功能可以組合。

9.4.10 對進入應急切斷保護機器處所的各主燃氣供應管線和至高壓設備的各燃氣供應管線，須提供能迅速探測機艙內燃氣管線破裂的裝置。當探測到破裂時，須自動關閉一個閥門，該閥門須位於機艙外部的或機艙內儘可能靠近機艙入口的燃氣供應管之上。此閥門可為獨立閥門或兼有其他功能，例如：主閥門。

9.5 機器處所外燃料分配的規定

9.5.1 穿過船舶圍閉處所的燃料管路須有二次圍閉保護。此圍閉可為有通風的導管或雙管壁管系。該導管或雙管壁管系須有每小時換氣 30 次的機械負壓通風並須具備 15.8 中要求的燃氣探測。主管機關也可接受提供同等安全水平的其他方案。

9.5.2 9.5.1 中的要求無需適用於穿過機械通風處所的全焊接燃氣透氣管道。

9.6 氣體安全機器處所內用氣設備燃料供應的規定

9.6.1 氣體安全機器處所內的燃料管路須被符合下列要求的雙套管或通風管完全圍閉：

- .1 燃氣管路須為內管包含燃氣的雙管壁管系。同心管之間的空間須以大於燃氣壓力的壓力用惰性氣體加壓。須提供指示管道間惰性氣體失壓的報警裝置。當內管含有高壓燃氣時，該系統須佈置成在主燃氣閥關閉後，主燃氣閥至發動機之間的管路須自動驅氣；或

- .2 燃氣管路須裝置於有通風的管道或導管之中。燃氣管和外管或導管管壁之間的空氣空間須具有能力為每小時至少換氣 30 次的機械負壓通風。但若設有探測到燃氣即自動灌充氮氣的佈置，此通風能力可降至每小時 10 次。風機馬達須符合對裝設區域所要求的爆炸保護規定。通風出口須用保護網覆蓋並位於易燃氣體-空氣混合物不能被點燃的位置；
或

- .3 主管機關也可接受提供同等安全水平的其他方案。

9.6.2 燃氣管和導管與注入閥門的連接須由導管完全覆蓋。其佈置須便利注入閥門和氣罐蓋的更換和/或檢修。發動機上的所有燃氣管直至將燃氣注入燃燒室內，也要求為雙導管。

9.7 至應急關閉（應急切斷）保護機器處所內用氣設備的燃氣供應的規定

9.7.1 燃氣供應系統內的壓力不得超過 1.0MPa。

9.7.2 燃氣供應管線的設計壓力須不低於 1.0MPa。

9.8 通風導管和外管防止內管燃氣泄漏設計的規定

9.8.1 燃料系統的外管或導管的設計壓力不得小於內管的最大工作壓力。或者，對於工作壓力大於 1.0MPa 的燃料管系，外管或導管的設計壓力，慮及任何破裂和通風佈置的局部瞬間峰壓，不得小於環狀空間內出現的最大積聚壓力。

9.8.2 對於高壓燃料管路，導管的設計壓力須為以下所列的較高者：

- .1 最大積聚壓力：破裂導致的環狀空間內燃氣流的靜壓力；

.2 破裂的瞬間峰壓：此壓力須取下式給出的臨界壓力：

$$p = p_0 \left(\frac{2}{k+1} \right)^{\frac{k}{k-1}}$$

式中：

p_0 = 內管最大工作壓力

$K = C_p/C_v$ 等壓比熱除以等容比熱

$K = 1.31$ （對於 CH_4 甲烷）

當承受以上壓力時，直管的切向薄膜應力不得超過抗拉強度除以 1.5（ $R_m/1.5$ ）。所有其他管路部件的額定壓力須反映出與直管相同的強度。

可用代表性試驗中的峰值壓力替代以上公式中峰值壓力，但須提交試驗報告。

9.8.3 強度驗證須基於證明導管或管道完整性的計算。作為計算的替代，強度可用代表性試驗驗證。

9.8.4 對於低壓燃料管路，導管尺度須為設計壓力不低於燃料管的最大工作壓力而設定。對導管須進行壓力試驗，證明其可承受燃料管道破斷時的預計最大壓力。

9.9 壓縮機和泵規定

9.9.1 如壓縮機或泵由穿過艙壁或甲板的軸驅動，艙壁貫穿須為氣密型。

9.9.2 壓縮機和泵須符合其預期用途。所有設備和機械須經適當試驗確

保其在海洋環境中使用的適合性。要考慮的項目包括但不限於：

- .1 環境；
- .2 船上震動和加速度；
- .3 縱搖、垂蕩和橫搖等的影響；和
- .4 氣體成分。

9.9.3 須做出佈置確保在任何情況下均不能將液化氣體注入氣體控制區或氣體燃料機器，除非該機器設計為可使用液態氣體運作。

9.9.4 壓縮機和泵須安裝高效和可靠運作所需的附件和儀錶。

10 包括推進和其他燃氣設備的動力產生

10.1 目標

10.1.1 本章目標是為安全和可靠地提供機械能、電能或熱能作出規定。

10.2 功能要求

本章與 3.2.1、3.2.11、3.2.13、3.2.16 和 3.2.17 中的功能要求有關，特別是，以下所列適用：

- .1 排氣系統須設置成防止任何未燃氣體燃料積聚；
- .2 除非設計強度可以承受最惡劣情況下泄漏氣體點燃造成的超壓，否則發動機部件或系統，若含有或可能含有可被點燃的氣體或空氣混合物，須安裝合適的壓力釋放系統。依照具體發動機的設計，這可包括空氣進氣集管和掃氣箱；
- .3 爆炸排放須引導至通常無人處；和

.4 所有用氣設備須有獨立的排氣系統。

10.3 活塞式內燃機的規定

10.3.1 一般要求

10.3.1.1 排氣系統須配備尺度足以防止在一缸點火失效後未燃燃氣在系統內點燃時的過度爆炸壓力的爆炸釋放通風。

10.3.1.2 對於活塞下空間直接與曲軸箱相連的發動機，須對燃氣在曲軸箱內積聚的潛在危險進行詳細評估並體現在發動機的安全理念中。

10.3.1.3 每一非二衝程十字頭式柴油機的發動機須為掃氣箱和集油槽安裝獨立於其他發動機的透氣系統。

10.3.1.4 如氣體能直接泄漏進入輔助系統介質（潤滑油，冷卻水），須在發動機排氣口安裝合適裝置以收集氣體，防止氣體擴散。從輔助系統介質中收集的氣體須向大氣中的安全位置排放。

10.3.1.5 對於裝有點火系統的發動機，接受氣體燃料前，須對每一裝置上的點火系統的正确運作進行驗證。

10.3.1.6 須設有監控設施，對燃料燃燒不良或缺火進行監測和探測。在探測到時，只要發動機關閉一缸運行就扭振而言可以接受，可以允許燃氣作業。

10.3.1.7 對於用本規則所涵蓋燃氣啟動的發動機，若在燃料供應閥開啟後的規定時間內發動機監測系統未探測到燃燒，該燃料供應閥須自動關閉。須提供確保將任何未燃燃料混合物從排氣系統中驅除的裝置。

10.3.2 雙燃料發動機的規定

10.3.2.1 在燃氣供應中斷時，發動機須能夠僅使用燃油不間斷地繼續運行。

10.3.2.2 須設有自動系統，在發動機動力波動最小的情況下從燃氣運行轉換至燃油運行及反之亦然。可接受的可靠性須經試驗證明。如燃燒燃氣時發動機運轉不穩定，發動機須自動轉換成燃油模式，須總能手動啟動燃氣系統關閉。

10.3.2.3 在正常停止或緊急停止時，須在停止點火前切斷燃氣供應。不提前或同時切斷對各缸或整個發動機的燃氣供應，須不可能停止點火。

10.3.3 燃氣發動機的規定

在正常停止或緊急停止時，須在停止點火前切斷燃氣供應。不提前或同時切斷對各缸或整個發動機的燃氣供應，須不可能停止點火。

10.3.4 多燃料發動機的規定

10.3.4.1 在切斷一種燃料供應時，發動機須能在發動機動力波動最小的情況下使用另一燃料繼續運行。

10.3.4.2 須設有自動系統，在發動機動力波動最小的情況下從一種燃料運行轉換至另一種燃料運行。可接受的可靠性須經試驗證明。如燃燒某一種燃料時發動機運轉不穩定，發動機須自動轉換成另一種燃料模式，須總能手動啟動。

	僅燃氣		雙燃料	多燃料
引燃介質	火花	引燃燃料	引燃燃料	N/A
主燃料	燃氣	燃氣	燃氣和/或燃油	燃氣和/或燃液

10.4 主和輔鍋爐的規定

10.4.1 每台鍋爐須具有專門的強制排氣系統。如能保證相關的安全功能，鍋爐強制排氣系統之間可設有聯通裝置供應急使用。

10.4.2 鍋爐燃燒室和煙道設計須防止任何氣體燃料積聚。

10.4.3 燃燒器須設計成在所有點火條件下保持穩定燃燒。

10.4.4 主推進鍋爐，須設有自動系統，在不中斷鍋爐燃燒的情況下從燃氣操作自動轉換至燃油操作。

10.4.5 氣體噴嘴和燃燒器控制系統的構成須使燃氣只能由已建立的燃油火焰點燃，除非鍋爐和燃燒設備係為使用燃氣點燃而設計並經主管機關認可。

10.4.6 須做出佈置，除非已確立並保持滿意的點火，確保自動切斷至燃燒器的燃氣流。

10.4.7 每個氣體燃燒器的燃料管路上須設置一個手動截止閥。

10.4.8 須為燃燒器熄火後使用惰性氣體對至燃燒器的燃氣供應管路自動除氣做出佈置。

10.4.9 對 10.4.4 所要求的燃料自動轉換系統須進行監測並由有報警，以確保其持續可用。

10.4.10 須採取措施確保在所有燃燒器熄滅時，再次點火前對鍋爐燃料室自動除氣。

10.4.11 須做出佈置使鍋爐除氣程序能夠人工啟動。

10.5 燃氣輪機的規定

10.5.1 除非以承受因泄漏燃氣點燃產生的最惡劣超壓的強度而設計，須慮及燃氣泄漏引發的爆炸，適當設計壓力釋放系統並安裝在排氣系統上。排氣系統煙道內的壓力釋放系統須通往安全位置，且遠離人員。

10.5.2 燃氣輪機可安裝在按照 5.6 和 9.7 中概述的緊急切斷原則所佈置的燃氣密圍閉處所內，但在該圍閉內，可接受壓力在 1.0MPa 以上的燃氣供應管道。

10.5.3 氣體探測系統和切斷功能須和對應急切斷保護機器處所述者相同。

10.5.4 該圍閉的通風須和 13 章中對應急切斷保護機器處所述者相同，但須另外安排完全冗餘（2 x 100%風機容量，來自不同電路）。

10.5.5 除單燃料燃氣輪機外，須設有自動系統，在發動機功率最小波動情況下，快速和便捷地從燃氣操作轉換至燃油操作及反之亦然。

10.5.6 須設有監控裝置，監測和探測運行期間會導致未燃燃氣進入排氣系統的不良燃燒。如探測到，須切斷燃氣供應。

10.5.7 每台渦輪機須設有排氣溫度高時自動停機裝置。

11 消防安全

11.1 目標

本章的目標是為涉及存儲，製備，輸送和使用天然氣為船舶燃料的所有系統部件做出防火，探火及滅火規定。

11.2 功能要求

本章與 3.2.2、3.2.4、3.2.5、3.2.7、3.2.12、3.2.14、3.2.15 和

3.2.17 中的功能要求有關。

11.3 防火要求

11.3.1 任何處所但凡含有燃料製備設備諸如泵，壓縮機，熱交換器，氣化器和壓力容器，須被視為 A 類防火機器處所。

11.3.2 任何面向開敞甲板上氣體存儲艙的起居處所，服務處所，控制站，脫險通道，機器處所，其邊界須被 A-60 級分隔屏蔽。A-60 級分隔須向上延伸至駕駛室甲板下部，及之上的任何邊界，包括駕駛室窗，須有 A-0 級分隔。此外，氣體存儲艙須按照《國際海運危險貨物規則》（《危規》）的要求與貨物隔離，在該規則中燃料艙被視為散貨包裝。對於《危規》的裝載和隔離要求，在開敞甲板上的燃料艙須被視為 2.1 級包裝。

11.3.3 包含燃料維護系統的處所須與 A 類機器處所或其他高失火風險艙室隔離。須用至少 900mm 的有 A-60 級絕熱層的隔離艙進行隔離。在確定包含燃料維護系統的處所與其他低失火火風險處所之間的絕熱時，燃料維護系統須按照《安全公約》規則第 11-2/9 條，被視為 A 類機器處所。各包含燃料維護系統的處所之間的邊界須或者是至少 900mm 的隔離艙或者是 A-60 分隔。對於 C 類艙，燃料存儲貨艙處所可被視為隔離艙。

11.3.4 燃料存儲貨艙處所不得用於機械或其他有火險的設備。

11.3.5 通入滾裝處所的燃料管路，根據其應用和預期管內壓力，其防火須由主管機關予以特殊考慮。

11.3.6 加注站須使用 A-60 級分隔與 A 類機器處所，起居處所，控制站及高火險處所隔離，但諸如液艙，留空處所，無或低失火風險輔助機器處所、衛浴和類似處所的隔熱標準可降至 A-0 級。

11.3.7 如緊急關閉（應急切斷）保護機器處所由單獨邊界分隔，則此邊界須為 A-60 級分隔。

11.4 消防總管的規定

11.4.1 以下所要求的水霧系統可為消防總管系統的一部分，但所要求的消防泵的容量和工作壓力要足以同時運作規定數量的消防栓和水龍帶以及水霧系統。

11.4.2 當燃料存儲艙位於開敞甲板，須在消防總管上安裝隔離閥以隔離消防總管上的毀壞部分。對消防總管的部分隔離不得停止隔離部分之前的消防管路供水。

11.5 水霧系統的規定

11.5.1 須安裝水霧系統覆蓋開敞甲板上燃料存儲艙的暴露部分以降溫和防火。

11.5.2 該水霧系統須覆蓋面向開敞甲板上存儲艙的上層建築、壓縮機艙、泵艙、貨物控制室、加注控制站、加注站及其他通常有人甲板室的邊界，除非該邊界距離存儲艙 10 米或更遠。

11.5.3 該水霧系統須設計成覆蓋以上規定的所有區域，最大水平投影面噴射率為 10l/min/m^2 ；垂直表面為 4l/min/m^2 。

11.5.4 為隔斷損壞的管段，在水霧系統總管上須每隔不超過 40m 安裝 1 個截止閥。或者將系統分成 2 個或以上的可獨立操作的區段，但須將必要的控制裝置集中安裝在易於接近且在受保護區域失火時不會無法接近的位置。

11.5.5 水霧泵容量須足以輸送規定水量至上述受保護區域中液壓要求

最高的位置。

11.5.6 若水霧系統非消防總管的一部分，則須通過一個截止閥提供與船舶消防總管的連接。

11.5.7 須將水霧系統遙控啟動裝置和對常規狀態下關閉的閥門的遠程操作系統集中安裝在易於接近且在受保護區域失火時不會無法接近的位置。

11.5.8 噴嘴須為經認可的直流型，且須佈置成確保將水有效分佈至全部受保護區域。

11.6 化學乾粉滅火系統的規定

11.6.1 須在加注站區域安裝固定的化學乾粉滅火系統以覆蓋所有可能的泄漏點。其排量須在最短 45 秒內為至少 3.5kg/s。該系統須為在被保護區域外便於人工釋放而佈置。

11.6.2 除國際海事組織文書中其他處所要求的任何其他便攜式滅火器外，須在加注站附近配備一個排量至少 5kg 的便攜乾粉滅火器。

11.7 失火探測和報警系統的規定

11.7.1 須為燃料存儲貨艙，甲板下燃料維護系統通風管隧及其他所有不能排除失火的氣體燃料系統艙室，安裝符合消防安全系統規則的固定失火探測和報警系統。

11.7.2 僅煙霧探測裝置不得被視為足以快速探測失火。

12 防爆

12.1 目標

本章的目的是對防爆和限制爆炸影響做出規定。

12.2 功能要求

本章與 3.2.2 至 3.2.5、3.2.7、3.2.8、3.2.12 至 3.2.14 及 3.2.17 中的功能要求有關，尤其是，以下所列適用：

須通過以下所列將爆炸的可能性降至最低：

- .1 減少點火源的數量；和
- .2 降低可燃混合物形成的可能性。

12.3 一般規定

12.3.1 開敞甲板上和本章未述及的其他處所內的危險區域須依據公認的標準予以確定。危險區域內安裝的電氣設備須符合同一標準。

12.3.2 除根據公認標準為作業目的所必需者外，電氣設備或電纜通常不得安裝在危險區域內。

12.3.3 裝置在受應急切斷（ESD）保護的機器處所內的電氣設備須滿足以下條件：

- .1 除失火與氣體碳氫探測裝置和失火和瓦斯報警外，照明和通風風扇須經發證為危險區域 1 區安全型；和
- .2 含有燃氣發動機的機器處所中的所有且未經發證為 1 區安全型的電氣設備，若該含有燃氣設備的處所中的兩個探測器探測到可燃氣體濃度超過最低可燃性極限的 40%時，須自動斷開連接。

12.4 區域分級的規定

12.4.1 區域分級是一個對可能出現爆炸性氣體環境的區域進行分析和分級的方法。分級的目的是允許選擇能夠在這些區域中安全運行的電器裝置。

12.4.2 為便於選擇適當的電氣設備和設計合適的電氣裝置，危險區域劃分為 0 區，1 區和 2 區，另見以下 12.5。

12.4.3 通風管須和所通風的處所有相同的分級。

12.5 危險區域分區

12.5.1 危險區域 0 區

12.5.1.1 該區包括，但不限於以下區域，燃料艙內部，任何壓力釋放管路或其他燃料艙透氣系統，含有燃料的管路和設備。

12.5.2 危險區域 1 區

該區域包括，但不限於：

- .1 液艙連接處所，燃料存儲貨艙處所和屏壁間處所；
- .2 按照 13.6 佈置通風系統的燃料準備艙室；
- .3 開敞甲板上或甲板上半圍閉處所的距燃料艙出口、燃氣或蒸汽出口、加注集管總閥、其他燃料閥、燃料管法蘭、燃料準備艙室的通風出口和用於釋放熱量變化引起的少量的氣體或蒸汽混合物的流動的燃料艙壓力釋放開口 3 米範圍之內的區域；
- .4 開敞甲板上或甲板上半圍閉處所的距燃料準備艙室入口、燃料準備艙室通風入口及所有 1 區處所的其他開口 1.5 米範

圍之內的區域；

- .5 開敞甲板上燃氣加注集管閥周圍的泄漏圍板內，以及該範圍外 3 米、上至甲板以上 2.4m 的區域；
- .6 含燃料管路所在的圍閉或半圍閉處所，如燃料管路周圍的導管，半圍閉加注站；
- .7 應急切斷保護機器處所在常規運作期間被視為非危險區域，但要求在探測到瓦斯泄漏後需要運作的設備經認證適合 1 區；
- .8 由空氣閘保護的處所在常規運作期間須視為非危險區域，但要求在被保護區域和危險區域之間失去壓差後需要運作的設備經認證適合 1 區；和
- .9 除 C 類艙外，燃料圍護處所外暴露於風雨下的外表面 2.4m 以內的區域。

12.5.3 危險區域 2 區

12.5.3.1 該區包含，但不限於 1 區的開敞或半圍閉處所周圍 1.5m 內的區域。

12.5.3.2 含有至液艙連接處所的栓閉艙口的處所。

13 通風

13.1 目標

本章的目的是為燃氣機器和設備安全運行所需的通風做出規定。

13.2 功能要求

本章涉及 3.2.2、3.2.5、3.2.8、3.2.10、3.2.12 至 3.2.14 和 3.2.17 中的功能要求。

13.3 一般規定

13.3.1 任何用於危險處所的通風管道須與用於非危險處所的通風管道隔離。通風設備須在船舶將運營的所有溫度和環境條件下運行。

13.3.2 通風機風扇的電動機不得設置於危險處所的通風管道內，除非電機經認證可在與所服務的處所相同的危險區內使用。

13.3.3 為包含瓦斯源的處所服務的通風機風扇的設計須滿足以下條件：

- .1 通風風扇不得在通風處所內或與該處所相連的通風系統內產生蒸氣點火源。通風風扇和風扇管道僅面對風扇的一面，須為如下界定的無火花構造：
 - .1 非金屬材料葉輪或機殼，對消除靜電予以適當注意；
 - .2 有色金屬葉輪和機殼；
 - .3 奧氏體不鏽鋼葉輪和機殼；
 - .4 鋁合金或鎂合金葉輪和鐵質（包括奧氏體不鏽鋼）機殼上面對葉輪的適宜厚度的環形非鐵質材料，並對該環形和機殼之間的靜電腐蝕予以適當注意；或
 - .5 鐵質（包括奧氏體不鏽鋼）葉輪和機殼的葉梢設計間隙不小於 13 毫米的任何組合。
- .2 在任何情況下，葉輪和套管之間的徑向氣隙不得小於葉輪軸承軸直徑的 0.1，但不得小於 2 毫米。該間隙無需大於 13

毫米。

- .3 對於鋁合金或鎂合金的固定或旋轉部件與鐵質的固定或旋轉部件的任何組合，不論其葉梢間隙大小，均視為有產生火花的危險，故不能用於這些處所。

13.3.4 為避免任何氣體積聚所要求的通風系統，除本規則內另有規定，須由各風扇具有足夠能力的數個獨立風扇組成。

13.3.5 危險圍閉處所的空氣吸入須取自，在無所考慮的進口時，將是無危險的區域。非危險圍閉處所的空氣吸入須取自離任何危險區域的邊界至少 1.5 米的非危險區域。當進口管道通過更危險的處所時，管道須為氣密，並有相對於該處所的過壓。

13.3.6 非危險區域的空氣出口須設在危險區域外。

13.3.7 危險圍閉區域的空氣出口須設在露天的，在無所考慮的空氣出口時，將是與所通風處所危險相同或更低的區域。

13.3.8 所要求的通風裝置的能力通常基於艙室的總容積。形狀複雜的艙室可能需要增加所要求的通風能力。

13.3.9 非危險區域若設有至危險區域的入口，須裝置空氣閘，並保持在相對於外部危險區域的超壓狀態。超壓通風須按以下要求設置：

- .1 初次啟動期間或失去超壓通風後，須要求未經認證為無加壓處所使用安全的任何電氣裝置在通電之前：
 - .1 進行驅氣（至少 5 次換氣）或通過測量確認該處所無危險；和
 - .2 對該處所加壓。

.2 須監測超壓通風的運行，在超壓通風故障時：

.1 須在有人的位置發出聲光報警；和

.2 如果超壓狀態不能立即恢復，須要求按照公認標準自動或按程序斷開電氣裝置的連接。

13.3.10 非危險處所若設有至危險圍閉處所的入口，須設置空氣閘，並且危險處所須保持相對於無危險處所的負壓。須監測危險處所抽吸通風的運行，在抽吸通風故障時：

.1 須在有人的位置發出聲光報警；和

.2 如果負壓狀態不能立即恢復，須要求按照公認標準自動或按程序斷開電氣裝置的連接。

13.4 液艙連接處所的規定

13.4.1 液艙連接處所須提供有效的抽吸式機械強制通風系統。須提供每小時至少換氣 30 次的通風能力。如果設有其他適當防爆手段，換氣率可以降低。替代安裝的等效性須經風險評估證明。

13.4.2 液艙連接處所的通風管道中須安裝經認可的自動故障安全防火風門。

13.5 機器處所的規定

13.5.1 包含燃氣設備的機器處所，其通風系統須獨立於所有其他通風系統。

13.5.2 受應急切斷（ESD）保護的機器處所須設有換氣能力每小時至少 30 次的通風設備。通風系統須確保所有處所空氣流動良好，並特別確保

探測到艙室內任何瓦斯氣窩的形成。作為替代，可以接受在正常運行中機器處所每小時至少換氣 15 次，但一旦在機器處所內探測到瓦斯，換氣次數將自動增至每小時 30 次的佈置。

13.5.3 對於應急切斷保護機器處所，通風裝置須提供充足的冗餘，以確保本組織可接受的標準中界定的高度水平可用通風能力。

13.5.4 應急切斷保護機艙的和燃氣安全機艙雙套管通風系統的通風風扇和數量和功率須為：若主配電板或應急配電板的獨立電路供電的一台風扇或主配電板或應急配電板的通用電路供電的一組風扇失靈，通風能力的下降不超過總通風能力的 50%。

13.6 燃料準備艙的規定

13.6.1 燃料準備艙須安裝有效的負壓機械通風系統，提供每小時至少換氣 30 次的通風能力。

13.6.2 通風風扇和數量和功率須為：若主配電板或應急配電板的獨立電路供電的一台風扇或主配電板或應急配電板的通用電路供電的一組風扇失靈，通風能力的下降不超過 50%。

13.6.3 燃料準備艙的通風系統須在泵或壓縮機工作時運轉。

13.7 燃料加注站的規定

不在露天甲板上的燃料加注站須有適當通風，以確保將燃料加注操作過程中釋放的任何蒸汽向外排除。如果自然通風不夠充足，須按照 8.3.1.1 條中要求的風險評估提供機械通風。

13.8 導管和雙套管的規定

13.8.1 包含燃料管系的導管和雙套管須安裝有效的抽吸式機械通風系

統，提供每小時至少換氣 30 次的通風能力。這不適用於滿足 9.6.1.1 條要求的機艙內的雙套管。

13.8.2 雙套管和氣體安全機艙內氣體閥門裝置處所的通風系統須獨立於所有其他通風系統。

13.8.3 雙套管路或導管的通風入口須始終位於遠離着火源的非危險區域。入口開口須安裝適合的金屬絲防護網和防止進水的裝置。

13.8.4 管道導管或雙套管的通風能力，如確保最小每秒 3 米的流速，可少於每小時換氣 30 次。導管須在安裝有燃料管道和其他部件後計算流速。

14 電氣裝置

14.1 目標

本章的目標是為電氣裝置作出規定，以在有易燃大氣時將起火的風險降至最低。

14.2 功能要求

本章與 3.2.1、3.2.2、3.2.4、3.2.7、3.2.8、3.2.11、3.2.13 和 3.2.16 至 3.2.18 中的功能要求相關。特別是，以下所列適用：

發電和配電系統及相關控制系統須設計成單個故障不會導致把燃料艙存儲壓力及船體結構溫度保持在正常運作限制內的能力喪失。

14.3 一般規定

14.3.1 電氣裝置須符合至少與本組織可接受標準等效的標準。

14.3.2 電氣設備或電纜，除作業或提高安全所必需者外，不得安裝在危

險區域內。

14.3.3 電氣設備，如按照 14.3.2 的規定安裝在危險區域內，須按照至少與本組織可接受標準等效的標準予以選擇、安裝和維護。

危險區域的設備須由經認證的測試機構或主管機關認可的通報機構評估和發證或登記。

14.3.4 對 14.2 中發電和配電系統的單一故障的模式和影響須按照至少與本組織可接受的標準等效的標準進行分析和記錄。

14.3.5 危險區域內的照明系統須分成至少 2 個分路。所有開關和保護裝置須分斷全部的極或相，並須位於非危險區域內。

14.3.6 船上電氣設備裝置的安裝須確保裝置外殼與船體的安全接地連接。

14.3.7 須設有在低液位時報警和在低-低液位發生時自動停止電動機的佈置。自動關閉可通過探測泵的低排放壓力、電動機的低電流或低液位予以實現。關閉時須在駕駛室、持續有人中央控制站或船上安全中心發出聲光報警。

14.3.8 潛式燃料泵電動機及其供電電纜可安裝在液化氣燃料圍護系統內。在除氣作業期間，須能切斷燃料泵電動機的供電電源。

14.3.9 對於具有來自危險開敞甲板的通道，且該通道由空氣閘予以保護的非危險處所，非經認證為安全類型的電氣設備，在該場所失去超壓時，須切斷其電力供應。

14.3.10 位於受空氣閘保護的處所內的推進、發電、操縱、操錨和繫泊用電氣設備，以及應急泵，須為經認證的安全類型。

15 控制、監測和安全系統

15.1 目標

本章的目的是為支持本規則其他章節中所涵蓋的燃氣裝置的有效和安全運作的控制、檢測和安全系統的佈置，作出規定。

15.2 功能要求

本章與 3.2.1、3.2.2、3.2.11、3.2.13 至 3.2.15，3.2.17 和 3.2.18 中的功能要求相關。特別是以下所列適用：

- .1 燃氣裝置的控制、檢測和安全系統須佈置成，在發生單一故障時，餘留的推進和發電能力符合 9.3.1 的要求；
- .2 須設有在發生表 1 所述的系統故障或其他由於進展過快而無法人工介入的故障狀態時自動切斷燃氣供應的燃氣安全系統；
- .3 對於受應急切斷保護的輪機配置，安全系統須在燃氣泄漏時關閉燃氣供應，此外並斷開該機器處所內所有非經認證為安全型的電氣設備；
- .4 安全功能須佈置在獨立於燃氣控制系統的專用燃氣安全系統內，以避免可能的同源故障。這包含電力供應及輸入和輸出信號；
- .5 含現場儀錶的安全系統的佈置須避免諸如因燃氣探測器故障或傳感器回路斷線導致的虛假關閉；和
- .6 當滿足規定需要兩個或更多的燃氣供應系統時，每個系統均須裝設其自身的獨立燃氣控制和燃氣安全系統。

15.3 一般規定

15.3.1 須配備允許當地和遠程讀取關鍵參數的適當儀器，以確保對包含燃料加注的全部燃氣設備的安全管理。

15.3.2 獨立液化氣儲藏液艙的每個液艙連接處所的艙底井須配備一個液位錶和溫度傳感器。艙底井達到高水位時須發出報警。低溫顯示須觸發安全系統。

15.3.3 對於非永久裝在船上的液艙，須如永久安裝的液艙一樣配備監測系統。

15.4 燃料加注和液化氣燃料液艙監測規定

15.4.1 液化氣燃料液艙的液位指示器

- .1 每個液化氣燃料液艙須安裝液位測量裝置，其佈置要確保液化氣燃料液艙在處於運作狀態時始終可獲得液位讀數。該裝置須設計成在液化氣燃料液艙的整個設計壓力範圍內以及在燃料操作溫度範圍內運作。
- .2 在僅安裝一個液位錶時，須佈置成能始終處於操作狀態而無需對液化氣燃料液艙進行清空或除氣。
- .3 液化氣燃料液艙的液位錶可為下列類型：
 - .1 間接式裝置，即通過用諸如稱重或在線流量測量確定燃料量；或
 - .2 不伸入液化氣燃料液艙的閉式裝置，諸如使用放射性同位素的裝置或超聲波裝置；

15.4.2 溢流控制

- .1 每個液化氣燃料液艙均須裝設一個獨立於其他液位指示器的高液位報警器，並在觸發時發出聲光報警。
- .2 另一個獨立於高液位報警器的傳感器，須以一種既避免加注管路中產生過大的液體壓力，又防止液化氣燃料液艙內被注滿液體的方式，自動啟動一個截止閥。
- .3 液化天然氣燃料液艙中傳感器的位置須能在交付使用前確認。交付後和每次進乾塢後第一次滿載，須通過提升液化氣燃料液艙中的燃料液位至報警點進行高位報警試驗。
- .4 高位報警和溢出報警的所有構件（包括電路和傳感器）須能進行功能試驗。在進行燃料操作前須按照 18.4.3 進行系統試驗。
- .5 如設有溢流控制系統越控裝置，該裝置須能防止不當操作。如進行越控，須在駕駛室、連續有人值班的中央控制站或船上安全中心給出連續視覺顯示。

15.4.3 每一液化氣燃料液艙的蒸汽空間均須設有一個直接讀數測量錶。此外，應為駕駛室、連續有人值班的中央控制站或船上安全中心提供間接顯示。

15.4.4 壓力顯示器須清晰標註液化氣燃料液艙內最高和最低允許壓力。

15.4.5 駕駛室、連續有人值班的中央控制站或船上安全中心內須設有一個高壓報警器，及如需要真空保護，設有一個低壓報警器。須在達到設定安全閥壓力之前，觸發報警。

15.4.6 每一燃料泵排放管路上和每個液體和蒸氣燃料的集合管上，須至少裝設一個局部壓力顯示器。

15.4.7 須設有就地讀數的集合管壓力顯示器，以顯示船舶集管閥和通岸軟管之間的壓力。

15.4.8 未設通向大氣開口的燃料存儲艙處所和屏壁間處所均須設置壓力顯示器。

15.4.9 所設置的壓力顯示器中須至少有一個能在整個的操作壓力範圍內進行顯示。

15.4.10 對於深潛式燃氣泵發動機及其供電電纜，須設有在低液位報警和在低-低液位時自動停止電動機的佈置。自動停機可通過檢測到泵的低排放壓力、電動機的低電流或低液位予以實現。停機須在駕駛室、連續有人值班的中央控制站或船上安全中心發出聲光報警。

15.4.11 除設有真空隔熱系統和壓力升高燃料排放裝置的獨立 C 型液艙外，各燃料艙須至少在三處設有測量和顯示燃料溫度的裝置；在艙的底部和中部以及艙的頂部低於允許液面之處。

15.5 燃料加注控制的規定

15.5.1 燃料加注須有可能在遠離加注站的安全位置予以控制。在此位置須能夠檢測到艙壓、艙溫，如 15.4.11 有要求，和艙的液位。8.5.3 和 11.5.7 中要求的遙控控制閥須能在此位置操縱。滿溢警報和自動關閉也須在此位置顯示。

15.5.2 如果加注管路的圍閉導管內的通風停機，須在燃料加注控制位置發出聲光警報。另見 15.8。

15.5.3 如果在加注管路的圍閉導管內檢測到瓦斯，須在加注控制位置提供聲光警報和緊急關閉。

15.6 燃氣壓縮機監測的規定

15.6.1 須在駕駛室和機艙控制室裝設燃氣壓縮機聲光警報。警報至少須包含瓦斯輸入低壓，瓦斯輸出低壓，瓦斯輸出高壓和壓縮機運行。

15.6.2 須設有艙壁軸封蓋和軸承的溫度監測及在駕駛室和連續有人值班的中央控制站自動發出持續的聲光警報。

15.7 燃氣發動機的監測的規定

除按照《安全公約》第 II-1 章 C 部分提供的儀錶外，須為以下所列，在駕駛室，發動機控制室和操縱平台上裝設顯示器：

- .1 燃氣發動機的發動機運行；或
- .2 雙燃料發動機的發動機運行和運行模式。

15.8 瓦斯探測的規定

15.8.1 固定瓦斯探測器須安裝在以下所列之中：

- .1 液艙連接處所；
- .2 圍繞燃料管道的所有導管；
- .3 含燃氣管道，燃氣設備或用氣設備的機器處所；
- .4 壓縮機艙和燃料準備艙；
- .5 含燃料管道或其他無導管燃料設備的其他圍閉處所；
- .6 可能積聚燃料蒸氣的其他圍閉或半圍閉處所，包括屏壁間

處所和除 C 型之外的獨立燃料艙的燃料存儲處所；

- .7 空氣閘；
- .8 燃氣加熱回路膨脹艙；
- .9 與燃料系統相關的發動機艙；和
- .10 如根據 4.2 要求的風險評估所需，起居和機器處所的通風進口。

15.8.2 每個應急切斷保護機器處所中須提供冗餘瓦斯探測系統。

15.8.3 每個處所內探測器的數量須慮及處所的尺寸、佈局和通風予以考慮。

15.8.4 探測設備須位於瓦斯可能聚集處及通風出口內。須運用氣體分散分析或物理煙霧試驗來找出最佳佈置。

15.8.5 氣體探測設備須按照公認標準設計、安裝和測試。

15.8.6 在氣體蒸氣達到最低爆炸性極限的 20% 時，須觸發聲光警報。兩個探測器處達到最低爆炸性極限的 40% 時，須觸發安全系統（見表 1 中的腳註 1）。

15.8.7 對於含燃氣發動機的機器處所中圍繞燃氣管路的有通風導管，其警報極限可設在最低爆炸性極限的 30%。兩個探測器處達到最低爆炸性極限的 60% 時，須觸發安全系統（見表格 1 中的註腳 1）。

15.8.8 氣體探測設備的聲光警報器須位於駕駛室或連續有人值班的中央控制站中。

15.8.9 本節要求的氣體探測須持續不間斷，沒有延遲。

15.9 失火探測規定

含燃氣發動機的機器處所和含燃料存儲處所的獨立液艙內探到失火時所要求的安全行動在以下表 1 中給出。

15.10 通風規定

15.10.1 任何所要求通風能力的喪失須在駕駛室或連續有人值班的中央控制站或安全中心發出聲光報警。

15.10.2 對於應急切斷保護機器處所，機艙通風喪失須觸發安全系統。

15.11 燃料供應系統安全功能的規定

15.11.1 如果由於觸發自動閥導致燃料供應中斷，在確定中斷原因和採取必要的預防措施前不得開啟燃料供應系統。一份做出如此指示的顯而易見的通知須佈置在燃料供應管線截止閥的操作站。

15.11.2 如發生燃料泄漏導致的燃料供應中斷，在發現泄漏並處理妥當之前，燃料供應不得運作。如此指示須佈置在機器處所的明顯位置。

15.11.3 含燃氣發動機的機器處所中須永久設置警告牌或佈告牌，表明在發動機使用燃氣運行時，不得進行帶有損壞燃料管路危險的起重作業。

15.11.4 須酌情在以下位置為手動遠程緊急停止壓縮機，泵和燃料供應做出佈置：

- .1 駕駛室；
- .2 貨物控制室；
- .3 船上安全中心；
- .4 發動機控制室；

.5 消防控制站；和

.6 臨近燃料準備室出口處。

瓦斯壓縮機也須為當地緊急停止做出佈置。

表 1：發動機燃氣供應系統監測

參數	警報	自動關閉液 艙的閥門 ⁶⁾	自動關閉含燃氣 發動機機器處所 的燃氣供應	備註
液艙連接處所內探測到瓦斯最低爆炸性極限的 20%時	X			
液艙連接處所內兩個探測器 ¹⁾ 探測到瓦斯最低爆炸性極限的 40%時	X	X		
燃料存儲處所探測到失火	X			
甲板下燃料圍護系統通風幹道 中探測到失火	X			
液艙連接處所艙底井高液位	X			
液艙連接處所艙底井低溫	X	X		
液艙與含燃氣發動機機器處所 之間的導管內檢測到瓦斯最低 爆炸性極限的 20%時	X			
液艙與含燃氣發動機機器處所 之間的導管內兩個檢測器 ¹⁾ 探 測到瓦斯最低爆炸性極限的 40%時	X	X ²⁾		
燃料準備室內探測到瓦斯最低 爆炸性極限的 20%時	X			
兩個檢測器在燃料準備室內探 測到瓦斯最低爆炸性極限的 40%時	X	X ²⁾		
含燃氣發動機機器處所中的導 管內探測到瓦斯最低爆炸性極 限的 30%時	X			如含燃氣發動機機器 處所裝設雙套管
含燃氣發動機機器處所中的導 管內兩個檢測器探測到瓦斯最 低爆炸性極限的 60%時	X		X ³⁾	如含燃氣發動機機器 處所裝設雙套管
含燃氣發動機的應急切斷保護 機器處所內探測到瓦斯最低爆 炸性極限的 20%時	X			

參數	警報	自動關閉液 艙的閥門 ⁶⁾	自動關閉含燃氣 發動機機器處所 的燃氣供應	備注
含燃氣發動機的應急切斷保護 機器處所內兩個探測器探測到 瓦斯最低爆炸性極限的 40%時	X		X	並須斷開非經認證為 含燃氣發動機機器處 所內安全的電子設備
液艙與含燃氣發動機機器處所 之間的導管內通風喪失	X		X ²⁾	
含燃氣發動機機器處所中的 導管內通風喪失 ⁵⁾	X		X ³⁾	如果包含燃氣發動機 的機器處所配備雙管 道
含燃氣發動機的應急切斷保護 機器處所內通風喪失	X		X	
含燃氣發動機機器處所內探測 到失火	X			
燃氣供應管道內燃氣壓力異常	X			
閥門控制驅動介質故障	X		X ⁴⁾	有必要的時間延遲
發動機自動關閉（發動機故 障）	X		X ⁴⁾	
手動觸發發動機緊急關閉	X		X	
1) 因冗餘原因要求兩個獨立的氣體探測器緊挨着放置。如瓦斯探測器是自我監測型，可允許裝置單一瓦斯探測器。 2) 如果燃料艙為多個發動機供氣，及不同的供應管路完全分隔並處於分隔的導管中，且各主閥配置在導管之外，則僅須關閉進入探測到瓦斯或通風喪失的導管的供應管道主閥。 3) 如果為多個發動機供應燃氣，及不同供應管路完全分隔處於分隔的導管中，且主閥配置在導管和含燃氣發動機機器處所之外，則僅須關閉進入探測到瓦斯或通風喪失的導管的供應管道主閥。 4) 僅關閉雙截斷和排放閥門組。 5) 如導管受惰性氣體保護（見 9.6.1.1），則惰性氣體過壓喪失須導致本表中給出的同樣行動。 6) 9.4.1 中所指閥門。				

附件

新穎構造燃料圍護系統設計中極限狀態方法的使用標準

1 通則

1.1 本標準的目標是為符合 6.4.16 節的新穎構造燃料圍護系統極限狀態設計提供程序和相關設計參數。

1.2 極限狀態設計是一種系統方法，對每個結構件按與 6.4.16 中列明的設計條件相關的可能失效模式進行評估。極限狀態可定義為超出此狀態後，結構或部分結構不再滿足規定。

1.3 極限狀態分為以下 3 類：

- .1 最終極限狀態（ULS），在完整（無破損）條件下，對應於最大承載能力，或在某些情況下，對應於最大適用應變、變形或屈曲和塑性破壞引起的結構不穩定；
- .2 疲勞極限狀態（FLS），對應於由於循環裝載的影響造成的劣化；和
- .3 意外極限狀態（ALS），與結構的抗意外狀況能力有關。

1.4 須依據燃料圍護系統概念酌情符合 6.4.1 至 6.4.14 節。

2 設計格式

2.1 本標準中的設計格式基於載荷和抗力因數設計格式。載荷和抗力因數設計格式的基本原則是驗證在任何情景下，對於任何所考慮的失效模式，設計載荷作用 L_d 不超過設計抗力 R_d ：

$$L_d \leq R_d$$

設計載荷 F_{dk} 通過特徵載荷與給出的載荷種類相關的載荷系數的乘積獲得：

$$F_{db} = \gamma_f \cdot F_k$$

式中：

γ_f 是載荷系數；和

F_k 是 6.4.9 至 6.4.12 節中規定的特徵載荷。

設計載荷作用 L_d （例如應力、應變、位移和振動）是從設計載荷導出的最不利組合載荷作用，可用下列公式表達：

$$L_d = q(F_{d1}, F_{d2}, \dots, F_{dN})$$

式中： q 表示由結構分析確定的載荷和載荷效應之間的函數關係。

設計抗力 R_d 由下式獲得：

$$R_d = \frac{R_k}{\gamma_R \cdot \gamma_c}$$

式中：

R_k 係指特性抗力。對於第 7 章涵蓋的材料，這可為但不限於規定的最小屈服應力、規定的最小抗拉強度、橫截面的塑性抗力和極限屈曲強度；

γ_R 係指界定為 $\gamma_R = \gamma_m \cdot \gamma_s$ 抗力因數；

γ_m 係指考慮到材料特性（材料系數）概率分佈的分項抗力系數；

γ_s 係指考慮到結構能力不確定性的分項抗力系數，例如建造

質量，確定能力包括精度分析所考慮的方法；和

γ_c 係指後果等級系數，說明有關燃料泄放和可能的人員受傷的故障的潛在後果。

2.2 燃料圍護設計須考慮到可能的故障結果。後果等級界定於表 1 中，以列明故障模式在與最終極限狀態、疲勞極限狀態或意外極限狀態有關時的故障後果。

表 1：後果等級

後果等級	定義
低	故障意味着少量燃料泄放。
中	故障意味着燃料泄放和可能造成人員受傷。
高	故障意味着大量燃料泄放和極有可能造成人員傷亡。

3 所要求的分析

3.1 三維有限元分析須作為液艙和船體的組合模型進行，包括適用的支持件和關鍵系統。須確定所有失效模式以避免意想不到的失效。須進行流體力學分析確定在不規則波中的特定船舶加速度和運動，以及船舶及其燃料圍護系統對這些力和運動的響應。

3.2 承受外部壓力和引起壓縮應力的其他載荷的液艙須按照公認標準進行屈曲強度分析。方法須充分考慮到理論和實際屈曲應力值之間的差別；此差別是因板不平整、板邊不對中、平直性、橢圓度以及在規定弧長或弦長範圍內存在的失圓度而引起。

3.3 疲勞和裂紋擴展分析須按照本標準第 5.1 段進行。

4 承載極限狀態

4.1 結構抗力可通過試驗或完整分析確定，並考慮到彈性和塑性材料特性。極限強度的安全裕量須以部分安全因數引入，並考慮到載荷和抗力（動載荷、壓力載荷、重力載荷、材料強度和屈曲能力）的隨機性。

4.2 分析中須考慮永久載荷、功能載荷和環境載荷包括晃蕩載荷的適當組合。評估承載極限狀態須至少使用 2 個具有表 2 中給出的分項載荷系數的載荷組合。

表 2：分項載荷系數

載荷組合	永久載荷	功能載荷	環境載荷
'a'	1.1	1.1	0.7
'b'	1.0	1.0	1.3

載荷組合 'a' 中的永久和功能載荷的載荷系數與適用於燃料圍護系統的通常良好受控和（或）規定的載荷有關，例如蒸氣壓力、燃料重量、系統自重等。更高的載荷系數會相關於預測模型中固有可變性和（或）不確定性更高的永久和功能載荷。

4.3 對於晃蕩載荷，主管機關可根據估算方法的可靠性，要求較大的載荷系數。

4.4 如燃料圍護系統的結構失效被視為極有可能造成人員受傷和大量燃料泄放，後果等級系數需須取作 $\gamma_c = 1.2$ 。如經風險評估證明並經主管機關認可，該值可降低。風險評估須考慮的因素包括但不限於設有完整或部份次屏壁以對船體結構提供泄漏保護及與擬載燃料相關的較小的危險。相反時，主管機關可確定較高值，例如，對於載運更危險或更高壓力燃料的船舶。在任何情況下，後果等級系數不得小於 1.0。

4.5 所用的載荷因數和抗力因數須使安全水平等於 6.4.2.1 至 6.4.2.6

節中所述的燃料圍護系統的安全水平。這可通過按已知的成功設計校準因數進行。

4.6 材料系數 γ_m 一般須反映材料力學性能的統計分佈，並需要與特定的力學特性一起解釋。對於第 6 章中界定的材料，材料系數 γ_m 可取作：

1.1 當主管機關規定的特有力學性能在力學性能的統計分佈中代表較低的 2.5% 分位數；或

1.0 當主管機關規定的特有力學性能代表一個足夠小的分位數，使力學性能比規定值低的概率極低並可忽略不計。

4.7 分項抗力系數 γ_{si} 一般須根據基於結構能力的不確定性予以確定，並考慮到建造公差、建造質量、所用分析方法的精度。

4.7.1 對於使用本標準 4.8 中給出的極限狀態衡準針對過度塑性變形的設計，分項抗力系數 γ_{si} 須取：

$$\gamma_{s1} = 0.76 \cdot \frac{B}{\kappa_1}$$

$$\gamma_{s2} = 0.76 \cdot \frac{D}{\kappa_2}$$

$$\kappa_1 = \text{Min} \left(\frac{R_m}{R_e} \cdot \frac{B}{A}; 1.0 \right)$$

$$\kappa_2 = \text{Min} \left(\frac{R_m}{R_e} \cdot \frac{D}{C}; 1.0 \right)$$

系數 A、B、C 和 D 的定義見 6.4.15.2.3.1。 R_m 和 R_e 的定義見 6.4.12.1.1.3。以上給出的分項抗力系數是校準至常規 B 型獨立液艙的結果。

4.8 針對過度塑性變形的設計

4.8.1 以下給出的應力驗收衡準涉及彈性應力分析。

4.8.2 燃料圍護系統的主要由結構中膜響應承受載荷的部份，須滿足下列極限狀態衡準：

$$\sigma_m \leq f$$

$$\sigma_L \leq 1.5f$$

$$\sigma_b \leq 1.5F$$

$$\sigma_L + \sigma_b \leq 1.5F$$

$$\sigma_m + \sigma_b \leq 1.5F$$

$$\sigma_m + \sigma_b + \sigma_g \leq 3.0F$$

$$\sigma_L + \sigma_b + \sigma_g \leq 3.0F$$

式中：

σ_m = 等效總體主膜應力

σ_L = 等效局部主膜應力

σ_b = 等效主彎曲應力

σ_g = 等效二階應力

$$f = \frac{R_e}{\gamma_{s1} \cdot \gamma_m \cdot \gamma_C}$$

$$F = \frac{R_e}{\gamma_{s2} \cdot \gamma_m \cdot \gamma_C}$$

指導性說明：

須通過合計各應力分量（ σ_x 、 σ_y 、 τ_{xy} ）求出上述應力總和，並之後須如下例中所示，基於得出的各應力分量計算出等效應力。

$$\sigma_L + \sigma_b = \sqrt{(\sigma_{Lx} + \sigma_{bx})^2 - (\sigma_{Lx} + \sigma_{bx})(\sigma_{Ly} + \sigma_{by}) + (\sigma_{Ly} + \sigma_{by})^2 + 3(\tau_{Lxy} + \tau_{bxy})^2}$$

4.8.3 燃料圍護系統的主要由縱桁、扶強材和板的彎曲承受載荷的部分，須滿足下列極限狀態衡準：

$$\sigma_{ms} + \sigma_{bp} \leq 1.25F \text{（見註 1 和 2）}$$

$$\sigma_{ms} + \sigma_{bp} + \sigma_{bs} \leq 1.25F \text{（見註 2）}$$

$$\sigma_{ms} + \sigma_{bp} + \sigma_{bs} + \sigma_{bt} + \sigma_g \leq 3.0F$$

註 1： 等效截面膜應力和主結構等效膜應力之和（ $\sigma_{ms} + \sigma_{bp}$ ）通常將直接從三維有限元分析獲得。

註 2： 考慮到設計概念、結構構成和應力計算所使用的方法，主管機關可修改系數 1.25。

式中：

σ_{ms} = 主結構的等效截面膜應力

σ_{bp} = 主結構的等效膜應力以及主結構彎曲造成的次結構和第三級結構中的應力

σ_{bs} = 次結構中的截面彎曲應力和次結構彎曲造成的第三級結構中的應力

σ_{bt} = 第三級結構中的截面彎曲應力

$\sigma_g =$ 等效二階應力

$$f = \frac{R_e}{\gamma_{s1} \cdot \gamma_m \cdot \gamma_c}$$

$$F = \frac{R_e}{\gamma_{s2} \cdot \gamma_m \cdot \gamma_c}$$

應力 σ_{ms} 、 σ_{bp} 、 σ_{bs} 和 σ_{bt} 的定義見 4.8.4。

指導性說明：

須通過合計各應力分量 (σ_x 、 σ_y 、 τ_{xy}) 求出上述應力總和，並之後須基於得出的各應力分量計算出等效應力。

殼板須按照主管機關的要求設計。當膜應力較大，另須適當考慮膜應力對板彎曲能力的影響。

4.8.4 截面應力種類

正應力是垂直於基準平面的應力分量。

等效截面膜應力係指在被考察結構橫截面範圍內，均勻分佈且等於應力平均值的正應力的分量。對於簡單形狀的結構截面，該截面膜應力等於本標準 4.8.2 中界定的膜應力。

截面彎曲應力係指彎曲作用下結構截面上線性分佈的正應力分量，如圖 1 所示。

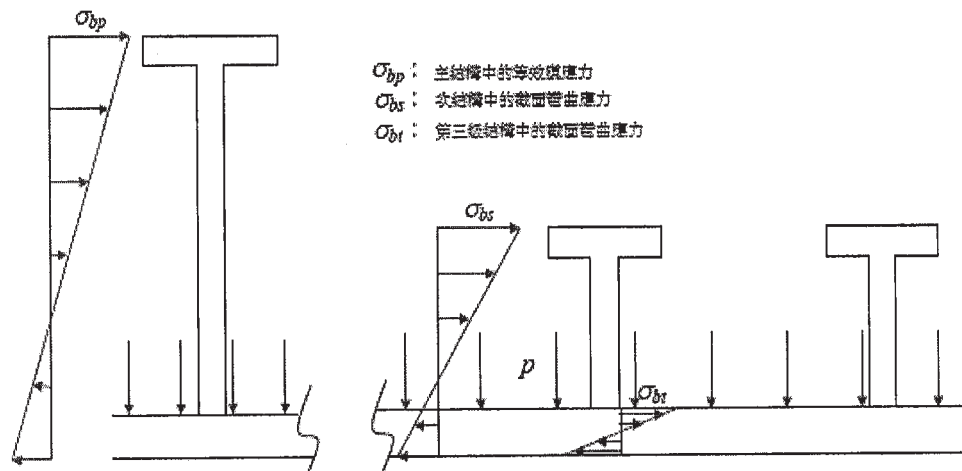


圖 1: 三種截面應力的定義
(應力 σ_{bp} 和 σ_{bs} 垂直於所示的橫截面)

4.9 除所應用的公認屈曲標準中另有規定外，防屈曲設計須採用相同的系數 γ_C 、 γ_m 、 γ_{si} 。在任何情況下，整體安全水平須不低於這些系數所給出安全水平。

5 疲勞極限狀態

5.1 6.4.12.2 中所述的疲勞設計條件，須依據燃料圍護系統概念，酌情予以遵守。對於按 6.4.16 和本標準設計的燃料圍護系統，需要進行疲勞分析。

5.2 對於所有載荷種類，疲勞極限狀態的載荷系數須取 1.0。

5.3 後果等級系數 γ_C 和抗力系數 γ_R 須取 1.0。

5.4 疲勞損壞須按 6.4.12.2.2 至 6.4.12.2.2.5 中所述進行計算。計算出的燃料圍護系統累積疲勞損壞比須小於或等於表 3 中給出的值。

表 3：許用最大累積疲勞損壞比

	後果等級		
<i>CW</i>	低	中	高
	1.0	0.5	0.5*

註*：須依據缺陷或裂痕等的可發現度等，按照 6.4.12.2.7 至 6.4.12.2.9 取較低值。

- 5.5 主管機關可確定較低值。
- 5.6 需按 6.4.12.2.6 至 6.4.12.2.9 的要求進行裂紋擴展分析。分析須按經主管機關認可的標準中規定的方法進行。
- 6 意外極限狀態
- 6.1 6.4.12.3 中所述的意外設計條件，須依據燃料圍護系統概念，酌情予以遵守。
- 6.2 慮及只要破損和變形不導致意外狀況升級則可接受該破損和變形，與最終極限狀態相比載荷系數和抗力系數可以放寬。
- 6.3 意外極限狀態的永久載荷、功能載荷和環境載荷的載荷系數須取 1.0。
- 6.4 6.4.9.3.3.8 和 6.4.9.5 中所述載荷無需相互合成，或與 6.4.9.4 中界定的環境載荷合成。
- 6.5 抗力系數 γ_R 一般須取 1.0。
- 6.6 後果等級系數 γ_C 一般須按本標準 4.4 的規定選取，但可慮及意外事故的性質而適當放寬。
- 6.7 特性抗力 R_k 一般須按最終極限狀態選取，但可慮及意外事故的性

質而適當放寬。

6.8 附加相關意外情景須根據風險評估確定。

7 試驗

7.1 按本標準設計的燃料圍護系統須依據燃料圍護系統的概念，酌情按 16.2 中所述的相同程度進行試驗。

B-1 部分

燃料就本部分中的規定而言，係指呈液態或氣態的天然氣。

16 製造，工藝和試驗

16.1 通則

16.1.1 製造、試驗、檢查以及文件須符合公認標準和本規則中給出的規定。

16.1.2 如規定或要求作焊後熱處理，其母材性能須在熱處理後的條件下按照第 7 章中適用列表予以確定，而焊縫性能須在熱處理後的條件下按照 16.3 予以確定。如果採用焊後熱處理，試驗規定可由主管機關酌情修改。

16.2 一般試驗規定和說明

16.2.1 拉伸試驗

16.2.1.1 拉伸試驗須按公認標準進行。

16.2.1.2 抗拉強度、屈服應力和伸長率須使主管機關滿意。對具有確定屈服點的碳錳鋼和其他材料，須考慮其屈強比的限制。

16.2.2 韌性試驗

16.2.2.1 除主管機關另有規定外，金屬材料的驗收試驗須包括夏比 V 型缺口衝擊韌性試驗。所述夏比 V 型規定是 3 個全尺寸（10mm × 10mm）試樣的最小平均衝擊能量值和對各式樣的最小單個衝擊能量值。夏比 V 型缺口試樣的尺寸和公差須符合公認標準。對尺寸小於 5.0mm 的試樣的試驗和規定須符合公認標準。小尺寸試樣的最小平均值須為：

夏比 V 型缺口試樣尺寸 (mm)	3 個試樣的最小平均衝擊能量(J)
10 × 10	KV
10 × 7.5	5/6KV
10 × 5.0	2/3KV

表中：

KV = 表 7.1 至表 7.4 中規定的衝擊能量值 (J)。

僅一個試樣的衝擊能量可低於規定的平均值，但不得低於該平均值的 70%。

16.2.2.2 對於母材，須儘可能按材料厚度截取最大尺寸的夏比 V 型缺口試樣，並使試樣位於儘實際可行地接近材料表面和其厚度中心之間的中點位置，並使缺口的長度方向垂直於材料表面（見圖 16.1）。

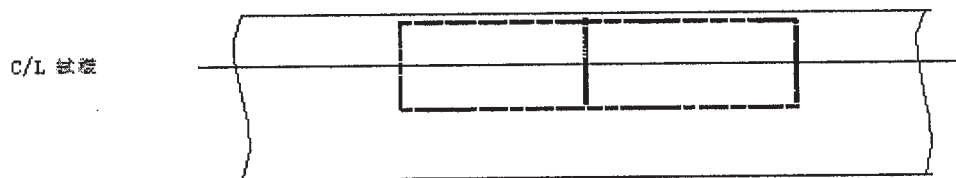


圖 16.1—母材試樣的取向

16.2.2.3 對於焊接試驗試樣，須儘可能按材料厚度截取最大尺寸的夏比 V 型缺口試樣，並儘量使試樣位於儘實際可行地接近材料表面和其厚度中心之間的中點位置。在各種情況下，從材料表面至試樣邊緣的距離，須約為 1mm 或更大。此外，對於雙 V 型坡口對接焊縫，須在更接近第 2 個焊接面處截取試樣。試樣一般須如圖 16.2 中所示，在各下列位置，在焊縫的中線上、在熔合線上和距離熔合線 1mm、3mm 和 5mm 處截取。

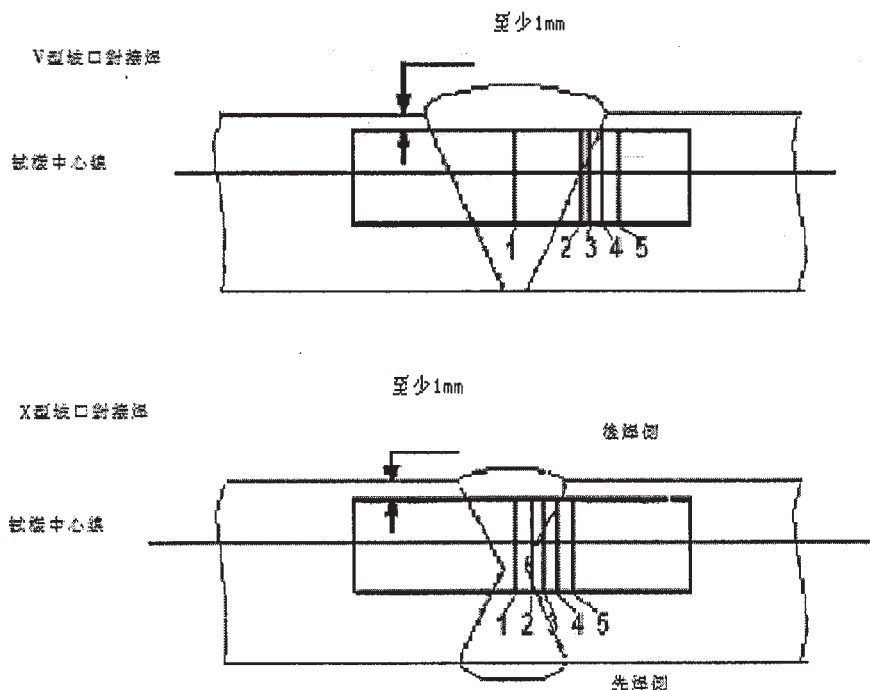


圖 16.2—焊接試樣的取向

圖 16.2 中的缺口位置：

- .1 焊縫中心線；
- .2 位於熔合線上；
- .3 熱影響區（HAZ）中，距熔合線 1mm；
- .4 熱影響區（HAZ）中，距熔合線 3mm；和
- .5 熱影響區（HAZ）中，距熔合線 5mm。

16.2.2.4 如果 3 個最初的夏比 V 型缺口試樣的平均衝擊能量沒有達到所述規定，或 1 個以上試樣的值低於所要求的平均值，或者 1 個試樣的值低於所允許的單個試樣最小值時，則可以從同一材料中再取 3 個附加試樣進行試驗並將所得的結果與原先獲得的試驗結果組合以形成 1 個新的平均值。如果這個新的平均值符合規定，及低於要求的平均值的個別結果不

多於 2 個且低於單個試樣要求值的試樣結果不多於 1 個，則可以接受此件或這批材料。

16.2.3 彎曲試驗

16.2.3.1 作為材料驗收試驗，彎曲試驗可予以免除，但對焊接試驗仍要求彎曲試驗。如進行彎曲試驗，須按照公認標準進行。

16.2.3.2 彎曲試驗須為橫向彎曲試驗，主管機關可酌情決定進行正彎、反彎或側彎試驗。如母材和焊縫金屬具有不同的強度級，則可要求以縱向彎曲試驗替代橫向彎曲試驗。

16.2.4 斷面觀察和其他試驗

16.2.4.1 主管機關也可要求按照公認標準對焊縫做宏觀斷面、微觀斷面觀察以及硬度試驗。

16.3 燃料圍護系統金屬材料的焊接和無損探傷

16.3.1 通則

16.3.1.1 本節須僅適用於主屏壁和次屏壁，包括構成次屏壁的內殼。驗收試驗係為碳鋼、碳錳鋼、鎳合金鋼和不鏽鋼規定的，但可為其他材料加以調整。主管機關可酌情決定免除對不鏽鋼和鋁合金焊接件的衝擊試驗，也可對任何材料特別要求做其他的試驗。

16.3.2 焊接耗材

16.3.2.1 用於燃料艙焊接的耗材須符合公認標準。對所有焊接耗材均須要求進行熔敷金屬試驗和對接焊縫試驗。拉伸試驗和夏比 V 型缺口衝擊試驗中所得的結果須符合公認標準。熔敷金屬的化學成分須作記錄以供查詢。

16.3.3 燃料艙和處理用壓力容器的焊接工藝試驗

16.3.3.1 對所有燃料艙和處理用壓力容器的對接焊縫均要求作焊接工藝試驗。

16.3.3.2 焊接試件須能代表：

- .1 每種母材；
- .2 每種焊接耗材和焊接方法；和
- .3 每種焊接位置。

16.3.3.3 對於板材的對接焊，試件的製備須使板材軋製方向平行於焊接方向。每種焊接工藝試驗所規定的材料厚度範圍須符合公認標準。製造廠可選擇進行射線檢查或超聲波檢查。

16.3.3.4 須使用從每個試件製作的試樣按 16.2 對燃料艙和處理用壓力容器進行以下焊接工藝試驗：

- .1 焊縫橫向拉力試驗；
- .2 公認標準要求的縱向全焊接試驗；
- .3 橫向彎曲試驗，可進行正彎、反彎或側彎試驗。如母材和焊縫金屬具有不同的強度級，則可要求以縱向彎曲試驗替代橫向彎曲試驗；
- .4 一組 3 個的夏比 V 型缺口衝擊試驗，一般在如圖 16.2 所示的下列各個位置上：
 - .1 焊縫的中心線；
 - .2 熔合線；

.3 距熔合線 1mm；

.4 距熔合線 3mm；和

.5 距熔合線 5mm；

.5 也可要求對焊縫做宏觀斷面、微觀斷面以及硬度檢驗。

16.3.3.5 每個試驗須滿足下列要求：

.1 拉力試驗：焊縫橫向抗拉強度不低於對相應母材規定的最低抗拉強度。對於鋁合金，須就低匹配焊縫的焊縫金屬強度（焊縫金屬的抗拉強度低於母材的抗拉強度）規定參照 6.4.12.1.1.3。在每種情況下，須記錄試樣破斷位置以供查詢；

.2 彎曲試驗：不接受試樣經直徑為 4 倍試樣厚度的彎芯彎曲 180°後的任何斷裂；和

.3 夏比 V 型缺口衝擊試驗：夏比 V 型缺口衝擊試驗須在對被連接母材所規定的溫度下進行。焊縫金屬衝擊試驗的結果，其最小平均衝擊能量（KV）須不低於 27J。對焊縫金屬小尺寸試樣和單個衝擊能量值的規定須符合 16.2.2。熔合線和熱影響區衝擊試驗結果須顯示出符合對母材所適用的橫向或縱向規定的最小平均衝擊能量（KV），對於小尺寸試樣，最小平均衝擊能量（KV）須符合 16.2.2。如果材料的厚度不允許截取全尺寸試樣或標準小尺寸試樣，則試驗方法和驗收標準須符合公認標準。

16.3.3.6 用於填角焊的工藝試驗須符合公認標準。在這種情況下，須選

擇具有良好衝擊性能的焊接耗材。

16.3.4 管材的焊接工藝試驗

對管材須進行焊接工藝試驗，該試驗須與 16.3.3 中對燃料艙規定的細節相似。

16.3.5 產品焊縫試驗

16.3.5.1 除膜式艙外，所有燃料艙和處理用壓力容器通常需對每 50m 左右的對接焊縫進行一次產品焊縫試驗，並須能代表各個焊接位置。對次屏壁須作與對注液艙所要求者相同類型的產品焊縫試驗，但經主管機關同意可減少試驗次數。除 16.3.5.2 至 16.3.5.5 規定的試驗外，可要求對燃料艙或次屏壁進行其他試驗。

16.3.5.2 對 A 型和 B 型獨立艙的產品焊縫試驗須包括彎曲試驗，及，如要求，一組 3 個夏比 V 型缺口的衝擊試驗。試驗須對每 50m 焊縫進行一次。夏比 V 型缺口衝擊試驗須使用缺口交替位於焊縫中心或熱影響區（基於工藝合格試驗結果的最危險位置）的試樣進行。對於奧氏體不鏽鋼，所有的缺口須位於焊縫的中心處。

16.3.5.3 對於 C 型獨立艙和處理用壓力容器，除 16.3.5.2 所列的試驗外，還要求進行焊縫橫向拉力試驗。拉力試驗須滿足 16.3.3.5 的規定。

16.3.5.4 質量保證/質量控制（QA/QC）計劃須確保材料製造商的質量手冊（QM）中規定的產品焊縫持續符合性。

16.3.5.5 膜式艙的試驗規定與 16.3.3 中所列的適用試驗規定相同。

16.3.6 無損探傷試驗

16.3.6.1 所有試驗程序和驗收標準須符合公認標準，除非設計方規定更

高的標準以滿足設計假定。原則上須使用射線檢查以發現內部缺陷。但是，可進行經認可的超聲波試驗程序替代射線檢查，但須選部分位置進行射線檢查以驗證其結果。射線和超聲波檢查記錄須予留存。

16.3.6.2 對於設計溫度為-20℃以下的 A 型獨立艙以及不論設計溫度如何的 B 型獨立艙，所有燃料艙殼板的全焊透對接焊縫須經受適於在其整個長度範圍內發現內部缺陷的無損探傷試驗。在與 16.3.6.1 所述的相同條件下，可進行超聲波替代射線檢查。

16.3.6.3 在所有情況下，燃料艙結構的其餘焊縫，包括扶強材以及其他附件和連接件的焊縫須在必要時用磁粉或着色滲透法進行檢查。

16.3.6.4 對於 C 型獨立艙，無損探傷的範圍須按公認標準為全部或部分，但要進行的控制須不少於以下所列：

.1 6.4.15.3.2.1.3 中所述全部無損探傷：

射線檢查：

.1 所有對接焊縫整個長度；

表面裂紋探測的無損探傷試驗：

.2 所有焊縫的 10%長度；

.3 整個長度內的開孔和噴管等周圍的加強環。

作為替代，16.3.6.1 中所述的超聲波檢查可代替部分射線檢查。此外，主管機關可要求對開孔周圍的加強環和噴嘴等焊縫全部進行超聲波檢查。

.2 6.4.15.3.2.1.3 中所述部分無損探傷：

射線檢查：

- .1 所有對接焊交叉處的接頭和在對接焊縫全部長度上均勻選取至少 10% 的長度；

表面裂紋探測的無損探傷試驗：

- .2 整個長度內的開孔和噴管等周圍的加強環；

超聲波檢查：

- .3 主管機關可根據每一具體情況提出要求。

16.3.6.5 質量保證/質量控制（QA/QC）計劃須確保材料製造商的質量手冊（QM）中規定的焊縫無損探傷的持續符合性。

16.3.6.6 管道檢查須按第 7 章的規定進行。

16.3.6.7 在認為必要時，須對次屏壁進行無損探傷以發現內部缺陷。如船體外殼為次屏壁的一部分，則須對所有舷側頂列板的對接焊縫以及舷側外板上的所有環縫和縱縫的交叉處進行射線檢查。

16.4 金屬材料構造的其他規定

16.4.1 通則

焊縫的檢查和無損探傷須符合 16.3.5 和 16.3.6 中的規定。如在設計中假定更高的標準或公差，也須予以滿足。

16.4.2 獨立艙

對於主要由回轉體構成的 C 型和 B 型艙，有關製造的公差，例如失圓、局部偏離正確形狀、焊接接頭的對中以及不同厚度板的削斜，須符合公認標準。這些公差還須與 6.4.15.2.3.1 和 6.4.15.3.3.2 中所述屈曲

分析相關。

16.4.3 次屏壁

建造期間，次屏壁的試驗和檢查規定須經主管機關認可或接受（另見 6.4.4.2.5 和 6.4.4.2.6）。

16.4.4 膜式艙

質量保證/質量控制（QA/QC）計劃須確保焊接工藝條件、設計細節、材料、建造、檢驗和部件的生產試驗的持續符合性。這些標準和工藝須在原型試驗計劃期間制定。

16.5 試驗

16.5.1 建造期間的試驗與檢查

16.5.1.1 所有液化氣燃料液艙和處理壓力容器須按 16.5.2 至 16.5.5 對所適用的液艙類型進行水壓或液壓氣動試驗。

16.5.1.2 所有液艙須進行密性試驗，該密性試驗可結合 16.5.1.1 中所述壓力試驗一起進行。

16.5.1.3 關於 6.3.3 的燃料圍護系統的氣密性須予以測試。

16.5.1.4 關於對次屏壁的檢查規定，須由主管機關慮及該次屏壁的可接觸性，在每一情況下予以確定（另見 6.4.4.2）。

16.5.1.5 對於設有新穎 B 型獨立液艙或按照 6.4.16 設計的液艙的船舶，主管機關可要求至少在一個原型液艙及其支持結構上須使用應變儀或其他適當的設備進行測量，以在 16.5.1.1 中所要求的試驗期間確認其應力水平。對於 C 型獨立液艙，依據其構型及其支持構件和附件的佈置，可要求

使用類似設備。

16.5.1.6 須按照主管機關的要求，在首次液化天然氣燃料加注期間，當液化氣燃料達到穩定熱工工況時，驗證燃料圍護系統的整體性能是否符合設計參數。需在船上保持驗證設計參數所必需的部件和設備的性能記錄，並可供主管機關使用。

16.5.1.7 第一次液化氣加注期間或剛剛完成之後，當達到熱工工況時，須對燃料圍護系統進行冷點檢查。無法目視檢查的絕熱表面完整性檢查，須按照主管機關的要求進行。

16.5.1.8 加熱裝置，如按 6.4.13.1.1.3 和 6.4.13.1.1.4 裝設，須對所要求的熱量輸出和熱量分佈進行測試。

16.5.2 A 型獨立液艙

須對所有 A 型獨立液艙進行水壓或液壓氣動試驗。進行這種試驗時，須使其應力儘可能接近設計應力，並使液艙頂的壓力至少相當於釋放閥的最大調定值。進行水壓-氣動試驗時，試驗條件須儘可能模擬液艙及其支持結構的設計載荷，包括動態分量，同時避免應力水平引起永久變形。

16.5.3 B 型獨立液艙

16.5.3.1 B 型獨立液艙須按下列要求進行水壓或水壓—氣動試驗：

- .1 須按 16.5.2.1 中對 A 型獨立液艙的要求進行試驗。
- .2 此外，在試驗條件下，主要構件中的最大主膜應力或最大彎曲應力須不超過材料（製成狀態）在試驗溫度下的屈服強度的 90%。為確保滿足上述條件，當計算表明此應力超

過該屈服強度的 75%時，須採用應變儀或其他合適的設備對一系列同樣液艙中的第一個液艙試驗加以監測。

16.5.4 C 型獨立液艙和其他壓力容器

16.5.4.1 每一壓力容器須以在液艙頂測得的不小於 $1.5P_0$ 的壓力進行水壓試驗。在壓力試驗期間的任何情況下，任何一點上計算所得的主膜應力不超過該材料在試驗溫度下的屈服應力的 90%。為確保滿足上述條件，如計算表明主膜應力超過屈服強度的 75%，則須採用應變儀或其他合適的設備對一系列同樣液艙中的第一個液艙試驗加以監測，但簡單的圓柱型或球型壓力容器除外。

16.5.4.2 試驗時所採用的水溫至少須比製成的材料的無延性轉變溫度高出 30°C 。

16.5.4.3 對每 25mm 的厚度，壓力須保持為 2 小時，但在任何情況下不得少於 2 小時。

16.5.4.4 如必要，可在 16.5.4.1 至 16.5.4.3 中所述條件下對液化氣燃料壓力容器進行水壓-氣動試驗。

16.5.4.5 測試採用較高許用應力的液艙，可依據工作溫度予以特別考慮。但需完全滿足 16.5.4.1 中的規定。

16.5.4.6 在裝配和完工後，須對每一壓力容器及其有關的部件進行適當的密性試驗，該試驗可酌情與 16.5.4.1 或 16.5.4.4 中所述壓力試驗一起進行。

16.5.4.7 對除液化氣燃料艙外的壓力容器的氣壓試驗，須根據個案予以考慮。僅在下述情況下，才允許進行氣壓試驗：容器的設計或其支持結

構無法安全注滿水，或容器無法乾燥或使用時不允許試驗介質痕跡殘留。

16.5.5 膜式液艙

16.5.5.1 設計開發試驗

16.5.5.1.1 在 6.4.15.4.1.2 中要求的設計開發試驗須包括對主屏壁及次屏壁的一系列分析和物理模型（包括角和接頭）的試驗以驗證其能夠承受在所有灌注水平下由靜、動和熱載荷引起的預期組合應變。這將以建造完整的液化燃料圍護系統的原型模型告終。分析和物理模型中考慮的試驗條件須代表液化燃料圍護系統在其使用壽命中可能遇到的最極端的營運狀態。6.4.4.2 中要求的次屏壁定期試驗的建議接受衡準可基於原型模型的試驗結果。

16.5.5.1.2 薄膜材料和薄膜中有代表性的焊接或連接接頭的疲勞性能須通過試驗確定。將絕熱系統繫固至船體結構的裝置的極限強度和疲勞性能須通過分析或試驗確定。

16.5.5.2 測試

- .1 當船上設有膜式液化氣燃料圍護系統時，對所有液艙和通常可能裝有液體並鄰接於支持薄膜的船體結構的其他處所，均須進行水壓試驗。
- .2 安裝液化氣燃料圍護系統前，對支持薄膜的所有液艙結構須進行密性試驗。
- .3 對管隧和通常不裝液體的其他艙室無需進行水壓試驗。

16.6 焊接、焊後熱處理和無損測試

16.6.1 通則

焊接須按 16.3 進行。

16.6.2 焊後熱處理

對碳鋼、碳錳鋼和低合金鋼製管道的所有對接焊縫均須進行焊後熱處理。主管機關可就相關管系的設計溫度和設計壓力，對壁厚小於 10mm 的管道免除消除熱應力的規定。

16.6.3 無損探測

除焊接前和焊接期間的正常控制以及為證明已按本段中的規定正確地進行焊接所需的對完工焊縫的目視檢查外，還須要求下列試驗：

- .1 對下列管系的對接焊縫作 100%射線或超聲波檢查；
 - .1 設計溫度低於-10℃；或
 - .2 設計壓力大於 10 MPa；或
 - .3 應急切斷保護機器處所內的燃氣供應管道；或
 - .4 內徑大於 75mm；或
 - .5 壁厚大於 10mm。
- .2 當該段管路的對接焊縫是用主管機關認可的自動焊接工藝焊成時，可同意逐漸減少射線或超聲波檢查的範圍，但在任何情況下，不得小於每一接縫的 10%。如發現缺陷，檢查範圍須增至 100%，並須包括檢查以前已接受的焊縫。僅在具備良好成文的質量保證程序和記錄可供對製造商一貫地製造合格焊縫的能力予以評估時，方可批准此認可。

- .3 對雙套燃料管外管中的對接焊縫的射線或超聲波檢查規定可減少至 10%。
- .4 對於 16.6.3.1 和 16.6.3.3 中未包括的其他管道的對接焊縫，須根據其用途、位置 and 材料進行射線或超聲波抽查或其他的無損傷測試。通常，至少須對 10% 的管道對接焊縫進行射線或超聲波檢查。

16.7 試驗規定

16.7.1 管路部件的型式試驗

閥門

須對工作溫度低於 -55℃ 的每種型式的管路部件進行下列型式試驗：

- .1 每種尺寸和型式的閥門須在全部作業壓力和溫度範圍內，以一定的間隔並直至額定設計壓力，進行閥座密性試驗。允許的泄漏率須滿足主管機關的要求。試驗期間，須對閥門的良好運作進行驗證。
- .2 每種尺寸和型式的閥門須按公認標準對流量進行認證。
- .3 承壓部件須至少以設計壓力的 1.5 倍進行壓力試驗。
- .4 應急截止閥，如具有熔點低於 925℃ 的材料，其型式試驗須包括按至少與本組織可接受標準等效的標準進行的防火試驗。

16.7.2 波紋管膨脹接頭

對按 7.3.6.4.3.1.3 可用於燃料艙以外的燃料管路上的每種波紋管膨脹接頭須進行下列型式試驗，如主管機關要求，對設置在燃料艙內的波紋管膨脹接頭也須進行下列型式試驗：

- .1 未經預先壓縮但有軸向限制的波紋管元件須經受不小於 5 倍設計壓力的壓力試驗而不破裂。試驗持續時間不得少於 5 分鐘。
- .2 須對原型膨脹接頭及其所有附件如法蘭、拉杆和鉸接件等，在製造商建議的最大位移條件下，以最低設計溫度和兩倍設計壓力經受測試而不產生永久變形。
- .3 對完整的膨脹接頭須進行循環試驗（熱運動），在壓力、溫度、軸向運動、旋轉運動和橫向運動等條件下，完整的膨脹接頭須能承受至少與實際使用中將遇到的同樣多的循環次數。當這些試驗與在營運溫度下的條件至少一樣嚴格時，允許在室溫下進行試驗。
- .4 對完整的膨脹接頭須在無內壓的情況下進行循環疲勞試驗（船體變形，船體加速和管道振動），即模擬相當於補償管段的波紋管運動的方式，在不高於 5Hz 的頻率下，至少循環 2,000,000 次。僅在因管路的佈置實際經受船舶變形載荷時，方要求進行這種試驗。

16.7.3 系統試驗規定

16.7.3.1 本節中的試驗規定適用於燃料液艙內外的管路。但主管機關可接受對燃料液艙內管路和開放管路放寬要求。

16.7.3.2 在裝配後，須使用適當的流體對所有燃料管路進行強度試驗。

液體管路的試驗壓力須至少為 1.5 倍設計壓力，蒸氣管路的試驗壓力須至少為 1.5 倍最大系統工作壓力。當完成對管系或系統部件的製造並配齊所有附件時，試驗可在船上安裝之前進行。對在船上焊接的接頭須至少以 1.5 倍設計壓力進行試驗。

16.7.3.3 燃料管系在船上組裝完工後，須使用空氣或其他適當介質進行泄漏試驗，試驗壓力取決於所採用的泄漏檢測方法。

16.7.3.4 在雙套燃料管系中，外管或導管也須進行壓力試驗，以證明其在管道破裂下可承受預計最大壓力。

16.7.3.5 對用於燃料或蒸氣操作的所有管系，包括閥、附件及附屬設備，需在首次燃料灌注作業之前，按照主管機關的要求，在正常工作狀態下進行試驗。

16.7.3.6 液化氣管系中的應急截止閥須在啟動後 30 秒內完全平穩關閉。船上須備閥門關閉時間及其操作特徵的資料，且關閉時間須能驗證並可重複。

16.7.3.7 8.5.8 和 15.4.2.2 中所述的閥門關閉時間（即從關閉信號啟動至閥完全關閉的時間）須不大於：

$$\frac{3600U}{BR} \text{ (秒)}$$

其中：

U = 發出操作信號時艙內液面以上的空距容積，(m³)；

BR = 船和岸上設施之間所同意的最大加注速率
(m³/h)；或

5 秒以最小值為準。

須慮及軟管或裝卸臂以及船上和岸上的相關管路系統，調整加注速率，以將閥關閉時的衝擊壓力限制在一個可承受的水平。

C-1 部分

就本部分中的規定而言，燃料係指處於液態或氣態的天然氣。

17 演習和應急演練

船上演習和演練要定期進行。例如氣體相關演習可包括：

- .1 桌面演習；
- .2 根據 18.2.3 所要求的燃料作業手冊審核加注燃料程序；
- .3 應對潛在的意外事件；
- .4 應急響應設備測試；和
- .5 檢查所指派的海員經過履行加燃料和應急響應期間所指派任務的培訓。

有關瓦斯的演習可納入《安全公約》所要求的定期演習中。

危險和事故控制的響應和安全系統須經檢查和測試。

18 操作

18.1 目標

本章的目標是確保氣體或低閃點燃料系統的裝載、儲存、操作、維護和檢查操作程序最大限度地降低對人員、船舶和環境的風險，並與常規油類燃料船舶的做法相一致，同時考慮到液體或氣體燃料的性質。

18.2 功能要求

本章涉及 3.2.1 至 3.2.3、3.2.9、3.2.11、3.2.15、3.2.16 和 3.2.17 中的功能要求。尤其是以下所列適用：

- .1 本規則所適用的所有船舶須備有本規則的副本或納入本規則規定的國家條例；
- .2 船上須備有所有與氣體相關的裝置的保養程序和資訊；
- .3 須向船舶提供操作程序，包括一份適當詳細的燃料作業手冊，使業經培訓人員能夠安全地操作燃料加注、存儲和輸送系統；及
- .4 須向船舶提供適當的應急程序。

18.3 維護規定

18.3.1 維護和修理程序須包括對液艙位置和相鄰處所的考慮（見第五章）。

18.3.2 燃料維護系統的營運檢驗，維護和測試要根據 6.4.1.8 所要求的檢查/檢驗計劃進行。

18.3.3 程序和資訊須包括安裝在爆炸危險處所和區域的電氣設備的維護。對爆炸危險處所內電氣裝置的檢查和維護須按照公認標準進行。

18.4 加注燃料操作規定

18.4.1 職責

18.4.1.1 任何加注燃料作業開始前，接收船的船長或其代表和燃料供應方代表（負責人，PIC）須：

- .1 書面同意輸送程序，包括冷卻和如必要，放氣；輸送中所有階段的最大傳輸速率和傳輸量。
- .2 書面同意緊急情況下要採取的行動。

.3 完成並簽署燃料安全檢查表。

18.4.1.2 完成燃料加注作業後，船舶負責人須接收並簽署燃料供應方負責人填妥並簽署的所交付燃料的燃料交付單，其中至少包含 C-1 部份附件中規定的信息。

18.4.2 控制、自動化和安全系統概述

18.4.2.1 18.2.3 所要求的燃料作業手冊須包括但不限於：

- .1 船舶從乾塢至乾塢的全部操作，包括系統冷卻和預熱、燃料加注，如適用，還包括卸載、取樣、惰化和驅氣程序；
- .2 燃料溫度和壓力控制，報警和安全系統；
- .3 系統限制，冷卻速率和加注前燃料存儲艙最高溫度，包括最低燃料溫度、最大液艙壓力、輸送速率、充裝極限和晃蕩限制；
- .4 惰性氣體系統操作；
- .5 消防和應急程序：消防系統的操作和維護以及滅火劑的使用；
- .6 特殊的燃料特性和特定燃料安全作業所需的特殊設備；
- .7 固定和便攜式氣體探測設備的操作和維護；
- .8 應急切斷系統和應急釋放系統，如安裝；和
- .9 對諸如泄漏、失火或潛在燃料層化導致翻轉的緊急情況中要採取的程序行動的說明。

18.4.2.2 燃料系統示意圖/管路和儀錶圖（P&ID）須予以複製並永久張

貼在船舶燃料控制站和燃料加注站中。

18.4.3 燃料加注前驗證

18.4.3.1 進行燃料加注操作前，須進行包括但不限於以下所列的燃料加注前驗證並在燃料加注安全檢查表中記錄：

- .1 所有通信方法，包括船岸連接（SSL），如安裝；
- .2 固定瓦斯和失火探測設備的操作；
- .3 便攜式氣體探測設備的操作；
- .4 遠程控制閥的操作；和
- .5 軟管和接頭的檢查。

18.4.3.2 成功驗證的文件須以雙方負責人簽署的業經相互認可並執行的燃料加注安全檢查表所表明。

18.4.4 船舶燃料加注源通信

18.4.4.1 船上負責人和燃料供應方負責人在加注操作期間須始終保持通信。一旦不能保持通信，須停止燃料加注，並在通信恢復前不得繼續。

18.4.4.2 燃料加注中所用通訊設備須符合主管機關可接受的此種設備的公認標準。

18.4.4.3 負責人須有與參與燃料加注操作的所有人員的直接和即時通訊。

18.4.4.4 船岸連接（SSL）或為自動緊急關閉通訊所提供的至燃料供應源的等效方法須與接收船和交付設施的應急切斷（ESD）系統相匹配。

18.4.5 電氣連接

交付設施所提供的用於燃料加注的軟管、輸送臂、管系和配件須電氣連通、適當絕緣，並須提供符合公認標準的安全水平。

18.4.6 輸送條件

18.4.6.1 燃料輸送期間，須在燃料加注區入口處張貼警告標誌，列明消防安全防範措施。

18.4.6.2 輸送操作時，燃料加注集管區域中的人員須僅限於必要人員。在該作業區附近當值或工作所有職員須穿着適當的個人防護裝備。不能維持輸送所需條件時須停止操作，在滿足所有必要條件前不得恢復輸送。

18.4.6.3 若通過安裝移動液艙加注燃料，其程序須提供與一體化燃料液艙和系統等效的安全水平。移動液艙須在裝船前灌注並需在與燃料系統連接之前予以適當繫固。

18.4.6.4 對於不是永久性安裝在船上的液艙，所有必要的液艙系統（管系、控制、安全系統、釋放系統等）與船舶燃料系統的連接均為“燃料加注”過程的組成部份並須在船舶駛離燃料方之前完成。海上航行或操縱期間不允許連接和斷開可移動艙。

18.5 圍閉處所進入規定

18.5.1 在正常操作情況下，工作人員不得進入燃料液艙，燃料儲存處所，留空處所，液艙連接處所或其他瓦斯或易燃蒸氣會積聚的圍閉處所，除非此等處所內空氣中的瓦斯含量經固定或移動設備確定，保證氧氣充足和沒有爆炸性氣體。

18.5.2 進入任何被指定為危險區域處所的人員不得將任何潛在火源引

入此等處所，除非已證實該處所業經除氣並保持在除氣狀態下。

18.6 燃料系統的惰化和驅氣規定

18.6.1 燃料系統惰化和驅氣的主要目的是防止在燃料系統的管系、液艙、設備和相鄰處所中、附近或周圍形成易燃大氣。

18.6.2 燃料系統的惰化和驅氣程序須確保不將空氣引入含有瓦斯氣體的管系或液艙，和不將瓦斯引入圍閉處所或燃料系統的相鄰處所內所含的空氣中。

18.7 燃料系統上或附近的熱工規定

18.7.1 易燃的、受碳氫化合物污染或由於燃燒可能釋放有毒煙氣的燃料艙、燃料管系和絕緣系統附近的熱工，須僅在此區域得到保護並證明可以安全進行熱工，且得到所有批准之後方進行。

附件

液化天然氣燃料裝艙單

液化天然氣燃料供給

船名： _____ 國際海事組織編號： _____

交付日期：

1. 液化天然氣-特性

甲烷數	--	
低卡（熱）值	MJ/kg	
高卡（熱）值	MJ/kg	
沃泊指數 Ws/Wi	MJ/m³	
密度	kg/m³	
壓力	MPa（abs）	
交付時液化天然氣溫度	°C	
存儲液艙中液化天然氣溫度	°C	
存儲液艙內壓力	MPa（abs）	

2. 液化天然氣-成分

甲烷，CH ₄	%（kg/kg）	
乙烷，C ₂ H ₆	%（kg/kg）	
丙烷，C ₃ H ₈	%（kg/kg）	
異丁烷，i C ₄ H ₁₀	%（kg/kg）	
N-丁烷，n C ₄ H ₁₀	%（kg/kg）	
戊烷，C ₅ H ₁₂	%（kg/kg）	
己烷；C ₆ H ₁₄	%（kg/kg）	
庚烷；C ₇ H ₁₆	%（kg/kg）	

氮氣，N ₂	% (kg/kg)	
硫，S	% (kg/kg)	
可忽略不計<5ppm 硫化氫，氫，氨，氯，氟，水		

3. 交付總淨值：_____t, _____MJ _____m³

淨液體交付：_____GJ

4. 簽字：

供應公司名稱，聯繫細節:_____

簽字：_____地點/港口_____日期：_____

接收方：_____

D 部分

19 培訓

19.1 目標

本章的目標是確保本規則所適用的船舶上的海員具備適當資質、業經培訓並具有經驗。

19.2 功能要求

各公司須確保使用氣體或其他低閃點燃料的船舶上的海員須已完成培訓，獲得與要承擔的職務和職責與責任相應的能力，並慮及經修正的培訓公約和規則中給出的規定。

RESOLUTION MSC.391(95)
(adopted on 11 June 2015)

**ADOPTION OF THE INTERNATIONAL CODE OF SAFETY FOR SHIPS USING GASES
OR OTHER LOW-FLASHPOINT FUELS (IGF CODE)**

THE MARITIME SAFETY COMMITTEE,

RECALLING Article 28(b) of the Convention on the International Maritime Organization concerning the function of the Committee,

RECOGNIZING the need for a mandatory code for ships using gases or other low-flashpoint fuels,

NOTING resolution MSC.392(95), by which it adopted, *inter alia*, amendments to chapters II-1, II-2 and the appendix to the annex of the International Convention for the Safety of Life at Sea, 1974 ("the Convention"), to make the provisions of the International Code of Safety for Ships using Gases or other Low-flashpoint Fuels (IGF Code) mandatory under the Convention,

HAVING CONSIDERED, at its ninety-fifth session, the draft International Code of Safety for Ships using Gases or other Low-flashpoint Fuels,

1 ADOPTS the IGF Code, the text of which is set out in the annex to the present resolution;

2 INVITES Contracting Governments to the Convention to note that the IGF Code will take effect on 1 January 2017 upon entry into force of amendments to chapters II-1, II-2 and the appendix to the annex of the Convention;

3 INVITES ALSO Contracting Governments to consider the voluntary application of the IGF Code, as far as practicable, to cargo ships of less than 500 gross tonnage using gases or other low-flashpoint fuels;

4 RECOGNIZES that requirements for additional low-flashpoint fuels will be added to the IGF Code, as and when they are developed by the Organization;

5 REQUESTS the Secretary-General of the Organization to transmit certified copies of the present resolution and the text of the IGF Code, contained in the annex, to all Contracting Governments to the Convention;

6 REQUESTS ALSO the Secretary-General of the Organization to transmit copies of the present resolution and the text of the IGF Code contained in the annex to all Members of the Organization which are not Contracting Governments to the Convention.

ANNEX**INTERNATIONAL CODE OF SAFETY FOR SHIPS USING GASES
OR OTHER LOW-FLASHPOINT FUELS (IGF CODE)****CONTENTS****1 PREAMBLE****PART A****2 GENERAL****2.1 Application****2.2 Definitions****2.3 Alternative design****3 GOAL AND FUNCTIONAL REQUIREMENTS****3.1 Goal****3.2 Functional requirements****4 GENERAL REQUIREMENTS****4.1 Goal****4.2 Risk assessment****4.3 Limitation of explosion consequences****PART A-1****SPECIFIC REQUIREMENTS FOR SHIPS USING NATURAL GAS AS FUEL****5 SHIP DESIGN AND ARRANGEMENT****5.1 Goal****5.2 Functional requirements****5.3 Regulations – General****5.4 Machinery space concepts****5.5 Regulations for gas safe machinery space****5.6 Regulations for ESD-protected machinery spaces****5.7 Regulations for location and protection of fuel piping****5.8 Regulations for fuel preparation room design****5.9 Regulations for bilge systems****5.10 Regulations for drip trays****5.11 Regulations for arrangement of entrances and other openings in enclosed spaces****5.12 Regulations for airlocks****6 FUEL CONTAINMENT SYSTEM****6.1 Goal****6.2 Functional requirements****6.3 Regulations – General**

- 6.4 Regulations for liquefied gas fuel containment
- 6.5 Regulations for portable liquefied gas fuel tanks
- 6.6 Regulations for CNG fuel containment
- 6.7 Regulations for pressure relief system
- 6.8 Regulations on loading limit for liquefied gas fuel tanks
- 6.9 Regulations for the maintaining of fuel storage condition
- 6.10 Regulations on atmospheric control within the fuel containment system
- 6.11 Regulations on atmosphere control within fuel storage hold spaces
(Fuel containment systems other than type C independent tanks)
- 6.12 Regulations on environmental control of spaces surrounding type C
independent tanks
- 6.13 Regulations on inerting
- 6.14 Regulations on inert gas production and storage on board
- 7 MATERIAL AND GENERAL PIPE DESIGN
 - 7.1 Goal
 - 7.2 Functional requirements
 - 7.3 Regulations for general pipe design
 - 7.4 Regulations for materials
- 8 BUNKERING
 - 8.1 Goal
 - 8.2 Functional requirements
 - 8.3 Regulations for bunkering station
 - 8.4 Regulations for manifold
 - 8.5 Regulations for bunkering system
- 9 FUEL SUPPLY TO CONSUMERS
 - 9.1 Goal
 - 9.2 Functional requirements
 - 9.3 Regulations on redundancy of fuel supply
 - 9.4 Regulations on safety functions of gas supply system
 - 9.5 Regulations for fuel distribution outside of machinery space
 - 9.6 Regulations for fuel supply to consumers in gas-safe machinery spaces
 - 9.7 Regulations for gas fuel supply to consumers in ESD-protected machinery
spaces
 - 9.8 Regulations for the design of ventilated duct, outer pipe against inner pipe
gas leakage
 - 9.9 Regulations for compressors and pumps

- 10 POWER GENERATION INCLUDING PROPULSION AND OTHER GAS CONSUMERS**
 - 10.1 Goal
 - 10.2 Functional requirements
 - 10.3 Regulations for internal combustion engines of piston type
 - 10.4 Regulations for main and auxiliary boilers
 - 10.5 Regulations for gas turbines
- 11 FIRE SAFETY**
 - 11.1 Goal
 - 11.2 Functional requirements
 - 11.3 Regulations for fire protection
 - 11.4 Regulations for fire main
 - 11.5 Regulations for water spray system
 - 11.6 Regulations for dry chemical powder fire-extinguishing system
 - 11.7 Regulations for fire detection and alarm system
- 12 EXPLOSION PREVENTION**
 - 12.1 Goal
 - 12.2 Functional requirements
 - 12.3 Regulations – General
 - 12.4 Regulations on area classification
 - 12.5 Hazardous area zones
- 13 VENTILATION**
 - 13.1 Goal
 - 13.2 Functional requirements
 - 13.3 Regulations – General
 - 13.4 Regulations for tank connection space
 - 13.5 Regulations for machinery spaces
 - 13.6 Regulations for fuel preparation room
 - 13.7 Regulations for bunkering station
 - 13.8 Regulations for ducts and double pipes
- 14 ELECTRICAL INSTALLATIONS**
 - 14.1 Goal
 - 14.2 Functional requirements
 - 14.3 Regulations – General
- 15 CONTROL, MONITORING AND SAFETY SYSTEMS**
 - 15.1 Goal
 - 15.2 Functional requirements
 - 15.3 Regulations – General

15.4 Regulations for bunkering and liquefied gas fuel tank monitoring

15.5 Regulations for bunkering control

15.6 Regulations for gas compressor monitoring

15.7 Regulations for gas engine monitoring

15.8 Regulations for gas detection

15.9 Regulations for fire detection

15.10 Regulations for ventilation

15.11 Regulations on safety functions of fuel supply systems

**ANNEX: STANDARD FOR THE USE OF LIMIT STATE METHODOLOGIES IN THE
DESIGN OF FUEL CONTAINMENT SYSTEMS OF NOVEL CONFIGURATION**

PART B-1

16 MANUFACTURE, WORKMANSHIP AND TESTING

16.1 General

16.2 General test regulations and specifications

16.3 Welding of metallic materials and non-destructive testing for the fuel
containment system

16.4 Other regulations for construction in metallic materials

16.5 Testing

16.6 Welding, post-weld heat treatment and non-destructive testing

16.7 Testing regulations

PART C-1

17 DRILLS AND EMERGENCY EXERCISES

18 OPERATION

18.1 Goal

18.2 Functional requirements

18.3 Regulations for maintenance

18.4 Regulations for bunkering operations

18.5 Regulations for enclosed space entry

18.6 Regulations for inerting and purging of fuel systems

18.7 Regulations for hot work on or near fuel systems

ANNEX: LNG-BUNKER DELIVERY NOTE

PART D

19 TRAINING

19.1 Goal

19.2 Functional requirements

1 PREAMBLE

The purpose of this Code is to provide an international standard for ships using low-flashpoint fuel, other than ships covered by the IGC Code.

The basic philosophy of this Code is to provide mandatory provisions for the arrangement, installation, control and monitoring of machinery, equipment and systems using low-flashpoint fuel to minimize the risk to the ship, its crew and the environment, having regard to the nature of the fuels involved.

Throughout the development of this Code it was recognized that it must be based upon sound naval architectural and engineering principles and the best understanding available of current operational experience, field data and research and development. Due to the rapidly evolving new fuels technology, the Organization will periodically review this Code, taking into account both experience and technical developments.

This Code addresses all areas that need special consideration for the usage of the low-flashpoint fuel. The basic philosophy of the IGF Code considers the goal based approach (MSC.1/Circ.1394). Therefore, goals and functional requirements were specified for each section forming the basis for the design, construction and operation.

The current version of this Code includes regulations to meet the functional requirements for natural gas fuel. Regulations for other low-flashpoint fuels will be added to this Code as, and when, they are developed by the Organization.

In the meantime, for other low-flashpoint fuels, compliance with the functional requirements of this Code must be demonstrated through alternative design.

PART A

2 GENERAL

2.1 Application

Unless expressly provided otherwise this Code applies to ships to which part G of SOLAS chapter II-1 applies.

2.2 Definitions

Unless otherwise stated below, definitions are as defined in SOLAS chapter II-2.

2.2.1 *Accident* means an uncontrolled event that may entail the loss of human life, personal injuries, environmental damage or the loss of assets and financial interests.

2.2.2 *Breadth (B)* means the greatest moulded breadth of the ship at or below the deepest draught (summer load line draught) (refer to SOLAS regulation II-1/2.8).

2.2.3 *Bunkering* means the transfer of liquid or gaseous fuel from land based or floating facilities into a ships' permanent tanks or connection of portable tanks to the fuel supply system.

2.2.4 *Certified safe type* means electrical equipment that is certified safe by the relevant authorities recognized by the Administration for operation in a flammable atmosphere based on a recognized standard.

2.2.5 *CNG* means compressed natural gas (see also 2.2.26).

2.2.6 *Control station* means those spaces defined in SOLAS chapter II-2 and additionally for this Code, the engine control room.

2.2.7 *Design temperature* for selection of materials is the minimum temperature at which liquefied gas fuel may be loaded or transported in the liquefied gas fuel tanks.

2.2.8 *Design vapour pressure " P_0 "* is the maximum gauge pressure, at the top of the tank, to be used in the design of the tank.

2.2.9 *Double block and bleed valve* means a set of two valves in series in a pipe and a third valve enabling the pressure release from the pipe between those two valves. The arrangement may also consist of a two-way valve and a closing valve instead of three separate valves.

2.2.10 *Dual fuel engines* means engines that employ fuel covered by this Code (with pilot fuel) and oil fuel. Oil fuels may include distillate and residual fuels.

2.2.11 *Enclosed space* means any space within which, in the absence of artificial ventilation, the ventilation will be limited and any explosive atmosphere will not be dispersed naturally.

2.2.12 *ESD* means emergency shutdown.

2.2.13 *Explosion* means a deflagration event of uncontrolled combustion.

2.2.14 *Explosion pressure relief* means measures provided to prevent the explosion pressure in a container or an enclosed space exceeding the maximum overpressure the container or space is designed for, by releasing the overpressure through designated openings.

2.2.15 *Fuel containment system* is the arrangement for the storage of fuel including tank connections. It includes where fitted, a primary and secondary barrier, associated insulation and any intervening spaces, and adjacent structure if necessary for the support of these elements. If the secondary barrier is part of the hull structure it may be a boundary of the fuel storage hold space.

The spaces around the fuel tank are defined as follows:

- .1 *Fuel storage hold space* is the space enclosed by the ship's structure in which a fuel containment system is situated. If tank connections are located in the fuel storage hold space, it will also be a tank connection space;
- .2 *Interbarrier space* is the space between a primary and a secondary barrier, whether or not completely or partially occupied by insulation or other material; and
- .3 *Tank connection space* is a space surrounding all tank connections and tank valves that is required for tanks with such connections in enclosed spaces.

2.2.16 *Filling limit (FL)* means the maximum liquid volume in a fuel tank relative to the total tank volume when the liquid fuel has reached the reference temperature.

2.2.17 *Fuel preparation room* means any space containing pumps, compressors and/or vaporizers for fuel preparation purposes.

2.2.18 *Gas* means a fluid having a vapour pressure exceeding 0.28 MPa absolute at a temperature of 37.8°C.

2.2.19 *Gas consumer* means any unit within the ship using gas as a fuel.

2.2.20 *Gas only engine* means an engine capable of operating only on gas, and not able to switch over to operation on any other type of fuel.

2.2.21 *Hazardous area* means an area in which an explosive gas atmosphere is or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of equipment.

2.2.22 *High pressure* means a maximum working pressure greater than 1.0 MPa.

2.2.23 *Independent tanks* are self-supporting, do not form part of the ship's hull and are not essential to the hull strength.

2.2.24 *LEL* means the lower explosive limit.

2.2.25 *Length (L)* is the length as defined in the International Convention on Load Lines in force.

2.2.26 *LNG* means liquefied natural gas.

2.2.27 *Loading limit (LL)* means the maximum allowable liquid volume relative to the tank volume to which the tank may be loaded.

2.2.28 *Low-flashpoint fuel* means gaseous or liquid fuel having a flashpoint lower than otherwise permitted under paragraph 2.1.1 of SOLAS regulation II-2/4.

2.2.29 *MARVS* means the maximum allowable relief valve setting.

2.2.30 *MAWP* means the maximum allowable working pressure of a system component or tank.

2.2.31 *Membrane tanks* are non-self-supporting tanks that consist of a thin liquid and gas tight layer (membrane) supported through insulation by the adjacent hull structure.

2.2.32 *Multi-fuel engines* means engines that can use two or more different fuels that are separate from each other.

2.2.33 *Non-hazardous area* means an area in which an explosive gas atmosphere is not expected to be present in quantities such as to require special precautions for the construction, installation and use of equipment.

2.2.34 *Open deck* means a deck having no significant fire risk that at least is open on both ends/sides, or is open on one end and is provided with adequate natural ventilation that is effective over the entire length of the deck through permanent openings distributed in the side plating or deckhead.

2.2.35 *Risk* is an expression for the combination of the likelihood and the severity of the consequences.

2.2.36 *Reference temperature* means the temperature corresponding to the vapour pressure of the fuel in a fuel tank at the set pressure of the pressure relief valves (PRVs).

2.2.37 *Secondary barrier* is the liquid-resisting outer element of a fuel containment system designed to afford temporary containment of any envisaged leakage of liquid fuel through the primary barrier and to prevent the lowering of the temperature of the ship's structure to an unsafe level.

2.2.38 *Semi-enclosed space* means a space where the natural conditions of ventilation are notably different from those on open deck due to the presence of structure such as roofs, windbreaks and bulkheads and which are so arranged that dispersion of gas may not occur.

2.2.39 *Source of release* means a point or location from which a gas, vapour, mist or liquid may be released into the atmosphere so that an explosive atmosphere could be formed.

2.2.40 *Unacceptable loss of power* means that it is not possible to sustain or restore normal operation of the propulsion machinery in the event of one of the essential auxiliaries becoming inoperative, in accordance with SOLAS regulation II-1/26.3.

2.2.41 *Vapour pressure* is the equilibrium pressure of the saturated vapour above the liquid, expressed in MPa absolute at a specified temperature.

2.3 Alternative design

2.3.1 This Code contains functional requirements for all appliances and arrangements related to the usage of low-flashpoint fuels.

2.3.2 Fuels, appliances and arrangements of low-flashpoint fuel systems may either:

- .1 deviate from those set out in this Code, or
- .2 be designed for use of a fuel not specifically addressed in this Code.

Such fuels, appliances and arrangements can be used provided that these meet the intent of the goal and functional requirements concerned and provide an equivalent level of safety of the relevant chapters.

2.3.3 The equivalence of the alternative design shall be demonstrated as specified in SOLAS regulation II-1/55 and approved by the Administration. However, the Administration shall not allow operational methods or procedures to be applied as an alternative to a particular fitting, material, appliance, apparatus, item of equipment, or type thereof which is prescribed by this Code.

3 GOAL AND FUNCTIONAL REQUIREMENTS

3.1 Goal

The goal of this Code is to provide for safe and environmentally-friendly design, construction and operation of ships and in particular their installations of systems for propulsion machinery, auxiliary power generation machinery and/or other purpose machinery using gas or low-flashpoint fuel as fuel.

3.2 Functional requirements

3.2.1 The safety, reliability and dependability of the systems shall be equivalent to that achieved with new and comparable conventional oil-fuelled main and auxiliary machinery.

3.2.2 The probability and consequences of fuel-related hazards shall be limited to a minimum through arrangement and system design, such as ventilation, detection and safety actions. In the event of gas leakage or failure of the risk reducing measures, necessary safety actions shall be initiated.

3.2.3 The design philosophy shall ensure that risk reducing measures and safety actions for the gas fuel installation do not lead to an unacceptable loss of power.

3.2.4 Hazardous areas shall be restricted, as far as practicable, to minimize the potential risks that might affect the safety of the ship, persons on board, and equipment.

3.2.5 Equipment installed in hazardous areas shall be minimized to that required for operational purposes and shall be suitably and appropriately certified.

3.2.6 Unintended accumulation of explosive, flammable or toxic gas concentrations shall be prevented.

3.2.7 System components shall be protected against external damages.

3.2.8 Sources of ignition in hazardous areas shall be minimized to reduce the probability of explosions.

3.2.9 It shall be arranged for safe and suitable fuel supply, storage and bunkering arrangements capable of receiving and containing the fuel in the required state without leakage. Other than when necessary for safety reasons, the system shall be designed to prevent venting under all normal operating conditions including idle periods.

3.2.10 Piping systems, containment and over-pressure relief arrangements that are of suitable design, construction and installation for their intended application shall be provided.

3.2.11 Machinery, systems and components shall be designed, constructed, installed, operated, maintained and protected to ensure safe and reliable operation.

3.2.12 Fuel containment system and machinery spaces containing source that might release gas into the space shall be arranged and located such that a fire or explosion in either will not lead to an unacceptable loss of power or render equipment in other compartments inoperable.

3.2.13 Suitable control, alarm, monitoring and shutdown systems shall be provided to ensure safe and reliable operation.

3.2.14 Fixed gas detection suitable for all spaces and areas concerned shall be arranged.

3.2.15 Fire detection, protection and extinction measures appropriate to the hazards concerned shall be provided.

3.2.16 Commissioning, trials and maintenance of fuel systems and gas utilization machinery shall satisfy the goal in terms of safety, availability and reliability.

3.2.17 The technical documentation shall permit an assessment of the compliance of the system and its components with the applicable rules, guidelines, design standards used and the principles related to safety, availability, maintainability and reliability.

3.2.18 A single failure in a technical system or component shall not lead to an unsafe or unreliable situation.

4 GENERAL REQUIREMENTS

4.1 Goal

The goal of this chapter is to ensure that the necessary assessments of the risks involved are carried out in order to eliminate or mitigate any adverse effect to the persons on board, the environment or the ship.

4.2 Risk assessment

4.2.1 A risk assessment shall be conducted to ensure that risks arising from the use of low-flashpoint fuels affecting persons on board, the environment, the structural strength or the integrity of the ship are addressed. Consideration shall be given to the hazards associated with physical layout, operation and maintenance, following any reasonably foreseeable failure.

4.2.2 For ships to which part A-1 applies, the risk assessment required by 4.2.1 need only be conducted where explicitly required by paragraphs 5.10.5, 5.12.3, 6.4.1.1, 6.4.15.4.7.2, 8.3.1.1, 13.4.1, 13.7 and 15.8.1.10 as well as by paragraphs 4.4 and 6.8 of the annex.

4.2.3 The risks shall be analysed using acceptable and recognized risk analysis techniques, and loss of function, component damage, fire, explosion and electric shock shall as a minimum be considered. The analysis shall ensure that risks are eliminated wherever possible. Risks which cannot be eliminated shall be mitigated as necessary. Details of risks, and the means by which they are mitigated, shall be documented to the satisfaction of the Administration.

4.3 Limitation of explosion consequences

An explosion in any space containing any potential sources of release and potential ignition sources shall not:

- .1 cause damage to or disrupt the proper functioning of equipment/systems located in any space other than that in which the incident occurs;
- .2 damage the ship in such a way that flooding of water below the main deck or any progressive flooding occur;
- .3 damage work areas or accommodation in such a way that persons who stay in such areas under normal operating conditions are injured;
- .4 disrupt the proper functioning of control stations and switchboard rooms necessary for power distribution;
- .5 damage life-saving equipment or associated launching arrangements;
- .6 disrupt the proper functioning of firefighting equipment located outside the explosion-damaged space;
- .7 affect other areas of the ship in such a way that chain reactions involving, inter alia, cargo, gas and bunker oil may arise; or
- .8 prevent persons access to life-saving appliances or impede escape routes.

PART A-1

SPECIFIC REQUIREMENTS FOR SHIPS USING NATURAL GAS AS FUEL

Fuel in the context of the regulations in this part means natural gas, either in its liquefied or gaseous state.

It should be recognized that the composition of natural gas may vary depending on the source of natural gas and the processing of the gas.

5 SHIP DESIGN AND ARRANGEMENT

5.1 Goal

The goal of this chapter is to provide for safe location, space arrangements and mechanical protection of power generation equipment, fuel storage systems, fuel supply equipment and refuelling systems.

5.2 Functional requirements

5.2.1 This chapter is related to functional requirements in 3.2.1 to 3.2.3, 3.2.5, 3.2.6, 3.2.8, 3.2.12 to 3.2.15 and 3.2.17. In particular the following apply:

- .1 the fuel tank(s) shall be located in such a way that the probability for the tank(s) to be damaged following a collision or grounding is reduced to a minimum taking into account the safe operation of the ship and other hazards that may be relevant to the ship;
- .2 fuel containment systems, fuel piping and other fuel sources of release shall be so located and arranged that released gas is led to a safe location in the open air;
- .3 the access or other openings to spaces containing fuel sources of release shall be so arranged that flammable, asphyxiating or toxic gas cannot escape to spaces that are not designed for the presence of such gases
- .4 fuel piping shall be protected against mechanical damage;
- .5 the propulsion and fuel supply system shall be so designed that safety actions after any gas leakage do not lead to an unacceptable loss of power; and
- .6 the probability of a gas explosion in a machinery space with gas or low-flashpoint fuelled machinery shall be minimized.

5.3 Regulations – General

5.3.1 Fuel storage tanks shall be protected against mechanical damage.

5.3.2 Fuel storage tanks and or equipment located on open deck shall be located to ensure sufficient natural ventilation, so as to prevent accumulation of escaped gas.

5.3.3 The fuel tank(s) shall be protected from external damage caused by collision or grounding in the following way:

- .1 The fuel tanks shall be located at a minimum distance of $B/5$ or 11.5 m, whichever is less, measured inboard from the ship side at right angles to the centreline at the level of the summer load line draught;

where:

B is the greatest moulded breadth of the ship at or below the deepest draught (summer load line draught) (refer to SOLAS regulation II-1/2.8).

- .2 The boundaries of each fuel tank shall be taken as the extreme outer longitudinal, transverse and vertical limits of the tank structure including its tank valves.

- .3 For independent tanks the protective distance shall be measured to the tank shell (the primary barrier of the tank containment system). For membrane tanks the distance shall be measured to the bulkheads surrounding the tank insulation.

- .4 In no case shall the boundary of the fuel tank be located closer to the shell plating or aft terminal of the ship than as follows:

- .1 For passenger ships: $B/10$ but in no case less than 0.8 m. However, this distance need not be greater than $B/15$ or 2 m whichever is less where the shell plating is located inboard of $B/5$ or 11.5 m, whichever is less, as required by 5.3.3.1.

- .2 For cargo ships:

- .1 for V_c below or equal 1,000 m³, 0.8 m;
- .2 for $1,000 \text{ m}^3 < V_c < 5,000 \text{ m}^3$, $0.75 + V_c \times 0.2/4,000$ m;
- .3 for $5,000 \text{ m}^3 \leq V_c < 30,000 \text{ m}^3$, $0.8 + V_c/25,000$ m; and
- .4 for $V_c \geq 30,000 \text{ m}^3$, 2 m,

where:

V_c corresponds to 100% of the gross design volume of the individual fuel tank at 20°C, including domes and appendages.

- .5 The lowermost boundary of the fuel tank(s) shall be located above the minimum distance of $B/15$ or 2.0 m, whichever is less, measured from the moulded line of the bottom shell plating at the centreline.
- .6 For multihull ships the value of B may be specially considered.
- .7 The fuel tank(s) shall be abaft a transverse plane at 0.08L measured from the forward perpendicular in accordance with SOLAS regulation II-1/8.1 for passenger ships, and abaft the collision bulkhead for cargo ships.

where:

L is the length as defined in the International Convention on Load Lines (refer to SOLAS regulation II-1/2.5).

- .8 For ships with a hull structure providing higher collision and/or grounding resistance, fuel tank location regulations may be specially considered in accordance with section 2.3.

5.3.4 As an alternative to 5.3.3.1 above, the following calculation method may be used to determine the acceptable location of the fuel tanks:

- .1 The value f_{CN} calculated as described in the following shall be less than 0.02 for passenger ships and 0.04 for cargo ships.
- .2 The f_{CN} is calculated by the following formulation:

$$f_{CN} = f_l \times f_t \times f_v$$

where:

f_l is calculated by use of the formulations for factor p contained in SOLAS regulation II-1/7-1.1.1.1. The value of x1 shall correspond to the distance from the aft terminal to the aftmost boundary of the fuel tank and the value of x 2 shall correspond to the distance from the aft terminal to the foremost boundary of the fuel tank.

f_t is calculated by use of the formulations for factor r contained in SOLAS regulation II-1/7-1.1.2, and reflects the probability that the damage penetrates beyond the outer boundary of the fuel tank. The formulation is:

$$f_t = 1 - r(x1, x2, b)$$

f_v is calculated by use of the formulations for factor v contained in SOLAS regulation II-1/7-2.6.1.1 and reflects the probability that the damage is not extending vertically above the lowermost boundary of the fuel tank. The formulations to be used are:

$$f_v = 1.0 - 0.8 \cdot ((H - d)/7.8), \text{ if } (H - d) \text{ is less than or equal to } 7.8 \text{ m. } f_v \text{ shall not be taken greater than } 1.$$

$$f_v = 0.2 - (0.2 \cdot ((H - d) - 7.8)/4.7), \text{ in all other cases } f_v \text{ shall not be taken less than } 0.$$

where:

H is the distance from baseline, in metres, to the lowermost boundary of the fuel tank; and

d is the deepest draught (summer load line draught).

- .3 The boundaries of each fuel tank shall be taken as the extreme outer longitudinal, transverse and vertical limits of the tank structure including its tank valves.

- .4 For independent tanks the protective distance shall be measured to the tank shell (the primary barrier of the tank containment system). For membrane tanks the distance shall be measured to the bulkheads surrounding the tank insulation.
 - .5 In no case shall the boundary of the fuel tank be located closer to the shell plating or aft terminal of the ship than as follows:
 - .1 For passenger ships: $B/10$ but in no case less than 0.8 m. However, this distance need not be greater than $B/15$ or 2 m whichever is less where the shell plating is located inboard of $B/5$ or 11.5 m, whichever is less, as required by 5.3.3.1.
 - .2 For cargo ships:
 - .1 for V_c below or equal 1,000 m³, 0.8 m;
 - .2 for $1,000 \text{ m}^3 < V_c < 5,000 \text{ m}^3$, $0.75 + V_c \times 0.2/4,000$ m;
 - .3 for $5,000 \text{ m}^3 \leq V_c < 30,000 \text{ m}^3$, $0.8 + V_c/25,000$ m; and
 - .4 for $V_c \geq 30,000 \text{ m}^3$, 2 m,
- where:
- V_c corresponds to 100% of the gross design volume of the individual fuel tank at 20°C, including domes and appendages.
- .6 In case of more than one non-overlapping fuel tank located in the longitudinal direction, f_{CN} shall be calculated in accordance with paragraph 5.3.4.2 for each fuel tank separately. The value used for the complete fuel tank arrangement is the sum of all values for f_{CN} obtained for each separate tank.
 - .7 In case the fuel tank arrangement is unsymmetrical about the centreline of the ship, the calculations of f_{CN} shall be calculated on both starboard and port side and the average value shall be used for the assessment. The minimum distance as set forth in paragraph 5.3.4.5 shall be met on both sides.
 - .8 For ships with a hull structure providing higher collision and/or grounding resistance, fuel tank location regulations may be specially considered in accordance with section 2.3.

5.3.5 When fuel is carried in a fuel containment system requiring a complete or partial secondary barrier:

- .1 fuel storage hold spaces shall be segregated from the sea by a double bottom; and
- .2 the ship shall also have a longitudinal bulkhead forming side tanks.

5.4 Machinery space concepts

5.4.1 In order to minimize the probability of a gas explosion in a machinery space with gas-fuelled machinery one of these two alternative concepts may be applied:

- .1 Gas safe machinery spaces: Arrangements in machinery spaces are such that the spaces are considered gas safe under all conditions, normal as well as abnormal conditions, i.e. inherently gas safe.

In a gas safe machinery space a single failure cannot lead to release of fuel gas into the machinery space.

- .2 ESD-protected machinery spaces: Arrangements in machinery spaces are such that the spaces are considered non-hazardous under normal conditions, but under certain abnormal conditions may have the potential to become hazardous. In the event of abnormal conditions involving gas hazards, emergency shutdown (ESD) of non-safe equipment (ignition sources) and machinery shall be automatically executed while equipment or machinery in use or active during these conditions shall be of a certified safe type.

In an ESD protected machinery space a single failure may result in a gas release into the space. Venting is designed to accommodate a probable maximum leakage scenario due to technical failures.

Failures leading to dangerous gas concentrations, e.g. gas pipe ruptures or blow out of gaskets are covered by explosion pressure relief devices and ESD arrangements.

5.5 Regulations for gas safe machinery space

5.5.1 A single failure within the fuel system shall not lead to a gas release into the machinery space.

5.5.2 All fuel piping within machinery space boundaries shall be enclosed in a gas tight enclosure in accordance with 9.6.

5.6 Regulations for ESD-protected machinery spaces

5.6.1 ESD protection shall be limited to machinery spaces that are certified for periodically unattended operation.

5.6.2 Measures shall be applied to protect against explosion, damage of areas outside of the machinery space and ensure redundancy of power supply. The following arrangement shall be provided but may not be limited to:

- .1 gas detector;
- .2 shutoff valve;
- .3 redundancy; and
- .4 efficient ventilation.

5.6.3 Gas supply piping within machinery spaces may be accepted without a gastight external enclosure on the following conditions:

- .1 Engines for generating propulsion power and electric power shall be located in two or more machinery spaces not having any common boundaries unless it can be documented that a single casualty will not affect both spaces.
- .2 The gas machinery space shall contain only a minimum of such necessary equipment, components and systems as are required to ensure that the gas machinery maintains its function.
- .3 A fixed gas detection system arranged to automatically shutdown the gas supply, and disconnect all electrical equipment or installations not of a certified safe type, shall be fitted.

5.6.4 Distribution of engines between the different machinery spaces shall be such that shutdown of fuel supply to any one machinery space does not lead to an unacceptable loss of power.

5.6.5 ESD protected machinery spaces separated by a single bulkhead shall have sufficient strength to withstand the effects of a local gas explosion in either space, without affecting the integrity of the adjacent space and equipment within that space.

5.6.6 ESD protected machinery spaces shall be designed to provide a geometrical shape that will minimize the accumulation of gases or formation of gas pockets.

5.6.7 The ventilation system of ESD-protected machinery spaces shall be arranged in accordance with 13.5.

5.7 Regulations for location and protection of fuel piping

5.7.1 Fuel pipes shall not be located less than 800 mm from the ship's side.

5.7.2 Fuel piping shall not be led directly through accommodation spaces, service spaces, electrical equipment rooms or control stations as defined in the SOLAS Convention.

5.7.3 Fuel pipes led through ro-ro spaces, special category spaces and on open decks shall be protected against mechanical damage.

5.7.4 Gas fuel piping in ESD protected machinery spaces shall be located as far as practicable from the electrical installations and tanks containing flammable liquids.

5.7.5 Gas fuel piping in ESD protected machinery spaces shall be protected against mechanical damage.

5.8 Regulations for fuel preparation room design

Fuel preparation rooms shall be located on an open deck, unless those rooms are arranged and fitted in accordance with the regulations of this Code for tank connection spaces.

5.9 Regulations for bilge systems

5.9.1 Bilge systems installed in areas where fuel covered by this Code can be present shall be segregated from the bilge system of spaces where fuel cannot be present.

5.9.2 Where fuel is carried in a fuel containment system requiring a secondary barrier, suitable drainage arrangements for dealing with any leakage into the hold or insulation spaces through the adjacent ship structure shall be provided. The bilge system shall not lead to pumps in safe spaces. Means of detecting such leakage shall be provided.

5.9.3 The hold or interbarrier spaces of type A independent tanks for liquid gas shall be provided with a drainage system suitable for handling liquid fuel in the event of fuel tank leakage or rupture.

5.10 Regulations for drip trays

5.10.1 Drip trays shall be fitted where leakage may occur which can cause damage to the ship structure or where limitation of the area which is effected from a spill is necessary.

5.10.2 Drip trays shall be made of suitable material.

5.10.3 The drip tray shall be thermally insulated from the ship's structure so that the surrounding hull or deck structures are not exposed to unacceptable cooling, in case of leakage of liquid fuel.

5.10.4 Each tray shall be fitted with a drain valve to enable rain water to be drained over the ship's side.

5.10.5 Each tray shall have a sufficient capacity to ensure that the maximum amount of spill according to the risk assessment can be handled.

5.11 Regulations for arrangement of entrances and other openings in enclosed spaces

5.11.1 Direct access shall not be permitted from a non-hazardous area to a hazardous area. Where such openings are necessary for operational reasons, an airlock which complies with 5.12 shall be provided.

5.11.2 If the fuel preparation room is approved located below deck, the room shall, as far as practicable, have an independent access direct from the open deck. Where a separate access from deck is not practicable, an airlock which complies with 5.12 shall be provided.

5.11.3 Unless access to the tank connection space is independent and direct from open deck it shall be arranged as a bolted hatch. The space containing the bolted hatch will be a hazardous space.

5.11.4 If the access to an ESD-protected machinery space is from another enclosed space in the ship, the entrances shall be arranged with an airlock which complies with 5.12.

5.11.5 For inerted spaces access arrangements shall be such that unintended entry by personnel shall be prevented. If access to such spaces is not from an open deck, sealing arrangements shall ensure that leakages of inert gas to adjacent spaces are prevented.

5.12 Regulations for airlocks

5.12.1 An airlock is a space enclosed by gastight bulkheads with two substantially gastight doors spaced at least 1.5 m and not more than 2.5 m apart. Unless subject to the requirements of the International Convention on Load Lines, the door sill shall not be less than 300 mm in height. The doors shall be self-closing without any holding back arrangements.

5.12.2 Airlocks shall be mechanically ventilated at an overpressure relative to the adjacent hazardous area or space.

5.12.3 The airlock shall be designed in a way that no gas can be released to safe spaces in case of the most critical event in the gas dangerous space separated by the airlock. The events shall be evaluated in the risk analysis according to 4.2.

5.12.4 Airlocks shall have a simple geometrical form. They shall provide free and easy passage, and shall have a deck area not less than 1.5 m². Airlocks shall not be used for other purposes, for instance as store rooms.

5.12.5 An audible and visual alarm system to give a warning on both sides of the airlock shall be provided to indicate if more than one door is moved from the closed position.

5.12.6 For non-hazardous spaces with access from hazardous spaces below deck where the access is protected by an airlock, upon loss of underpressure in the hazardous space access to the space is to be restricted until the ventilation has been reinstated. Audible and visual alarms shall be given at a manned location to indicate both loss of pressure and opening of the airlock doors when pressure is lost.

5.12.7 Essential equipment required for safety shall not be de-energized and shall be of a certified safe type. This may include lighting, fire detection, public address, general alarms systems.

6 FUEL CONTAINMENT SYSTEM

6.1 Goal

The goal of this chapter is to provide that gas storage is adequate so as to minimize the risk to personnel, the ship and the environment to a level that is equivalent to a conventional oil fuelled ship.

6.2 Functional requirements

This chapter relates to functional requirements in 3.2.1, 3.2.2, 3.2.5 and 3.2.8 to 3.2.17. In particular the following apply:

- .1 the fuel containment system shall be so designed that a leak from the tank or its connections does not endanger the ship, persons on board or the environment. Potential dangers to be avoided include:
 - .1 exposure of ship materials to temperatures below acceptable limits;
 - .2 flammable fuels spreading to locations with ignition sources;
 - .3 toxicity potential and risk of oxygen deficiency due to fuels and inert gases;
 - .4 restriction of access to muster stations, escape routes and life-saving appliances (LSA); and
 - .5 reduction in availability of LSA.
- .2 the pressure and temperature in the fuel tank shall be kept within the design limits of the containment system and possible carriage requirements of the fuel;

- .3 the fuel containment arrangement shall be so designed that safety actions after any gas leakage do not lead to an unacceptable loss of power; and
- .4 if portable tanks are used for fuel storage, the design of the fuel containment system shall be equivalent to permanent installed tanks as described in this chapter.

6.3 Regulations – General

6.3.1 Natural gas in a liquid state may be stored with a maximum allowable relief valve setting (MARVS) of up to 1.0 MPa.

6.3.2 The Maximum Allowable Working Pressure (MAWP) of the gas fuel tank shall not exceed 90% of the Maximum Allowable Relief Valve Setting (MARVS).

6.3.3 A fuel containment system located below deck shall be gas tight towards adjacent spaces.

6.3.4 All tank connections, fittings, flanges and tank valves must be enclosed in gas tight tank connection spaces, unless the tank connections are on open deck. The space shall be able to safely contain leakage from the tank in case of leakage from the tank connections.

6.3.5 Pipe connections to the fuel storage tank shall be mounted above the highest liquid level in the tanks, except for fuel storage tanks of type C. Connections below the highest liquid level may however also be accepted for other tank types after special consideration by the Administration.

6.3.6 Piping between the tank and the first valve which release liquid in case of pipe failure shall have equivalent safety as the type C tank, with dynamic stress not exceeding the values given in 6.4.15.3.1.2.

6.3.7 The material of the bulkheads of the tank connection space shall have a design temperature corresponding with the lowest temperature it can be subject to in a probable maximum leakage scenario. The tank connection space shall be designed to withstand the maximum pressure build up during such a leakage. Alternatively, pressure relief venting to a safe location (mast) can be provided.

6.3.8 The probable maximum leakage into the tank connection space shall be determined based on detail design, detection and shutdown systems.

6.3.9 If piping is connected below the liquid level of the tank it has to be protected by a secondary barrier up to the first valve.

6.3.10 If liquefied gas fuel storage tanks are located on open deck the ship steel shall be protected from potential leakages from tank connections and other sources of leakage by use of drip trays. The material is to have a design temperature corresponding to the temperature of the fuel carried at atmospheric pressure. The normal operation pressure of the tanks shall be taken into consideration for protecting the steel structure of the ship.

6.3.11 Means shall be provided whereby liquefied gas in the storage tanks can be safely emptied.

6.3.12 It shall be possible to empty, purge and vent fuel storage tanks with fuel piping systems. Instructions for carrying out these procedures must be available on board. Inerting shall be performed with an inert gas prior to venting with dry air to avoid an explosion hazardous atmosphere in tanks and fuel pipes. See detailed regulations in 6.10.

6.4 Regulations for liquefied gas fuel containment

6.4.1 General

6.4.1.1 The risk assessment required in 4.2 shall include evaluation of the ship's liquefied gas fuel containment system, and may lead to additional safety measures for integration into the overall vessel design.

6.4.1.2 The design life of fixed liquefied gas fuel containment system shall not be less than the design life of the ship or 20 years, whichever is greater.

6.4.1.3 The design life of portable tanks shall not be less than 20 years.

6.4.1.4 Liquefied gas fuel containment systems shall be designed in accordance with North Atlantic environmental conditions and relevant long-term sea state scatter diagrams for unrestricted navigation. Less demanding environmental conditions, consistent with the expected usage, may be accepted by the Administration for liquefied gas fuel containment systems used exclusively for restricted navigation. More demanding environmental conditions may be required for liquefied gas fuel containment systems operated in conditions more severe than the North Atlantic environment.

6.4.1.5 Liquefied gas fuel containment systems shall be designed with suitable safety margins:

- .1 to withstand, in the intact condition, the environmental conditions anticipated for the liquefied gas fuel containment system's design life and the loading conditions appropriate for them, which shall include full homogeneous and partial load conditions and partial filling to any intermediate levels; and
- .2 being appropriate for uncertainties in loads, structural modelling, fatigue, corrosion, thermal effects, material variability, aging and construction tolerances.

6.4.1.6 The liquefied gas fuel containment system structural strength shall be assessed against failure modes, including but not limited to plastic deformation, buckling and fatigue. The specific design conditions that shall be considered for the design of each liquefied gas fuel containment system are given in 6.4.15. There are three main categories of design conditions:

- .1 Ultimate Design Conditions – The liquefied gas fuel containment system structure and its structural components shall withstand loads liable to occur during its construction, testing and anticipated use in service, without loss of structural integrity. The design shall take into account proper combinations of the following loads:
 - .1 internal pressure;
 - .2 external pressure;
 - .3 dynamic loads due to the motion of the ship in all loading conditions;
 - .4 thermal loads;
 - .5 sloshing loads;
 - .6 loads corresponding to ship deflections;
 - .7 tank and liquefied gas fuel weight with the corresponding reaction in way of supports;

- .8 insulation weight;
 - .9 loads in way of towers and other attachments; and
 - .10 test loads.
- .2 Fatigue Design Conditions – The liquefied gas fuel containment system structure and its structural components shall not fail under accumulated cyclic loading.
- .3 Accidental Design Conditions – The liquefied gas fuel containment system shall meet each of the following accident design conditions (accidental or abnormal events), addressed in this Code:
- .1 Collision – The liquefied gas fuel containment system shall withstand the collision loads specified in 6.4.9.5.1 without deformation of the supports or the tank structure in way of the supports likely to endanger the tank and its supporting structure.
 - .2 Fire – The liquefied gas fuel containment systems shall sustain without rupture the rise in internal pressure specified in 6.7.3.1 under the fire scenarios envisaged therein.
 - .3 Flooded compartment causing buoyancy on tank – the anti-flotation arrangements shall sustain the upward force, specified in 6.4.9.5.2 and there shall be no endangering plastic deformation to the hull. Plastic deformation may occur in the fuel containment system provided it does not endanger the safe evacuation of the ship.

6.4.1.7 Measures shall be applied to ensure that scantlings required meet the structural strength provisions and are maintained throughout the design life. Measures may include, but are not limited to, material selection, coatings, corrosion additions, cathodic protection and inerting.

6.4.1.8 An inspection/survey plan for the liquefied gas fuel containment system shall be developed and approved by the Administration. The inspection/survey plan shall identify aspects to be examined and/or validated during surveys throughout the liquefied gas fuel containment system's life and, in particular, any necessary in-service survey, maintenance and testing that was assumed when selecting liquefied gas fuel containment system design parameters. The inspection/survey plan may include specific critical locations as per 6.4.12.2.8 or 6.4.12.2.9.

6.4.1.9 Liquefied gas fuel containment systems shall be designed, constructed and equipped to provide adequate means of access to areas that need inspection as specified in the inspection/survey plan. Liquefied gas fuel containment systems, including all associated internal equipment shall be designed and built to ensure safety during operations, inspection and maintenance.

6.4.2 Liquefied gas fuel containment safety principles

6.4.2.1 The containment systems shall be provided with a complete secondary liquid-tight barrier capable of safely containing all potential leakages through the primary barrier and, in conjunction with the thermal insulation system, of preventing lowering of the temperature of the ship structure to an unsafe level.

6.4.2.2 The size and configuration or arrangement of the secondary barrier may be reduced or omitted where an equivalent level of safety can be demonstrated in accordance with 6.4.2.3 to 6.4.2.5 as applicable.

6.4.2.3 Liquefied gas fuel containment systems for which the probability for structural failures to develop into a critical state has been determined to be extremely low but where the possibility of leakages through the primary barrier cannot be excluded, shall be equipped with a partial secondary barrier and small leak protection system capable of safely handling and disposing of the leakages (a critical state means that the crack develops into unstable condition).

The arrangements shall comply with the following:

- .1

failure developments that can be reliably detected before reaching a critical state (e.g. by gas detection or inspection) shall have a sufficiently long development time for remedial actions to be taken; and
- .2

failure developments that cannot be safely detected before reaching a critical state shall have a predicted development time that is much longer than the expected lifetime of the tank.

6.4.2.4 No secondary barrier is required for liquefied gas fuel containment systems, e.g. type C independent tanks, where the probability for structural failures and leakages through the primary barrier is extremely low and can be neglected.

6.4.2.5 For independent tanks requiring full or partial secondary barrier, means for safely disposing of leakages from the tank shall be arranged.

6.4.3 Secondary barriers in relation to tank types

Secondary barriers in relation to the tank types defined in 6.4.15 shall be provided in accordance with the following table.

Basic tank type	Secondary barrier requirements
Membrane	Complete secondary barrier
Independent	
Type A	Complete secondary barrier
Type B	Partial secondary barrier
Type C	No secondary barrier required

6.4.4 Design of secondary barriers

The design of the secondary barrier, including spray shield if fitted, shall be such that:

- .1

it is capable of containing any envisaged leakage of liquefied gas fuel for a period of 15 days unless different criteria apply for particular voyages, taking into account the load spectrum referred to in 6.4.12.2.6;
- .2

physical, mechanical or operational events within the liquefied gas fuel tank that could cause failure of the primary barrier shall not impair the due function of the secondary barrier, or vice versa;

- .3 failure of a support or an attachment to the hull structure will not lead to loss of liquid tightness of both the primary and secondary barriers;
- .4 it is capable of being periodically checked for its effectiveness by means of a visual inspection or other suitable means acceptable to the Administration;
- .5 the methods required in 6.4.4.4 shall be approved by the Administration and shall include, as a minimum:
 - .1 details on the size of defect acceptable and the location within the secondary barrier, before its liquid tight effectiveness is compromised;
 - .2 accuracy and range of values of the proposed method for detecting defects in .1 above;
 - .3 scaling factors to be used in determining the acceptance criteria if full-scale model testing is not undertaken; and
 - .4 effects of thermal and mechanical cyclic loading on the effectiveness of the proposed test.
- .6 the secondary barrier shall fulfil its functional requirements at a static angle of heel of 30°.

6.4.5 Partial secondary barriers and primary barrier small leak protection system

6.4.5.1 Partial secondary barriers as permitted in 6.4.2.3 shall be used with a small leak protection system and meet all the regulations in 6.4.4.

The small leak protection system shall include means to detect a leak in the primary barrier, provision such as a spray shield to deflect any liquefied gas fuel down into the partial secondary barrier, and means to dispose of the liquid, which may be by natural evaporation.

6.4.5.2 The capacity of the partial secondary barrier shall be determined, based on the liquefied gas fuel leakage corresponding to the extent of failure resulting from the load spectrum referred to in 6.4.12.2.6, after the initial detection of a primary leak. Due account may be taken of liquid evaporation, rate of leakage, pumping capacity and other relevant factors.

6.4.5.3 The required liquid leakage detection may be by means of liquid sensors, or by an effective use of pressure, temperature or gas detection systems, or any combination thereof.

6.4.5.4 For independent tanks for which the geometry does not present obvious locations for leakage to collect, the partial secondary barrier shall also fulfil its functional requirements at a nominal static angle of trim.

6.4.6 Supporting arrangements

6.4.6.1 The liquefied gas fuel tanks shall be supported by the hull in a manner that prevents bodily movement of the tank under the static and dynamic loads defined in 6.4.9.2 to 6.4.9.5, where applicable, while allowing contraction and expansion of the tank under temperature variations and hull deflections without undue stressing of the tank and the hull.

6.4.6.2 Anti-flotation arrangements shall be provided for independent tanks and capable of withstanding the loads defined in 6.4.9.5.2 without plastic deformation likely to endanger the hull structure.

6.4.6.3 Supports and supporting arrangements shall withstand the loads defined in 6.4.9.3.3.8 and 6.4.9.5, but these loads need not be combined with each other or with wave-induced loads.

6.4.7 Associated structure and equipment

6.4.7.1 Liquefied gas fuel containment systems shall be designed for the loads imposed by associated structure and equipment. This includes pump towers, liquefied gas fuel domes, liquefied gas fuel pumps and piping, stripping pumps and piping, nitrogen piping, access hatches, ladders, piping penetrations, liquid level gauges, independent level alarm gauges, spray nozzles, and instrumentation systems (such as pressure, temperature and strain gauges).

6.4.8 Thermal insulation

6.4.8.1 Thermal insulation shall be provided as required to protect the hull from temperatures below those allowable (see 6.4.13.1.1) and limit the heat flux into the tank to the levels that can be maintained by the pressure and temperature control system applied in 6.9.

6.4.9 Design loads

6.4.9.1 General

6.4.9.1.1 This section defines the design loads that shall be considered with regard to regulations in 6.4.10 to 6.4.12. This includes load categories (permanent, functional, environmental and accidental) and the description of the loads.

6.4.9.1.2 The extent to which these loads shall be considered depends on the type of tank, and is more fully detailed in the following paragraphs.

6.4.9.1.3 Tanks, together with their supporting structure and other fixtures, shall be designed taking into account relevant combinations of the loads described below.

6.4.9.2 Permanent loads

6.4.9.2.1 Gravity loads

The weight of tank, thermal insulation, loads caused by towers and other attachments shall be considered.

6.4.9.2.2 Permanent external loads

Gravity loads of structures and equipment acting externally on the tank shall be considered.

6.4.9.3 Functional loads

6.4.9.3.1 Loads arising from the operational use of the tank system shall be classified as functional loads.

6.4.9.3.2 All functional loads that are essential for ensuring the integrity of the tank system, during all design conditions, shall be considered.

6.4.9.3.3 As a minimum, the effects from the following criteria, as applicable, shall be considered when establishing functional loads:

- (a) internal pressure

- (b) external pressure
- (c) thermally induced loads
- (d) vibration
- (e) interaction loads
- (f) loads associated with construction and installation
- (g) test loads
- (h) static heel loads
- (i) weight of liquefied gas fuel
- (j) sloshing
- (k) wind impact, wave impacts and green sea effect for tanks installed on open deck.

6.4.9.3.3.1 Internal pressure

- .1 In all cases, including 6.4.9.3.3.1.2, P_0 shall not be less than MARVS.
- .2 For liquefied gas fuel tanks where there is no temperature control and where the pressure of the liquefied gas fuel is dictated only by the ambient temperature, P_0 shall not be less than the gauge vapour pressure of the liquefied gas fuel at a temperature of 45°C except as follows:
 - .1 Lower values of ambient temperature may be accepted by the Administration for ships operating in restricted areas. Conversely, higher values of ambient temperature may be required.
 - .2 For ships on voyages of restricted duration, P_0 may be calculated based on the actual pressure rise during the voyage and account may be taken of any thermal insulation of the tank.
- .3 Subject to special consideration by the Administration and to the limitations given in 6.4.15 for the various tank types, a vapour pressure P_h higher than P_0 may be accepted for site specific conditions (harbour or other locations), where dynamic loads are reduced.
- .4 Pressure used for determining the internal pressure shall be:
 - .1 $(P_{gd})_{max}$ is the associated liquid pressure determined using the maximum design accelerations.
 - .2 $(P_{gd\ site})_{max}$ is the associated liquid pressure determined using site specific accelerations.
 - .3 P_{eq} should be the greater of P_{eq1} and P_{eq2} calculated as follows:

$$P_{eq1} = P_0 + (P_{gd})_{max} \text{ (MPa),}$$

$$P_{eq2} = P_h + (P_{gd\ site})_{max} \text{ (MPa).}$$

- .5 The internal liquid pressures are those created by the resulting acceleration of the centre of gravity of the liquefied gas fuel due to the motions of the ship referred to in 6.4.9.4.1.1. The value of internal liquid pressure P_{gd} resulting from combined effects of gravity and dynamic accelerations shall be calculated as follows:

$$P_{gd} = \alpha_{\beta} Z_{\beta} (\rho / (1.02 \times 10^5)) \text{ (MPa)}$$

where:

α_{β} = dimensionless acceleration (i.e. relative to the acceleration of gravity), resulting from gravitational and dynamic loads, in an arbitrary direction β ; (see figure 6.4.1).

For large tanks, an acceleration ellipsoid, taking account of transverse vertical and longitudinal accelerations, should be used.

Z_{β} = largest liquid height (m) above the point where the pressure is to be determined measured from the tank shell in the β direction (see figure 6.4.2).

Tank domes considered to be part of the accepted total tank volume shall be taken into account when determining Z_{β} unless the total volume of tank domes V_d does not exceed the following value:

$$V_d = V_t \left(\frac{100 - FL}{FL} \right)$$

where:

V_t = tank volume without any domes; and

FL = filling limit according to 6.8.

ρ = maximum liquefied gas fuel density (kg/m³) at the design temperature.

The direction that gives the maximum value $(P_{gd})_{max}$ or $(P_{gd\ site})_{max}$ shall be considered. Where acceleration components in three directions need to be considered, an ellipsoid shall be used instead of the ellipse in figure 6.4.1. The above formula applies only to full tanks.

- 29 -

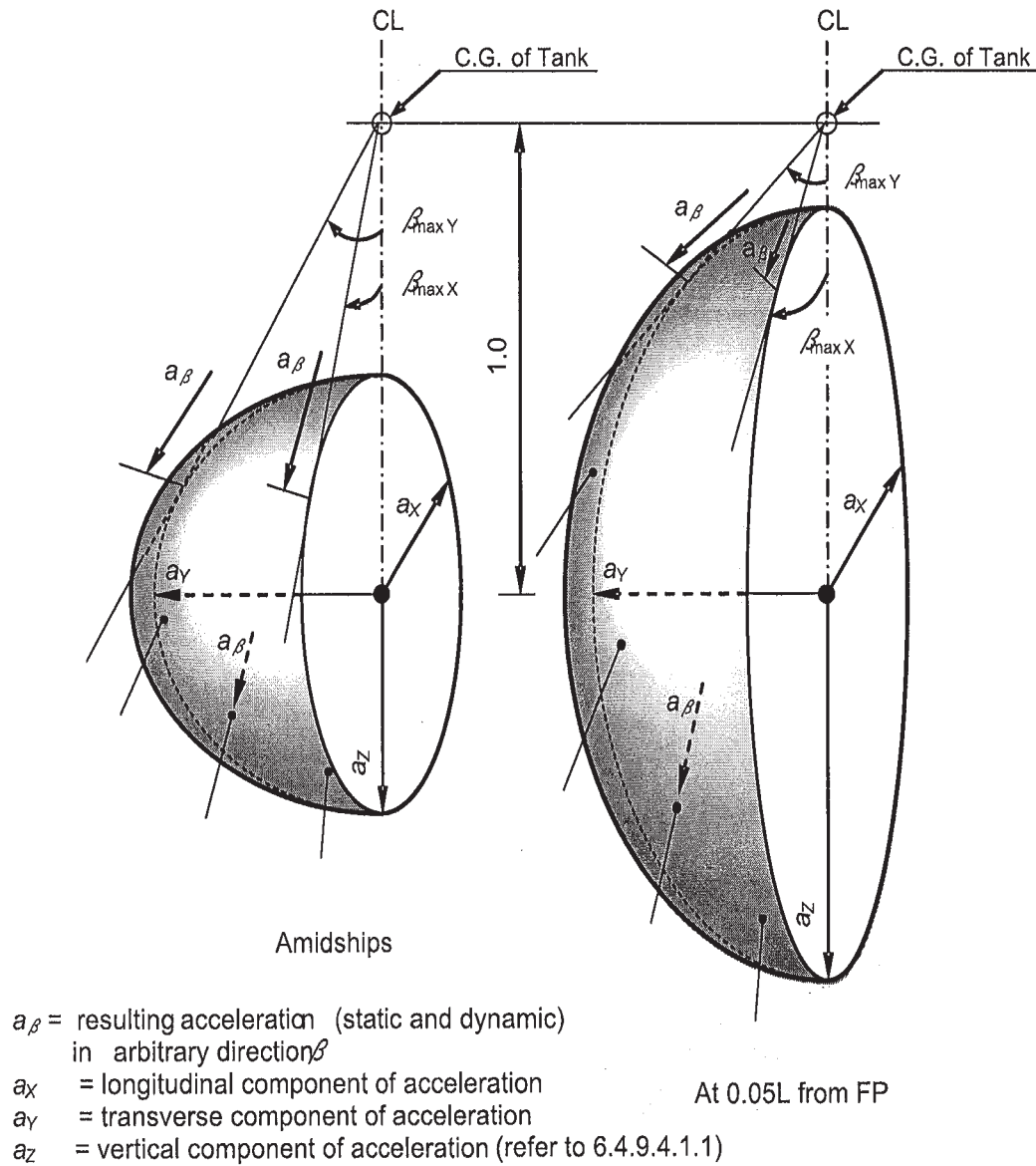


Figure 6.4.1 – Acceleration ellipsoid

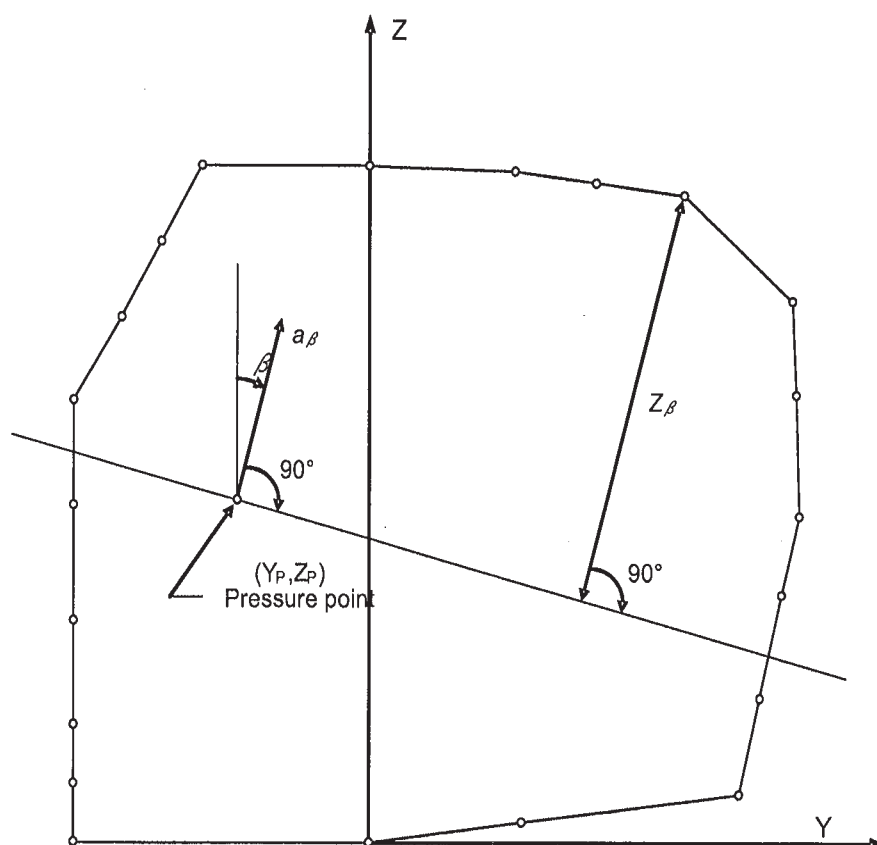


Figure 6.4.2 – Determination of internal pressure heads

6.4.9.3.3.2 External pressure

External design pressure loads shall be based on the difference between the minimum internal pressure and the maximum external pressure to which any portion of the tank may be simultaneously subjected.

6.4.9.3.3.3 Thermally induced loads

6.4.9.3.3.3.1 Transient thermally induced loads during cooling down periods shall be considered for tanks intended for liquefied gas fuel temperatures below minus 55°C.

6.4.9.3.3.3.2 Stationary thermally induced loads shall be considered for liquefied gas fuel containment systems where the design supporting arrangements or attachments and operating temperature may give rise to significant thermal stresses (see paragraph 6.9.2).

6.4.9.3.3.4 Vibration

The potentially damaging effects of vibration on the liquefied gas fuel containment system shall be considered.

6.4.9.3.3.5 Interaction loads

The static component of loads resulting from interaction between liquefied gas fuel containment system and the hull structure, as well as loads from associated structure and equipment, shall be considered.

6.4.9.3.3.6 Loads associated with construction and installation

Loads or conditions associated with construction and installation shall be considered, e.g. lifting.

6.4.9.3.3.7 Test loads

Account shall be taken of the loads corresponding to the testing of the liquefied gas fuel containment system referred to in 16.5.

6.4.9.3.3.8 Static heel loads

Loads corresponding to the most unfavourable static heel angle within the range 0° to 30° shall be considered.

6.4.9.3.3.9 Other loads

Any other loads not specifically addressed, which could have an effect on the liquefied gas fuel containment system, shall be taken into account.

6.4.9.4 *Environmental loads*

6.4.9.4.1 Environmental loads are defined as those loads on the liquefied gas fuel containment system that are caused by the surrounding environment and that are not otherwise classified as a permanent, functional or accidental load.

6.4.9.4.1.1 Loads due to ship motion

The determination of dynamic loads shall take into account the long-term distribution of ship motion in irregular seas, which the ship will experience during its operating life. Account may be taken of the reduction in dynamic loads due to necessary speed reduction and variation of heading. The ship's motion shall include surge, sway, heave, roll, pitch and yaw. The accelerations acting on tanks shall be estimated at their centre of gravity and include the following components:

- .1 vertical acceleration: motion accelerations of heave, pitch and, possibly roll (normal to the ship base);
- .2 transverse acceleration: motion accelerations of sway, yaw and roll and gravity component of roll; and
- .3 longitudinal acceleration: motion accelerations of surge and pitch and gravity component of pitch.

Methods to predict accelerations due to ship motion shall be proposed and approved by the Administration.

Ships for restricted service may be given special consideration.

6.4.9.4.1.2 Dynamic interaction loads

Account shall be taken of the dynamic component of loads resulting from interaction between liquefied gas fuel containment systems and the hull structure, including loads from associated structures and equipment.

6.4.9.4.1.3 Sloshing loads

The sloshing loads on a liquefied gas fuel containment system and internal components shall be evaluated for the full range of intended filling levels.

6.4.9.4.1.4 Snow and ice loads

Snow and icing shall be considered, if relevant.

6.4.9.4.1.5 Loads due to navigation in ice

Loads due to navigation in ice shall be considered for ships intended for such service.

6.4.9.4.1.6 Green sea loading

Account shall be taken to loads due to water on deck.

6.4.9.4.1.7 Wind loads

Account shall be taken to wind generated loads as relevant.

6.4.9.5 *Accidental loads*

Accidental loads are defined as loads that are imposed on a liquefied gas fuel containment system and it's supporting arrangements under abnormal and unplanned conditions.

6.4.9.5.1 Collision load

The collision load shall be determined based on the fuel containment system under fully loaded condition with an inertial force corresponding to "a" in the table below in forward direction and "a/2" in the aft direction, where "g" is gravitational acceleration.

Ship length (L)	Design acceleration (a)
L > 100 m	0,5 g
60 < L ≤ 100 m	$\left(2 - \frac{3(L - 60)}{80}\right) g$
L ≤ 60 m	2g

Special consideration should be given to ships with Froude number (Fn) > 0,4.

6.4.9.5.2 Loads due to flooding on ship

For independent tanks, loads caused by the buoyancy of a fully submerged empty tank shall be considered in the design of anti-flotation chocks and the supporting structure in both the adjacent hull and tank structure.

6.4.10 *Structural integrity*

6.4.10.1 General

6.4.10.1.1 The structural design shall ensure that tanks have an adequate capacity to sustain all relevant loads with an adequate margin of safety. This shall take into account the possibility of plastic deformation, buckling, fatigue and loss of liquid and gas tightness.

6.4.10.1.2 The structural integrity of liquefied gas fuel containment systems can be demonstrated by compliance with 6.4.15, as appropriate for the liquefied gas fuel containment system type.

6.4.10.1.3 For other liquefied gas fuel containment system types, that are of novel design or differ significantly from those covered by 6.4.15, the structural integrity shall be demonstrated by compliance with 6.4.16.

6.4.11 Structural analysis

6.4.11.1 Analysis

6.4.11.1.1 The design analyses shall be based on accepted principles of statics, dynamics and strength of materials.

6.4.11.1.2 Simplified methods or simplified analyses may be used to calculate the load effects, provided that they are conservative. Model tests may be used in combination with, or instead of, theoretical calculations. In cases where theoretical methods are inadequate, model or full-scale tests may be required.

6.4.11.1.3 When determining responses to dynamic loads, the dynamic effect shall be taken into account where it may affect structural integrity.

6.4.11.2 Load scenarios

6.4.11.2.1 For each location or part of the liquefied gas fuel containment system to be considered and for each possible mode of failure to be analysed, all relevant combinations of loads that may act simultaneously shall be considered.

6.4.11.2.2 The most unfavourable scenarios for all relevant phases during construction, handling, testing and in service conditions shall be considered.

6.4.11.2.3 When the static and dynamic stresses are calculated separately and unless other methods of calculation are justified, the total stresses shall be calculated according to:

$$\begin{aligned}\sigma_x &= \sigma_{x,st} \pm \sqrt{\sum (\sigma_{x,dyn})^2} \\ \sigma_y &= \sigma_{y,st} \pm \sqrt{\sum (\sigma_{y,dyn})^2} \\ \sigma_z &= \sigma_{z,st} \pm \sqrt{\sum (\sigma_{z,dyn})^2} \\ \tau_{xy} &= \tau_{xy,st} \pm \sqrt{\sum (\tau_{xy,dyn})^2} \\ \tau_{xz} &= \tau_{xz,st} \pm \sqrt{\sum (\tau_{xz,dyn})^2} \\ \tau_{yz} &= \tau_{yz,st} \pm \sqrt{\sum (\tau_{yz,dyn})^2}\end{aligned}$$

where:

$\sigma_{x,st}$, $\sigma_{y,st}$, $\sigma_{z,st}$, $\tau_{xy,st}$, $\tau_{xz,st}$ and $\tau_{yz,st}$ are static stresses; and

$\sigma_{x,dyn}$, $\sigma_{y,dyn}$, $\sigma_{z,dyn}$, $\tau_{xy,dyn}$, $\tau_{xz,dyn}$ and $\tau_{yz,dyn}$ are dynamic stresses,

each shall be determined separately from acceleration components and hull strain components due to deflection and torsion.

6.4.12 Design conditions

All relevant failure modes shall be considered in the design for all relevant load scenarios and design conditions. The design conditions are given in the earlier part of this chapter, and the load scenarios are covered by 6.4.11.2.

6.4.12.1 Ultimate design condition

6.4.12.1.1 Structural capacity may be determined by testing, or by analysis, taking into account both the elastic and plastic material properties, by simplified linear elastic analysis or by the provisions of this Code:

- .1

Plastic deformation and buckling shall be considered.
- .2

Analysis shall be based on characteristic load values as follows:

Permanent loads	Expected values
Functional loads	Specified values
Environmental loads	For wave loads: most probable largest load encountered during 10 ⁸ wave encounters.
- .3

For the purpose of ultimate strength assessment the following material parameters apply:

.1

R_e = specified minimum yield stress at room temperature (N/mm²). If the stress-strain curve does not show a defined yield stress, the 0.2% proof stress applies.

.2

R_m = specified minimum tensile strength at room temperature (N/mm²).

For welded connections where under-matched welds, i.e. where the weld metal has lower tensile strength than the parent metal, are unavoidable, such as in some aluminium alloys, the respective R_e and R_m of the welds, after any applied heat treatment, shall be used. In such cases the transverse weld tensile strength shall not be less than the actual yield strength of the parent metal. If this cannot be achieved, welded structures made from such materials shall not be incorporated in liquefied gas fuel containment systems.

The above properties shall correspond to the minimum specified mechanical properties of the material, including the weld metal in the as fabricated condition. Subject to special consideration by the Administration, account may be taken of the enhanced yield stress and tensile strength at low temperature.

- .4 The equivalent stress σ_c (von Mises, Huber) shall be determined by:

$$\sigma_c = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - \sigma_x \sigma_y - \sigma_x \sigma_z - \sigma_y \sigma_z + 3(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2)}$$

where:

σ_x = total normal stress in x-direction;
 σ_y = total normal stress in y-direction;
 σ_z = total normal stress in z-direction;
 τ_{xy} = total shear stress in x-y plane;
 τ_{xz} = total shear stress in x-z plane; and
 τ_{yz} = total shear stress in y-z plane.

The above values shall be calculated as described in 6.4.11.2.3.

- .5 Allowable stresses for materials other than those covered by 7.4 shall be subject to approval by the Administration in each case.
- .6 Stresses may be further limited by fatigue analysis, crack propagation analysis and buckling criteria.

6.4.12.2 Fatigue Design Condition

- .1 The fatigue design condition is the design condition with respect to accumulated cyclic loading.
- .2 Where a fatigue analysis is required the cumulative effect of the fatigue load shall comply with:

$$\sum \frac{n_i}{N_i} + \frac{n_{Loading}}{N_{Loading}} \leq C_w$$

where:

n_i = number of stress cycles at each stress level during the life of the tank;
 N_i = number of cycles to fracture for the respective stress level according to the Wohler (S-N) curve;
 $n_{Loading}$ = number of loading and unloading cycles during the life of the tank not to be less than 1000. Loading and unloading cycles include a complete pressure and thermal cycle;
 $N_{Loading}$ = number of cycles to fracture for the fatigue loads due to loading and unloading; and
 C_w = maximum allowable cumulative fatigue damage ratio.

The fatigue damage shall be based on the design life of the tank but not less than 10^8 wave encounters.

.3 Where required, the liquefied gas fuel containment system shall be subject to fatigue analysis, considering all fatigue loads and their appropriate combinations for the expected life of the liquefied gas fuel containment system. Consideration shall be given to various filling conditions.

.4 Design S-N curves used in the analysis shall be applicable to the materials and weldments, construction details, fabrication procedures and applicable state of the stress envisioned.

The S-N curves shall be based on a 97.6% probability of survival corresponding to the mean-minus-two-standard-deviation curves of relevant experimental data up to final failure. Use of S-N curves derived in a different way requires adjustments to the acceptable Cw values specified in 6.4.12.2.7 to 6.4.12.2.9.

.5 Analysis shall be based on characteristic load values as follows:

Permanent loads	Expected values
Functional loads	Specified values or specified history
Environmental loads	Expected load history, but not less than 10^8 cycles

If simplified dynamic loading spectra are used for the estimation of the fatigue life, those shall be specially considered by the Administration.

.6 Where the size of the secondary barrier is reduced, as is provided for in 6.4.2.3, fracture mechanics analyses of fatigue crack growth shall be carried out to determine:

- .1 crack propagation paths in the structure, where necessitated by 6.4.12.2.7 to 6.4.12.2.9, as applicable;
- .2 crack growth rate;
- .3 the time required for a crack to propagate to cause a leakage from the tank;
- .4 the size and shape of through thickness cracks; and
- .5 the time required for detectable cracks to reach a critical state after penetration through the thickness.

The fracture mechanics are in general based on crack growth data taken as a mean value plus two standard deviations of the test data. Methods for fatigue crack growth analysis and fracture mechanics shall be based on recognized standards.

In analysing crack propagation the largest initial crack not detectable by the inspection method applied shall be assumed, taking into account the allowable non-destructive testing and visual inspection criterion as applicable.

Crack propagation analysis specified in 6.4.12.2.7 the simplified load distribution and sequence over a period of 15 days may be used. Such distributions may be obtained as indicated in figure 6.4.3. Load distribution and sequence for longer periods, such as in 6.4.12.2.8 and 6.4.12.2.9 shall be approved by the Administration.

The arrangements shall comply with 6.4.12.2.7 to 6.4.12.2.9 as applicable.

- .7 For failures that can be reliably detected by means of leakage detection:

C_w shall be less than or equal to 0.5.

Predicted remaining failure development time, from the point of detection of leakage till reaching a critical state, shall not be less than 15 days unless different regulations apply for ships engaged in particular voyages.

- .8 For failures that cannot be detected by leakage but that can be reliably detected at the time of in-service inspections:

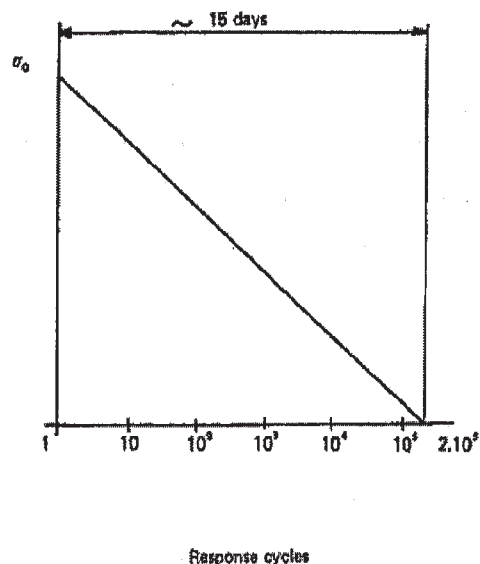
C_w shall be less than or equal to 0.5.

Predicted remaining failure development time, from the largest crack not detectable by in-service inspection methods until reaching a critical state, shall not be less than three (3) times the inspection interval.

- .9 In particular locations of the tank where effective defect or crack development detection cannot be assured, the following, more stringent, fatigue acceptance criteria shall be applied as a minimum:

C_w shall be less than or equal to 0.1.

Predicted failure development time, from the assumed initial defect until reaching a critical state, shall not be less than three (3) times the lifetime of the tank.



σ_0 = most probable maximum stress over the life of the ship

Response cycle scale is logarithmic; the value of 2.10^5 is given as an example of estimate.

Figure 6.4.3 – Simplified load distribution

6.4.12.3 *Accidental design condition*

6.4.12.3.1 The accidental design condition is a design condition for accidental loads with extremely low probability of occurrence.

6.4.12.3.2 Analysis shall be based on the characteristic values as follows:

Permanent loads	Expected values
Functional loads	Specified values
Environmental loads	Specified values
Accidental loads	Specified values or expected values

Loads mentioned in 6.4.9.3.3.8 and 6.4.9.5 need not be combined with each other or with wave-induced loads.

6.4.13 *Materials and construction*

6.4.13.1 *Materials*

6.4.13.1.1 Materials forming ship structure

6.4.13.1.1.1 To determine the grade of plate and sections used in the hull structure, a temperature calculation shall be performed for all tank types. The following assumptions shall be made in this calculation:

- .1 The primary barrier of all tanks shall be assumed to be at the liquefied gas fuel temperature.
- .2 In addition to .1 above, where a complete or partial secondary barrier is required it shall be assumed to be at the liquefied gas fuel temperature at atmospheric pressure for any one tank only.
- .3 For worldwide service, ambient temperatures shall be taken as 5°C for air and 0°C for seawater. Higher values may be accepted for ships operating in restricted areas and conversely, lower values may be imposed by the Administration for ships trading to areas where lower temperatures are expected during the winter months.
- .4 Still air and sea water conditions shall be assumed, i.e. no adjustment for forced convection.
- .5 Degradation of the thermal insulation properties over the life of the ship due to factors such as thermal and mechanical ageing, compaction, ship motions and tank vibrations as defined in 6.4.13.3.6 and 6.4.13.3.7 shall be assumed.
- .6 The cooling effect of the rising boil-off vapour from the leaked liquefied gas fuel shall be taken into account where applicable.
- .7 Credit for hull heating may be taken in accordance with 6.4.13.1.1.3, provided the heating arrangements are in compliance with 6.4.13.1.1.4.
- .8 No credit shall be given for any means of heating, except as described in 6.4.13.1.1.3.
- .9 For members connecting inner and outer hulls, the mean temperature may be taken for determining the steel grade.

6.4.13.1.1.2 The materials of all hull structures for which the calculated temperature in the design condition is below 0°C, due to the influence of liquefied gas fuel temperature, shall be in accordance with table 7.5. This includes hull structure supporting the liquefied gas fuel tanks, inner bottom plating, longitudinal bulkhead plating, transverse bulkhead plating, floors, webs, stringers and all attached stiffening members.

6.4.13.1.1.3 Means of heating structural materials may be used to ensure that the material temperature does not fall below the minimum allowed for the grade of material specified in table 7.5. In the calculations required in 6.4.13.1.1.1, credit for such heating may be taken in accordance with the following principles:

- .1 for any transverse hull structure;
- .2 for longitudinal hull structure referred to in 6.4.13.1.1.2 where colder ambient temperatures are specified, provided the material remains suitable for the ambient temperature conditions of plus 5°C for air and 0°C for seawater with no credit taken in the calculations for heating; and
- .3 as an alternative to 6.4.13.1.1.3.2, for longitudinal bulkhead between liquefied gas fuel tanks, credit may be taken for heating provided the material remain suitable for a minimum design temperature of minus 30°C, or a temperature 30°C lower than that determined by 6.4.13.1.1.1 with the heating considered, whichever is less. In this case, the ship's longitudinal strength shall comply with SOLAS regulation II-1/3-1 for both when those bulkhead(s) are considered effective and not.

6.4.13.1.1.4 The means of heating referred to in 6.4.13.1.1.3 shall comply with the following:

- .1 the heating system shall be arranged so that, in the event of failure in any part of the system, standby heating can be maintained equal to no less than 100% of the theoretical heat requirement;
- .2 the heating system shall be considered as an essential auxiliary. All electrical components of at least one of the systems provided in accordance with 6.4.13.1.1.3.1 shall be supplied from the emergency source of electrical power; and
- .3 the design and construction of the heating system shall be included in the approval of the containment system by the Administration.

6.4.13.2 *Materials of primary and secondary barriers*

6.4.13.2.1 Metallic materials used in the construction of primary and secondary barriers not forming the hull, shall be suitable for the design loads that they may be subjected to, and be in accordance with table 7.1, 7.2 or 7.3.

6.4.13.2.2 Materials, either non-metallic or metallic but not covered by tables 7.1, 7.2 and 7.3, used in the primary and secondary barriers may be approved by the Administration considering the design loads that they may be subjected to, their properties and their intended use.

6.4.13.2.3 Where non-metallic materials, including composites, are used for or incorporated in the primary or secondary barriers, they shall be tested for the following properties, as applicable, to ensure that they are adequate for the intended service:

- .1 compatibility with the liquefied gas fuels;
- .2 ageing;
- .3 mechanical properties;
- .4 thermal expansion and contraction;
- .5 abrasion;
- .6 cohesion;
- .7 resistance to vibrations;
- .8 resistance to fire and flame spread; and
- .9 resistance to fatigue failure and crack propagation.

6.4.13.2.4 The above properties, where applicable, shall be tested for the range between the expected maximum temperature in service and 5°C below the minimum design temperature, but not lower than minus196°C.

6.4.13.2.5 Where non-metallic materials, including composites, are used for the primary and secondary barriers, the joining processes shall also be tested as described above.

6.4.13.2.6 Consideration may be given to the use of materials in the primary and secondary barrier, which are not resistant to fire and flame spread, provided they are protected by a suitable system such as a permanent inert gas environment, or are provided with a fire retardant barrier.

6.4.13.3 *Thermal insulation and other materials used in liquefied gas fuel containment systems*

6.4.13.3.1 Load-bearing thermal insulation and other materials used in liquefied gas fuel containment systems shall be suitable for the design loads.

6.4.13.3.2 Thermal insulation and other materials used in liquefied gas fuel containment systems shall have the following properties, as applicable, to ensure that they are adequate for the intended service:

- .1 compatibility with the liquefied gas fuels;
- .2 solubility in the liquefied gas fuel;
- .3 absorption of the liquefied gas fuel;
- .4 shrinkage;
- .5 ageing;
- .6 closed cell content;
- .7 density;
- .8 mechanical properties, to the extent that they are subjected to liquefied gas fuel and other loading effects, thermal expansion and contraction;

- .9 abrasion;
- .10 cohesion;
- .11 thermal conductivity;
- .12 resistance to vibrations;
- .13 resistance to fire and flame spread; and
- .14 resistance to fatigue failure and crack propagation.

6.4.13.3.3 The above properties, where applicable, shall be tested for the range between the expected maximum temperature in service and 5°C below the minimum design temperature, but not lower than minus 196°C.

6.4.13.3.4 Due to location or environmental conditions, thermal insulation materials shall have suitable properties of resistance to fire and flame spread and shall be adequately protected against penetration of water vapour and mechanical damage. Where the thermal insulation is located on or above the exposed deck, and in way of tank cover penetrations, it shall have suitable fire resistance properties in accordance with a recognized standard or be covered with a material having low flame spread characteristics and forming an efficient approved vapour seal.

6.4.13.3.5 Thermal insulation that does not meet recognized standards for fire resistance may be used in fuel storage hold spaces that are not kept permanently inerted, provided its surfaces are covered with material with low flame spread characteristics and that forms an efficient approved vapour seal.

6.4.13.3.6 Testing for thermal conductivity of thermal insulation shall be carried out on suitably aged samples.

6.4.13.3.7 Where powder or granulated thermal insulation is used, measures shall be taken to reduce compaction in service and to maintain the required thermal conductivity and also prevent any undue increase of pressure on the liquefied gas fuel containment system.

6.4.14 Construction processes

6.4.14.1 Weld joint design

6.4.14.1.1 All welded joints of the shells of independent tanks shall be of the in-plane butt weld full penetration type. For dome-to-shell connections only, tee welds of the full penetration type may be used depending on the results of the tests carried out at the approval of the welding procedure. Except for small penetrations on domes, nozzle welds are also to be designed with full penetration.

6.4.14.1.2 Welding joint details for type C independent tanks, and for the liquid-tight primary barriers of type B independent tanks primarily constructed of curved surfaces, shall be as follows:

- .1 All longitudinal and circumferential joints shall be of butt welded, full penetration, double vee or single vee type. Full penetration butt welds shall be obtained by double welding or by the use of backing rings. If used, backing rings shall be removed except from very small process pressure vessels. Other edge preparations may be permitted, depending on the results of the

tests carried out at the approval of the welding procedure. For connections of tank shell to a longitudinal bulkhead of type C bilobe tanks, tee welds of the full penetration type may be accepted.

- .2 The bevel preparation of the joints between the tank body and domes and between domes and relevant fittings shall be designed according to a standard acceptable to the Administration. All welds connecting nozzles, domes or other penetrations of the vessel and all welds connecting flanges to the vessel or nozzles shall be full penetration welds.

6.4.14.2 *Design for gluing and other joining processes*

6.4.14.2.1 The design of the joint to be glued (or joined by some other process except welding) shall take account of the strength characteristics of the joining process.

6.4.15 **Tank types**

6.4.15.1 *Type A independent tanks*

6.4.15.1.1 Design basis

6.4.15.1.1.1 Type A independent tanks are tanks primarily designed using classical ship-structural analysis procedures in accordance with the requirements of the Administration. Where such tanks are primarily constructed of plane surfaces, the design vapour pressure P_0 shall be less than 0.07 MPa.

6.4.15.1.1.2 A complete secondary barrier is required as defined in 6.4.3. The secondary barrier shall be designed in accordance with 6.4.4.

6.4.15.1.2 Structural analysis

6.4.15.1.2.1 A structural analysis shall be performed taking into account the internal pressure as indicated in 6.4.9.3.3.1, and the interaction loads with the supporting and keying system as well as a reasonable part of the ship's hull.

6.4.15.1.2.2 For parts, such as structure in way of supports, not otherwise covered by the regulations in this Code, stresses shall be determined by direct calculations, taking into account the loads referred to in 6.4.9.2 to 6.4.9.5 as far as applicable, and the ship deflection in way of supports.

6.4.15.1.2.3 The tanks with supports shall be designed for the accidental loads specified in 6.4.9.5. These loads need not be combined with each other or with environmental loads.

6.4.15.1.3 Ultimate design condition

6.4.15.1.3.1 For tanks primarily constructed of plane surfaces, the nominal membrane stresses for primary and secondary members (stiffeners, web frames, stringers, girders), when calculated by classical analysis procedures, shall not exceed the lower of $R_m/2.66$ or $R_e/1.33$ for nickel steels, carbon-manganese steels, austenitic steels and aluminium alloys, where R_m and R_e are defined in 6.4.12.1.1.3. However, if detailed calculations are carried out for the primary members, the equivalent stress σ_e , as defined in 6.4.12.1.1.4, may be increased over that indicated above to a stress acceptable to the Administration. Calculations shall take into account the effects of bending, shear, axial and torsional deformation as well as the hull/liquefied gas fuel tank interaction forces due to the deflection of the hull structure and liquefied gas fuel tank bottoms.

6.4.15.1.3.2 Tank boundary scantlings shall meet at least the requirements of the Administration for deep tanks taking into account the internal pressure as indicated in 6.4.9.3.3.1 and any corrosion allowance required by 6.4.1.7.

6.4.15.1.3.3 The liquefied gas fuel tank structure shall be reviewed against potential buckling.

6.4.15.1.4 Accidental design condition

6.4.15.1.4.1 The tanks and the tank supports shall be designed for the accidental loads and design conditions specified in 6.4.9.5 and 6.4.1.6.3 as relevant.

6.4.15.1.4.2 When subjected to the accidental loads specified in 6.4.9.5, the stress shall comply with the acceptance criteria specified in 6.4.15.1.3, modified as appropriate taking into account their lower probability of occurrence.

6.4.15.2 *Type B independent tanks*

6.4.15.2.1 Design basis

6.4.15.2.1.1 Type B independent tanks are tanks designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. Where such tanks are primarily constructed of plane surfaces (prismatic tanks) the design vapour pressure P_0 shall be less than 0.07 MPa.

6.4.15.2.1.2 A partial secondary barrier with a protection system is required as defined in 6.4.3. The small leak protection system shall be designed according to 6.4.5.

6.4.15.2.2 Structural analysis

6.4.15.2.2.1 The effects of all dynamic and static loads shall be used to determine the suitability of the structure with respect to:

- .1 plastic deformation;
- .2 buckling;
- .3 fatigue failure; and
- .4 crack propagation.

Finite element analysis or similar methods and fracture mechanics analysis or an equivalent approach, shall be carried out.

6.4.15.2.2.2 A three-dimensional analysis shall be carried out to evaluate the stress levels, including interaction with the ship's hull. The model for this analysis shall include the liquefied gas fuel tank with its supporting and keying system, as well as a reasonable part of the hull.

6.4.15.2.2.3 A complete analysis of the particular ship accelerations and motions in irregular waves, and of the response of the ship and its liquefied gas fuel tanks to these forces and motions, shall be performed unless the data is available from similar ships.

6.4.15.2.3 Ultimate design condition

6.4.15.2.3.1 Plastic deformation

For type B independent tanks, primarily constructed of bodies of revolution, the allowable stresses shall not exceed:

σ_m σ_L σ_b $\sigma_L + \sigma_b$ $\sigma_m + \sigma_b$ $\sigma_m + \sigma_b + \sigma_g$ $\sigma_L + \sigma_b + \sigma_g$

$\leq f$ $\leq 1.5f$ $\leq 1.5F$ $\leq 1.5F$ $\leq 1.5F$ $\leq 3.0F$ $\leq 3.0F$

where:

- σ_m = equivalent primary general membrane stress;
- σ_L = equivalent primary local membrane stress;
- σ_b = equivalent primary bending stress;
- σ_g = equivalent secondary stress;
- f = the lesser of (R_m / A) or (R_e / B); and
- F = the lesser of (R_m / C) or (R_e / D),

with R_m and R_e as defined in 6.4.12.1.1.3. With regard to the stresses σ_m , σ_L , σ_g and σ_b see also the definition of stress categories in 6.4.15.2.3.6.

The values A and B shall have at least the following minimum values:

	Nickel steels and carbon manganese steels	Austenitic steel	Aluminium alloys
A	3	3.5	4
B	2	1.6	1.5
C	3	3	3
D	1.5	1.5	1.5

The above figures may be altered considering the design condition considered in acceptance with the Administration. For type B independent tanks, primarily constructed of plane surfaces, the allowable membrane equivalent stresses applied for finite element analysis shall not exceed:

- .1for nickel steels and carbon-manganese steels, the lesser of $R_m/2$ or $R_e/1.2$;
- .2for austenitic steels, the lesser of $R_m/2.5$ or $R_e/1.2$; and
- .3for aluminium alloys, the lesser of $R_m/2.5$ or $R_e/1.2$.

The above figures may be amended considering the locality of the stress, stress analysis methods and design condition considered in acceptance with the Administration.

The thickness of the skin plate and the size of the stiffener shall not be less than those required for type A independent tanks.

6.4.15.2.3.2 Buckling

Buckling strength analyses of liquefied gas fuel tanks subject to external pressure and other loads causing compressive stresses shall be carried out in accordance with recognized standards. The method shall adequately account for the difference in theoretical and actual buckling stress as a result of plate edge misalignment, lack of straightness or flatness, ovality and deviation from true circular form over a specified arc or chord length, as applicable.

6.4.15.2.3.3 Fatigue design condition

6.4.15.2.3.3.1 Fatigue and crack propagation assessment shall be performed in accordance with the provisions of 6.4.12.2. The acceptance criteria shall comply with 6.4.12.2.7, 6.4.12.2.8 or 6.4.12.2.9, depending on the detectability of the defect.

6.4.15.2.3.3.2 Fatigue analysis shall consider construction tolerances.

6.4.15.2.3.3.3 Where deemed necessary by the Administration, model tests may be required to determine stress concentration factors and fatigue life of structural elements.

6.4.15.2.3.4 Accidental design condition

6.4.15.2.3.4.1 The tanks and the tank supports shall be designed for the accidental loads and design conditions specified in 6.4.9.5 and 6.4.1.6.3, as relevant.

6.4.15.2.3.4.2 When subjected to the accidental loads specified in 6.4.9.5, the stress shall comply with the acceptance criteria specified in 6.4.15.2.3, modified as appropriate, taking into account their lower probability of occurrence.

6.4.15.2.3.5 Marking

Any marking of the pressure vessel shall be achieved by a method that does not cause unacceptable local stress raisers.

6.4.15.2.3.6 Stress categories

For the purpose of stress evaluation, stress categories are defined in this section as follows:

- .1 *Normal stress* is the component of stress normal to the plane of reference.
- .2 *Membrane stress* is the component of normal stress that is uniformly distributed and equal to the average value of the stress across the thickness of the section under consideration.
- .3 *Bending stress* is the variable stress across the thickness of the section under consideration, after the subtraction of the membrane stress.
- .4 *Shear stress* is the component of the stress acting in the plane of reference.
- .5 *Primary stress* is a stress produced by the imposed loading, which is necessary to balance the external forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or at least in gross deformations.

- .6 *Primary general membrane stress* is a primary membrane stress that is so distributed in the structure that no redistribution of load occurs as a result of yielding.
- .7 *Primary local membrane stress* arises where a membrane stress produced by pressure or other mechanical loading and associated with a primary or a discontinuity effect produces excessive distortion in the transfer of loads for other portions of the structure. Such a stress is classified as a primary local membrane stress, although it has some characteristics of a secondary stress. A stress region may be considered as local, if:

$$S_1 \leq 0.5\sqrt{Rt}; \text{ and}$$

$$S_1 \geq 2.5\sqrt{Rt}$$

where:

S_1 = distance in the meridional direction over which the equivalent stress exceeds $1.1f$;

S_2 = distance in the meridional direction to another region where the limits for primary general membrane stress are exceeded;

R = mean radius of the vessel;

t = wall thickness of the vessel at the location where the primary general membrane stress limit is exceeded; and

f = allowable primary general membrane stress.

- .8 *Secondary stress* is a normal stress or shear stress developed by constraints of adjacent parts or by self-constraint of a structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur.

6.4.15.3 Type C independent tanks

6.4.15.3.1 Design basis

6.4.15.3.1.1 The design basis for type C independent tanks is based on pressure vessel criteria modified to include fracture mechanics and crack propagation criteria. The minimum design pressure defined in 6.4.15.3.1.2 is intended to ensure that the dynamic stress is sufficiently low so that an initial surface flaw will not propagate more than half the thickness of the shell during the lifetime of the tank.

6.4.15.3.1.2 The design vapour pressure shall not be less than:

$$P_0 = 0.2 + AC(\rho_r)^{1.5} \text{ (MPa)}$$

where:

$$A = 0.00185 \left(\frac{\sigma_m}{\Delta\sigma_A} \right)^2$$

with:

σ_m = design primary membrane stress;

$\Delta\sigma_A$ = allowable dynamic membrane stress (double amplitude at probability level $Q = 10^{-8}$) and equal to:

- 55 N/mm² for ferritic-perlitic, martensitic and austenitic steel;
- 25 N/mm² for aluminium alloy (5083-O);

C = a characteristic tank dimension to be taken as the greatest of the following:

h , $0.75b$ or 0.45ℓ ,

with:

h = height of tank (dimension in ship's vertical direction) (m);

b = width of tank (dimension in ship's transverse direction) (m);

ℓ = length of tank (dimension in ship's longitudinal direction) (m);

ρ_r = the relative density of the cargo ($\rho_r = 1$ for fresh water) at the design temperature.

6.4.15.3.2 Shell thickness

6.4.15.3.2.1 In considering the shell thickness the following apply:

- .1 for pressure vessels, the thickness calculated according to 6.4.15.3.2.4 shall be considered as a minimum thickness after forming, without any negative tolerance;
- .2 for pressure vessels, the minimum thickness of shell and heads including corrosion allowance, after forming, shall not be less than 5 mm for carbon manganese steels and nickel steels, 3 mm for austenitic steels or 7 mm for aluminium alloys; and

- .3 the welded joint efficiency factor to be used in the calculation according to 6.4.15.3.2.4 shall be 0.95 when the inspection and the non-destructive testing referred to in 16.3.6.4 are carried out. This figure may be increased up to 1.0 when account is taken of other considerations, such as the material used, type of joints, welding procedure and type of loading. For process pressure vessels the Administration may accept partial non-destructive examinations, but not less than those of 16.3.6.4, depending on such factors as the material used, the design temperature, the nil ductility transition temperature of the material as fabricated and the type of joint and welding procedure, but in this case an efficiency factor of not more than 0.85 shall be adopted. For special materials the above-mentioned factors shall be reduced, depending on the specified mechanical properties of the welded joint.

6.4.15.3.2.2 The design liquid pressure defined in 6.4.9.3.3.1 shall be taken into account in the internal pressure calculations.

6.4.15.3.2.3 The design external pressure P_e , used for verifying the buckling of the pressure vessels, shall not be less than that given by:

$$P_e = P_1 + P_2 + P_3 + P_4 \quad (\text{MPa})$$

where:

P_1 = setting value of vacuum relief valves. For vessels not fitted with vacuum relief valves P_1 shall be specially considered, but shall not in general be taken as less than 0.025 MPa.

P_2 = the set pressure of the pressure relief valves (PRVs) for completely closed spaces containing pressure vessels or parts of pressure vessels; elsewhere $P_2 = 0$.

P_3 = compressive actions in or on the shell due to the weight and contraction of thermal insulation, weight of shell including corrosion allowance and other miscellaneous external pressure loads to which the pressure vessel may be subjected. These include, but are not limited to, weight of domes, weight of towers and piping, effect of product in the partially filled condition, accelerations and hull deflection. In addition, the local effect of external or internal pressures or both shall be taken into account.

P_4 = external pressure due to head of water for pressure vessels or part of pressure vessels on exposed decks; elsewhere $P_4 = 0$.

6.4.15.3.2.4 Scantlings based on internal pressure shall be calculated as follows:

The thickness and form of pressure-containing parts of pressure vessels, under internal pressure, as defined in 6.4.9.3.3.1, including flanges, shall be determined. These calculations shall in all cases be based on accepted pressure vessel design theory. Openings in pressure-containing parts of pressure vessels shall be reinforced in accordance with a recognized standard acceptable to the Administration.

6.4.15.3.2.5 Stress analysis in respect of static and dynamic loads shall be performed as follows:

- .1 pressure vessel scantlings shall be determined in accordance with 6.4.15.3.2.1 to 6.4.15.3.2.4 and 6.4.15.3.3;

- .2 calculations of the loads and stresses in way of the supports and the shell attachment of the support shall be made. Loads referred to in 6.4.9.2 to 6.4.9.5 shall be used, as applicable. Stresses in way of the supports shall be to a recognized standard acceptable to the Administration. In special cases a fatigue analysis may be required by the Administration; and
- .3 if required by the Administration, secondary stresses and thermal stresses shall be specially considered.

6.4.15.3.3 Ultimate design condition

6.4.15.3.3.1 Plastic deformation

For type C independent tanks, the allowable stresses shall not exceed:

$$\begin{aligned}
 \sigma_m &\leq f \\
 \sigma_L &\leq 1.5f \\
 \sigma_b &\leq 1.5f \\
 \sigma_L + \sigma_b &\leq 1.5f \\
 \sigma_m + \sigma_b &\leq 1.5f \\
 \sigma_m + \sigma_b + \sigma_g &\leq 3.0f \\
 \sigma_L + \sigma_b + \sigma_g &\leq 3.0f
 \end{aligned}$$

where:

σ_m = equivalent primary general membrane stress;

σ_L = equivalent primary local membrane stress;

σ_b = equivalent primary bending stress;

σ_g = equivalent secondary stress; and

f = the lesser of R_m/A or R_e/B ,

with R_m and R_e as defined in 6.4.12.1.1.3. With regard to the stresses σ_m , σ_L , σ_g and σ_b see also the definition of stress categories in 6.4.15.2.3.6. The values A and B shall have at least the following minimum values:

	Nickel steels and carbon-manganese steels	Austenitic steels	Aluminium alloys
A	3	3.5	4
B	1.5	1.5	1.5

6.4.15.3.3.2 Buckling criteria shall be as follows:

The thickness and form of pressure vessels subject to external pressure and other loads causing compressive stresses shall be based on calculations using accepted pressure vessel buckling theory and shall adequately account for the difference in theoretical and actual buckling stress as a result of plate edge misalignment, ovality and deviation from true circular form over a specified arc or chord length.

6.4.15.3.4 Fatigue design condition

6.4.15.3.4.1 For type C independent tanks where the liquefied gas fuel at atmospheric pressure is below minus 55°C, the Administration may require additional verification to check their compliance with 6.4.15.3.1.1, regarding static and dynamic stress depending on the tank size, the configuration of the tank and arrangement of its supports and attachments.

6.4.15.3.4.2 For vacuum insulated tanks, special attention shall be made to the fatigue strength of the support design and special considerations shall also be made to the limited inspection possibilities between the inside and outer shell.

6.4.15.3.5 Accidental design condition

6.4.15.3.5.1 The tanks and the tank supports shall be designed for the accidental loads and design conditions specified in 6.4.9.5 and 6.4.1.6.3, as relevant.

6.4.15.3.5.2 When subjected to the accidental loads specified in 6.4.9.5, the stress shall comply with the acceptance criteria specified in 6.4.15.3.3.1, modified as appropriate taking into account their lower probability of occurrence.

6.4.15.3.6 Marking

The required marking of the pressure vessel shall be achieved by a method that does not cause unacceptable local stress raisers.

6.4.15.4 Membrane tanks

6.4.15.4.1 Design basis

6.4.15.4.1.1 The design basis for membrane containment systems is that thermal and other expansion or contraction is compensated for without undue risk of losing the tightness of the membrane.

6.4.15.4.1.2 A systematic approach, based on analysis and testing, shall be used to demonstrate that the system will provide its intended function in consideration of the identified in service events as specified in 6.4.15.4.2.1.

6.4.15.4.1.3 A complete secondary barrier is required as defined in 6.4.3. The secondary barrier shall be designed according to 6.4.4.

6.4.15.4.1.4 The design vapour pressure P_0 shall not normally exceed 0.025 MPa. If the hull scantlings are increased accordingly and consideration is given, where appropriate, to the strength of the supporting thermal insulation, P_0 may be increased to a higher value but less than 0.070 MPa.

6.4.15.4.1.5 The definition of membrane tanks does not exclude designs such as those in which non-metallic membranes are used or where membranes are included or incorporated into the thermal insulation.

6.4.15.4.1.6 The thickness of the membranes shall normally not exceed 10 mm.

6.4.15.4.1.7 The circulation of inert gas throughout the primary and the secondary insulation spaces, in accordance with 6.11.1 shall be sufficient to allow for effective means of gas detection.

6.4.15.4.2 Design considerations

6.4.15.4.2.1 Potential incidents that could lead to loss of fluid tightness over the life of the membranes shall be evaluated. These include, but are not limited to:

- .1 Ultimate design events:
 - .1 tensile failure of membranes;
 - .2 compressive collapse of thermal insulation;
 - .3 thermal ageing;
 - .4 loss of attachment between thermal insulation and hull structure;
 - .5 loss of attachment of membranes to thermal insulation system;
 - .6 structural integrity of internal structures and their associated supporting structures; and
 - .7 failure of the supporting hull structure.
- .2 Fatigue design events:
 - .1 fatigue of membranes including joints and attachments to hull structure;
 - .2 fatigue cracking of thermal insulation;
 - .3 fatigue of internal structures and their associated supporting structures; and
 - .4 fatigue cracking of inner hull leading to ballast water ingress.
- .3 Accident design events:
 - .1 accidental mechanical damage (such as dropped objects inside the tank while in service);
 - .2 accidental over pressurization of thermal insulation spaces;
 - .3 accidental vacuum in the tank; and
 - .4 water ingress through the inner hull structure.

Designs where a single internal event could cause simultaneous or cascading failure of both membranes are unacceptable.

6.4.15.4.2.2 The necessary physical properties (mechanical, thermal, chemical, etc.) of the materials used in the construction of the liquefied gas fuel containment system shall be established during the design development in accordance with 6.4.15.4.1.2.

6.4.15.4.3 Loads, load combinations

Particular consideration shall be paid to the possible loss of tank integrity due to either an overpressure in the interbarrier space, a possible vacuum in the liquefied gas fuel tank, the sloshing effects, to hull vibration effects, or any combination of these events.

6.4.15.4.4 Structural analyses

6.4.15.4.4.1 Structural analyses and/or testing for the purpose of determining the ultimate strength and fatigue assessments of the liquefied gas fuel containment and associated structures and equipment noted in 6.4.7 shall be performed. The structural analysis shall provide the data required to assess each failure mode that has been identified as critical for the liquefied gas fuel containment system.

6.4.15.4.4.2 Structural analyses of the hull shall take into account the internal pressure as indicated in 6.4.9.3.3.1. Special attention shall be paid to deflections of the hull and their compatibility with the membrane and associated thermal insulation.

6.4.15.4.4.3 The analyses referred to in 6.4.15.4.4.1 and 6.4.15.4.4.2 shall be based on the particular motions, accelerations and response of ships and liquefied gas fuel containment systems.

6.4.15.4.5 Ultimate design condition

6.4.15.4.5.1 The structural resistance of every critical component, sub-system, or assembly, shall be established, in accordance with 6.4.15.4.1.2, for in-service conditions.

6.4.15.4.5.2 The choice of strength acceptance criteria for the failure modes of the liquefied gas fuel containment system, its attachments to the hull structure and internal tank structures, shall reflect the consequences associated with the considered mode of failure.

6.4.15.4.5.3 The inner hull scantlings shall meet the regulations for deep tanks, taking into account the internal pressure as indicated in 6.4.9.3.3.1 and the specified appropriate regulations for sloshing load as defined in 6.4.9.4.1.3.

6.4.15.4.6 Fatigue design condition

6.4.15.4.6.1 Fatigue analysis shall be carried out for structures inside the tank, i.e. pump towers, and for parts of membrane and pump tower attachments, where failure development cannot be reliably detected by continuous monitoring.

6.4.15.4.6.2 The fatigue calculations shall be carried out in accordance with 6.4.12.2, with relevant regulations depending on:

- .1 the significance of the structural components with respect to structural integrity; and
- .2 availability for inspection.

6.4.15.4.6.3 For structural elements for which it can be demonstrated by tests and/or analyses that a crack will not develop to cause simultaneous or cascading failure of both membranes, C_w shall be less than or equal to 0.5.

6.4.15.4.6.4 Structural elements subject to periodic inspection, and where an unattended fatigue crack can develop to cause simultaneous or cascading failure of both membranes, shall satisfy the fatigue and fracture mechanics regulations stated in 6.4.12.2.8.

6.4.15.4.6.5 Structural element not accessible for in-service inspection, and where a fatigue crack can develop without warning to cause simultaneous or cascading failure of both membranes, shall satisfy the fatigue and fracture mechanics regulations stated in 6.4.12.2.9.

6.4.15.4.7 Accidental design condition

6.4.15.4.7.1 The containment system and the supporting hull structure shall be designed for the accidental loads specified in 6.4.9.5. These loads need not be combined with each other or with environmental loads.

6.4.15.4.7.2 Additional relevant accidental scenarios shall be determined based on a risk analysis. Particular attention shall be paid to securing devices inside of tanks.

6.4.16 Limit state design for novel concepts

6.4.16.1 Fuel containment systems that are of a novel configuration that cannot be designed using section 6.4.15 shall be designed using this section and 6.4.1 to 6.4.14, as applicable. Fuel containment system design according to this section shall be based on the principles of limit state design which is an approach to structural design that can be applied to established design solutions as well as novel designs. This more generic approach maintains a level of safety similar to that achieved for known containment systems as designed using 6.4.15.

6.4.16.2.1 The limit state design is a systematic approach where each structural element is evaluated with respect to possible failure modes related to the design conditions identified in 6.4.1.6. A limit state can be defined as a condition beyond which the structure, or part of a structure, no longer satisfies the regulations.

6.4.16.2.2 For each failure mode, one or more limit states may be relevant. By consideration of all relevant limit states, the limit load for the structural element is found as the minimum limit load resulting from all the relevant limit states. The limit states are divided into the three following categories:

- .1 Ultimate limit states (ULS), which correspond to the maximum load-carrying capacity or, in some cases, to the maximum applicable strain or deformation; under intact (undamaged) conditions.
- .2 Fatigue limit states (FLS), which correspond to degradation due to the effect of time varying (cyclic) loading.
- .3 Accident limit states (ALS), which concern the ability of the structure to resist accidental situations.

6.4.16.3 The procedure and relevant design parameters of the limit state design shall comply with the Standards for the Use of limit state methodologies in the design of fuel containment systems of novel configuration (LSD Standard), as set out in the annex to part A-1.

6.5 Regulations for portable liquefied gas fuel tanks

6.5.1 The design of the tank shall comply with 6.4.15.3. The tank support (container frame or truck chassis) shall be designed for the intended purpose.

6.5.2 Portable fuel tanks shall be located in dedicated areas fitted with:

- .1 mechanical protection of the tanks depending on location and cargo operations;
- .2 if located on open deck: spill protection and water spray systems for cooling; and
- .3 if located in an enclosed space: the space is to be considered as a tank connection space.

6.5.3 Portable fuel tanks shall be secured to the deck while connected to the ship systems. The arrangement for supporting and fixing the tanks shall be designed for the maximum expected static and dynamic inclinations, as well as the maximum expected values of acceleration, taking into account the ship characteristics and the position of the tanks.

6.5.4 Consideration shall be given to the strength and the effect of the portable fuel tanks on the ship's stability.

6.5.5 Connections to the ship's fuel piping systems shall be made by means of approved flexible hoses or other suitable means designed to provide sufficient flexibility.

6.5.6 Arrangements shall be provided to limit the quantity of fuel spilled in case of inadvertent disconnection or rupture of the non-permanent connections.

6.5.7 The pressure relief system of portable tanks shall be connected to a fixed venting system.

6.5.8 Control and monitoring systems for portable fuel tanks shall be integrated in the ship's control and monitoring system. Safety system for portable fuel tanks shall be integrated in the ship's safety system (e.g. shutdown systems for tank valves, leak/gas detection systems).

6.5.9 Safe access to tank connections for the purpose of inspection and maintenance shall be ensured.

6.5.10 After connection to the ship's fuel piping system,

- .1 with the exception of the pressure relief system in 6.5.6 each portable tank shall be capable of being isolated at any time;
- .2 isolation of one tank shall not impair the availability of the remaining portable tanks; and
- .3 the tank shall not exceed its filling limits as given in 6.8.

6.6 Regulations for CNG fuel containment

6.6.1 The storage tanks to be used for CNG shall be certified and approved by the Administration.

6.6.2 Tanks for CNG shall be fitted with pressure relief valves with a set point below the design pressure of the tank and with outlet located as required in 6.7.2.7 and 6.7.2.8.

6.6.3 Adequate means shall be provided to depressurize the tank in case of a fire which can affect the tank.

6.6.4 Storage of CNG in enclosed spaces is normally not acceptable, but may be permitted after special consideration and approval by the Administration provided the following is fulfilled in addition to 6.3.4 to 6.3.6:

- .1 adequate means are provided to depressurize and inert the tank in case of a fire which can affect the tank;
- .2 all surfaces within such enclosed spaces containing the CNG storage are provided with suitable thermal protection against any lost high-pressure gas and resulting condensation unless the bulkheads are designed for the lowest temperature that can arise from gas expansion leakage; and

- .3 a fixed fire-extinguishing system is installed in the enclosed spaces containing the CNG storage. Special consideration should be given to the extinguishing of jet-fires.

6.7 Regulations for pressure relief system

6.7.1 General

6.7.1.1 All fuel storage tanks shall be provided with a pressure relief system appropriate to the design of the fuel containment system and the fuel being carried. Fuel storage hold spaces, interbarrier spaces, tank connection spaces and tank cofferdams, which may be subject to pressures beyond their design capabilities, shall also be provided with a suitable pressure relief system. Pressure control systems specified in 6.9 shall be independent of the pressure relief systems.

6.7.1.2 Fuel storage tanks which may be subject to external pressures above their design pressure shall be fitted with vacuum protection systems.

6.7.2 Pressure relief systems for liquefied gas fuel tanks

6.7.2.1 If fuel release into the vacuum space of a vacuum insulated tank cannot be excluded, the vacuum space shall be protected by a pressure relief device which shall be connected to a vent system if the tanks are located below deck. On open deck a direct release into the atmosphere may be accepted by the Administration for tanks not exceeding the size of a 40 ft container if the released gas cannot enter safe areas.

6.7.2.2 Liquefied gas fuel tanks shall be fitted with a minimum of 2 pressure relief valves (PRVs) allowing for disconnection of one PRV in case of malfunction or leakage.

6.7.2.3 Interbarrier spaces shall be provided with pressure relief devices. For membrane systems, the designer shall demonstrate adequate sizing of interbarrier space PRVs.

6.7.2.4 The setting of the PRVs shall not be higher than the vapour pressure that has been used in the design of the tank. Valves comprising not more than 50% of the total relieving capacity may be set at a pressure up to 5% above MARVS to allow sequential lifting, minimizing unnecessary release of vapour.

6.7.2.5 The following temperature regulations apply to PRVs fitted to pressure relief systems:

- .1 PRVs on fuel tanks with a design temperature below 0°C shall be designed and arranged to prevent their becoming inoperative due to ice formation;
- .2 the effects of ice formation due to ambient temperatures shall be considered in the construction and arrangement of PRVs;
- .3 PRVs shall be constructed of materials with a melting point above 925°C. Lower melting point materials for internal parts and seals may be accepted provided that fail-safe operation of the PRV is not compromised; and
- .4 sensing and exhaust lines on pilot operated relief valves shall be of suitably robust construction to prevent damage.

6.7.2.6 In the event of a failure of a fuel tank PRV a safe means of emergency isolation shall be available.

- .1 procedures shall be provided and included in the operation manual (refer to chapter 18);

- .2 the procedures shall allow only one of the installed PRVs for the liquefied gas fuel tanks to be isolated, physical interlocks shall be included to this effect; and
- .3 isolation of the PRV shall be carried out under the supervision of the master. This action shall be recorded in the ship's log, and at the PRV.

6.7.2.7 Each pressure relief valve installed on a liquefied gas fuel tank shall be connected to a venting system, which shall be:

- .1 so constructed that the discharge will be unimpeded and normally be directed vertically upwards at the exit;
- .2 arranged to minimize the possibility of water or snow entering the vent system; and
- .3 arranged such that the height of vent exits shall normally not be less than B/3 or 6 m, whichever is the greater, above the weather deck and 6 m above working areas and walkways. However, vent mast height could be limited to lower value according to special consideration by the Administration.

6.7.2.8 The outlet from the pressure relief valves shall normally be located at least 10 m from the nearest:

- .1 air intake, air outlet or opening to accommodation, service and control spaces, or other non-hazardous area; and
- .2 exhaust outlet from machinery installations.

6.7.2.9 All other fuel gas vent outlets shall also be arranged in accordance with 6.7.2.7 and 6.7.2.8. Means shall be provided to prevent liquid overflow from gas vent outlets, due to hydrostatic pressure from spaces to which they are connected.

6.7.2.10 In the vent piping system, means for draining liquid from places where it may accumulate shall be provided. The PRVs and piping shall be arranged so that liquid can, under no circumstances, accumulate in or near the PRVs.

6.7.2.11 Suitable protection screens of not more than 13 mm square mesh shall be fitted on vent outlets to prevent the ingress of foreign objects without adversely affecting the flow.

6.7.2.12 All vent piping shall be designed and arranged not to be damaged by the temperature variations to which it may be exposed, forces due to flow or the ship's motions.

6.7.2.13 PRVs shall be connected to the highest part of the fuel tank. PRVs shall be positioned on the fuel tank so that they will remain in the vapour phase at the filling limit (FL) as given in 6.8, under conditions of 15° list and 0.015L trim, where L is defined in 2.2.25.

6.7.3 Sizing of pressure relieving system

6.7.3.1 Sizing of pressure relief valves

6.7.3.1.1 PRVs shall have a combined relieving capacity for each liquefied gas fuel tank to discharge the greater of the following, with not more than a 20% rise in liquefied gas fuel tank pressure above the MARVS:

- .1 the maximum capacity of the liquefied gas fuel tank inerting system if the maximum attainable working pressure of the liquefied gas fuel tank inerting system exceeds the MARVS of the liquefied gas fuel tanks; or

.2 vapours generated under fire exposure computed using the following formula:

$$Q = FGA^{0.82} \text{ (m}^3\text{/s)}$$

where:

Q = minimum required rate of discharge of air at standard conditions of 273.15 Kelvin (K) and 0.1013 MPa.

F = fire exposure factor for different liquefied gas fuel types:

F = 1.0 for tanks without insulation located on deck;

F = 0.5 for tanks above the deck when insulation is approved by the Administration. (Approval will be based on the use of a fireproofing material, the thermal conductance of insulation, and its stability under fire exposure);

F = 0.5 for uninsulated independent tanks installed in holds;

F = 0.2 for insulated independent tanks in holds (or uninsulated independent tanks in insulated holds);

F = 0.1 for insulated independent tanks in inerted holds (or uninsulated independent tanks in inerted, insulated holds); and

F = 0.1 for membrane tanks.

For independent tanks partly protruding through the weather decks, the fire exposure factor shall be determined on the basis of the surface areas above and below deck.

G = gas factor according to formula:

$$G = \frac{12.4}{LD} \sqrt{\frac{ZT}{M}}$$

where:

T = temperature in Kelvin at relieving conditions, i.e. 120% of the pressure at which the pressure relief valve is set;

L = latent heat of the material being vaporized at relieving conditions, in kJ/kg;

D = a constant based on relation of specific heats k and is calculated as follows:

$$D = \sqrt{k \left(\frac{2}{k+1} \right)^{\frac{k+1}{k-1}}}$$

where:

k = ratio of specific heats at relieving conditions, and the value of which is between 1.0 and 2.2. If k is not known, $D = 0.606$ shall be used;

Z = compressibility factor of the gas at relieving conditions; if not known, $Z = 1.0$ shall be used;

M = molecular mass of the product.

The gas factor of each liquefied gas fuel to be carried is to be determined and the highest value shall be used for PRV sizing.

A = external surface area of the tank (m^2), as for different tank types, as shown in figure 6.7.1.

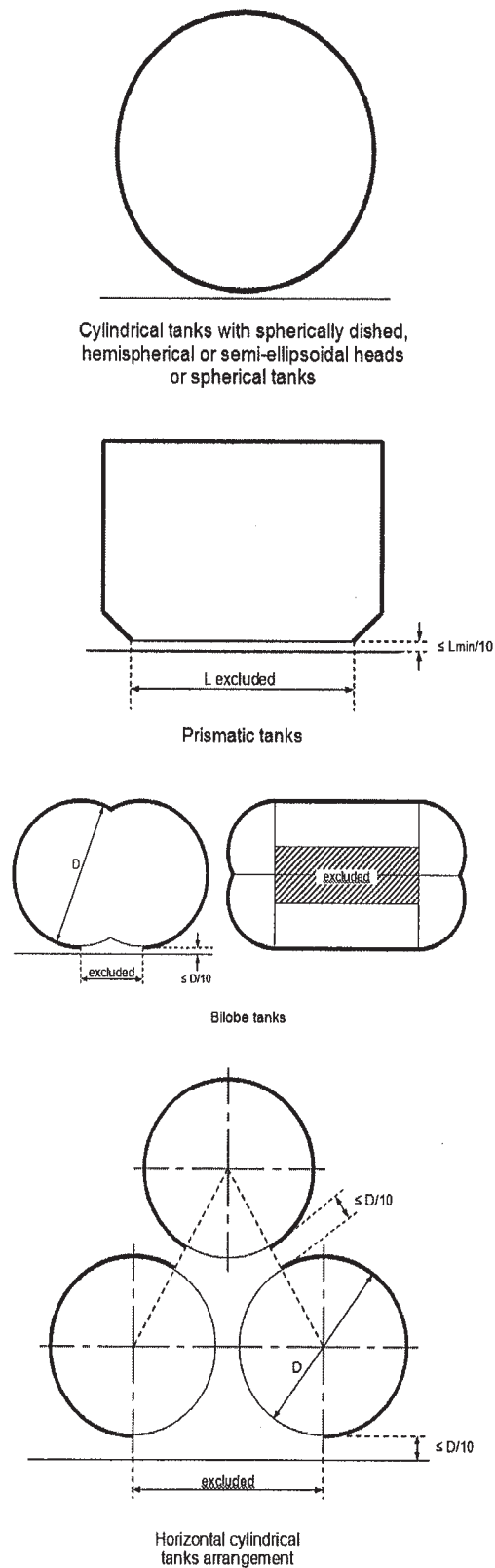


Figure 6.7.1

6.7.3.1.2 For vacuum insulated tanks in fuel storage hold spaces and for tanks in fuel storage hold spaces separated from potential fire loads by coffer dams or surrounded by ship spaces with no fire load the following applies:

If the pressure relief valves have to be sized for fire loads the fire factors according may be reduced to the following values:

$$F = 0.5 \text{ to } F = 0.25$$

$$F = 0.2 \text{ to } F = 0.1$$

The minimum fire factor is $F = 0.1$

6.7.3.1.3 The required mass flow of air at relieving conditions is given by:

$$M_{air} = Q * \rho_{air} \text{ (kg/s)}$$

where density of air (ρ_{air}) = 1.293 kg/m³ (air at 273.15 K, 0.1013 MPa).

6.7.3.2 Sizing of vent pipe system

6.7.3.2.1 Pressure losses upstream and downstream of the PRVs, shall be taken into account when determining their size to ensure the flow capacity required by 6.7.3.1.

6.7.3.2.2 Upstream pressure losses

- .1 the pressure drop in the vent line from the tank to the PRV inlet shall not exceed 3% of the valve set pressure at the calculated flow rate, in accordance with 6.7.3.1;
- .2 pilot-operated PRVs shall be unaffected by inlet pipe pressure losses when the pilot senses directly from the tank dome; and
- .3 pressure losses in remotely sensed pilot lines shall be considered for flowing type pilots.

6.7.3.2.3 Downstream pressure losses

- .1 Where common vent headers and vent masts are fitted, calculations shall include flow from all attached PRVs.
- .2 The built-up back pressure in the vent piping from the PRV outlet to the location of discharge to the atmosphere, and including any vent pipe interconnections that join other tanks, shall not exceed the following values:
 - .1 for unbalanced PRVs: 10% of MARVS;
 - .2 for balanced PRVs: 30% of MARVS; and
 - .3 for pilot operated PRVs: 50% of MARVS.

Alternative values provided by the PRV manufacturer may be accepted.

6.7.3.2.4 To ensure stable PRV operation, the blow-down shall not be less than the sum of the inlet pressure loss and 0.02 MARVS at the rated capacity.

6.8 Regulations on loading limit for liquefied gas fuel tanks

6.8.1 Storage tanks for liquefied gas shall not be filled to more than a volume equivalent to 98% full at the reference temperature as defined in 2.2.36.

A loading limit curve for actual fuel loading temperatures shall be prepared from the following formula:

$$LL = FL \rho_R / \rho_L$$

where:

LL = loading limit as defined in 2.2.27, expressed in per cent;

FL = filling limit as defined in 2.2.16 expressed in per cent, here 98%;

ρ_R = relative density of fuel at the reference temperature; and

ρ_L = relative density of fuel at the loading temperature.

6.8.2 In cases where the tank insulation and tank location make the probability very small for the tank contents to be heated up due to an external fire, special considerations may be made to allow a higher loading limit than calculated using the reference temperature, but never above 95%. This also applies in cases where a second system for pressure maintenance is installed, (refer to 6.9). However, if the pressure can only be maintained / controlled by fuel consumers, the loading limit as calculated in 6.8.1 shall be used.

6.9 Regulations for the maintaining of fuel storage condition

6.9.1 Control of tank pressure and temperature

6.9.1.1 With the exception of liquefied gas fuel tanks designed to withstand the full gauge vapour pressure of the fuel under conditions of the upper ambient design temperature, liquefied gas fuel tanks' pressure and temperature shall be maintained at all times within their design range by means acceptable to the Administration, e.g. by one of the following methods:

- .1 reliquefaction of vapours;
- .2 thermal oxidation of vapours;
- .3 pressure accumulation; or
- .4 liquefied gas fuel cooling.

The method chosen shall be capable of maintaining tank pressure below the set pressure of the tank pressure relief valves for a period of 15 days assuming full tank at normal service pressure and the ship in idle condition, i.e. only power for domestic load is generated.

6.9.1.2 Venting of fuel vapour for control of the tank pressure is not acceptable except in emergency situations.

6.9.2 Design of systems

6.9.2.1 For worldwide service, the upper ambient design temperature shall be sea 32°C and air 45°C. For service in particularly hot or cold zones, these design temperatures shall be increased or decreased, to the satisfaction of the Administration.

6.9.2.2 The overall capacity of the system shall be such that it can control the pressure within the design conditions without venting to atmosphere.

6.9.3 Reliquefaction systems

6.9.3.1 The reliquefaction system shall be designed and calculated according to 6.9.3.2. The system has to be sized in a sufficient way also in case of no or low consumption.

6.9.3.2 The reliquefaction system shall be arranged in one of the following ways:

- .1 a direct system where evaporated fuel is compressed, condensed and returned to the fuel tanks;
- .2 an indirect system where fuel or evaporated fuel is cooled or condensed by refrigerant without being compressed;
- .3 a combined system where evaporated fuel is compressed and condensed in a fuel/refrigerant heat exchanger and returned to the fuel tanks; or
- .4 if the reliquefaction system produces a waste stream containing methane during pressure control operations within the design conditions, these waste gases shall, as far as reasonably practicable, be disposed of without venting to atmosphere.

6.9.4 Thermal oxidation systems

6.9.4.1 Thermal oxidation can be done by either consumption of the vapours according to the regulations for consumers described in this Code or in a dedicated gas combustion unit (GCU). It shall be demonstrated that the capacity of the oxidation system is sufficient to consume the required quantity of vapours. In this regard, periods of slow steaming and/or no consumption from propulsion or other services of the ship shall be considered.

6.9.5 Compatibility

6.9.5.1 Refrigerants or auxiliary agents used for refrigeration or cooling of fuel shall be compatible with the fuel they may come in contact with (not causing any hazardous reaction or excessively corrosive products). In addition, when several refrigerants or agents are used, these shall be compatible with each other.

6.9.6 Availability of systems

6.9.6.1 The availability of the system and its supporting auxiliary services shall be such that in case of a single failure (of mechanical non-static component or a component of the control systems) the fuel tank pressure and temperature can be maintained by another service/system.

6.9.6.2 Heat exchangers that are solely necessary for maintaining the pressure and temperature of the fuel tanks within their design ranges shall have a standby heat exchanger unless they have a capacity in excess of 25% of the largest required capacity for pressure control and they can be repaired on board without external sources.

6.10 Regulations on atmospheric control within the fuel containment system

6.10.1 A piping system shall be arranged to enable each fuel tank to be safely gas-freed, and to be safely filled with fuel from a gas-free condition. The system shall be arranged to minimize the possibility of pockets of gas or air remaining after changing the atmosphere.

6.10.2 The system shall be designed to eliminate the possibility of a flammable mixture existing in the fuel tank during any part of the atmosphere change operation by utilizing an inerting medium as an intermediate step.

6.10.3 Gas sampling points shall be provided for each fuel tank to monitor the progress of atmosphere change.

6.10.4 Inert gas utilized for gas freeing of fuel tanks may be provided externally to the ship.

6.11 Regulations on atmosphere control within fuel storage hold spaces (Fuel containment systems other than type C independent tanks)

6.11.1 Interbarrier and fuel storage hold spaces associated with liquefied gas fuel containment systems requiring full or partial secondary barriers shall be inerted with a suitable dry inert gas and kept inerted with make-up gas provided by a shipboard inert gas generation system, or by shipboard storage, which shall be sufficient for normal consumption for at least 30 days. Shorter periods may be considered by the Administration depending on the ship's service.

6.11.2 Alternatively, the spaces referred to in 6.11.1 requiring only a partial secondary barrier may be filled with dry air provided that the ship maintains a stored charge of inert gas or is fitted with an inert gas generation system sufficient to inert the largest of these spaces, and provided that the configuration of the spaces and the relevant vapour detection systems, together with the capability of the inerting arrangements, ensures that any leakage from the liquefied gas fuel tanks will be rapidly detected and inerting effected before a dangerous condition can develop. Equipment for the provision of sufficient dry air of suitable quality to satisfy the expected demand shall be provided.

6.12 Regulations on environmental control of spaces surrounding type C independent tanks

6.12.1 Spaces surrounding liquefied gas fuel tanks shall be filled with suitable dry air and be maintained in this condition with dry air provided by suitable air drying equipment. This is only applicable for liquefied gas fuel tanks where condensation and icing due to cold surfaces is an issue.

6.13 Regulations on inerting

6.13.1 Arrangements to prevent back-flow of fuel vapour into the inert gas system shall be provided as specified below.

6.13.2 To prevent the return of flammable gas to any non-hazardous spaces, the inert gas supply line shall be fitted with two shutoff valves in series with a venting valve in between (double block and bleed valves). In addition, a closable non-return valve shall be installed between the double block and bleed arrangement and the fuel system. These valves shall be located outside non-hazardous spaces.

6.13.3 Where the connections to the fuel piping systems are non-permanent, two non-return valves may be substituted for the valves required in 6.13.2.

6.13.4 The arrangements shall be such that each space being inerted can be isolated and the necessary controls and relief valves, etc. shall be provided for controlling pressure in these spaces.

6.13.5 Where insulation spaces are continually supplied with an inert gas as part of a leak detection system, means shall be provided to monitor the quantity of gas being supplied to individual spaces.

6.14 Regulations on inert gas production and storage on board

6.14.1 The equipment shall be capable of producing inert gas with oxygen content at no time greater than 5% by volume. A continuous-reading oxygen content meter shall be fitted to the

inert gas supply from the equipment and shall be fitted with an alarm set at a maximum of 5% oxygen content by volume.

6.14.2 An inert gas system shall have pressure controls and monitoring arrangements appropriate to the fuel containment system.

6.14.3 Where a nitrogen generator or nitrogen storage facilities are installed in a separate compartment outside of the engine-room, the separate compartment shall be fitted with an independent mechanical extraction ventilation system, providing a minimum of 6 air changes per hour. A low oxygen alarm shall be fitted.

6.14.4 Nitrogen pipes shall only be led through well ventilated spaces. Nitrogen pipes in enclosed spaces shall:

- be fully welded;
- have only a minimum of flange connections as needed for fitting of valves; and
- be as short as possible.

7 MATERIAL AND GENERAL PIPE DESIGN

7.1 Goal

7.1.1 The goal of this chapter is to ensure the safe handling of fuel, under all operating conditions, to minimize the risk to the ship, personnel and to the environment, having regard to the nature of the products involved.

7.2 Functional requirements

7.2.1 This chapter relates to functional requirements in 3.2.1, 3.2.5, 3.2.6, 3.2.8, 3.2.9 and 3.2.10. In particular the following apply:

7.2.1.1 Fuel piping shall be capable of absorbing thermal expansion or contraction caused by extreme temperatures of the fuel without developing substantial stresses.

7.2.1.2 Provision shall be made to protect the piping, piping system and components and fuel tanks from excessive stresses due to thermal movement and from movements of the fuel tank and hull structure.

7.2.1.3 If the fuel gas contains heavier constituents that may condense in the system, means for safely removing the liquid shall be fitted.

7.2.1.4 Low temperature piping shall be thermally isolated from the adjacent hull structure, where necessary, to prevent the temperature of the hull from falling below the design temperature of the hull material.

7.3 Regulations for general pipe design

7.3.1 General

7.3.1.1 Fuel pipes and all the other piping needed for a safe and reliable operation and maintenance shall be colour marked in accordance with a standard at least equivalent to those acceptable to the Organization.

7.3.1.2 Where tanks or piping are separated from the ship's structure by thermal isolation, provision shall be made for electrically bonding to the ship's structure both the piping and the tanks. All gasketed pipe joints and hose connections shall be electrically bonded.

7.3.1.3 All pipelines or components which may be isolated in a liquid full condition shall be provided with relief valves.

7.3.1.4 Pipework, which may contain low temperature fuel, shall be thermally insulated to an extent which will minimize condensation of moisture.

7.3.1.5 Piping other than fuel supply piping and cabling may be arranged in the double wall piping or duct provided that they do not create a source of ignition or compromise the integrity of the double pipe or duct. The double wall piping or duct shall only contain piping or cabling necessary for operational purposes.

7.3.2 Wall thickness

7.3.2.1 The minimum wall thickness shall be calculated as follows:

$$t = (t_0 + b + c) / (1 - a/100) \text{ (mm)}$$

where:

t_0 = theoretical thickness

$$t_0 = PD / (2.0Ke + P) \text{ (mm)}$$

with:

P = design pressure (MPa) referred to in 7.3.3;

D = outside diameter (mm);

K = allowable stress (N/mm²) referred to in 7.3.4; and

e = efficiency factor equal to 1.0 for seamless pipes and for longitudinally or spirally welded pipes, delivered by approved manufacturers of welded pipes, that are considered equivalent to seamless pipes when non-destructive testing on welds is carried out in accordance with recognized standards. In other cases an efficiency factor of less than 1.0, in accordance with recognized standards, may be required depending on the manufacturing process;

b = allowance for bending (mm). The value of b shall be chosen so that the calculated stress in the bend, due to internal pressure only, does not exceed the allowable stress. Where such justification is not given, b shall be:

$$b = D \cdot t_0 / 2.5r \text{ (mm)}$$

with:

r = mean radius of the bend (mm);

- c = corrosion allowance (mm). If corrosion or erosion is expected the wall thickness of the piping shall be increased over that required by other design regulations. This allowance shall be consistent with the expected life of the piping; and
- a = negative manufacturing tolerance for thickness (%).

7.3.2.2 The absolute minimum wall thickness shall be in accordance with a standard acceptable to the Administration.

7.3.3 *Design condition*

7.3.3.1 The greater of the following design conditions shall be used for piping, piping system and components as appropriate:

- .1 for systems or components which may be separated from their relief valves and which contain only vapour at all times, vapour pressure at 45°C assuming an initial condition of saturated vapour in the system at the system operating pressure and temperature; or
- .2 the MARVS of the fuel tanks and fuel processing systems; or
- .3 the pressure setting of the associated pump or compressor discharge relief valve; or
- .4 the maximum total discharge or loading head of the fuel piping system; or
- .5 the relief valve setting on a pipeline system.

7.3.3.2 Piping, piping systems and components shall have a minimum design pressure of 1.0 MPa except for open ended lines where it is not to be less than 0.5 MPa.

7.3.4 *Allowable stress*

7.3.4.1 For pipes made of steel including stainless steel, the allowable stress to be considered in the formula of the strength thickness in 7.3.2.1 shall be the lower of the following values:

$$R_m/2.7 \text{ or } R_e/1.8$$

where:

R_m = specified minimum tensile strength at room temperature (N/mm²); and

R_e = specified minimum yield stress at room temperature (N/mm²). If the stress strain curve does not show a defined yield stress, the 0.2% proof stress applies.

7.3.4.2 Where necessary for mechanical strength to prevent damage, collapse, excessive sag or buckling of pipes due to superimposed loads, the wall thickness shall be increased over that required by 7.3.2 or, if this is impracticable or would cause excessive local stresses, these loads shall be reduced, protected against or eliminated by other design methods. Such superimposed loads may be due to; supports, ship deflections, liquid pressure surge during transfer operations, the weight of suspended valves, reaction to loading arm connections, or otherwise.

7.3.4.3 For pipes made of materials other than steel, the allowable stress shall be considered by the Administration.

7.3.4.4 High pressure fuel piping systems shall have sufficient constructive strength. This shall be confirmed by carrying out stress analysis and taking into account:

- .1 stresses due to the weight of the piping system;
- .2 acceleration loads when significant; and
- .3 internal pressure and loads induced by hog and sag of the ship.

7.3.4.5 When the design temperature is minus 110°C or colder, a complete stress analysis, taking into account all the stresses due to weight of pipes, including acceleration loads if significant, internal pressure, thermal contraction and loads induced by hog and sag of the ship shall be carried out for each branch of the piping system.

7.3.5 Flexibility of piping

7.3.5.1 The arrangement and installation of fuel piping shall provide the necessary flexibility to maintain the integrity of the piping system in the actual service situations, taking potential for fatigue into account.

7.3.6 Piping fabrication and joining details

7.3.6.1 Flanges, valves and other fittings shall comply with a standard acceptable to the Administration, taking into account the design pressure defined in 7.3.3.1. For bellows and expansion joints used in vapour service, a lower minimum design pressure than defined in 7.3.3.1 may be accepted.

7.3.6.2 All valves and expansion joints used in high pressure fuel piping systems shall be approved according to a standard acceptable to the Administration.

7.3.6.3 The piping system shall be joined by welding with a minimum of flange connections. Gaskets shall be protected against blow-out.

7.3.6.4 Piping fabrication and joining details shall comply with the following:

7.3.6.4.1 Direct connections

- .1 Butt-welded joints with complete penetration at the root may be used in all applications. For design temperatures colder than minus 10°C, butt welds shall be either double welded or equivalent to a double welded butt joint. This may be accomplished by use of a backing ring, consumable insert or inert gas back-up on the first pass. For design pressures in excess of 1.0 MPa and design temperatures of minus 10°C or colder, backing rings shall be removed.
- .2 Slip-on welded joints with sleeves and related welding, having dimensions in accordance with recognized standards, shall only be used for instrument lines and open-ended lines with an external diameter of 50 mm or less and design temperatures not colder than minus 55°C.
- .3 Screwed couplings complying with recognized standards shall only be used for accessory lines and instrumentation lines with external diameters of 25 mm or less.

7.3.6.4.2 Flanged connections

- .1 Flanges in flange connections shall be of the welded neck, slip-on or socket welded type; and
- .2 For all piping except open ended, the following restrictions apply:
 - .1 For design temperatures colder than minus 55°C, only welded neck flanges shall be used; and
 - .2 For design temperatures colder than minus 10°C, slip-on flanges shall not be used in nominal sizes above 100 mm and socket welded flanges shall not be used in nominal sizes above 50 mm.

7.3.6.4.3 Expansion joints

Where bellows and expansion joints are provided in accordance with 7.3.6.1 the following apply:

- .1 if necessary, bellows shall be protected against icing;
- .2 slip joints shall not be used except within the liquefied gas fuel storage tanks; and
- .3 bellows shall normally not be arranged in enclosed spaces.

7.3.6.4.4 Other connections

Piping connections shall be joined in accordance with 7.3.6.4.1 to 7.3.6.4.3 but for other exceptional cases the Administration may consider alternative arrangements.

7.4 Regulations for materials

7.4.1 Metallic materials

7.4.1.1 Materials for fuel containment and piping systems shall comply with the minimum regulations given in the following tables:

Table 7.1: Plates, pipes (seamless and welded), sections and forgings for fuel tanks and process pressure vessels for design temperatures not lower than 0°C.

Table 7.2: Plates, sections and forgings for fuel tanks, secondary barriers and process pressure vessels for design temperatures below 0°C and down to minus 55°C.

Table 7.3: Plates, sections and forgings for fuel tanks, secondary barriers and process pressure vessels for design temperatures below minus 55°C and down to minus 165°C.

Table 7.4: Pipes (seamless and welded), forgings and castings for fuel and process piping for design temperatures below 0°C and down to minus 165°C.

Table 7.5: Plates and sections for hull structures required by 6.4.13.1.1.2.

Table 7.1

PLATES, PIPES (SEAMLESS AND WELDED) ^{1, 2} , SECTIONS AND FORGINGS FOR FUEL TANKS AND PROCESS PRESSURE VESSELS FOR DESIGN TEMPERATURES NOT LOWER THAN 0°C		
CHEMICAL COMPOSITION AND HEAT TREATMENT		
◆ Carbon-manganese steel		
◆ Fully killed fine grain steel		
◆ Small additions of alloying elements by agreement with the Administration		
◆ Composition limits to be approved by the Administration		
◆ Normalized, or quenched and tempered ⁴		
TENSILE AND TOUGHNESS (IMPACT) TEST REGULATIONS		
Sampling frequency		
◆ Plates	Each "piece" to be tested	
◆ Sections and forgings	Each "batch" to be tested.	
Mechanical properties		
◆ Tensile properties	Specified minimum yield stress not to exceed 410 N/mm ^{2 5}	
Toughness (Charpy V-notch test)		
◆ Plates	Transverse test pieces. Minimum average energy value (KV) 27J	
◆ Sections and forgings	Longitudinal test pieces. Minimum average energy (KV) 41J	
◆ Test temperature	Thickness t (mm)	Test temperature (°C)
	T ≤ 20	0
	20 < t ≤40 ³	-20
Notes		
1. For seamless pipes and fittings normal practice applies. The use of longitudinally and spirally welded pipes shall be specially approved by the Administration.		
2. Charpy V-notch impact tests are not required for pipes.		
3. This Table is generally applicable for material thicknesses up to 40 mm. Proposals for greater thicknesses shall be approved by the Administration.		
4. A controlled rolling procedure or thermo-mechanical controlled processing (TMCP) may be used as an alternative.		
5. Materials with specified minimum yield stress exceeding 410 N/mm ² may be approved by the Administration. For these materials, particular attention shall be given to the hardness of the welded and heat affected zones.		

Table 7.2

PLATES, SECTIONS AND FORGINGS ¹ FOR FUEL TANKS, SECONDARY BARRIERS AND PROCESS PRESSURE VESSELS FOR DESIGN TEMPERATURES BELOW 0°C AND DOWN TO MINUS 55°C Maximum thickness 25 mm ²				
CHEMICAL COMPOSITION AND HEAT TREATMENT				
◆ Carbon-manganese steel				
◆ Fully killed, aluminium treated fine grain steel				
◆ Chemical composition (ladle analysis)				
C	Mn	Si	S	P
0.16% max. ³	0.70-1.60%	0.10-0.50%	0.025% max.	0.025% max.
Optional additions: Alloys and grain refining elements may be generally in accordance with the following				
Ni	Cr	Mo	Cu	Nb
0.80% max.	0.25% max.	0.08% max.	0.35% max.	0.05% max.
V				
0.10% max.				
Al content total 0.020% min. (Acid soluble 0.015% min.)				
◆ Normalized, or quenched and tempered ⁴				
TENSILE AND TOUGHNESS (IMPACT) TEST REGULATIONS				
Sampling frequency				
◆ Plates	Each 'piece' to be tested			
◆ Sections and forgings	Each 'batch' to be tested			
Mechanical properties				
◆ Tensile properties	Specified minimum yield stress not to exceed 410 N/mm ² . ⁵			
Toughness (Charpy V-notch test)				
◆ Plates	Transverse test pieces. Minimum average energy value (KV) 27J			
◆ Sections and forgings	Longitudinal test pieces. Minimum average energy (KV) 41J			
◆ Test temperature	5°C below the design temperature or -20°C whichever is lower			
Notes				
1. The Charpy V-notch and chemistry regulations for forgings may be specially considered by the Administration.				
2. For material thickness of more than 25 mm, Charpy V-notch tests shall be conducted as follows:				
Material thickness (mm)		Test temperature (°C)		
25 < t ≤ 30		10°C below design temperature or -20°C whichever is lower		
30 < t ≤ 35		15°C below design temperature or -20°C whichever is lower		
35 < t ≤ 40		20°C below design temperature		
40 < t		Temperature approved by the Administration		
The impact energy value shall be in accordance with the table for the applicable type of test specimen. Materials for tanks and parts of tanks which are completely thermally stress relieved after welding may be tested at a temperature 5°C below design temperature or -20°C whichever is lower.				
For thermally stress relieved reinforcements and other fittings, the test temperature shall be the same as that required for the adjacent tank-shell thickness.				
3. By special agreement with the Administration, the carbon content may be increased to 0.18% maximum provided the design temperature is not lower than -40°C				
4. A controlled rolling procedure or thermo-mechanical controlled processing (TMCP) may be used as an alternative.				
5. Materials with specified minimum yield stress exceeding 410 N/mm ² may be approved by the Administration. For these materials, particular attention shall be given to the hardness of the welded and heat affected zones.				
Guidance:				
For materials exceeding 25 mm in thickness for which the test temperature is -60°C or lower, the application of specially treated steels or steels in accordance with table 7.3 may be necessary.				

Table 7.3

PLATES, SECTIONS AND FORGINGS ¹ FOR FUEL TANKS, SECONDARY BARRIERS AND PROCESS PRESSURE VESSELS FOR DESIGN TEMPERATURES BELOW MINUS 55°C AND DOWN TO MINUS 165°C ² Maximum thickness 25 mm ^{3, 4}										
Minimum design temp. (°C)	Chemical composition ⁵ and heat treatment	Impact test temp. (°C)								
-60	1.5% nickel steel – normalized or normalized and tempered or quenched and tempered or TMCP ^{see note 6}	-65								
-65	2.25% nickel steel – normalized or normalized and tempered or quenched and tempered or TMCP ^{6, 7}	-70								
-90	3.5% nickel steel – normalized or normalized and tempered or quenched and tempered or TMCP ^{6, 7}	-95								
-105	5% nickel steel – normalized or normalized and tempered or quenched and tempered ^{6, 7 and 8}	-110								
-165	9% nickel steel – double normalized and tempered or quenched and tempered ⁶	-196								
-165	Austenitic steels, such as types 304, 304L, 316, 316L, 321 and 347 solution treated ⁹	-196								
-165	Aluminium alloys; such as type 5083 annealed	Not required								
-165	Austenitic Fe-Ni alloy (36% nickel) Heat treatment as agreed	Not required								
TENSILE AND TOUGHNESS (IMPACT) TEST REGULATIONS										
Sampling frequency										
◆ Plates	Each 'piece' to be tested									
◆ Sections and forgings	Each 'batch' to be tested									
Toughness (Charpy V-notch test)										
◆ Plates	Transverse test pieces. Minimum average energy value (KV) 27J									
◆ Sections and forgings	Longitudinal test pieces. Minimum average energy (KV) 41J									
Notes										
1. The impact test required for forgings used in critical applications shall be subject to special consideration by the Administration.										
2. The regulations for design temperatures below –165°C shall be specially agreed with the Administration.										
3. For materials 1.5% Ni, 2.25% Ni, 3.5% Ni and 5% Ni, with thicknesses greater than 25 mm, the impact tests shall be conducted as follows:										
<table><tr><th>Material thickness (mm)</th><th>Test temperature (°C)</th></tr><tr><td>25 < t ≤ 30</td><td>10°C below design temperature</td></tr><tr><td>30 < t ≤ 35</td><td>15°C below design temperature</td></tr><tr><td>35 < t ≤ 40</td><td>20°C below design temperature</td></tr></table>			Material thickness (mm)	Test temperature (°C)	25 < t ≤ 30	10°C below design temperature	30 < t ≤ 35	15°C below design temperature	35 < t ≤ 40	20°C below design temperature
Material thickness (mm)	Test temperature (°C)									
25 < t ≤ 30	10°C below design temperature									
30 < t ≤ 35	15°C below design temperature									
35 < t ≤ 40	20°C below design temperature									
The energy value shall be in accordance with the table for the applicable type of test specimen. For material thickness of more than 40 mm, the Charpy V-notch values shall be specially considered.										
4. For 9% Ni steels, austenitic stainless steels and aluminium alloys, thickness greater than 25 mm may be used.										
5. The chemical composition limits shall be in accordance with recognized standards.										
6. Thermo-mechanical controlled processing (TMCP) nickel steels will be subject to acceptance by the Administration.										
7. A lower minimum design temperature for quenched and tempered steels may be specially agreed with the Administration.										
8. A specially heat treated 5% nickel steel, for example triple heat treated 5% nickel steel, may be used down to –165°C, provided that the impact tests are carried out at –196°C.										
9. The impact test may be omitted subject to agreement with the Administration.										

PIPES (SEAMLESS AND WELDED)¹, FORGINGS² AND CASTINGS² FOR FUEL AND PROCESS PIPING FOR DESIGN TEMPERATURES BELOW 0°C AND DOWN TO MINUS 165°C³
Maximum thickness 25 mm

PLATES AND SECTIONS FOR HULL STRUCTURES REQUIRED BY 6.4.13.1.1.2								
Minimum design temperature of hull structure (°C)	Maximum thickness (mm) for steel grades							
	A	B	D	E	AH	DH	EH	FH
0 and above	Recognized Standards							
down to -5	15	25	30	50	25	45	50	50
down to -10	x	20	25	50	20	40	50	50
down to -20	x	x	20	50	x	30	50	50
down to -30	x	x	x	40	x	20	40	50
Below -30	In accordance with table 7.2 except that the thickness limitation given in table 7.2 and in footnote 2 of that table does not apply.							

Notes
 'x' means steel grade not to be used.

7.4.1.2 Materials having a melting point below 925°C shall not be used for piping outside the fuel tanks.

7.4.1.3 For CNG tanks, the use of materials not covered above may be specially considered by the Administration.

7.4.1.4 Where required the outer pipe or duct containing high pressure gas in the inner pipe shall as a minimum fulfil the material regulations for pipe materials with design temperature down to minus 55°C in table 7.4.

7.4.1.5 The outer pipe or duct around liquefied gas fuel pipes shall as a minimum fulfil the material regulations for pipe materials with design temperature down to minus 165°C in table 7.4.

8 BUNKERING

8.1 Goal

8.1.1 The goal of this chapter is to provide for suitable systems on board the ship to ensure that bunkering can be conducted without causing danger to persons, the environment or the ship.

8.2 Functional requirements

8.2.1 This chapter relates to functional requirements in 3.2.1 to 3.2.11 and 3.2.13 to 3.2.17. In particular the following apply:

8.2.1.1 The piping system for transfer of fuel to the storage tank shall be designed such that any leakage from the piping system cannot cause danger to personnel, the environment or the ship.

8.3 Regulations for bunkering station

8.3.1 General

8.3.1.1 The bunkering station shall be located on open deck so that sufficient natural ventilation is provided. Closed or semi-enclosed bunkering stations shall be subject to special consideration within the risk assessment.

8.3.1.2 Connections and piping shall be so positioned and arranged that any damage to the fuel piping does not cause damage to the ship's fuel containment system resulting in an uncontrolled gas discharge.

8.3.1.3 Arrangements shall be made for safe management of any spilled fuel.

8.3.1.4 Suitable means shall be provided to relieve the pressure and remove liquid contents from pump suctions and bunker lines. Liquid is to be discharged to the liquefied gas fuel tanks or other suitable location.

8.3.1.5 The surrounding hull or deck structures shall not be exposed to unacceptable cooling, in case of leakage of fuel.

8.3.1.6 For CNG bunkering stations, low temperature steel shielding shall be considered to determine if the escape of cold jets impinging on surrounding hull structure is possible.

8.3.2 Ships' fuel hoses

8.3.2.1 Liquid and vapour hoses used for fuel transfer shall be compatible with the fuel and suitable for the fuel temperature.

8.3.2.2 Hoses subject to tank pressure, or the discharge pressure of pumps or vapour compressors, shall be designed for a bursting pressure not less than five times the maximum pressure the hose can be subjected to during bunkering.

8.4 Regulations for manifold

8.4.1 The bunkering manifold shall be designed to withstand the external loads during bunkering. The connections at the bunkering station shall be of dry-disconnect type equipped with additional safety dry break-away coupling/self-sealing quick release. The couplings shall be of a standard type.

8.5 Regulations for bunkering system

8.5.1 An arrangement for purging fuel bunkering lines with inert gas shall be provided.

8.5.2 The bunkering system shall be so arranged that no gas is discharged to the atmosphere during filling of storage tanks.

8.5.3 A manually operated stop valve and a remote operated shutdown valve in series, or a combined manually operated and remote valve shall be fitted in every bunkering line close to the connecting point. It shall be possible to operate the remote valve in the control location for bunkering operations and/or from another safe location.

8.5.4 Means shall be provided for draining any fuel from the bunkering pipes upon completion of operation.

8.5.5 Bunkering lines shall be arranged for inerting and gas freeing. When not engaged in bunkering, the bunkering pipes shall be free of gas, unless the consequences of not gas freeing are evaluated and approved.

8.5.6 In case bunkering lines are arranged with a cross-over it shall be ensured by suitable isolation arrangements that no fuel is transferred inadvertently to the ship side not in use for bunkering.

8.5.7 A ship-shore link (SSL) or an equivalent means for automatic and manual ESD communication to the bunkering source shall be fitted.

8.5.8 If not demonstrated to be required at a higher value due to pressure surge considerations a default time as calculated in accordance with 16.7.3.7 from the trigger of the alarm to full closure of the remote operated valve required by 8.5.3 shall be adjusted.

9 FUEL SUPPLY TO CONSUMERS

9.1 Goal

The goal of this chapter is to ensure safe and reliable distribution of fuel to the consumers.

9.2 Functional requirements

This chapter is related to functional requirements in 3.2.1 to 3.2.6, 3.2.8 to 3.2.11 and 3.2.13 to 3.2.17. In particular the following apply:

- .1 the fuel supply system shall be so arranged that the consequences of any release of fuel will be minimized, while providing safe access for operation and inspection;
- .2 the piping system for fuel transfer to the consumers shall be designed in a way that a failure of one barrier cannot lead to a leak from the piping system into the surrounding area causing danger to the persons on board, the environment or the ship; and
- .3 fuel lines outside the machinery spaces shall be installed and protected so as to minimize the risk of injury to personnel and damage to the ship in case of leakage.

9.3 Regulations on redundancy of fuel supply

9.3.1 For single fuel installations the fuel supply system shall be arranged with full redundancy and segregation all the way from the fuel tanks to the consumer, so that a leakage in one system does not lead to an unacceptable loss of power.

9.3.2 For single fuel installations, the fuel storage shall be divided between two or more tanks. The tanks shall be located in separate compartments.

9.3.3 For type C tank only, one tank may be accepted if two completely separate tank connection spaces are installed for the one tank.

9.4 Regulations on safety functions of gas supply system

9.4.1 Fuel storage tank inlets and outlets shall be provided with valves located as close to the tank as possible. Valves required to be operated during normal operation which are not accessible shall be remotely operated. Tank valves whether accessible or not shall be automatically operated when the safety system required in 15.2.2 is activated.

9.4.2 The main gas supply line to each gas consumer or set of consumers shall be equipped with a manually operated stop valve and an automatically operated "master gas fuel valve" coupled in series or a combined manually and automatically operated valve. The valves shall be situated in the part of the piping that is outside the machinery space containing gas consumers, and placed as near as possible to the installation for heating the gas, if fitted. The master gas fuel valve shall automatically cut off the gas supply when activated by the safety system required in 15.2.2.

9.4.3 The automatic master gas fuel valve shall be operable from safe locations on escape routes inside a machinery space containing a gas consumer, the engine control room, if applicable; outside the machinery space, and from the navigation bridge.

9.4.4 Each gas consumer shall be provided with "double block and bleed" valves arrangement. These valves shall be arranged as outlined in .1 or .2 so that when the safety system required in 15.2.2 is activated this will cause the shutoff valves that are in series to close automatically and the bleed valve to open automatically and:

- .1 the two shutoff valves shall be in series in the gas fuel pipe to the gas consuming equipment. The bleed valve shall be in a pipe that vents to a safe

location in the open air that portion of the gas fuel piping that is between the two valves in series; or

- .2 the function of one of the shutoff valves in series and the bleed valve can be incorporated into one valve body, so arranged that the flow to the gas utilization unit will be blocked and the ventilation opened.

9.4.5 The two valves shall be of the fail-to-close type, while the ventilation valve shall be fail-to-open.

9.4.6 The double block and bleed valves shall also be used for normal stop of the engine.

9.4.7 In cases where the master gas fuel valve is automatically shutdown, the complete gas supply branch downstream of the double block and bleed valve shall be automatically ventilated assuming reverse flow from the engine to the pipe.

9.4.8 There shall be one manually operated shutdown valve in the gas supply line to each engine upstream of the double block and bleed valves to assure safe isolation during maintenance on the engine.

9.4.9 For single-engine installations and multi-engine installations, where a separate master valve is provided for each engine, the master gas fuel valve and the double block and bleed valve functions can be combined.

9.4.10 For each main gas supply line entering an ESD protected machinery space, and each gas supply line to high pressure installations means shall be provided for rapid detection of a rupture in the gas line in the engine-room. When rupture is detected a valve shall be automatically shut off. This valve shall be located in the gas supply line before it enters the engine-room or as close as possible to the point of entry inside the engine-room. It can be a separate valve or combined with other functions, e.g. the master valve.

9.5 Regulations for fuel distribution outside of machinery space

9.5.1 Where fuel pipes pass through enclosed spaces in the ship, they shall be protected by a secondary enclosure. This enclosure can be a ventilated duct or a double wall piping system. The duct or double wall piping system shall be mechanically underpressure ventilated with 30 air changes per hour, and gas detection as required in 15.8 shall be provided. Other solutions providing an equivalent safety level may also be accepted by the Administration.

9.5.2 The requirement in 9.5.1 need not be applied for fully welded fuel gas vent pipes led through mechanically ventilated spaces.

9.6 Regulations for fuel supply to consumers in gas-safe machinery spaces

9.6.1 Fuel piping in gas-safe machinery spaces shall be completely enclosed by a double pipe or duct fulfilling one of the following conditions:

- .1 the gas piping shall be a double wall piping system with the gas fuel contained in the inner pipe. The space between the concentric pipes shall be pressurized with inert gas at a pressure greater than the gas fuel pressure. Suitable alarms shall be provided to indicate a loss of inert gas pressure between the pipes. When the inner pipe contains high pressure gas, the system shall be so arranged that the pipe between the master gas valve and the engine is automatically purged with inert gas when the master gas valve is closed; or

- .2 the gas fuel piping shall be installed within a ventilated pipe or duct. The air space between the gas fuel piping and the wall of the outer pipe or duct shall be equipped with mechanical underpressure ventilation having a capacity of at least 30 air changes per hour. This ventilation capacity may be reduced to 10 air changes per hour provided automatic filling of the duct with nitrogen upon detection of gas is arranged for. The fan motors shall comply with the required explosion protection in the installation area. The ventilation outlet shall be covered by a protection screen and placed in a position where no flammable gas-air mixture may be ignited; or
- .3 other solutions providing an equivalent safety level may also be accepted by the Administration.

9.6.2 The connecting of gas piping and ducting to the gas injection valves shall be completely covered by the ducting. The arrangement shall facilitate replacement and/or overhaul of injection valves and cylinder covers. The double ducting is also required for all gas pipes on the engine itself, until gas is injected into the chamber.

9.7 Regulations for gas fuel supply to consumers in ESD-protected machinery spaces

- 9.7.1 The pressure in the gas fuel supply system shall not exceed 1.0 MPa.
- 9.7.2 The gas fuel supply lines shall have a design pressure not less than 1.0 MPa.

9.8 Regulations for the design of ventilated duct, outer pipe against inner pipe gas leakage

9.8.1 The design pressure of the outer pipe or duct of fuel systems shall not be less than the maximum working pressure of the inner pipe. Alternatively for fuel piping systems with a working pressure greater than 1.0 MPa, the design pressure of the outer pipe or duct shall not be less than the maximum built-up pressure arising in the annular space considering the local instantaneous peak pressure in way of any rupture and the ventilation arrangements.

9.8.2 For high-pressure fuel piping the design pressure of the ducting shall be taken as the higher of the following:

- .1 the maximum built-up pressure: static pressure in way of the rupture resulting from the gas flowing in the annular space;
- .2 local instantaneous peak pressure in way of the rupture: this pressure shall be taken as the critical pressure given by the following expression:

$$p = p_0 \left(\frac{2}{k+1} \right)^{\frac{k}{k-1}}$$

where:

p_0 = maximum working pressure of the inner pipe

k = C_p/C_v constant pressure specific heat divided by the constant volume specific heat

$k = 1.31$ for CH_4

The tangential membrane stress of a straight pipe shall not exceed the tensile strength divided by 1.5 ($R_m/1.5$) when subjected to the above pressures. The pressure ratings of all other piping components shall reflect the same level of strength as straight pipes.

As an alternative to using the peak pressure from the above formula, the peak pressure found from representative tests can be used. Test reports shall then be submitted.

9.8.3 Verification of the strength shall be based on calculations demonstrating the duct or pipe integrity. As an alternative to calculations, the strength can be verified by representative tests.

9.8.4 For low pressure fuel piping the duct shall be dimensioned for a design pressure not less than the maximum working pressure of the fuel pipes. The duct shall be pressure tested to show that it can withstand the expected maximum pressure at fuel pipe rupture.

9.9 Regulations for compressors and pumps

9.9.1 If compressors or pumps are driven by shafting passing through a bulkhead or deck, the bulkhead penetration shall be of gastight type.

9.9.2 Compressors and pumps shall be suitable for their intended purpose. All equipment and machinery shall be such as to be adequately tested to ensure suitability for use within a marine environment. Such items to be considered would include, but not be limited to:

- .1 environmental;
- .2 shipboard vibrations and accelerations;
- .3 effects of pitch, heave and roll motions, etc.; and
- .4 gas composition.

9.9.3 Arrangements shall be made to ensure that under no circumstances liquefied gas can be introduced in the gas control section or gas-fuelled machinery, unless the machinery is designed to operate with gas in liquid state.

9.9.4 Compressors and pumps shall be fitted with accessories and instrumentation necessary for efficient and reliable function.

10 POWER GENERATION INCLUDING PROPULSION AND OTHER GAS CONSUMERS

10.1 Goal

10.1.1 The goal of this chapter is to provide safe and reliable delivery of mechanical, electrical or thermal energy.

10.2 Functional requirements

This chapter is related to functional requirements in 3.2.1, 3.2.11, 3.2.13, 3.2.16 and 3.2.17. In particular the following apply:

- .1 the exhaust systems shall be configured to prevent any accumulation of un-burnt gaseous fuel;
- .2 unless designed with the strength to withstand the worst case over pressure due to ignited gas leaks, engine components or systems containing or likely

to contain an ignitable gas and air mixture shall be fitted with suitable pressure relief systems. Dependent on the particular engine design this may include the air inlet manifolds and scavenge spaces;

- .3 the explosion venting shall be led away from where personnel may normally be present; and
- .4 all gas consumers shall have a separate exhaust system.

10.3 Regulations for internal combustion engines of piston type

10.3.1 General

10.3.1.1 The exhaust system shall be equipped with explosion relief ventilation sufficiently dimensioned to prevent excessive explosion pressures in the event of ignition failure of one cylinder followed by ignition of the unburned gas in the system.

10.3.1.2 For engines where the space below the piston is in direct communication with the crankcase a detailed evaluation regarding the hazard potential of fuel gas accumulation in the crankcase shall be carried out and reflected in the safety concept of the engine.

10.3.1.3 Each engine other than two-stroke crosshead diesel engines shall be fitted with vent systems independent of other engines for crankcases and sumps.

10.3.1.4 Where gas can leak directly into the auxiliary system medium (lubricating oil, cooling water), an appropriate means shall be fitted after the engine outlet to extract gas in order to prevent gas dispersion. The gas extracted from auxiliary systems media shall be vented to a safe location in the atmosphere.

10.3.1.5 For engines fitted with ignition systems, prior to admission of gas fuel, correct operation of the ignition system on each unit shall be verified.

10.3.1.6 A means shall be provided to monitor and detect poor combustion or misfiring. In the event that it is detected, gas operation may be allowed provided that the gas supply to the concerned cylinder is shut off and provided that the operation of the engine with one cylinder cut-off is acceptable with respects to torsional vibrations.

10.3.1.7 For engines starting on fuels covered by this Code, if combustion has not been detected by the engine monitoring system within an engine specific time after the opening of the fuel supply valve, the fuel supply valve shall be automatically shut off. Means to ensure that any unburnt fuel mixture is purged away from the exhaust system shall be provided.

10.3.2 Regulations for dual fuel engines

10.3.2.1 In case of shutoff of the gas fuel supply, the engines shall be capable of continuous operation by oil fuel only without interruption.

10.3.2.2 An automatic system shall be fitted to change over from gas fuel operation to oil fuel operation and vice versa with minimum fluctuation of the engine power. Acceptable reliability shall be demonstrated through testing. In the case of unstable operation on engines when gas firing, the engine shall automatically change to oil fuel mode. Manual activation of gas system shutdown shall always be possible.

10.3.2.3 In case of a normal stop or an emergency shutdown, the gas fuel supply shall be shut off not later than the ignition source. It shall not be possible to shut off the ignition source without first or simultaneously closing the gas supply to each cylinder or to the complete engine.

10.3.3 Regulations for gas-only engines

In case of a normal stop or an emergency shutdown, the gas fuel supply shall be shut off not later than the ignition source. It shall not be possible to shut off the ignition source without first or simultaneously closing the gas supply to each cylinder or to the complete engine.

10.3.4 Regulations for multi-fuel engines

10.3.4.1 In case of shutoff of one fuel supply, the engines shall be capable of continuous operation by an alternative fuel with minimum fluctuation of the engine power.

10.3.4.2 An automatic system shall be fitted to change over from one fuel operation to an alternative fuel operation with minimum fluctuation of the engine power. Acceptable reliability shall be demonstrated through testing. In the case of unstable operation on an engine when using a particular fuel, the engine shall automatically change to an alternative fuel mode. Manual activation shall always be possible.

	GAS ONLY		DUAL FUEL	MULTI FUEL
IGNITION MEDIUM	Spark	Pilot fuel	Pilot fuel	N/A
MAIN FUEL	Gas	Gas	Gas and/ or Oil fuel	Gas and/ or Liquid

10.4 Regulations for main and auxiliary boilers

10.4.1 Each boiler shall have a dedicated forced draught system. A crossover between boiler force draught systems may be fitted for emergency use providing that any relevant safety functions are maintained.

10.4.2 Combustion chambers and uptakes of boilers shall be designed to prevent any accumulation of gaseous fuel.

10.4.3 Burners shall be designed to maintain stable combustion under all firing conditions.

10.4.4 On main/propulsion boilers an automatic system shall be provided to change from gas fuel operation to oil fuel operation without interruption of boiler firing.

10.4.5 Gas nozzles and the burner control system shall be configured such that gas fuel can only be ignited by an established oil fuel flame, unless the boiler and combustion equipment is designed and approved by the Administration to light on gas fuel.

10.4.6 There shall be arrangements to ensure that gas fuel flow to the burner is automatically cut off unless satisfactory ignition has been established and maintained.

10.4.7 On the fuel pipe of each gas burner a manually operated shutoff valve shall be fitted.

10.4.8 Provisions shall be made for automatically purging the gas supply piping to the burners, by means of an inert gas, after the extinguishing of these burners.

10.4.9 The automatic fuel changeover system required by 10.4.4 shall be monitored with alarms to ensure continuous availability.

10.4.10 Arrangements shall be made that, in case of flame failure of all operating burners, the combustion chambers of the boilers are automatically purged before relighting.

10.4.11 Arrangements shall be made to enable the boilers purging sequence to be manually activated.

10.5 Regulations for gas turbines

10.5.1 Unless designed with the strength to withstand the worst case over pressure due to ignited gas leaks, pressure relief systems shall be suitably designed and fitted to the exhaust system, taking into consideration of explosions due to gas leaks. Pressure relief systems within the exhaust uptakes shall be lead to a safe location, away from personnel.

10.5.2 The gas turbine may be fitted in a gas-tight enclosure arranged in accordance with the ESD principle outlined in 5.6 and 9.7, however a pressure above 1.0 MPa in the gas supply piping may be accepted within this enclosure.

10.5.3 Gas detection systems and shutdown functions shall be as outlined for ESD protected machinery spaces.

10.5.4 Ventilation for the enclosure shall be as outlined in chapter 13 for ESD protected machinery spaces, but shall in addition be arranged with full redundancy (2 x 100% capacity fans from different electrical circuits).

10.5.5 For other than single fuel gas turbines, an automatic system shall be fitted to change over easily and quickly from gas fuel operation to oil fuel operation and vice versa with minimum fluctuation of the engine power.

10.5.6 Means shall be provided to monitor and detect poor combustion that may lead to unburnt fuel gas in the exhaust system during operation. In the event that it is detected, the fuel gas supply shall be shutdown.

10.5.7 Each turbine shall be fitted with an automatic shutdown device for high exhaust temperatures.

11 FIRE SAFETY

11.1 Goal

The goal of this chapter is to provide for fire protection, detection and fighting for all system components related to the storage, conditioning, transfer and use of natural gas as ship fuel.

11.2 Functional requirements

This chapter is related to functional requirements in 3.2.2, 3.2.4, 3.2.5, 3.2.7, 3.2.12, 3.2.14, 3.2.15 and 3.2.17.

11.3 Regulations for fire protection

11.3.1 Any space containing equipment for the fuel preparation such as pumps, compressors, heat exchangers, vaporizers and pressure vessels shall be regarded as a machinery space of category A for fire protection purposes.

11.3.2 Any boundary of accommodation spaces, service spaces, control stations, escape routes and machinery spaces, facing fuel tanks on open deck, shall be shielded by A-60 class divisions. The A-60 class divisions shall extend up to the underside of the deck of the

navigation bridge, and any boundaries above that, including navigation bridge windows, shall have A-0 class divisions. In addition, fuel tanks shall be segregated from cargo in accordance with the requirements of the International Maritime Dangerous Goods (IMDG) Code where the fuel tanks are regarded as bulk packaging. For the purposes of the stowage and segregation requirements of the IMDG Code, a fuel tank on the open deck shall be considered a class 2.1 package.

11.3.3 The space containing fuel containment system shall be separated from the machinery spaces of category A or other rooms with high fire risks. The separation shall be done by a cofferdam of at least 900 mm with insulation of A-60 class. When determining the insulation of the space containing fuel containment system from other spaces with lower fire risks, the fuel containment system shall be considered as a machinery space of category A, in accordance with SOLAS regulation II-2/9. The boundary between spaces containing fuel containment systems shall be either a cofferdam of at least 900 mm or A-60 class division. For type C tanks, the fuel storage hold space may be considered as a cofferdam.

11.3.4 The fuel storage hold space shall not be used for machinery or equipment that may have a fire risk.

11.3.5 The fire protection of fuel pipes led through ro-ro spaces shall be subject to special consideration by the Administration depending on the use and expected pressure in the pipes.

11.3.6 The bunkering station shall be separated by A-60 class divisions towards machinery spaces of category A, accommodation, control stations and high fire risk spaces, except for spaces such as tanks, voids, auxiliary machinery spaces of little or no fire risk, sanitary and similar spaces where the insulation standard may be reduced to class A-0.

11.3.7 If an ESD protected machinery space is separated by a single boundary, the boundary shall be of A-60 class division.

11.4 Regulations for fire main

11.4.1 The water spray system required below may be part of the fire main system provided that the required fire pump capacity and working pressure are sufficient for the operation of both the required numbers of hydrants and hoses and the water spray system simultaneously.

11.4.2 When the fuel storage tank(s) is located on the open deck, isolating valves shall be fitted in the fire main in order to isolate damaged sections of the fire main. Isolation of a section of fire main shall not deprive the fire line ahead of the isolated section from the supply of water.

11.5 Regulations for water spray system

11.5.1 A water spray system shall be installed for cooling and fire prevention to cover exposed parts of fuel storage tank(s) located on open deck.

11.5.2 The water spray system shall also provide coverage for boundaries of the superstructures, compressor rooms, pump-rooms, cargo control rooms, bunkering control stations, bunkering stations and any other normally occupied deck houses that face the storage tank on open decks unless the tank is located 10 metres or more from the boundaries.

11.5.3 The system shall be designed to cover all areas as specified above with an application rate of 10 l/min/m² for the largest horizontal projected surfaces and 4 l/min/m² for vertical surfaces.

11.5.4 Stop valves shall be fitted in the water spray application main supply line(s), at intervals not exceeding 40 metres, for the purpose of isolating damaged sections. Alternatively, the system may be divided into two or more sections that may be operated independently, provided the necessary controls are located together in a readily accessible position not likely to be inaccessible in case of fire in the areas protected.

11.5.5 The capacity of the water spray pump shall be sufficient to deliver the required amount of water to the hydraulically most demanding area as specified above in the areas protected.

11.5.6 If the water spray system is not part of the fire main system, a connection to the ship's fire main through a stop valve shall be provided.

11.5.7 Remote start of pumps supplying the water spray system and remote operation of any normally closed valves to the system shall be located in a readily accessible position which is not likely to be inaccessible in case of fire in the areas protected.

11.5.8 The nozzles shall be of an approved full bore type and they shall be arranged to ensure an effective distribution of water throughout the space being protected.

11.6 Regulations for dry chemical powder fire-extinguishing system

11.6.1 A permanently installed dry chemical powder fire-extinguishing system shall be installed in the bunkering station area to cover all possible leak points. The capacity shall be at least 3.5 kg/s for a minimum of 45 s. The system shall be arranged for easy manual release from a safe location outside the protected area.

11.6.2 In addition to any other portable fire extinguishers that may be required elsewhere in IMO instruments, one portable dry powder extinguisher of at least 5 kg capacity shall be located near the bunkering station.

11.7 Regulations for fire detection and alarm system

11.7.1 A fixed fire detection and fire alarm system complying with the Fire Safety Systems Code shall be provided for the fuel storage hold spaces and the ventilation trunk for fuel containment system below deck, and for all other rooms of the fuel gas system where fire cannot be excluded.

11.7.2 Smoke detectors alone shall not be considered sufficient for rapid detection of a fire.

12 EXPLOSION PREVENTION

12.1 Goal

The goal of this chapter is to provide for the prevention of explosions and for the limitation of effects from explosion.

12.2 Functional requirements

This chapter is related to functional requirements in 3.2.2 to 3.2.5, 3.2.7, 3.2.8, 3.2.12 to 3.2.14 and 3.2.17. In particular the following apply:

The probability of explosions shall be reduced to a minimum by:

- .1 reducing number of sources of ignition; and
- .2 reducing the probability of formation of ignitable mixtures.

12.3 Regulations – General

12.3.1 Hazardous areas on open deck and other spaces not addressed in this chapter shall be decided based on a recognized standard. The electrical equipment fitted within hazardous areas shall be according to the same standard.

12.3.2 Electrical equipment and wiring shall in general not be installed in hazardous areas unless essential for operational purposes based on a recognized standard.

12.3.3 Electrical equipment fitted in an ESD-protected machinery space shall fulfil the following:

- .1 in addition to fire and gas hydrocarbon detectors and fire and gas alarms, lighting and ventilation fans shall be certified safe for hazardous area zone 1; and
- .2 all electrical equipment in a machinery space containing gas-fuelled engines, and not certified for zone 1 shall be automatically disconnected, if gas concentration above 40% LEL is detected by two detectors in the space containing gas-fuelled consumers.

12.4 Regulations on area classification

12.4.1 Area classification is a method of analysing and classifying the areas where explosive gas atmospheres may occur. The object of the classification is to allow the selection of electrical apparatus able to be operated safely in these areas.

12.4.2 In order to facilitate the selection of appropriate electrical apparatus and the design of suitable electrical installations, hazardous areas are divided into zones 0, 1 and 2. See also 12.5 below.

12.4.3 Ventilation ducts shall have the same area classification as the ventilated space.

12.5 Hazardous area zones

12.5.1 Hazardous area zone 0

This zone includes, but is not limited to the interiors of fuel tanks, any pipework for pressure-relief or other venting systems for fuel tanks, pipes and equipment containing fuel.

12.5.2 Hazardous area zone 1

This zone includes, but is not limited to:

- .1 tank connection spaces, fuel storage hold spaces and interbarrier spaces;
- .2 fuel preparation room arranged with ventilation according to 13.6;
- .3 areas on open deck, or semi-enclosed spaces on deck, within 3 m of any fuel tank outlet, gas or vapour outlet, bunker manifold valve, other fuel valve, fuel pipe flange, fuel preparation room ventilation outlets and fuel tank openings for pressure release provided to permit the flow of small volumes of gas or vapour mixtures caused by thermal variation;
- .4 areas on open deck or semi-enclosed spaces on deck, within 1.5 m of fuel preparation room entrances, fuel preparation room ventilation inlets and other openings into zone 1 spaces;

- .5 areas on the open deck within spillage coamings surrounding gas bunker manifold valves and 3 m beyond these, up to a height of 2.4 m above the deck;
- .6 enclosed or semi-enclosed spaces in which pipes containing fuel are located, e.g. ducts around fuel pipes, semi-enclosed bunkering stations;
- .7 the ESD-protected machinery space is considered a non-hazardous area during normal operation, but will require equipment required to operate following detection of gas leakage to be certified as suitable for zone 1;
- .8 a space protected by an airlock is considered as non-hazardous area during normal operation, but will require equipment required to operate following loss of differential pressure between the protected space and the hazardous area to be certified as suitable for zone 1; and
- .9 except for type C tanks, an area within 2.4 m of the outer surface of a fuel containment system where such surface is exposed to the weather.

12.5.3 Hazardous area zone 2

12.5.3.1 This zone includes, but is not limited to areas within 1.5 m surrounding open or semi-enclosed spaces of zone 1.

12.5.3.2 Space containing bolted hatch to tank connection space.

13 VENTILATION

13.1 Goal

The goal of this chapter is to provide for the ventilation required for safe operation of gas-fuelled machinery and equipment.

13.2 Functional requirements

This chapter is related to functional requirements in 3.2.2, 3.2.5, 3.2.8, 3.2.10, 3.2.12 to 3.2.14 and 3.2.17.

13.3 Regulations – General

13.3.1 Any ducting used for the ventilation of hazardous spaces shall be separate from that used for the ventilation of non-hazardous spaces. The ventilation shall function at all temperatures and environmental conditions the ship will be operating in.

13.3.2 Electric motors for ventilation fans shall not be located in ventilation ducts for hazardous spaces unless the motors are certified for the same hazard zone as the space served.

13.3.3 Design of ventilation fans serving spaces containing gas sources shall fulfil the following:

- .1 Ventilation fans shall not produce a source of vapour ignition in either the ventilated space or the ventilation system associated with the space. Ventilation fans and fan ducts, in way of fans only, shall be of non-sparking construction defined as:

- .1 impellers or housings of non-metallic material, due regard being paid to the elimination of static electricity;
 - .2 impellers and housings of non-ferrous metals;
 - .3 impellers and housings of austenitic stainless steel;
 - .4 impellers of aluminium alloys or magnesium alloys and a ferrous (including austenitic stainless steel) housing on which a ring of suitable thickness of non-ferrous materials is fitted in way of the impeller, due regard being paid to static electricity and corrosion between ring and housing; or
 - .5 any combination of ferrous (including austenitic stainless steel) impellers and housings with not less than 13 mm tip design clearance.
- .2 In no case shall the radial air gap between the impeller and the casing be less than 0.1 of the diameter of the impeller shaft in way of the bearing but not less than 2 mm. The gap need not be more than 13 mm.
- .3 Any combination of an aluminium or magnesium alloy fixed or rotating component and a ferrous fixed or rotating component, regardless of tip clearance, is considered a sparking hazard and shall not be used in these places.

13.3.4 Ventilation systems required to avoid any gas accumulation shall consist of independent fans, each of sufficient capacity, unless otherwise specified in this Code.

13.3.5 Air inlets for hazardous enclosed spaces shall be taken from areas that, in the absence of the considered inlet, would be non-hazardous. Air inlets for non-hazardous enclosed spaces shall be taken from non-hazardous areas at least 1.5 m away from the boundaries of any hazardous area. Where the inlet duct passes through a more hazardous space, the duct shall be gas-tight and have over-pressure relative to this space.

13.3.6 Air outlets from non-hazardous spaces shall be located outside hazardous areas.

13.3.7 Air outlets from hazardous enclosed spaces shall be located in an open area that, in the absence of the considered outlet, would be of the same or lesser hazard than the ventilated space.

13.3.8 The required capacity of the ventilation plant is normally based on the total volume of the room. An increase in required ventilation capacity may be necessary for rooms having a complicated form.

13.3.9 Non-hazardous spaces with entry openings to a hazardous area shall be arranged with an airlock and be maintained at overpressure relative to the external hazardous area. The overpressure ventilation shall be arranged according to the following:

- .1 During initial start-up or after loss of overpressure ventilation, before energizing any electrical installations not certified safe for the space in the absence of pressurization, it shall be required to:
 - .1 proceed with purging (at least 5 air changes) or confirm by measurements that the space is non-hazardous; and
 - .2 pressurize the space.

- .2 Operation of the overpressure ventilation shall be monitored and in the event of failure of the overpressure ventilation:
 - .1 an audible and visual alarm shall be given at a manned location; and
 - .2 if overpressure cannot be immediately restored, automatic or programmed, disconnection of electrical installations according to a recognized standard shall be required.

13.3.10 Non-hazardous spaces with entry openings to a hazardous enclosed space shall be arranged with an airlock and the hazardous space shall be maintained at underpressure relative to the non-hazardous space. Operation of the extraction ventilation in the hazardous space shall be monitored and in the event of failure of the extraction ventilation:

- .1 an audible and visual alarm shall be given at a manned location; and
- .2 if underpressure cannot be immediately restored, automatic or programmed, disconnection of electrical installations according to a recognized standard in the non-hazardous space shall be required.

13.4 Regulations for tank connection space

13.4.1 The tank connection space shall be provided with an effective mechanical forced ventilation system of extraction type. A ventilation capacity of at least 30 air changes per hour shall be provided. The rate of air changes may be reduced if other adequate means of explosion protection are installed. The equivalence of alternative installations shall be demonstrated by a risk assessment.

13.4.2 Approved automatic fail-safe fire dampers shall be fitted in the ventilation trunk for the tank connection space.

13.5 Regulations for machinery spaces

13.5.1 The ventilation system for machinery spaces containing gas-fuelled consumers shall be independent of all other ventilation systems.

13.5.2 ESD protected machinery spaces shall have ventilation with a capacity of at least 30 air changes per hour. The ventilation system shall ensure a good air circulation in all spaces, and in particular ensure that any formation of gas pockets in the room are detected. As an alternative, arrangements whereby under normal operation the machinery spaces are ventilated with at least 15 air changes an hour is acceptable provided that, if gas is detected in the machinery space, the number of air changes will automatically be increased to 30 an hour.

13.5.3 For ESD protected machinery spaces the ventilation arrangements shall provide sufficient redundancy to ensure a high level of ventilation availability as defined in a standard acceptable to the Organization.

13.5.4 The number and power of the ventilation fans for ESD protected engine-rooms and for double pipe ventilation systems for gas safe engine-rooms shall be such that the capacity is not reduced by more than 50% of the total ventilation capacity if a fan with a separate circuit from the main switchboard or emergency switchboard or a group of fans with common circuit from the main switchboard or emergency switchboard, is inoperable.

13.6 Regulations for fuel preparation room

13.6.1 Fuel preparation rooms, shall be fitted with effective mechanical ventilation system of the underpressure type, providing a ventilation capacity of at least 30 air changes per hour.

13.6.2 The number and power of the ventilation fans shall be such that the capacity is not reduced by more than 50%, if a fan with a separate circuit from the main switchboard or emergency switchboard or a group of fans with common circuit from the main switchboard or emergency switchboard, is inoperable.

13.6.3 Ventilation systems for fuel preparation rooms, shall be in operation when pumps or compressors are working.

13.7 Regulations for bunkering station

Bunkering stations that are not located on open deck shall be suitably ventilated to ensure that any vapour being released during bunkering operations will be removed outside. If the natural ventilation is not sufficient, mechanical ventilation shall be provided in accordance with the risk assessment required by 8.3.1.1.

13.8 Regulations for ducts and double pipes

13.8.1 Ducts and double pipes containing fuel piping shall be fitted with effective mechanical ventilation system of the extraction type, providing a ventilation capacity of at least 30 air changes per hour. This is not applicable to double pipes in the engine-room if fulfilling 9.6.1.1.

13.8.2 The ventilation system for double piping and for gas valve unit spaces in gas safe engine-rooms shall be independent of all other ventilation systems.

13.8.3 The ventilation inlet for the double wall piping or duct shall always be located in a non-hazardous area away from ignition sources. The inlet opening shall be fitted with a suitable wire mesh guard and protected from ingress of water.

13.8.4 The capacity of the ventilation for a pipe duct or double wall piping may be below 30 air changes per hour if a flow velocity of minimum 3 m/s is ensured. The flow velocity shall be calculated for the duct with fuel pipes and other components installed.

14 ELECTRICAL INSTALLATIONS

14.1 Goal

The goal of this chapter is to provide for electrical installations that minimize the risk of ignition in the presence of a flammable atmosphere.

14.2 Functional requirements

This chapter is related to functional requirements in 3.2.1, 3.2.2, 3.2.4, 3.2.7, 3.2.8, 3.2.11, 3.2.13 and 3.2.16 to 3.2.18. In particular the following apply:

Electrical generation and distribution systems, and associated control systems, shall be designed such that a single fault will not result in the loss of ability to maintain fuel tank pressures and hull structure temperature within normal operating limits.

14.3 Regulations – General

14.3.1 Electrical installations shall be in compliance with a standard at least equivalent to those acceptable to the Organization.

14.3.2 Electrical equipment or wiring shall not be installed in hazardous areas unless essential for operational purposes or safety enhancement.

14.3.3 Where electrical equipment is installed in hazardous areas as provided in 14.3.2 it shall be selected, installed and maintained in accordance with standards at least equivalent to those acceptable to the Organization.

Equipment for hazardous areas shall be evaluated and certified or listed by an accredited testing authority or notified body recognized by the Administration.

14.3.4 Failure modes and effects of single failure for electrical generation and distribution systems in 14.2 shall be analysed and documented to be at least equivalent to those acceptable to the Organization.

14.3.5 The lighting system in hazardous areas shall be divided between at least two branch circuits. All switches and protective devices shall interrupt all poles or phases and shall be located in a non-hazardous area.

14.3.6 The installation on board of the electrical equipment units shall be such as to ensure the safe bonding to the hull of the units themselves.

14.3.7 Arrangements shall be made to alarm in low-liquid level and automatically shutdown the motors in the event of low-low liquid level. The automatic shutdown may be accomplished by sensing low pump discharge pressure, low motor current, or low-liquid level. This shutdown shall give an audible and visual alarm on the navigation bridge, continuously manned central control station or onboard safety centre.

14.3.8 Submerged fuel pump motors and their supply cables may be fitted in liquefied gas fuel containment systems. Fuel pump motors shall be capable of being isolated from their electrical supply during gas-freeing operations.

14.3.9 For non-hazardous spaces with access from hazardous open deck where the access is protected by an airlock, electrical equipment which is not of the certified safe type shall be de-energized upon loss of overpressure in the space.

14.3.10 Electrical equipment for propulsion, power generation, manoeuvring, anchoring and mooring, as well as emergency fire pumps, that are located in spaces protected by airlocks, shall be of a certified safe type.

15 CONTROL, MONITORING AND SAFETY SYSTEMS

15.1 Goal

The goal of this chapter is to provide for the arrangement of control, monitoring and safety systems that support an efficient and safe operation of the gas-fuelled installation as covered in the other chapters of this Code.

15.2 Functional requirements

This chapter is related to functional requirements in 3.2.1, 3.2.2, 3.2.11, 3.2.13 to 3.2.15, 3.2.17 and 3.2.18. In particular the following apply:

- .1 the control, monitoring and safety systems of the gas-fuelled installation shall be so arranged that the remaining power for propulsion and power generation is in accordance with 9.3.1 in the event of single failure;

- .2 a gas safety system shall be arranged to close down the gas supply system automatically, upon failure in systems as described in table 1 and upon other fault conditions which may develop too fast for manual intervention;
- .3 for ESD protected machinery configurations the safety system shall shutdown gas supply upon gas leakage and in addition disconnect all non-certified safe type electrical equipment in the machinery space;
- .4 the safety functions shall be arranged in a dedicated gas safety system that is independent of the gas control system in order to avoid possible common cause failures. This includes power supplies and input and output signal;
- .5 the safety systems including the field instrumentation shall be arranged to avoid spurious shutdown, e.g. as a result of a faulty gas detector or a wire break in a sensor loop; and
- .6 where two or more gas supply systems are required to meet the regulations, each system shall be fitted with its own set of independent gas control and gas safety systems.

15.3 Regulations – General

15.3.1 Suitable instrumentation devices shall be fitted to allow a local and a remote reading of essential parameters to ensure a safe management of the whole fuel-gas equipment including bunkering.

15.3.2 A bilge well in each tank connection space of an independent liquefied gas storage tank shall be provided with both a level indicator and a temperature sensor. Alarm shall be given at high level in the bilge well. Low temperature indication shall activate the safety system.

15.3.3 For tanks not permanently installed in the ship a monitoring system shall be provided as for permanently installed tanks.

15.4 Regulations for bunkering and liquefied gas fuel tank monitoring

15.4.1 Level indicators for liquefied gas fuel tanks

- .1 Each liquefied gas fuel tank shall be fitted with liquid level gauging device(s), arranged to ensure a level reading is always obtainable whenever the liquefied gas fuel tank is operational. The device(s) shall be designed to operate throughout the design pressure range of the liquefied gas fuel tank and at temperatures within the fuel operating temperature range.
- .2 Where only one liquid level gauge is fitted it shall be arranged so that it can be maintained in an operational condition without the need to empty or gas-free the tank.
- .3 Liquefied gas fuel tank liquid level gauges may be of the following types:
 - .1 indirect devices, which determine the amount of fuel by means such as weighing or in-line flow metering; or
 - .2 closed devices, which do not penetrate the liquefied gas fuel tank, such as devices using radio-isotopes or ultrasonic devices;

15.4.2 Overflow control

- .1 Each liquefied gas fuel tank shall be fitted with a high liquid level alarm operating independently of other liquid level indicators and giving an audible and visual warning when activated.
- .2 An additional sensor operating independently of the high liquid level alarm shall automatically actuate a shutoff valve in a manner that will both avoid excessive liquid pressure in the bunkering line and prevent the liquefied gas fuel tank from becoming liquid full.
- .3 The position of the sensors in the liquefied gas fuel tank shall be capable of being verified before commissioning. At the first occasion of full loading after delivery and after each dry-docking, testing of high level alarms shall be conducted by raising the fuel liquid level in the liquefied gas fuel tank to the alarm point.
- .4 All elements of the level alarms, including the electrical circuit and the sensor(s), of the high, and overfill alarms, shall be capable of being functionally tested. Systems shall be tested prior to fuel operation in accordance with 18.4.3.
- .5 Where arrangements are provided for overriding the overflow control system, they shall be such that inadvertent operation is prevented. When this override is operated continuous visual indication is to be provided at the navigation bridge, continuously manned central control station or onboard safety centre.

15.4.3 The vapour space of each liquefied gas fuel tank shall be provided with a direct reading gauge. Additionally, an indirect indication is to be provided on the navigation bridge, continuously manned central control station or onboard safety centre.

15.4.4 The pressure indicators shall be clearly marked with the highest and lowest pressure permitted in the liquefied gas fuel tank.

15.4.5 A high-pressure alarm and, if vacuum protection is required, a low-pressure alarm shall be provided on the navigation bridge and at a continuously manned central control station or onboard safety centre. Alarms shall be activated before the set pressures of the safety valves are reached.

15.4.6 Each fuel pump discharge line and each liquid and vapour fuel manifold shall be provided with at least one local pressure indicator.

15.4.7 Local-reading manifold pressure indicator shall be provided to indicate the pressure between ship's manifold valves and hose connections to the shore.

15.4.8 Fuel storage hold spaces and interbarrier spaces without open connection to the atmosphere shall be provided with pressure indicator.

15.4.9 At least one of the pressure indicators provided shall be capable of indicating throughout the operating pressure range.

15.4.10 For submerged fuel-pump motors and their supply cables, arrangements shall be made to alarm in low-liquid level and automatically shutdown the motors in the event of low-low liquid level. The automatic shutdown may be accomplished by sensing low pump discharge pressure, low motor current, or low-liquid level. This shutdown shall give an audible and visual alarm on the navigation bridge, continuously manned central control station or onboard safety centre.

15.4.11 Except for independent tanks of type C supplied with vacuum insulation system and pressure build-up fuel discharge unit, each fuel tank shall be provided with devices to measure and indicate the temperature of the fuel in at least three locations; at the bottom and middle of the tank as well as the top of the tank below the highest allowable liquid level.

15.5 Regulations for bunkering control

15.5.1 Control of the bunkering shall be possible from a safe location remote from the bunkering station. At this location the tank pressure, tank temperature if required by 15.4.11, and tank level shall be monitored. Remotely controlled valves required by 8.5.3 and 11.5.7 shall be capable of being operated from this location. Overfill alarm and automatic shutdown shall also be indicated at this location.

15.5.2 If the ventilation in the ducting enclosing the bunkering lines stops, an audible and visual alarm shall be provided at the bunkering control location, see also 15.8.

15.5.3 If gas is detected in the ducting around the bunkering lines an audible and visual alarm and emergency shutdown shall be provided at the bunkering control location.

15.6 Regulations for gas compressor monitoring

15.6.1 Gas compressors shall be fitted with audible and visual alarms both on the navigation bridge and in the engine control room. As a minimum the alarms shall include low gas input pressure, low gas output pressure, high gas output pressure and compressor operation.

15.6.2 Temperature monitoring for the bulkhead shaft glands and bearings shall be provided, which automatically give a continuous audible and visual alarm on the navigation bridge or in a continuously manned central control station.

15.7 Regulations for gas engine monitoring

In addition to the instrumentation provided in accordance with part C of SOLAS chapter II-1, indicators shall be fitted on the navigation bridge, the engine control room and the manoeuvring platform for:

- .1 operation of the engine in case of gas-only engines; or
- .2 operation and mode of operation of the engine in the case of dual fuel engines.

15.8 Regulations for gas detection

15.8.1 Permanently installed gas detectors shall be fitted in:

- .1 the tank connection spaces;
- .2 all ducts around fuel pipes;
- .3 machinery spaces containing gas piping, gas equipment or gas consumers;
- .4 compressor rooms and fuel preparation rooms;
- .5 other enclosed spaces containing fuel piping or other fuel equipment without ducting;
- .6 other enclosed or semi-enclosed spaces where fuel vapours may accumulate including interbarrier spaces and fuel storage hold spaces of independent tanks other than type C;

- .7 airlocks;
- .8 gas heating circuit expansion tanks;
- .9 motor rooms associated with the fuel systems; and
- .10 at ventilation inlets to accommodation and machinery spaces if required based on the risk assessment required in 4.2.

15.8.2 In each ESD-protected machinery space, redundant gas detection systems shall be provided.

15.8.3 The number of detectors in each space shall be considered taking into account the size, layout and ventilation of the space.

15.8.4 The detection equipment shall be located where gas may accumulate and in the ventilation outlets. Gas dispersal analysis or a physical smoke test shall be used to find the best arrangement.

15.8.5 Gas detection equipment shall be designed, installed and tested in accordance with a recognized standard.

15.8.6 An audible and visible alarm shall be activated at a gas vapour concentration of 20% of the lower explosion limit (LEL). The safety system shall be activated at 40% of LEL at two detectors (see footnote 1 in table 1).

15.8.7 For ventilated ducts around gas pipes in the machinery spaces containing gas-fuelled engines, the alarm limit can be set to 30% LEL. The safety system shall be activated at 60% of LEL at two detectors (see footnote 1 in table 1).

15.8.8 Audible and visible alarms from the gas detection equipment shall be located on the navigation bridge or in the continuously manned central control station.

15.8.9 Gas detection required by this section shall be continuous without delay.

15.9 Regulations for fire detection

Required safety actions at fire detection in the machinery space containing gas-fuelled engines and rooms containing independent tanks for fuel storage hold spaces are given in table 1 below.

15.10 Regulations for ventilation

15.10.1 Any loss of the required ventilating capacity shall give an audible and visual alarm on the navigation bridge or in a continuously manned central control station or safety centre.

15.10.2 For ESD protected machinery spaces the safety system shall be activated upon loss of ventilation in engine-room.

15.11 Regulations on safety functions of fuel supply systems

15.11.1 If the fuel supply is shut off due to activation of an automatic valve, the fuel supply shall not be opened until the reason for the disconnection is ascertained and the necessary precautions taken. A readily visible notice giving instruction to this effect shall be placed at the operating station for the shutoff valves in the fuel supply lines.

15.11.2 If a fuel leak leading to a fuel supply shutdown occurs, the fuel supply shall not be operated until the leak has been found and dealt with. Instructions to this effect shall be placed in a prominent position in the machinery space.

15.11.3 A caution placard or signboard shall be permanently fitted in the machinery space containing gas-fuelled engines stating that heavy lifting, implying danger of damage to the fuel pipes, shall not be done when the engine(s) is running on gas.

15.11.4 Compressors, pumps and fuel supply shall be arranged for manual remote emergency stop from the following locations as applicable:

- .1 navigation bridge;
- .2 cargo control room;
- .3 onboard safety centre;
- .4 engine control room;
- .5 fire control station; and
- .6 adjacent to the exit of fuel preparation rooms.

The gas compressor shall also be arranged for manual local emergency stop.

Table 1: Monitoring of gas supply system to engines

Parameter	Alarm	Automatic shutdown of tank valve ⁶⁾	Automatic shutdown of gas supply to machinery space containing gas-fuelled engines	Comments
Gas detection in tank connection space at 20% LEL	X			
Gas detection on two detectors ¹⁾ in tank connection space at 40% LEL	X	X		
Fire detection in fuel storage hold space	X			
Fire detection in ventilation trunk for fuel containment system below deck	X			
Bilge well high level in tank connection space	X			
Bilge well low temperature in tank connection space	X	X		

Parameter	Alarm	Automatic shutdown of tank valve ⁶⁾	Automatic shutdown of gas supply to machinery space containing gas-fuelled engines	Comments
Gas detection in duct between tank and machinery space containing gas-fuelled engines at 20% LEL	X			
Gas detection on two detectors ¹⁾ in duct between tank and machinery space containing gas-fuelled engines at 40% LEL	X	X ²⁾		
Gas detection in fuel preparation room at 20% LEL	X			
Gas detection on two detectors ¹⁾ in fuel preparation room at 40% LEL	X	X ²⁾		
Gas detection in duct inside machinery space containing gas-fuelled engines at 30% LEL	X			If double pipe fitted in machinery space containing gas-fuelled engines
Gas detection on two detectors ¹⁾ in duct inside machinery space containing gas-fuelled engines at 60% LEL	X		X ³⁾	If double pipe fitted in machinery space containing gas-fuelled engines
Gas detection in ESD protected machinery space containing gas-fuelled engines at 20% LEL	X			
Gas detection on two detectors ¹⁾ in ESD protected machinery space containing gas-fuelled engines at 40% LEL	X		X	It shall also disconnect non certified safe electrical equipment in machinery space containing gas-fuelled engines
Loss of ventilation in duct between tank and machinery space containing gas-fuelled engines	X		X ²⁾	

Parameter	Alarm	Automatic shutdown of tank valve ⁶⁾	Automatic shutdown of gas supply to machinery space containing gas-fuelled engines	Comments
Loss of ventilation in duct inside machinery space containing gas-fuelled engines ⁵⁾	X		X ³⁾	If double pipe fitted in machinery space containing gas-fuelled engines
Loss of ventilation in ESD protected machinery space containing gas-fuelled engines	X		X	
Fire detection in machinery space containing gas-fuelled engines	X			
Abnormal gas pressure in gas supply pipe	X			
Failure of valve control actuating medium	X		X ⁴⁾	Time delayed as found necessary
Automatic shutdown of engine (engine failure)	X		X ⁴⁾	
Manually activated emergency shutdown of engine	X		X	
1) Two independent gas detectors located close to each other are required for redundancy reasons. If the gas detector is of self-monitoring type the installation of a single gas detector can be permitted. 2) If the tank is supplying gas to more than one engine and the different supply pipes are completely separated and fitted in separate ducts and with the master valves fitted outside of the duct, only the master valve on the supply pipe leading into the duct where gas or loss of ventilation is detected shall close. 3) If the gas is supplied to more than one engine and the different supply pipes are completely separated and fitted in separate ducts and with the master valves fitted outside of the duct and outside of the machinery space containing gas-fuelled engines, only the master valve on the supply pipe leading into the duct where gas or loss of ventilation is detected shall close. 4) Only double block and bleed valves to close. 5) If the duct is protected by inert gas (see 9.6.1.1) then loss of inert gas overpressure shall lead to the same actions as given in this table. 6) Valves referred to in 9.4.1.				

ANNEX

STANDARD FOR THE USE OF LIMIT STATE METHODOLOGIES IN THE DESIGN OF FUEL CONTAINMENT SYSTEMS OF NOVEL CONFIGURATION

1 GENERAL

1.1 The purpose of this standard is to provide procedures and relevant design parameters of limit state design of fuel containment systems of a novel configuration in accordance with section 6.4.16.

1.2 Limit state design is a systematic approach where each structural element is evaluated with respect to possible failure modes related to the design conditions identified in 6.4.1.6. A limit state can be defined as a condition beyond which the structure, or part of a structure, no longer satisfies the regulations.

1.3 The limit states are divided into the three following categories:

- .1 Ultimate Limit States (ULS), which correspond to the maximum load-carrying capacity or, in some cases, to the maximum applicable strain, deformation or instability in structure resulting from buckling and plastic collapse; under intact (undamaged) conditions;
- .2 Fatigue Limit States (FLS), which correspond to degradation due to the effect of cyclic loading; and
- .3 Accident Limit States (ALS), which concern the ability of the structure to resist accident situations.

1.4 Section 6.4.1 through to section 6.4.14 shall be complied with as applicable depending on the fuel containment system concept.

2 DESIGN FORMAT

2.1 The design format in this standard is based on a Load and Resistance Factor Design format. The fundamental principle of the Load and Resistance Factor Design format is to verify that design load effects, L_d , do not exceed design resistances, R_d , for any of the considered failure modes in any scenario:

$$L_d \leq R_d$$

A design load F_{dk} is obtained by multiplying the characteristic load by a load factor relevant for the given load category:

$$F_{dk} = \gamma_f \cdot F_k$$

where:

γ_f is load factor; and

F_k is the characteristic load as specified in section 6.4.9 through to section 6.4.12.

A design load effect L_d (e.g. stresses, strains, displacements and vibrations) is the most unfavourable combined load effect derived from the design loads, and may be expressed by:

$$L_d = q(F_{d1}, F_{d2}, \dots, F_{dN})$$

where q denotes the functional relationship between load and load effect determined by structural analyses.

The design resistance R_d is determined as follows:

$$R_d = \frac{R_k}{\gamma_R \cdot \gamma_C}$$

where:

- R_k is the characteristic resistance. In case of materials covered by chapter 7, it may be, but not limited to, specified minimum yield stress, specified minimum tensile strength, plastic resistance of cross sections, and ultimate buckling strength;
- γ_R is the resistance factor, defined as $\gamma_R = \gamma_m \cdot \gamma_s$;
- γ_m is the partial resistance factor to take account of the probabilistic distribution of the material properties (material factor);
- γ_s is the partial resistance factor to take account of the uncertainties on the capacity of the structure, such as the quality of the construction, method considered for determination of the capacity including accuracy of analysis; and
- γ_C is the consequence class factor, which accounts for the potential results of failure with regard to release of fuel and possible human injury.

2.2 Fuel containment design shall take into account potential failure consequences. Consequence classes are defined in table 1, to specify the consequences of failure when the mode of failure is related to the Ultimate Limit State, the Fatigue Limit State, or the Accident Limit State.

Table 1: Consequence classes

Consequence class	Definition
Low	Failure implies minor release of the fuel.
Medium	Failure implies release of the fuel and potential for human injury.
High	Failure implies significant release of the fuel and high potential for human injury/fatality.

3 REQUIRED ANALYSES

3.1 Three-dimensional finite element analyses shall be carried out as an integrated model of the tank and the ship hull, including supports and keying system as applicable. All the failure modes shall be identified to avoid unexpected failures. Hydrodynamic analyses shall be carried out to determine the particular ship accelerations and motions in irregular waves, and the response of the ship and its fuel containment systems to these forces and motions.

3.2 Buckling strength analyses of fuel tanks subject to external pressure and other loads causing compressive stresses shall be carried out in accordance with recognized standards. The method shall adequately account for the difference in theoretical and actual buckling stress as a result of plate out of flatness, plate edge misalignment, straightness, ovality and deviation from true circular form over a specified arc or chord length, as relevant.

3.3 Fatigue and crack propagation analysis shall be carried out in accordance with paragraph 5.1 of this standard.

4 ULTIMATE LIMIT STATES

4.1 Structural resistance may be established by testing or by complete analysis taking account of both elastic and plastic material properties. Safety margins for ultimate strength shall be introduced by partial factors of safety taking account of the contribution of stochastic nature of loads and resistance (dynamic loads, pressure loads, gravity loads, material strength, and buckling capacities).

4.2 Appropriate combinations of permanent loads, functional loads and environmental loads including sloshing loads shall be considered in the analysis. At least two load combinations with partial load factors as given in table 2 shall be used for the assessment of the ultimate limit states.

Table 2: Partial load factors

Load combination	Permanent loads	Functional loads	Environmental loads
'a'	1.1	1.1	0.7
'b'	1.0	1.0	1.3

The load factors for permanent and functional loads in load combination 'a' are relevant for the normally well-controlled and/or specified loads applicable to fuel containment systems such as vapour pressure, fuel weight, system self-weight, etc. Higher load factors may be relevant for permanent and functional loads where the inherent variability and/or uncertainties in the prediction models are higher.

4.3 For sloshing loads, depending on the reliability of the estimation method, a larger load factor may be required by the Administration.

4.4 In cases where structural failure of the fuel containment system are considered to imply high potential for human injury and significant release of fuel, the consequence class factor shall be taken as $\gamma_c = 1.2$. This value may be reduced if it is justified through risk analysis and subject to the approval by the Administration. The risk analysis shall take account of factors including, but not limited to, provision of full or partial secondary barrier to protect hull structure from the leakage and less hazards associated with intended fuel. Conversely, higher values may be fixed by the Administration, for example, for ships carrying more hazardous or higher pressure fuel. The consequence class factor shall in any case not be less than 1.0.

4.5 The load factors and the resistance factors used shall be such that the level of safety is equivalent to that of the fuel containment systems as described in sections 6.4.2.1 to 6.4.2.5. This may be carried out by calibrating the factors against known successful designs.

4.6 The material factor γ_m shall in general reflect the statistical distribution of the mechanical properties of the material, and needs to be interpreted in combination with the specified characteristic mechanical properties. For the materials defined in chapter 6, the material factor γ_m may be taken as:

- 1.1 when the characteristic mechanical properties specified by the Administration typically represents the lower 2.5% quantile in the statistical distribution of the mechanical properties; or
- 1.0 when the characteristic mechanical properties specified by the Administration represents a sufficiently small quantile such that the probability of lower mechanical properties than specified is extremely low and can be neglected.

4.7 The partial resistance factors γ_{si} shall in general be established based on the uncertainties in the capacity of the structure considering construction tolerances, quality of construction, the accuracy of the analysis method applied, etc.

4.7.1 For design against excessive plastic deformation using the limit state criteria given in paragraph 4.8 of this standard, the partial resistance factors γ_{si} shall be taken as follows:

$$\gamma_{s1} = 0.76 \cdot \frac{B}{\kappa_1}$$

$$\gamma_{s2} = 0.76 \cdot \frac{D}{\kappa_2}$$

$$\kappa_1 = \text{Min} \left(\frac{R_m}{R_e} \cdot \frac{B}{A}; 1.0 \right)$$

$$\kappa_2 = \text{Min} \left(\frac{R_m}{R_e} \cdot \frac{D}{C}; 1.0 \right)$$

Factors A, B, C and D are defined in 6.4.15.2.3.1. R_m and R_e are defined in 6.4.12.1.1.3.

The partial resistance factors given above are the results of calibration to conventional type B independent tanks.

4.8 Design against excessive plastic deformation

4.8.1 Stress acceptance criteria given below refer to elastic stress analyses.

4.8.2 Parts of fuel containment systems where loads are primarily carried by membrane response in the structure shall satisfy the following limit state criteria:

$$\sigma_m \leq f$$

$$\sigma_L \leq 1.5f$$

$$\sigma_b \leq 1.5F$$

$$\sigma_L + \sigma_b \leq 1.5F$$

$$\sigma_m + \sigma_b \leq 1.5F$$

$$\sigma_m + \sigma_b + \sigma_g \leq 3.0F$$

$$\sigma_L + \sigma_b + \sigma_g \leq 3.0F$$

where:

σ_m = equivalent primary general membrane stress

σ_L = equivalent primary local membrane stress

σ_b = equivalent primary bending stress

σ_g = equivalent secondary stress

$$f = \frac{R_e}{\gamma_{s1} \cdot \gamma_m \cdot \gamma_C}$$

$$F = \frac{R_e}{\gamma_{s2} \cdot \gamma_m \cdot \gamma_C}$$

Guidance Note:

The stress summation described above shall be carried out by summing up each stress component ($\sigma_x, \sigma_y, \tau_{xy}$), and subsequently the equivalent stress shall be calculated based on the resulting stress components as shown in the example below.

$$\sigma_L + \sigma_b = \sqrt{(\sigma_{Lx} + \sigma_{bx})^2 - (\sigma_{Lx} + \sigma_{bx})(\sigma_{Ly} + \sigma_{by}) + (\sigma_{Ly} + \sigma_{by})^2 + 3(\tau_{Lxy} + \tau_{bxy})^2}$$

4.8.3 Parts of fuel containment systems where loads are primarily carried by bending of girders, stiffeners and plates, shall satisfy the following limit state criteria:

$$\sigma_{ms} + \sigma_{bp} \leq 1.25F \quad (\text{see notes 1, 2})$$

$$\sigma_{ms} + \sigma_{bp} + \sigma_{bs} \leq 1.25F \quad (\text{see note 2})$$

$$\sigma_{ms} + \sigma_{bp} + \sigma_{bs} + \sigma_{bt} + \sigma_g \leq 3.0F$$

Note 1: The sum of equivalent section membrane stress and equivalent membrane stress in primary structure ($\sigma_{ms} + \sigma_{bp}$) will normally be directly available from three-dimensional finite element analyses.

Note 2: The coefficient, 1.25, may be modified by the Administration considering the design concept, configuration of the structure, and the methodology used for calculation of stresses.

where:

σ_{ms} = equivalent section membrane stress in primary structure

σ_{bp} = equivalent membrane stress in primary structure and stress in secondary and tertiary structure caused by bending of primary structure

σ_{bs} = section bending stress in secondary structure and stress in tertiary structure caused by bending of secondary structure

σ_{bt} = section bending stress in tertiary structure

σ_g = equivalent secondary stress

$$f = \frac{R_e}{\gamma_{s1} \cdot \gamma_m \cdot \gamma_C}$$

$$F = \frac{R_e}{\gamma_{s2} \cdot \gamma_m \cdot \gamma_C}$$

The stresses σ_{ms} , σ_{bp} , σ_{bs} , and σ_{bt} are defined in 4.8.4.

Guidance Note:

The stress summation described above shall be carried out by summing up each stress component ($\sigma_x, \sigma_y, \tau_{xy}$), and subsequently the equivalent stress shall be calculated based on the resulting stress components.

Skin plates shall be designed in accordance with the requirements of the Administration. When membrane stress is significant, the effect of the membrane stress on the plate bending capacity shall be appropriately considered in addition.

4.8.4 Section stress categories

Normal stress is the component of stress normal to the plane of reference.

Equivalent section membrane stress is the component of the normal stress that is uniformly distributed and equal to the average value of the stress across the cross section of the structure under consideration. If this is a simple shell section, the section membrane stress is identical to the membrane stress defined in paragraph 4.8.2 of this standard.

Section bending stress is the component of the normal stress that is linearly distributed over a structural section exposed to bending action, as illustrated in figure 1.

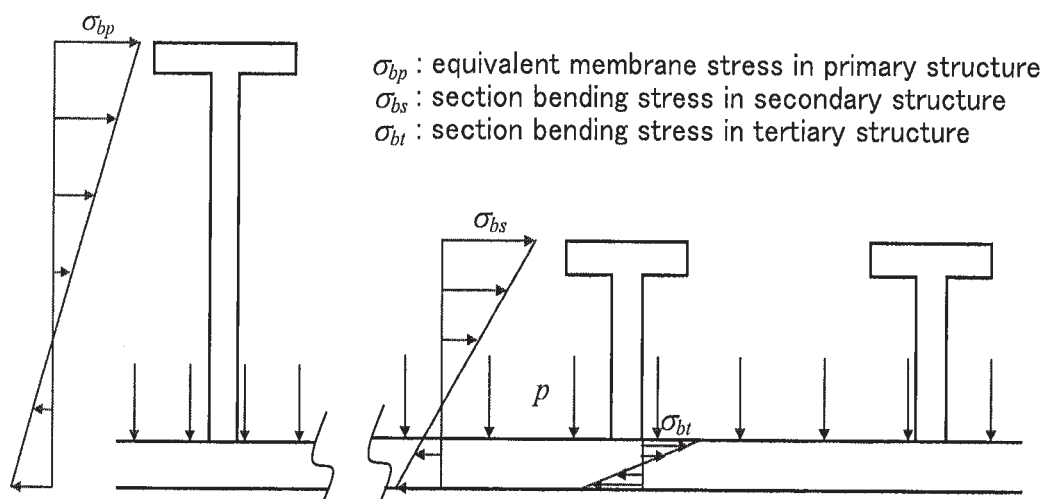


Figure 1: Definition of the three categories of section stress
(Stresses σ_{bp} and σ_{bs} are normal to the cross section shown.)

4.9 The same factors γ_C , γ_m , γ_{si} shall be used for design against buckling unless otherwise stated in the applied recognized buckling standard. In any case the overall level of safety shall not be less than given by these factors.

5 FATIGUE LIMIT STATES

5.1 Fatigue design condition as described in 6.4.12.2 shall be complied with as applicable depending on the fuel containment system concept. Fatigue analysis is required for the fuel containment system designed under 6.4.16 and this standard.

- 5.2 The load factors for FLS shall be taken as 1.0 for all load categories.
- 5.3 Consequence class factor γ_C and resistance factor γ_R shall be taken as 1.0.
- 5.4 Fatigue damage shall be calculated as described in 6.4.12.2.2 to 6.4.12.2.5. The calculated cumulative fatigue damage ratio for the fuel containment systems shall be less than or equal to the values given in table 3.

Table 3: Maximum allowable cumulative fatigue damage ratio

C_W	Consequence class		
	Low	Medium	High
	1.0	0.5	0.5*

Note*: Lower value shall be used in accordance with 6.4.12.2.7 to 6.4.12.2.9, depending on the detectability of defect or crack, etc.

- 5.5 Lower values may be fixed by the Administration.
- 5.6 Crack propagation analyses are required in accordance with 6.4.12.2.6 to 6.4.12.2.9. The analysis shall be carried out in accordance with methods laid down in a standard recognized by the Administration.

6 ACCIDENT LIMIT STATES

- 6.1 Accident design condition as described in 6.4.12.3 shall be complied with as applicable, depending on the fuel containment system concept.
- 6.2 Load and resistance factors may be relaxed compared to the ultimate limit state considering that damages and deformations can be accepted as long as this does not escalate the accident scenario.
- 6.3 The load factors for ALS shall be taken as 1.0 for permanent loads, functional loads and environmental loads.
- 6.4 Loads mentioned in 6.4.9.3.3.8 and 6.4.9.5 need not be combined with each other or with environmental loads, as defined in 6.4.9.4.
- 6.5 Resistance factor γ_R shall in general be taken as 1.0.
- 6.6 Consequence class factors γ_C shall in general be taken as defined in paragraph 4.4 of this standard, but may be relaxed considering the nature of the accident scenario.
- 6.7 The characteristic resistance R_k shall in general be taken as for the ultimate limit state, but may be relaxed considering the nature of the accident scenario.
- 6.8 Additional relevant accident scenarios shall be determined based on a risk analysis.

7 TESTING

- 7.1 Fuel containment systems designed according to this standard shall be tested to the same extent as described in 16.2, as applicable depending on the fuel containment system concept.

PART B-1

Fuel in the context of the regulations in this part means natural gas, either in its liquefied or gaseous state.

16 MANUFACTURE, WORKMANSHIP AND TESTING**16.1 General**

16.1.1 The manufacture, testing, inspection and documentation shall be in accordance with recognized standards and the regulations given in this Code.

16.1.2 Where post-weld heat treatment is specified or required, the properties of the base material shall be determined in the heat treated condition, in accordance with the applicable tables of chapter 7, and the weld properties shall be determined in the heat treated condition in accordance with 16.3. In cases where a post-weld heat treatment is applied, the test regulations may be modified at the discretion of the Administration.

16.2 General test regulations and specifications**16.2.1 Tensile test**

16.2.1.1 Tensile testing shall be carried out in accordance with recognized standards.

16.2.1.2 Tensile strength, yield stress and elongation shall be to the satisfaction of the Administration. For carbon-manganese steel and other materials with definitive yield points, consideration shall be given to the limitation of the yield to tensile ratio.

16.2.2 Toughness test

16.2.2.1 Acceptance tests for metallic materials shall include Charpy V-notch toughness tests unless otherwise specified by the Administration. The specified Charpy V-notch regulations are minimum average energy values for three full size (10 mm × 10 mm) specimens and minimum single energy values for individual specimens. Dimensions and tolerances of Charpy V-notch specimens shall be in accordance with recognized standards. The testing and regulations for specimens smaller than 5.0 mm in size shall be in accordance with recognized standards. Minimum average values for sub-sized specimens shall be:

Charpy V-notch specimen size (mm)	Minimum average energy of three specimens
10 x 10	KV
10 x 7.5	5/6 KV
10 x 5.0	2/3 KV

where:

KV = the energy values (J) specified in tables 7.1 to 7.4.

Only one individual value may be below the specified average value, provided it is not less than 70% of that value.

16.2.2.2 For base metal, the largest size Charpy V-notch specimens possible for the material thickness shall be machined with the specimens located as near as practicable to a point midway between the surface and the centre of the thickness and the length of the notch perpendicular to the surface as shown in figure 16.1.

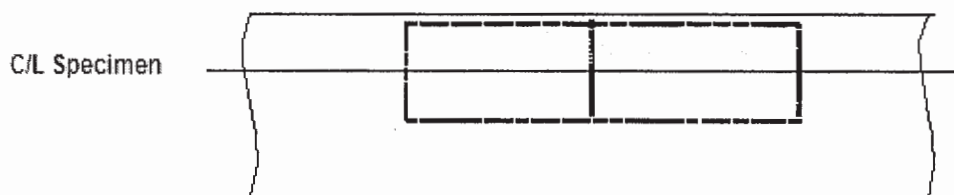


Figure 16.1 – Orientation of base metal test specimen

16.2.2.3 For a weld test specimen, the largest size Charpy V-notch specimens possible for the material thickness shall be machined, with the specimens located as near as practicable to a point midway between the surface and the centre of the thickness. In all cases the distance from the surface of the material to the edge of the specimen shall be approximately 1 mm or greater. In addition, for double-V butt welds, specimens shall be machined closer to the surface of the second welded section. The specimens shall be taken generally at each of the following locations, as shown in figure 16.2, on the centreline of the welds, the fusion line and 1 mm, 3 mm and 5 mm from the fusion line.

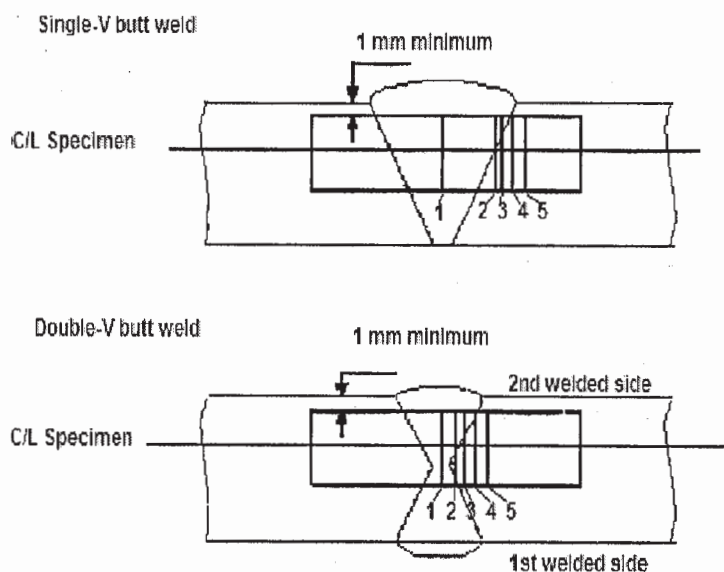


Figure 16.2 – Orientation of weld test specimen

Notch locations in figure 16.2:

- .1 centreline of the weld;
- .2 on fusion line;
- .3 in heat-affected zone (HAZ), 1 mm from fusion line;
- .4 in HAZ, 3 mm from fusion line; and
- .5 in HAZ, 5 mm from fusion line.

16.2.2.4 If the average value of the three initial Charpy V-notch specimens fails to meet the stated regulations, or the value for more than one specimen is below the required average value, or when the value for one specimen is below the minimum value permitted for a single specimen, three additional specimens from the same material may be tested and the results combined with those previously obtained to form a new average. If this new average complies with the regulations and if no more than two individual results are lower, than the required average and no more than one result is lower than the required value for a single specimen, the piece or batch may be accepted.

16.2.3 Bend test

16.2.3.1 The bend test may be omitted as a material acceptance test, but is required for weld tests. Where a bend test is performed, this shall be done in accordance with recognized standards.

16.2.3.2 The bend tests shall be transverse bend tests, which may be face, root or side bends at the discretion of the Administration. However, longitudinal bend tests may be required in lieu of transverse bend tests in cases where the base material and weld metal have different strength levels.

16.2.4 Section observation and other testing

Macrosection, microsection observations and hardness tests may also be required by the Administration, and they shall be carried out in accordance with recognized standards, where required.

16.3 Welding of metallic materials and non-destructive testing for the fuel containment system

16.3.1 General

This section shall apply to primary and secondary barriers only, including the inner hull where this forms the secondary barrier. Acceptance testing is specified for carbon, carbon-manganese, nickel alloy and stainless steels, but these tests may be adapted for other materials. At the discretion of the Administration, impact testing of stainless steel and aluminium alloy weldments may be omitted and other tests may be specially required for any material.

16.3.2 Welding consumables

Consumables intended for welding of fuel tanks shall be in accordance with recognized standards. Deposited weld metal tests and butt weld tests shall be required for all consumables. The results obtained from tensile and Charpy V-notch impact tests shall be in accordance with recognized standards. The chemical composition of the deposited weld metal shall be recorded for information.

16.3.3 Welding procedure tests for fuel tanks and process pressure vessels

16.3.3.1 Welding procedure tests for fuel tanks and process pressure vessels are required for all butt welds.

16.3.3.2 The test assemblies shall be representative of:

- .1 each base material;
- .2 each type of consumable and welding process; and
- .3 each welding position.

16.3.3.3 For butt welds in plates, the test assemblies shall be so prepared that the rolling direction is parallel to the direction of welding. The range of thickness qualified by each welding procedure test shall be in accordance with recognized standards. Radiographic or ultrasonic testing may be performed at the option of the fabricator.

16.3.3.4 The following welding procedure tests for fuel tanks and process pressure vessels shall be done in accordance with 16.2 with specimens made from each test assembly:

- .1 cross-weld tensile tests;
- .2 longitudinal all-weld testing where required by the recognized standards;
- .3 transverse bend tests, which may be face, root or side bends. However, longitudinal bend tests may be required in lieu of transverse bend tests in cases where the base material and weld metal have different strength levels;
- .4 one set of three Charpy V-notch impacts, generally at each of the following locations, as shown in figure 16.2:
 - .1 centreline of the welds;
 - .2 fusion line;
 - .3 1 mm from the fusion line;
 - .4 3 mm from the fusion line; and
 - .5 5 mm from the fusion line;
- .5 macrosection, microsection and hardness survey may also be required.

16.3.3.5 Each test shall satisfy the following:

- .1 tensile tests: cross-weld tensile strength is not to be less than the specified minimum tensile strength for the appropriate parent materials. For aluminium alloys, reference shall be made to 6.4.12.1.1.3 with regard to the regulations for weld metal strength of under-matched welds (where the weld metal has a lower tensile strength than the parent metal). In every case, the position of fracture shall be recorded for information;
- .2 bend tests: no fracture is acceptable after a 180° bend over a former of a diameter four times the thickness of the test pieces; and
- .3 Charpy V-notch impact tests: Charpy V-notch tests shall be conducted at the temperature prescribed for the base material being joined. The results of weld metal impact tests, minimum average energy (KV), shall be no less than 27 J. The weld metal regulations for sub-size specimens and single energy values shall be in accordance with 16.2.2. The results of fusion line and heat affected zone impact tests shall show a minimum average energy (KV) in accordance with the transverse or longitudinal regulations of the base material, whichever is applicable, and for sub-size specimens, the minimum average energy (KV) shall be in accordance with 16.2.2. If the material thickness does not permit machining either full-size or standard sub-size specimens, the testing procedure and acceptance standards shall be in accordance with recognized standards.

16.3.3.6 Procedure tests for fillet welding shall be in accordance with recognized standards. In such cases, consumables shall be so selected that exhibit satisfactory impact properties.

16.3.4 Welding procedure tests for piping

Welding procedure tests for piping shall be carried out and shall be similar to those detailed for fuel tanks in 16.3.3.

16.3.5 Production weld tests

16.3.5.1 For all fuel tanks and process pressure vessels except membrane tanks, production weld tests shall generally be performed for approximately each 50 m of butt-weld joints and shall be representative of each welding position. For secondary barriers, the same type production tests as required for primary tanks shall be performed, except that the number of tests may be reduced subject to agreement with the Administration. Tests, other than those specified in 16.3.5.2 to 16.3.5.5 may be required for fuel tanks or secondary barriers.

16.3.5.2 The production tests for types A and B independent tanks shall include bend tests and, where required for procedure tests, one set of three Charpy V-notch tests. The tests shall be made for each 50 m of weld. The Charpy V-notch tests shall be made with specimens having the notch alternately located in the centre of the weld and in the heat affected zone (most critical location based on procedure qualification results). For austenitic stainless steel, all notches shall be in the centre of the weld.

16.3.5.3 For type C independent tanks and process pressure vessels, transverse weld tensile tests are required in addition to the tests listed in 16.3.5.2. Tensile tests shall meet regulation 16.3.3.5.

16.3.5.4 The quality assurance/quality control (QA/QC) program shall ensure the continued conformity of the production welds as defined in the material manufacturers quality manual (QM).

16.3.5.5 The test regulations for membrane tanks are the same as the applicable test regulations listed in 16.3.3.

16.3.6 Non-destructive testing

16.3.6.1 All test procedures and acceptance standards shall be in accordance with recognized standards, unless the designer specifies a higher standard in order to meet design assumptions. Radiographic testing shall be used in principle to detect internal defects. However, an approved ultrasonic test procedure in lieu of radiographic testing may be conducted, but in addition supplementary radiographic testing at selected locations shall be carried out to verify the results. Radiographic and ultrasonic testing records shall be retained.

16.3.6.2 For type A independent tanks where the design temperature is below -20°C, and for type B independent tanks, regardless of temperature, all full penetration butt welds of the shell plating of fuel tanks shall be subjected to non-destructive testing suitable to detect internal defects over their full length. Ultrasonic testing in lieu of radiographic testing may be carried out under the same conditions as described in 16.3.6.1.

16.3.6.3 In each case the remaining tank structure, including the welding of stiffeners and other fittings and attachments, shall be examined by magnetic particle or dye penetrant methods as considered necessary.

16.3.6.4 For type C independent tanks, the extent of non-destructive testing shall be total or partial according to recognized standards, but the controls to be carried out shall not be less than the following:

- .1 Total non-destructive testing referred to in 6.4.15.3.2.1.3
Radiographic testing:

- .1 all butt welds over their full length.

Non-destructive testing for surface crack detection:

- .2 all welds over 10% of their length;
 - .3 reinforcement rings around holes, nozzles, etc. over their full length.

As an alternative, ultrasonic testing, as described in 16.3.6.1, may be accepted as a partial substitute for the radiographic testing. In addition, the Administration may require total ultrasonic testing on welding of reinforcement rings around holes, nozzles, etc.

- .2 Partial non-destructive testing referred to in 6.4.15.3.2.1.3:

Radiographic testing:

- .1 all butt welded crossing joints and at least 10% of the full length of butt welds at selected positions uniformly distributed.

Non-destructive testing for surface crack detection:

- .2 reinforcement rings around holes, nozzles, etc. over their full length.

Ultrasonic testing:

- .3 as may be required by the Administration in each instance.

16.3.6.5 The quality assurance/quality control (QA/QC) program shall ensure the continued conformity of the non-destructive testing of welds, as defined in the material manufacturer's quality manual (QM).

16.3.6.6 Inspection of piping shall be carried out in accordance with the regulations of chapter 7.

16.3.6.7 The secondary barrier shall be non-destructive tested for internal defects as considered necessary. Where the outer shell of the hull is part of the secondary barrier, all sheer strake butts and the intersections of all butts and seams in the side shell shall be tested by radiographic testing.

16.4 Other regulations for construction in metallic materials

16.4.1 General

Inspection and non-destructive testing of welds shall be in accordance with regulations in 16.3.5 and 16.3.6. Where higher standards or tolerances are assumed in the design, they shall also be satisfied.

16.4.2 Independent tank

For type C tanks and type B tanks primarily constructed of bodies of revolution the tolerances relating to manufacture, such as out-of-roundness, local deviations from the true form, welded joints alignment and tapering of plates having different thicknesses, shall comply with recognized standards. The tolerances shall also be related to the buckling analysis referred to in 6.4.15.2.3.1 and 6.4.15.3.3.2.

16.4.3 Secondary barriers

During construction the regulations for testing and inspection of secondary barriers shall be approved or accepted by the Administration (see also 6.4.4.5 and 6.4.4.6).

16.4.4 Membrane tanks

The quality assurance/quality control (QA/QC) program shall ensure the continued conformity of the weld procedure qualification, design details, materials, construction, inspection and production testing of components. These standards and procedures shall be developed during the prototype testing programme.

16.5 Testing

16.5.1 Testing and inspections during construction

16.5.1.1 All liquefied gas fuel tanks and process pressure vessels shall be subjected to hydrostatic or hydro-pneumatic pressure testing in accordance with 16.5.2 to 16.5.5, as applicable for the tank type.

16.5.1.2 All tanks shall be subject to a tightness test which may be performed in combination with the pressure test referred to in 16.5.1.1.

16.5.1.3 The gas tightness of the fuel containment system with reference to 6.3.3 shall be tested.

16.5.1.4 Regulations with respect to inspection of secondary barriers shall be decided by the Administration in each case, taking into account the accessibility of the barrier (see also 6.4.4).

16.5.1.5 The Administration may require that for ships fitted with novel type B independent tanks, or tanks designed according to 6.4.16 at least one prototype tank and its support shall be instrumented with strain gauges or other suitable equipment to confirm stress levels during the testing required in 16.5.1.1. Similar instrumentation may be required for type C independent tanks, depending on their configuration and on the arrangement of their supports and attachments.

16.5.1.6 The overall performance of the fuel containment system shall be verified for compliance with the design parameters during the first LNG bunkering, when steady thermal conditions of the liquefied gas fuel are reached, in accordance with the requirements of the Administration. Records of the performance of the components and equipment, essential to verify the design parameters, shall be maintained on board and be available to the Administration.

16.5.1.7 The fuel containment system shall be inspected for cold spots during or immediately following the first LNG bunkering, when steady thermal conditions are reached. Inspection of the integrity of thermal insulation surfaces that cannot be visually checked shall be carried out in accordance with the requirements of the Administration.

16.5.1.8 Heating arrangements, if fitted in accordance with 6.4.13.1.1.3 and 6.4.13.1.1.4, shall be tested for required heat output and heat distribution.

16.5.2 Type A independent tanks

All type A independent tanks shall be subjected to a hydrostatic or hydro-pneumatic pressure testing. This test shall be performed such that the stresses approximate, as far as practicable, the design stresses, and that the pressure at the top of the tank corresponds at least to the MARVS. When a hydropneumatic test is performed, the conditions shall simulate, as far as practicable, the design loading of the tank and of its support structure including dynamic components, while avoiding stress levels that could cause permanent deformation.

16.5.3 Type B independent tanks

Type B independent tanks shall be subjected to a hydrostatic or hydro-pneumatic pressure testing as follows:

- .1 The test shall be performed as required in 16.5.2 for type A independent tanks.
- .2 In addition, the maximum primary membrane stress or maximum bending stress in primary members under test conditions shall not exceed 90% of the yield strength of the material (as fabricated) at the test temperature. To ensure that this condition is satisfied, when calculations indicate that this stress exceeds 75% of the yield strength the test of the first of a series of identical tanks shall be monitored by the use of strain gauges or other suitable equipment.

16.5.4 Type C independent tanks and other pressure vessels

16.5.4.1 Each pressure vessel shall be subjected to a hydrostatic test at a pressure measured at the top of the tanks, of not less than $1.5 P_0$. In no case during the pressure test shall the calculated primary membrane stress at any point exceed 90% of the yield strength of the material at the test temperature. To ensure that this condition is satisfied where calculations indicate that this stress will exceed 0.75 times the yield strength, the test of the first of a series of identical tanks shall be monitored by the use of strain gauges or other suitable equipment in pressure vessels other than simple cylindrical and spherical pressure vessels.

16.5.4.2 The temperature of the water used for the test shall be at least 30°C above the nil-ductility transition temperature of the material, as fabricated.

16.5.4.3 The pressure shall be held for 2 hours per 25 mm of thickness, but in no case less than 2 hours.

16.5.4.4 Where necessary for liquefied gas fuel pressure vessels, a hydro-pneumatic test may be carried out under the conditions prescribed in 16.5.4.1 to 16.5.4.3.

16.5.4.5 Special consideration may be given to the testing of tanks in which higher allowable stresses are used, depending on service temperature. However, regulation in 16.5.4.1 shall be fully complied with.

16.5.4.6 After completion and assembly, each pressure vessel and its related fittings shall be subjected to an adequate tightness test, which may be performed in combination with the pressure testing referred to in 16.5.4.1 or 16.5.4.4 as applicable.

16.5.4.7 Pneumatic testing of pressure vessels other than liquefied gas fuel tanks shall be considered on an individual case basis. Such testing shall only be permitted for those vessels designed or supported such that they cannot be safely filled with water, or for those vessels that cannot be dried and are to be used in a service where traces of the testing medium cannot be tolerated.

16.5.5 Membrane tanks

16.5.5.1 Design development testing

16.5.5.1.1 The design development testing required in 6.4.15.4.1.2 shall include a series of analytical and physical models of both the primary and secondary barriers, including corners and joints, tested to verify that they will withstand the expected combined strains due to static, dynamic and thermal loads at all filling levels. This will culminate in the construction of a prototype scaled model of the complete liquefied gas fuel containment system. Testing conditions considered in the analytical and physical model shall represent the most extreme service conditions the liquefied gas fuel containment system will be likely to encounter over its life. Proposed acceptance criteria for periodic testing of secondary barriers required in 6.4.4 may be based on the results of testing carried out on the prototype scaled model.

16.5.5.1.2 The fatigue performance of the membrane materials and representative welded or bonded joints in the membranes shall be determined by tests. The ultimate strength and fatigue performance of arrangements for securing the thermal insulation system to the hull structure shall be determined by analyses or tests.

16.5.5.2 Testing

- .1 In ships fitted with membrane liquefied gas fuel containment systems, all tanks and other spaces that may normally contain liquid and are adjacent to the hull structure supporting the membrane, shall be hydrostatically tested.
- .2 All hold structures supporting the membrane shall be tested for tightness before installation of the liquefied gas fuel containment system.
- .3 Pipe tunnels and other compartments that do not normally contain liquid need not be hydrostatically tested.

16.6 Welding, post-weld heat treatment and non-destructive testing

16.6.1 General

Welding shall be carried out in accordance with 16.3.

16.6.2 Post-weld heat treatment

Post-weld heat treatment shall be required for all butt welds of pipes made with carbon, carbon-manganese and low alloy steels. The Administration may waive the regulations for thermal stress relieving of pipes with wall thickness less than 10 mm in relation to the design temperature and pressure of the piping system concerned.

16.6.3 Non-destructive testing

In addition to normal controls before and during the welding, and to the visual inspection of the finished welds, as necessary for proving that the welding has been carried out correctly and according to the regulations in this paragraph, the following tests shall be required:

- .1 100% radiographic or ultrasonic inspection of butt-welded joints for piping systems with;
 - .1 design temperatures colder than minus 10°C; or
 - .2 design pressure greater than 1.0 MPa; or
 - .3 gas supply pipes in ESD protected machinery spaces; or

- .4 inside diameters of more than 75 mm; or
- .5 wall thicknesses greater than 10 mm.
- .2 When such butt welded joints of piping sections are made by automatic welding procedures approved by the Administration, then a progressive reduction in the extent of radiographic or ultrasonic inspection can be agreed, but in no case to less than 10% of each joint. If defects are revealed the extent of examination shall be increased to 100% and shall include inspection of previously accepted welds. This approval can only be granted if well-documented quality assurance procedures and records are available to assess the ability of the manufacturer to produce satisfactory welds consistently.
- .3 The radiographic or ultrasonic inspection regulation may be reduced to 10% for butt-welded joints in the outer pipe of double-walled fuel piping.
- .4 For other butt-welded joints of pipes not covered by 16.6.3.1 and 16.6.3.3, spot radiographic or ultrasonic inspection or other non-destructive tests shall be carried out depending upon service, position and materials. In general, at least 10% of butt-welded joints of pipes shall be subjected to radiographic or ultrasonic inspection.

16.7 Testing regulations

16.7.1 Type testing of piping components

Valves

Each type of piping component intended to be used at a working temperature below minus 55°C shall be subject to the following type tests:

- .1 Each size and type of valve shall be subjected to seat tightness testing over the full range of operating pressures and temperatures, at intervals, up to the rated design pressure of the valve. Allowable leakage rates shall be to the requirements of the Administration. During the testing satisfactory operation of the valve shall be verified.
- .2 The flow or capacity shall be certified to a recognized standard for each size and type of valve.
- .3 Pressurized components shall be pressure tested to at least 1.5 times the design pressure.
- .4 For emergency shutdown valves, with materials having melting temperatures lower than 925°C, the type testing shall include a fire test to a standard at least equivalent to those acceptable to the Organization.

16.7.2 Expansion bellows

The following type tests shall be performed on each type of expansion bellows intended for use on fuel piping outside the fuel tank as found acceptable in 7.3.6.4.3.1.3 and where required by the Administration, on those installed within the fuel tanks:

- .1 Elements of the bellows, not pre-compressed, but axially restrained shall be pressure tested at not less than five times the design pressure without bursting. The duration of the test shall not be less than five minutes.

- .2 A pressure test shall be performed on a type expansion joint, complete with all the accessories such as flanges, stays and articulations, at the minimum design temperature and twice the design pressure at the extreme displacement conditions recommended by the manufacturer without permanent deformation.
- .3 A cyclic test (thermal movements) shall be performed on a complete expansion joint, which shall withstand at least as many cycles under the conditions of pressure, temperature, axial movement, rotational movement and transverse movement as it will encounter in actual service. Testing at ambient temperature is permitted when this testing is at least as severe as testing at the service temperature.
- .4 A cyclic fatigue test (ship deformation, ship accelerations and pipe vibrations) shall be performed on a complete expansion joint, without internal pressure, by simulating the bellows movement corresponding to a compensated pipe length, for at least 2,000,000 cycles at a frequency not higher than 5 Hz. This test is only required when, due to the piping arrangement, ship deformation loads are actually experienced.

16.7.3 System testing regulations

16.7.3.1 The regulations for testing in this section apply to fuel piping inside and outside the fuel tanks. However, relaxation from these regulations for piping inside fuel tanks and open ended piping may be accepted by the Administration.

16.7.3.2 After assembly, all fuel piping shall be subjected to a strength test with a suitable fluid. The test pressure shall be at least 1.5 times the design pressure for liquid lines and 1.5 times the maximum system working pressure for vapour lines. When piping systems or parts of systems are completely manufactured and equipped with all fittings, the test may be conducted prior to installation on board the ship. Joints welded on board shall be tested to at least 1.5 times the design pressure.

16.7.3.3 After assembly on board, the fuel piping system shall be subjected to a leak test using air, or other suitable medium to a pressure depending on the leak detection method applied.

16.7.3.4 In double wall fuel piping systems the outer pipe or duct shall also be pressure tested to show that it can withstand the expected maximum pressure at pipe rupture.

16.7.3.5 All piping systems, including valves, fittings and associated equipment for handling fuel or vapours, shall be tested under normal operating conditions not later than at the first bunkering operation, in accordance with the requirements of the Administration.

16.7.3.6 Emergency shutdown valves in liquefied gas piping systems shall close fully and smoothly within 30 s of actuation. Information about the closure time of the valves and their operating characteristics shall be available on board, and the closing time shall be verifiable and repeatable.

16.7.3.7 The closing time of the valve referred to in 8.5.8 and 15.4.2.2 (i.e. time from shutdown signal initiation to complete valve closure) shall not be greater than:

$$\frac{3600U}{BR} \text{ (second)}$$

where:

U = ullage volume at operating signal level (m³);

BR = maximum bunkering rate agreed between ship and shore facility (m³/h); or

5 seconds, whichever is the least.

The bunkering rate shall be adjusted to limit surge pressure on valve closure to an acceptable level, taking into account the bunkering hose or arm, the ship and the shore piping systems, where relevant.

PART C-1

Fuel in the context of the regulations in this part means natural gas, either in its liquefied or gaseous state.

17 DRILLS AND EMERGENCY EXERCISES

Drills and emergency exercises on board shall be conducted at regular intervals.

Such gas-related exercises could include for example:

- .1 tabletop exercise;
- .2 review of fueling procedures based in the fuel handling manual required by 18.2.3;
- .3 responses to potential contingences;
- .4 tests of equipment intended for contingency response; and
- .5 reviews that assigned seafarers are trained to perform assigned duties during fuelling and contingency response.

Gas related exercises may be incorporated into periodical drills required by SOLAS.

The response and safety system for hazards and accident control shall be reviewed and tested.

18 OPERATION

18.1 Goal

The goal of this chapter is to ensure that operational procedures for the loading, storage, operation, maintenance, and inspection of systems for gas or low-flashpoint fuels minimize the risk to personnel, the ship and the environment and that are consistent with practices for a conventional oil fuelled ship whilst taking into account the nature of the liquid or gaseous fuel.

18.2 Functional requirements

This chapter relates to the functional requirements in 3.2.1 to 3.2.3, 3.2.9, 3.2.11, 3.2.15, 3.2.16 and 3.2.17. In particular the following apply:

- .1 a copy of this Code, or national regulations incorporating the provisions of this Code, shall be on board every ship covered by this Code;
- .2 maintenance procedures and information for all gas related installations shall be available on board;
- .3 the ship shall be provided with operational procedures including a suitably detailed fuel handling manual, such that trained personnel can safely operate the fuel bunkering, storage and transfer systems; and
- .4 the ship shall be provided with suitable emergency procedures.

18.3 Regulations for maintenance

18.3.1 Maintenance and repair procedures shall include considerations with respect to the tank location and adjacent spaces (see chapter 5).

18.3.2 In-service survey, maintenance and testing of the fuel containment system are to be carried out in accordance with the inspection/survey plan required by 6.4.1.8.

18.3.3 The procedures and information shall include maintenance of electrical equipment that is installed in explosion hazardous spaces and areas. The inspection and maintenance of electrical installations in explosion hazardous spaces shall be performed in accordance with a recognized standard.

18.4 Regulations for bunkering operations

18.4.1 Responsibilities

18.4.1.1 Before any bunkering operation commences, the master of the receiving ship or his representative and the representative of the bunkering source (Persons In Charge, PIC) shall:

- .1 agree in writing the transfer procedure, including cooling down and if necessary, gassing up; the maximum transfer rate at all stages and volume to be transferred;
- .2 agree in writing action to be taken in an emergency; and
- .3 complete and sign the bunker safety checklist.

18.4.1.2 Upon completion of bunkering operations the ship PIC shall receive and sign a Bunker Delivery Note for the fuel delivered, containing at least the information specified in the annex to part C-1, completed and signed by the bunkering source PIC.

18.4.2 Overview of control, automation and safety systems

18.4.2.1 The fuel handling manual required by 18.2.3 shall include but is not limited to:

- .1 overall operation of the ship from dry-dock to dry-dock, including procedures for system cool down and warm up, bunker loading and, where appropriate, discharging, sampling, inerting and gas freeing;
- .2 bunker temperature and pressure control, alarm and safety systems;
- .3 system limitations, cool down rates and maximum fuel storage tank temperatures prior to bunkering, including minimum fuel temperatures, maximum tank pressures, transfer rates, filling limits and sloshing limitations;
- .4 operation of inert gas systems;
- .5 firefighting and emergency procedures: operation and maintenance of firefighting systems and use of extinguishing agents;
- .6 specific fuel properties and special equipment needed for the safe handling of the particular fuel;
- .7 fixed and portable gas detection operation and maintenance of equipment;
- .8 emergency shutdown and emergency release systems, where fitted; and

- .9 a description of the procedural actions to take in an emergency situation, such as leakage, fire or potential fuel stratification resulting in rollover.

18.4.2.2 A fuel system schematic/piping and instrumentation diagram (P&ID) shall be reproduced and permanently mounted in the ship's bunker control station and at the bunker station.

18.4.3 Pre-bunkering verification

18.4.3.1 Prior to conducting bunkering operations, pre-bunkering verification including, but not limited to the following, shall be carried out and documented in the bunker safety checklist:

- .1 all communications methods, including ship shore link (SSL), if fitted;
- .2 operation of fixed gas and fire detection equipment;
- .3 operation of portable gas detection equipment;
- .4 operation of remote controlled valves; and
- .5 inspection of hoses and couplings.

18.4.3.2 Documentation of successful verification shall be indicated by the mutually agreed and executed bunkering safety checklist signed by both PIC's.

18.4.4 Ship bunkering source communications

18.4.4.1 Communications shall be maintained between the ship PIC and the bunkering source PIC at all times during the bunkering operation. In the event that communications cannot be maintained, bunkering shall stop and not resume until communications are restored.

18.4.4.2 Communication devices used in bunkering shall comply with recognized standards for such devices acceptable to the Administration.

18.4.4.3 PIC's shall have direct and immediate communication with all personnel involved in the bunkering operation.

18.4.4.4 The ship shore link (SSL) or equivalent means to a bunkering source provided for automatic ESD communications, shall be compatible with the receiving ship and the delivering facility ESD system.

18.4.5 Electrical bonding

Hoses, transfer arms, piping and fittings provided by the delivering facility used for bunkering shall be electrically continuous, suitably insulated and shall provide a level of safety compliant with recognized standards.

18.4.6 Conditions for transfer

18.4.6.1 Warning signs shall be posted at the access points to the bunkering area listing fire safety precautions during fuel transfer.

18.4.6.2 During the transfer operation, personnel in the bunkering manifold area shall be limited to essential staff only. All staff engaged in duties or working in the vicinity of the operations shall wear appropriate personal protective equipment (PPE). A failure to maintain

the required conditions for transfer shall be cause to stop operations and transfer shall not be resumed until all required conditions are met.

18.4.6.3 Where bunkering is to take place via the installation of portable tanks, the procedure shall provide an equivalent level of safety as integrated fuel tanks and systems. Portable tanks shall be filled prior to loading on board the ship and shall be properly secured prior to connection to the fuel system.

18.4.6.4 For tanks not permanently installed in the ship, the connection of all necessary tank systems (piping, controls, safety system, relief system, etc.) to the fuel system of the ship is part of the "bunkering" process and shall be finished prior to ship departure from the bunkering source. Connecting and disconnecting of portable tanks during the sea voyage or manoeuvring is not permitted.

18.5 Regulations for enclosed space entry

18.5.1 Under normal operational circumstances, personnel shall not enter fuel tanks, fuel storage hold spaces, void spaces, tank connection spaces or other enclosed spaces where gas or flammable vapours may accumulate, unless the gas content of the atmosphere in such space is determined by means of fixed or portable equipment to ensure oxygen sufficiency and absence of an explosive atmosphere.

18.5.2 Personnel entering any space designated as a hazardous area shall not introduce any potential source of ignition into the space unless it has been certified gas-free and maintained in that condition.

18.6 Regulations for inerting and purging of fuel systems

18.6.1 The primary objective in inerting and purging of fuel systems is to prevent the formation of a combustible atmosphere in, near or around fuel system piping, tanks, equipment and adjacent spaces.

18.6.2 Procedures for inerting and purging of fuel systems shall ensure that air is not introduced into piping or a tank containing gas atmospheres, and that gas is not introduced into air contained in enclosures or spaces adjacent to fuel systems.

18.7 Regulations for hot work on or near fuel systems

18.7.1 Hot work in the vicinity of fuel tanks, fuel piping and insulation systems that may be flammable, contaminated with hydrocarbons, or that may give off toxic fumes as a product of combustion shall only be undertaken after the area has been secured and proven safe for hot work and all approvals have been obtained.

ANNEX

LNG-BUNKER DELIVERY NOTE
LNG AS FUEL FOR

SHIP NAME: _____ IMO NO.: _____

Date of delivery:

1. LNG-Properties

Methane number	--	
Lower calorific (heating) value	MJ/kg	
Higher calorific (heating) value	MJ/kg	
Wobbe Indices Ws / WI	MJ/m³	
Density	kg/m³	
Pressure	MPa (abs)	
LNG temperature delivered	°C	
LNG temperature in storage tank(s)	°C	
Pressure in storage tank(s)	MPa (abs)	

2. LNG-Composition

Methane, CH ₄	% (kg/kg)	
Ethane, C ₂ H ₆	% (kg/kg)	
Propane, C ₃ H ₈	% (kg/kg)	
Isobutane, i C ₄ H ₁₀	% (kg/kg)	
N-Butane, n C ₄ H ₁₀	% (kg/kg)	
Pentane, C ₅ H ₁₂	% (kg/kg)	
Hexane, C ₆ H ₁₄	% (kg/kg)	
Heptane, C ₇ H ₁₆	% (kg/kg)	
Nitrogen, N ₂	% (kg/kg)	
Sulphur, S	% (kg/kg)	
negligible<5ppm hydrogen sulphide, hydrogen, ammonia, chlorine, fluorine, water		

3. Net Total delivered: _____ t, _____ MJ _____ m³

Net Liquid delivery: _____ GJ

4. Signature(s):

Supplier Company Name, contact details: _____

Signature: _____ Place/Port _____ date: _____

Receiver: _____

PART D

19 TRAINING

19.1 Goal

The goal of this chapter is to ensure that seafarers on board ships to which this Code applies are adequately qualified, trained and experienced.

19.2 Functional requirements

Companies shall ensure that seafarers on board ships using gases or other low-flashpoint fuels shall have completed training to attain the abilities that are appropriate to the capacity to be filled and duties and responsibilities to be taken up, taking into account the provisions given in the STCW Convention and Code, as amended.