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(ADN Safety Committee)**

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Special authorizations, derogations and equivalents

Request for a derogation for the Damen River Tanker (DRT)-Ecoliner

Transmitted by the Government of the Netherlands

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TNO report

Assessment of hazard identification study chemical tanker design Ecoliner

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Summary

Technical evidence, supporting a hazard identification study on the design of a natural gas fuelled chemical inland waterway tanker, has been assessed. The storage of the gas will be as liquid at cryogenic temperature (LNG). With exception of the location of the fuel tanks, the general conclusion is that in principle, LNG as bunker fuel is sufficiently safe. In addition, although these are not considered as show stoppers, some other safety issues are still to be resolved.

The most important issues are:
- protection of the LNG storage tank against ship collisions,
- how to handle LNG leakage from the cold box drip tray to the deck,
- how to prevent overfilling and uncontrolled pressure build up, during bunkering,
- prevention of accumulation of dangerous gas concentrations in the engine room.

Contents

1 Introduction

There are currently three initiatives in progress on the use of natural gas as bunker fuel on inland waterway tankers. The ships will sail European waters, mostly the ARA (Amsterdam Rotterdam Antwerp) waterways and the river Rhine with adjacent rivers and canals. The natural gas will be stored in liquefied condition in insulated pressure vessels. There will be no reliquefication facility on board, hence the tanks will be designed to cope with a pressure build up.

Safety studies have been carried out for all three initiatives. Documentation related to the studies has been submitted to the responsible authorities, CCNR (Central Commission for the Navigation of the Rhine) and UN ECE (United Nations Economic Council Europe).

DGLM (The Netherlands Directorate General Aeronautics and Maritime transport) has requested TNO to assess the technical evidence currently available and formulate a recommendation on how to progress.

There are significant differences between the three project initiatives, therefore it has been decided to formulate the recommendations for each initiative separately.

This report refers to the design of a motor tank ship Ecoliner.

An appropriate way to assess a novel technology is to conduct a formal safet assessment (FSA). According IMO standards [7] a formal safety assessment consists of five distinctive steps as shown in Table 1.1.

Table 1.1 FSA steps

step	***description***
1	HAZARD IDENTIFICATION
2	RISK ANALYSIS
3	RISK CONTROL OPTIONS
4	COST BENEFIT ASSESSMENT
5	RECOMMENDATIONS FOR DECISION MAKING

The documentation submitted to CCR/UN-ECE suggest a hazard identification study (HAZID) has been carried out (step 1). However the technical documentations is not restricted to a hazard identification study. Mitigation actions are also reported which formally are a part of the "*risk control options*" activity (step 3).
Many hazards as identified, are already covered IGC [3] code, IGF [2] code (IGF has a preliminary status only) and the design code for cryogenic vessels [5]. It is reasonable to state that when the LNG fuel system complies with these codes with respect to a hazard, sufficient safety is ensured related to this hazard. In such cases the associated risk needs not to be quantified as such and the FSA needs not be carried out to its full effect. From the available documentation is becomes evident that this approach has been chosen.
However some hazards are outside the scope of current safety codes. Obviously these are best addressed in a FSA fashion.

2 Approach

The work allocated to TNO has been carried out through making seven distinct steps:

1. Study available information as submitted to authorities;
2. Identify additional information required;
3. Obtain additional information required;
4. Study additional information;
5. Discuss findings with relevant stakeholders;
6. Assess and verify available material;
7. Report the assessment.

Activities 1 and 2 of the study took place at the TNO offices. During this part a review of a number of HAZID documents was carried out. Requests for additional information were made.
Discussions were held with representatives from Bureau Veritas in Rotterdam in which the findings of this initial assessment were discussed. A visit was paid to MTS Argonon, which features an LNG installation, currently under construction at shipyard TRICO in Rotterdam. An important aim of the discussions was to acquire additional information identified by TNO to be missing in the HAZID study. Moreover clarifications were obtained on some unresolved issues.

Some reference material, available in the public domain, has also been considered while making the assessment.

When dealing with industrial activities where safety issues are relevant, such as building and operating chemical plants or building and operating (offshore) oil exploitation facilities, it is common to conduct an FSA (formal safety assessment, see introduction).
The philosophy related to FSA has been used by TNO as a guideline while assessing the available technical evidence.

The approach in [1] annex 6, is slightly different from a FSA. The document introduces the concept of the safety case, which may be regarded as a way of conducting an FSA. Table 2.1 lists the elements of this safety case.

Table 2.1 Safety case documentation (taken from [1])

i) **Management Summary**
- Safety Case Objectives
- Safety Case Compilation Process
- Endorsement by owner
- Endorsement by Class Society

ii) **Project Execution**
- Safety Execution Plan
- Safety Action Register (Design change actions and close-outs)

iii) **System Description**
- Tank design and arrangement
- Bunkering system
- Pressure builup/gas processing
- Machinery room arrangement
- Gas burning machinery

iv) **Safety Assessment**
- Design Compliance Standards
- Hazard Identification (HAZID) Study
- FMEA study as required by HAZID
- Hazard operability study (HAZOP) as required

As can be seen a HAZID is only one element of a safety case. In principle the other elements should be dealt with as well in order to complete the safety case. However it should be mentioned that a break down of a safety case into elements should be regarded as a guideline. Hence discarding some of the elements may be quite acceptable as long as the safety assessments yields convincing results.

In order to provide some additional structure, Table 2.2 was drafted, which is used as an (additional) guidance during the assessment.

Table 2.2 hardware systems and operational modes

		1	2	3	4	5	6
		sailing	manoeuvring	idle moored	(un)loading moored	bunkering moored	construction, repair, maintenance and demolition
1	LNG storage tank (*in operation mode*)	tank impact with bridge no issue protected by superstructure, ship impact, excessive pressure build up due to heating, sloshing damage, cargo tank slides/topples due to ship accelerations	ship impact, excessive pressure build up due to heating, sloshing damage, cargo tank slides/topples due to ship accelerations	ship impact, excessive pressure build up due to heating	ship impact, excessive pressure build up due to heating, dropped objects	ship impact, excessive pressure build up due to heating, cargo tank, dropped objects, pressure build up due to bunkering fault	<tank will not be gas free> dropped objects, leakage and hot work, LNG reactivity with other substances
2	Bunkering system (a*longside*)	n.a.	n.a.	n.a.	n.a.	Broken bunker hose (LNG spill on deck), gas release (explosion, fire), frozen couplings (quick release impossible), loss of control due to incorrect pressure reading or incorrect level reading or frozen valves or bad communication or software problems (tank pressure increases), liquid through venting system, damage to human skin, ship/shore, material failure, frostbite personnel	unnoticed damage to system
3	Pressure build up system (*pressure build up, underway*)	spill on deck, PCV 51 leaking in line, gas in ER, pressure build up above design	spill on deck, PCV 51 leaking in line, gas in ER, pressure build up above design	leakage of (liquid)gas in coolwater, leakage of coolwater into gas	spill on deck, PCV 51 leaking in line, gas in ER, pressure build up above design	spill on deck, PCV 51 leaking in line, gas in ER, pressure build up above design	mechanical damage (dropped objects, etc.), electric wire cut, sensor damage
4	Gas conditioning system (underway)	freezing heat exchanger, LNG spill on deck, uncuntrolled flow,	freezing heat exchanger, LNG spill on deck, uncuntrolled flow,	freezing heat exchanger, LNG spill on deck, uncuntrolled flow,	freezing heat exchanger, LNG spill on deck, uncuntrolled flow,	freezing heat exchanger, LNG spill on deck, uncuntrolled flow,	
5	Gas turbine arrangement (underway)	gas/vent air mixture, gas escape, gas cannot be shut off,	gas/vent air mixture, gas escape, gas cannot be shut off,	gas/vent air mixture, gas escape, gas cannot be shut off,	gas/vent air mixture, gas escape, gas cannot be shut off,	gas/vent air mixture, gas escape, gas cannot be shut off,	
6	Machinery arrangement (underway)	inner pipe failure, fan failure, short-circuit main switch board,	inner pipe failure, fan failure, short-circuit main switch board,	inner pipe failure, fan failure, short-circuit main switch board,	inner pipe failure, fan failure, short-circuit main switch board,	inner pipe failure, fan failure, short-circuit main switch board,	
7	Otto engine, incl. gas supply (underway)	leakage, exhaust failure due to explosion, gas release, gas enters	leakage, exhaust failure due to explosion, gas release, gas enters	leakage, exhaust failure due to explosion, gas release, gas enters	leakage, exhaust failure due to explosion, gas release, gas enters	leakage, exhaust failure due to explosion, gas release, gas enters	

3 Technical evidence CCR and UN ECE, 13-08-2011

3.1 Description technical evidence

The following documents have been made available to TNO by the DGTL prior to the study:

Recommendation DRT 1145 ROSR
Recommendation DRT 1145 ROSR annex 1
Recommendation DRT 1145 ROSR annex 2
Recommendation DRT 1145 ROSR annex 3
Recommendation DRT 1145 ROSR annex 4
Recommendation DRT 1145 ROSR annex 5
Recommendation DRT 1145 ROSR annex 6
Att 1 000-000 General Arrangement
Att 2a 000-003 LNG irt accomodation
Att 2b 000-003a LNG irt accomodation
Att 2c 000-003B LNG irt accomodation
Att 3 675-000 Sprinkler LNG
Att 4 Monitoring of Gas Supply Systems
Att 5 321-000 LNG - NG diagram with gastight enclosures
Att 6 200-000 Layout Engine Room and Ventilation
Att 7 400-000 Power Management
Att 8 Safety sheet LNG

These documents were reviewed by TNO. The following criteria were considered:

- Was a structured, generally accepted, approach used for the HAZID?
- Were all Hazards addressed / identified?
- Were corrective measures proposed for these hazards?
- Do the corrective measures proposed provide a sufficient risk reduction?

3.2 Gaps

The review of the HAZID study resulted in the questions and requests as listed below.

The issues were discussed with Bureau Veritas Rotterdam.

1. . Has a risk ranking been made following the HAZID as reported ref. [1]? A risk ranking will help to assess the necessity of safeguards.
2. . Has any assessment been done w.r.t. ship-ship collisions? Are there arguments why contact with the LNG tank can be ruled out? A safe distance between tank wall and ship side of 1000 mm seems too small.
3. . The documentation does not seem to address external safety issues, e.g. risks to terminals during loading and unloading. Are there reasons why this aspect may be irrelevant?

Moreover an update was requested on the current status of the pending issues as listed below.

4. Collision with bridge (no issue).
5. . In service inspection of LNG tanks needs further consideration.
6. . Bunkering procedure identified as main hazard, automated bunkering procedure proposed for further consideration.
7. . Location of bunkering manifolds indicated as unresolved.
8. . Pressure regulating control valve identified as potential cause of pressure build up.
9. . Drip tray below cold box, may discharge LNG on deck.
10. CFD analyses proposed to demonstrate adequate ventilation in gas dangerous spaces.

It is noted that LNG spill from a fractured bunkering hose had not been considered. Additional data will be requested. This will be addressed under gap item no. 6, *bunkering procedure*.

Another issue to be considered is human error. Handling cryogenic liquids and flammable gas safely requires knowledge, skills and an attitude. In this document referred to as issue 11.

4 Additional evidence

4.1 Discussions

The issues mentioned in the previous paragraph were discussed. Also a visit was paid to MV Argonon, a type C tanker also featuring an LNG fuel installation.

Issues (reference to numbering in previous paragraph) :

1. No risk ranking was carried out. It was / is the intention to address all issues, i.e. to propose / install adequate safety barriers for *all* risks identified.
2. It is argued that ship-ship collisions, that might affect the LNG tanks on board, are implicitly covered in IGF which observes safe distances between tanks and ship sides of at least 760 mm. No evidence is available to demonstrate this distance provides sufficient safety in case if inland waterway tankers. This issue is not yet resolved.
3. Loading/unloading was considered a main risk in the HAZID studies. There is a need to address a potential (L)NG spilled and the consequences. The latter should also include the effect of the cold LNG on the structural integrity of the ship.
4. Collision with a bridge is no issue for this ship, because the superstructure protects the tank.
5. The LNG tanks were built according to the specifications for the road tankers used for LNG transport [5]. Also the inspection regime for road tankers will be followed. This was considered (more than) adequate, because road tankers are likely to be exposed to larger shocks / vibrations during operation than ships.
6. The bunkering procedure was considered to pose the higher risk. Therefore this activity must be performed by skilled personnel only. Also automatic safety measures will be installed that would generate an automatic shut off (safety valves) to limit the volumes spilled during loading (see also nr 3 above). Also level indicators would be installed that would generate alarms and eventually shut down the loading operation. Further details w.r.t. the bunkering system including bunkering procedures should be described.
7. The location of the bunkering manifold must be chosen carefully because of vulnerability to mechanical damage and potential spill of LNG on deck. Further details to be specified.
8. The pressure regulating control valve in the pressure build up system has been identified as a potential hazard. Mitigating measures have been suggested, however it is not yet clear which will be used.
9. *(left unused deliberately)*
10. A point of on-going concern is the potential of gas built-up (i.e. an explosive gas-air mixture) in the engine rooms. It has not yet been demonstrated whether ventilation will be sufficient guarantee for an explosion free environment. The gas detection proposed might be unreliable because it might generate false alarms (leading to ignoring of alarms or by-passing the shut-off systems) or it could be in the wrong place (which means no detection). Odoration of the gas will help if the machine room is visited regularly. TNO therefore remains of the opinion that the potential for a built

up of an explosive atmosphere (in an area with numerous ignition sources) is still there. This issue needs to be further addressed.

4.2 Additional information

Issue 8. Pressure build up.
A calculation result is available on tank venting [4]. It demonstrates that a tank, filled at 70%, exposed to an ambient temperature of 40 Celcius and a allowable pressure of 8 bar, will vent after 25 days.

4.3 Assessment of additional technical evidence and gaps

Issue 2. Ship-Ship collisions
This issue is dealt with by referring to IMO IGF code which implies that hull penetrations due to collisions, larger than 760 mm, are unlikely. No evidence seems to be available that a ship colliding into the stern of the Ecoliner will not exceed a penetration of 760 mm. This needs to be further substantiated. However cryogenic storage tanks may have a large impact resistance (crashworthiness) due to the materials used for construction and the geometric properties. This resistance may be larger than the expected impact energy. It is suggested to give this scenario due consideration and secure documentation on impact resistance (crashworthiness) of cryogenic storage tanks.
Another approach may be to conduct a limited risk assessment through considering both the probability of tank fracture and the associated effect of (L)NG spill. It seems reasonable to use effect distance as an characteristic parameter to quantify the effect. If it is demonstrated that the probability of LNG bunker tank fracture times the associated affected area is much smaller than the probability of cargo tank failure times the associated affected area, a probability larger than nil of tank failure due to an impact, may be acceptable. See also **Issue 3**.

Issue 3. External safety
This issue is dealt implicitly only. It may be argued that effect distances associated with chemical tankers are substantially larger than those associated with LNG quantities currently envisaged as bunker fuel. It is noted that chemical tankers are subject to restrictions w.r.t. sailing areas and places for anchoring and mooring. Hence no further considerations are required at this stage.
However, when LNG fuel storage capacities increase substantially (>200 m3), this issue needs to be reconsidered.
When LNG fuel is considered for general cargo or container ships, the external safety issue needs to be addressed explicitly.

Issue 4. Calculation collision with a bridge
Since the superstructure protects the tanks, this scenario is no issue.

Issue 6 LNG spill on deck.
Information on how to prevent LNG storage tank overloading, e.g. through liquid level detection and high-high alarms, or, alternatively, technical evidence showing that overfilling will not have any adverse effects is still to be provided.

Issue 10. Gas/air mixture accumulation in engine room.
The geometry of the engine rooms seems to make them prone to gas accumulation. This issue needs to be addressed.

Issue 11. Human element.
There is general consensus on the required knowledge, skills and attitude of crew dealing with LNG bunker fuel. It is fortunate that chemical tankers are proposed as pioneers in using LNG as bunker fuel, because crews are qualified (ADN) to deal with hazardous substances, i.e. the cargo. However handling LNG requires additional knowledge and skill. It is still to be resolved who will teach the knowledge and skills and how many crew members trained on the LNG aspect must be on board.
When LNG fuel is considered for general cargo or container ships, the external safety issue needs to be addressed because crews may not have any ADN qualification.

General remarks
Any safety assessment on a technology used in a new environment is a tremendous task. The main issue is overlooking the obvious. Also in the case of LNG as bunker fuel on inland waterway ships making sure that all relevant hazards have been addressed must remain on top of the priority list. Moreover accessibility of safety case documentation requires further attention.

5 Conclusions and recommendations

The general impression from the technical evidence studied so far, is that applying LNG as bunker fuel may cause a safety issue with regard to the location of the tanks on the aft deck. The impact absorbing capacity (crashworthiness) of the tanks is however unknown and should be further investigated. The impact absorbing capacity of these tanks may be sufficient to make them intrinsically safe.
Another approach is conducting a limited risk assessment as outlined in the 2nd paragraph under **Issue 2**.

Availability technical evidence.
Some technical evidence is not always readily available although it seems likely that it exists. Some issues, already identified in the HASID, still need to be resolved.

Collision with bridge.
Tank damage due to collision with bridge is no issue for this ship.

Brittle fracture main deck due to LNG spill.
LNG spill on deck due to rupture of the bunker hose is to be investigated.

Dangerous gas concentration in ER.
The issue of dangerous gas concentrations in the ER needs further supporting evidence. Smoke tests are recommended.

References

[1] Recommendation to inspection bodies relating to the rhine vessel inspection regulations, on motor tank vessel “Damen River Tanker – 1145 Ecoliner”, type C tanker, official ID number 54314 and BV reg. no. 20629A. Versie 18-8-2011

[2] IGF, draft International code on safety for Gas-Fuelled ships, IMO

[3] IGC, International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, 1993 Edition, IMO

[4] E-mail communication Dohmeijer, Dec. 2011.

[5] EN13458-2 Cryogenic vessel – Static vacuum insulated vessels Part 2: Design, fabrication, inspection and testing

[6] NFPA 57, Liquefied Natural (LNG) Vehicular Fuel Systems Code 2002 Edition

[7] Guidelines for formal safety assessment (FSA) for use in the IMO rule making process, MSC/Circ.1023, MEPC/Circ.392, 5 April 2002

6 Signature

Delft, <datum>	Placeholder
<naam afdelingshoofd> Head of department	Ir. Alex W. Vredeveldt, Dr. J. Reinders Author

In addition to the initial Hazid study and the TNO report further research was done on what would happen with the LNG storage tanks onboard the Ecoliner of Damen after a collision.

Based upon a study made at the Helsinki University of technology and at the Schelde yard in Vlissingen it can be concluded that there is a low probability that a collision will take place at the location of the LNG tanks and that when such a collision takes place the majority of the available energy will be absorbed by a rotation of the struck ship (kinetic energy) and that a relative small amount (20%) has to be absorbed by the ship structure. The amount of energy that has to be absorbed by the ship structure is a factor 3 less compared to a location amidships which makes the location at least as collision resistant as a ship with a special energy absorbing structure in its cargo area.

Please find the report “considerations for collision scenario on LNG tanks Damen River liner” made by Mr Broekhuijsen of Damen Schelde attached (Attachment 10a).

The next study calculated the effect of LNG spill if a storage tank would rupture and all LNG would be spilled.

Attached you will find the calculation made by Mr Broekhuijsen of Damen Schelde, report “Effect analysis LNG spill DRT 1145 EL” (Attachment 10b).

DAMEN SCHELDE NAVAL SHIPBUILDING

MEMO

aan	Willem Kroon	datum	17 Januari 2012
c.c.	Rob Schuurmans, Liesbeth den Haan	referentie	E10109
Afzender	Joep Broekhuijsen		
Onderwerp	Considerations for collision scenario on LNG tanks		

Considerations for collision scenario on LNG tanks Damen River Tanker – Eco liner

In this document a number of considerations are given for the review of the collision scenario "colliding with LNG tanks placed at the aft ship".

For inland waterway tankers with enlarged cargo tanks the energy absorption capacity of the ship construction amidships has to be calculated and compared with a reference ship according to the guidance for enlarged cargo tanks within the ADNR [1]. Starting form a worst case approach the following assumptions are made:

1. For a collision scenario amidships the whole ship, including added water mass, has to undergo a sway motion, assuming an inelastic collision scenario. This implies that a large part of the available collision energy as to be absorbed by the ship's s construction. This assumption has been verified by Tabri [2] with experimental research. Tabri shows that for a collision location amidships 60% of the available collision energy has to be absorbed by the ship structure. Where for a striking scenario at 75% of the ships length only 38% had to be absorbed by the ship structure.
   The LNG tanks for the Damen River Tanker are placed at a position at approximately 90% of the ships length where it can is estimated that the collision energy to be absorbed by the ship structure will be around 20%. The rest of the available energy will be transformed into kinetic rotation energy of the struck ship.
   The same trend can be absorbed for the penetration depth as a function of the collision location. Where collisions amidships result in a larger penetration compared with collisions near the front or the aft of the ship.

2. According to the guidance for enlarged cargo tanks within the ADNR different collision scenarios in longitudinal directions are determined based on the structural layout of the ship. A distinction is made between colliding on bulkhead, on web and between webs. The collision scenarios are weighted, where the ratio between the 'calculated span length' and the cargo tank length is determined. When we add the collision scenario 'colliding on LNG tanks' to the longitudinal collision scenario's all the scenarios can be weighted by determining the ratio between the calculated span length and the total ship length. For the collision scenario 'colliding at LNG tanks' this implies that in only 6.6% of the collisions will take place at the location of the LNG tanks.

Conclusion

From 1 and 2 it can be concluded that there is a low probability that a collision will take place at the location of the LNG tanks and that when such a collision takes place the majority of the available energy will be absorbed by a rotation of the struck ship (kinetic energy) and that a relative small amount (20%) has to be absorbed by the ship structure. The amount of energy that has to be absorbed by the ship structure is a factor 3 less compared to a location amidships which makes the lacation at least as collision resistant as a ship with a special energy absorbing structure in its cargo area.

References:

1. ADNR 2009, 9.3.1 Constructievoorschriften voor tankschepen, 9.3.4 Alternatieve constructies,
2. Tabri, K, Broekhuijsen, J, Parametric study on ship collision based on experimental testing, 2007 International Conference on Collision and Grounding of Ships, Hamburg

EFFECT ANALYSIS LNG SPILL DRT 1145 EL

-

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1. INTRODUCTION

Bodewes Binnenvaart B.V. has developed an inland waterway Type C tanker design that uses liquefied natural gas as bunker fuel. The ship will sail in European waters, mostly the ARA (Amsterdam Rotterdam Antwerp) waterways and the river Rhine with adjacent rivers and canals. The natural gas will be stored in liquefied condition in insulated pressure vessels.

This report contains an effect analysis for an accidental spill scenario in the case of a ship collision with the LNG pressure vessel. The same accident scenarios will be taken into account as used for the effect analysis carried out for Type C tankers with enlarged cargo tanks. A comparison will be made with effect distances found for conventional Type C tanker cargo outflow in the event of a collision.

2. SCENARIOS

The different accident scenarios considered in the study on the effect for enlarged cargo tanks [1] concern a collision at the location of the cargo tank where the tank boundary is breached. As a result of the collision release of product is taking place.
For the DRT 1145 EL a collision at the location of the LNG tanks will be assumed where both the stainless steel drip tray as the tank boundary are breached. The amount of release depends on the size of the hole in the LNG tank, the amount of LNG leaving the cargo tank and the place of the hole.
The most severe scenario that has been assessed concerns a hole size in the tank of $2m^2$.
The most severe location of the hole for the LNG tank would be a $2m^2$ hole located at the bottom of the tank. When it is further assumed that the LNG driven tanker sails at ballast draft with 100% filled LNG tanks the worst case scenario is considered.

Two hazards associated with LNG bunker fuel in the environment have been given consideration:

- Maximum pool radius on the water [m], assuming that direct contact with the cargo is lethal
- 10 kW/m^2. This is the quantity for heat radiation intensity. The calculated effects are the effects of a ‘late pool fire’ (pool fire of the maximum pool).

3. MODELLING OF PHYSICS

In Sandia report SAND2004-6258 [2] a procedure is given for the effect analysis of an LNG spill over water.

The diameter of the spill can be determined by assuming a steady state where the mass coming in is balanced by the mass going out, due to the heat flux from the heating of the water below and from the fire above. According to Cook et al. [3] the burning rate on water is 2.5 times greater than the burning rate on land. For LNG a mass burning rate of 0.353 [kg/m^{2}s] is used.

$$(\rho A v)_{in} = (\rho A v)_{out}$$

$$\left(\frac{dV}{dt}\right)_{average} = \frac{-(Av)_{out}}{2} = -\frac{C_d A_0}{2}\sqrt{2gh_i}$$

$$D = \sqrt{\frac{4}{\pi v_{total}}\left(\frac{dV}{dt}\right)_{average}}$$

Where:

0.6	C_D	- Dicharge coefficient	[-]		
2	A_0	- Cross sectional area of hole	[m^2]		
9.81	g	- Gravity accelaration	[m/s^2]		
4.5	h_i	- Initial height of fluid	[m]	(air draft - Tballast)	
21.98	A_t	- Cross sectional area of tank	[m^2]		
7.84E-04	v_{total}	- burn rate	[m/s]		

The diameter of the spill becomes

diameter spill	96	[m]

A right cylinder, solid flame model is used to model the pool fire. The effect of wind on the flame is considered negligible. The Moorhouse correlation for LNG was used to calculate the flame height [4].

$$H = 6.2D\left(\frac{\dot{m}''}{\rho_a\sqrt{gD}}\right)^{0.254} u_{10}^{*-0.044}$$

Where:

0.353	m"	- Mass burning rate per unit area	[kg/m²s]
1.25	rho_a	- ambient air density	[kg/m³]
1	u_{10}	- non dimensional wind speed	[-]

The Flame height becomes

flame height	180	[m]

The radiative flux incident upon an object can be determined by:

$$q'' = E_p \tau_{atm} F$$

Where:

10	q"	- thermal radiation intensity	[kW/m²]
220	E	- average emmissive power	[kW/m²]
	F_{12}	- view factor	
	τ_{atm}	- atmospheric transmissivity	

Both the transmissivity and the view factor are dependent on the distance the object is away form the source. The distance to 10 kW/m^2 can be calculated using the following relations

$$F_{12,\max} = \sqrt{F_{12,H}^2 + F_{12,V}^2}$$

$$F_{12,H} = \frac{(B-1/S)}{\pi\sqrt{B^2-1}}\tan^{-1}\sqrt{\frac{(B+1)(S-1)}{(B-1)(S+1)}} - \frac{(A-1/S)}{\pi\sqrt{A^2-1}}\tan^{-1}\sqrt{\frac{(A+1)(S-1)}{(A-1)(S+1)}}$$

$$F_{12,V} = \frac{1}{\pi S}\tan^{-1}\left(\frac{h}{\sqrt{S^2-1}}\right) - \frac{h}{\pi S}\tan^{-1}\sqrt{\frac{(S-1)}{(S+1)}} + \frac{Ah}{\pi S\sqrt{A^2-1}}\tan^{-1}\sqrt{\frac{(A+1)(S-1)}{(A-1)(S+1)}}$$

$$A = \frac{h^2+S^2+1}{2S} \qquad B = \frac{1+S^2}{2S}$$

$$S = \frac{2L}{D} \qquad h = \frac{2H}{D}$$

Where:

L	- distance between the center of the cylinder to the target				[m]
H	- height of the cylinder				[m]
D	- cylinder diameter				[m]

$$\tau_{atm} = 1.5092 - 0.0708\ln[sP_{w,sat}(T_a)RH/100]$$

Where:

288	T_a	- atmospheric temperature	[K]
80	RH	- humidity	[%]
	s	- distance traveled	[m]

$$P_{w,sat} = \exp\left[25.897 - \frac{5319.4}{T_a}\right]$$

The distance to10 kW/m^2 becomes

10 kW/m^2	255	[m]

4. RESULTS AND CONCLUSION EFFECT CALCULATIONS

In the following table the results of the LNG spill effect calculation are shown together with the results for the 380 m^3 Type C tanker cargo tank for the typical products as used in reference [1].

		Max pool radius [m]	10 kW/m^2
2 m^2 hole size	Benzene	234	263
	Acrylonitrite	249	575
	n-Hexane	235	264
	n-Nonane	236	283
	Acetic acid	234	261
	LNG	95	255

Comparing the effects it can be concluded that the calculated maximum pool radius and the distance related to the 10 kW/m^2 heat radiation intensity are the lowest for the LNG spill. Therefore it can be concluded that for the Type C tanker DRT 1145 EL no additional effect distance can be associated with LNG. It is further noted that the DRT 1145 EL has a stainless steel drip tray installed underneath the LNG tanks that can contain 100% of one tank volume. This decreases the pool radius to the dimensions of the drip tray and the 10 kW/m^2 distance will be decreased accordingly. Furthermore it should be noted that chemical tankers are subject to restrictions w.r.t. sailing areas and places for anchoring and mooring.

5. REFERENCES

[1] A.W. Vredeveldt, M.J. Wolf, J. Broekhuijsen, E. Gret, Safe transport of hazardous cargo through crashworthy side structures, 2004, International Conference on Collision and Grounding of Ships, Izu Japan
[2] SANDIA report, SAND2004-6258, Unlimited Release, Printed December 2004, Guidance on Risk Analysis and Safety, Implications of a Large Liquified Natural gas (LNG) Spill over Water
[3] J. Cook, Z. Bahrami, R.J. Whitehouse, A comprehensive program for calculation of flame radiation levels, J. Loss Prev. Process Ind., 3, pp 150-155, 1990
[5] P.J. Dinenno, SFPE handbook of fire protection engineering, Society of Fire Protection Engineers, 2002

Memorandum

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To
Ministry I en M,
mr. Gert Mensink
mr. Rens Vermeulen

From
A.W. Vredeveldt

Copy to
mrs. Liesbeth den Haan (BV),
mr. Rob Schuurmans (Bodewes),
mr. Willem Kroon (Bodewes)

Subject
Assessment additional information on hazard identification study chemical tanker design Ecoliner

Date
16 May 2012

Our reference
TNO-060-DTM-2012-01538

Direct dialling
+31 88 866 33 72

Further discussions were held between TNO, Bureau Veritas and Bodewes Shipyards Millingen on the “Damen River Tanker – 1145 Ecoliner”, which features LNG cryogenic bunker tanks. The discussions focussed on the vulnerability of the bunker tanks at their location aft of the superstructure, as earlier identified by TNO.

Bodewes has tabled additional analysis results, carried out by their sister company, Damen Naval Shipyards, on the effects of LNG spillage. The analysis shows that the effect of LNG spillage, proves much smaller than the effects associated with cargo spillage.

Bodewes has also decided to reduce the size of the bunker tanks in order to ensure a distance between tanks and deck edges of at least 1/5th of the ships beam, which is in excess of the minimum requirement of 760 mm, as currently specified in the ‘IGF Code’.

Based on this information and the findings reported in the TNO draft report, “Assessment of hazard identification study chemical tanker design Ecoliner”, dated April 23rd 2012, TNO concludes as follows.

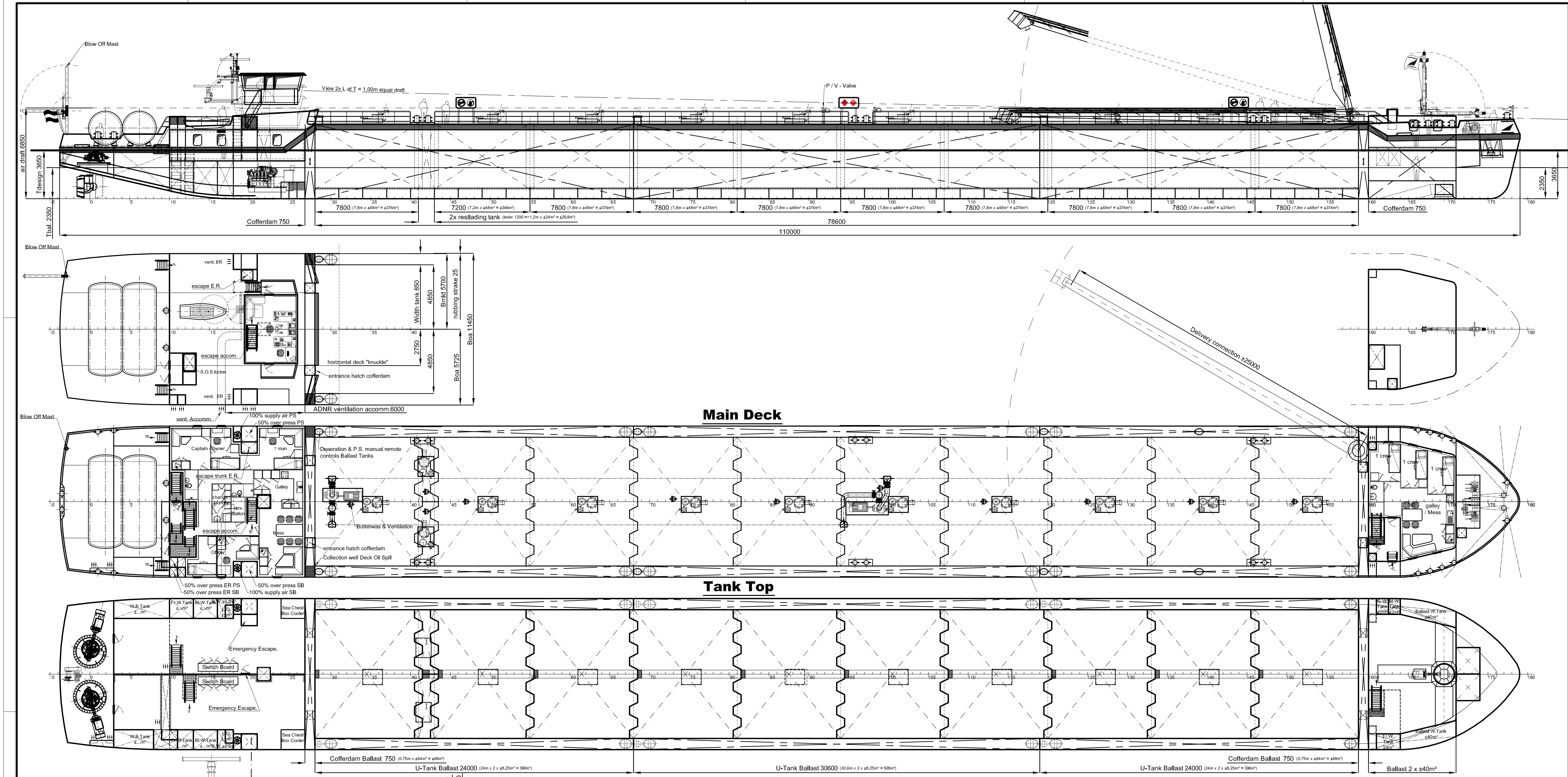
The current design is based on tank locations where the distance between the tank shells and the deck edge is at least 1/5th of the ships beam, which is in excess of the minimum allowable distance of 760 mm, as specified in IGF. Hence it seems reasonable to consider the current location of the tanks to be sufficiently safe[1].

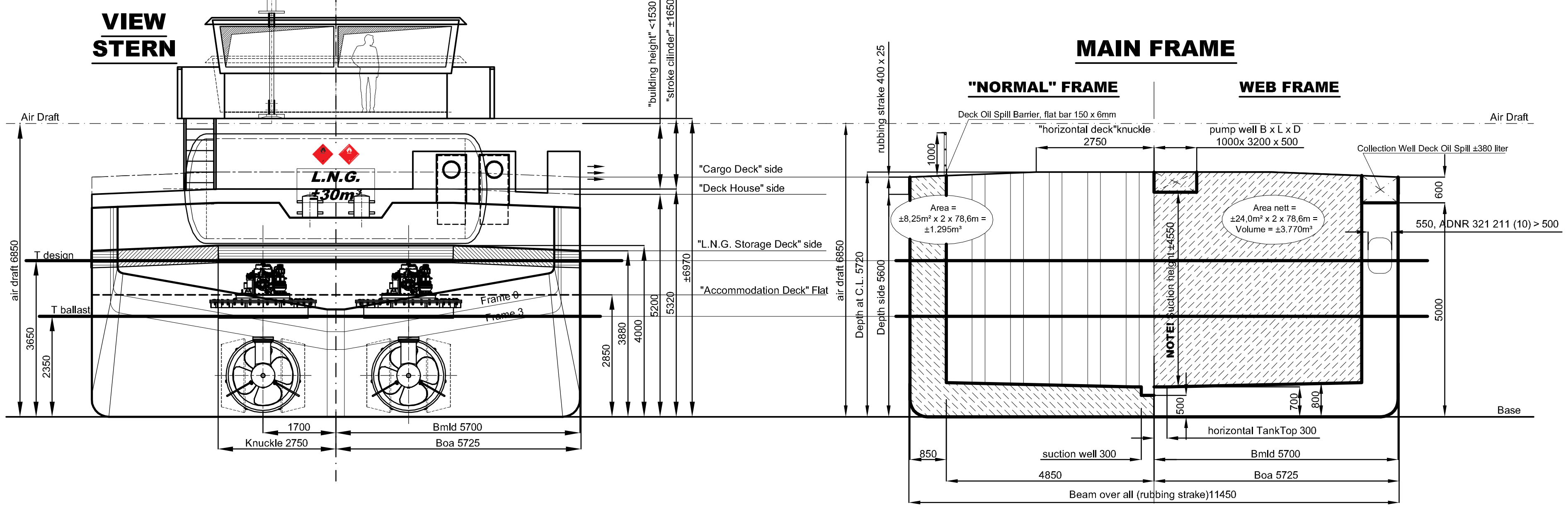
It is also noted that from the effect analysis it has become clear that effect distances related to (L)NG release are much smaller than those associated with release of chemical cargo.

Finally it is noted that the Ecoliner will be a type-C tanker according ADN, which means that the ship operation is subject to strict regulations with respect to areas where the ship is allowed to sail. It implies that (L)NG release is not likely to occur in the vicinity of other ships or areas accessible to the general public.

Based on these considerations TNO supports the request for an exemption to use LNG as bunker fuel on the “Damen River Tanker – 1145 Ecoliner”, type C tanker, official ID number 54314 and BV reg. no. 20629A.

[1] Bodewes acknowledges the need for a better understanding of the vulnerability of LNG bunker tanks on board ships in general, especially in case of inland waterway ships and coasters. It intends to participate in a joint industry project which will further investigate such vulnerability with respect to impact due to ship collisions and dropped objects.





DRT - 1145 - EL

Main Dimensions

Length	o.a.	approx.	110,00	m.
Breadth	moulded		11,40	m.
Breadth	o.a.	approx	11,45	m.
Depth	at side midship		5,60	m.
	at center line		5,72	m.
Air draft	above base line	approx.	6,85	m.
Airdraft	at T = 2,35 m.	approx.	4,50	m.
Draft	scantling		3,65	m.
Draft	ballast	approx.	2,35	m.

Cargo Tanks

Dead Weight	at T = 3,30 m.	approx.	2.600	tons
10x Volume Cargo Tanks (including slob)		approx.	3.770	m³
2x Volume Slob Tanks		approx.	2x 28	m³

Tank Volumes

L.N.G. Tanks (2x)		approx.	55,8	m³
Fresh Water	aft ship	approx.	2x 5	m³
	fore ship	approx.	4	m³
Water Ballast	aft ship	approx.	....	m³
	mid ship	approx.	1.390	m³
	fore ship	approx.	120	m³
Grey Water	aft ship	approx.	2	m³
	fore ship	approx.	2	m³
Black Water	aft ship	approx.	2	m³
	fore ship	approx.	2	m³
Lubrication Oil	aft ship	approx.	2	m³
Dirty Oil	aft ship	approx.	2	m³

Class / Authorities

I.V.W. (Directive 2006/87/EC)
- "Richtlijnen C.E. markering"
- R.O.S.R.
- "Continue vaart"
- "aantekening één mansradar vaart"

A.D.N. (Directive 2008/68/EC)
- type C
- 50 kPa

Bureau Veritas
- ✠ 5 IN (0.6) Z
- Tanker / Double Hull
- DP = 57.5 kPa / TP = 65 kPa
- A.D.N. Type C
- ✠ M.C.

rev.	date	inspected
REV1	DATE	INSPECT

☐ For approval
☐ For information
☐ For construction
☐ Stamped approved by class

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Nederland
Rijndijk 6566 CG Millingen a/d Rijn Netherlands Telephone 0481438 238 Telefax 0481 433 166 info@bodewes-millingen.nl www.bodewesmillingen.nl

Damen River Tanker - Eco Liner
DRT-1145- EL, Type C

drawn: WK	date: 2012-07-07	scale:	
proj. no.: Sneekes	ident. to drw. no.:		
yard no.:	derived fr. drw. no.:		
Copyright by willemkroon@home.nl	drw. no.: 000-000, 2012-07-07		

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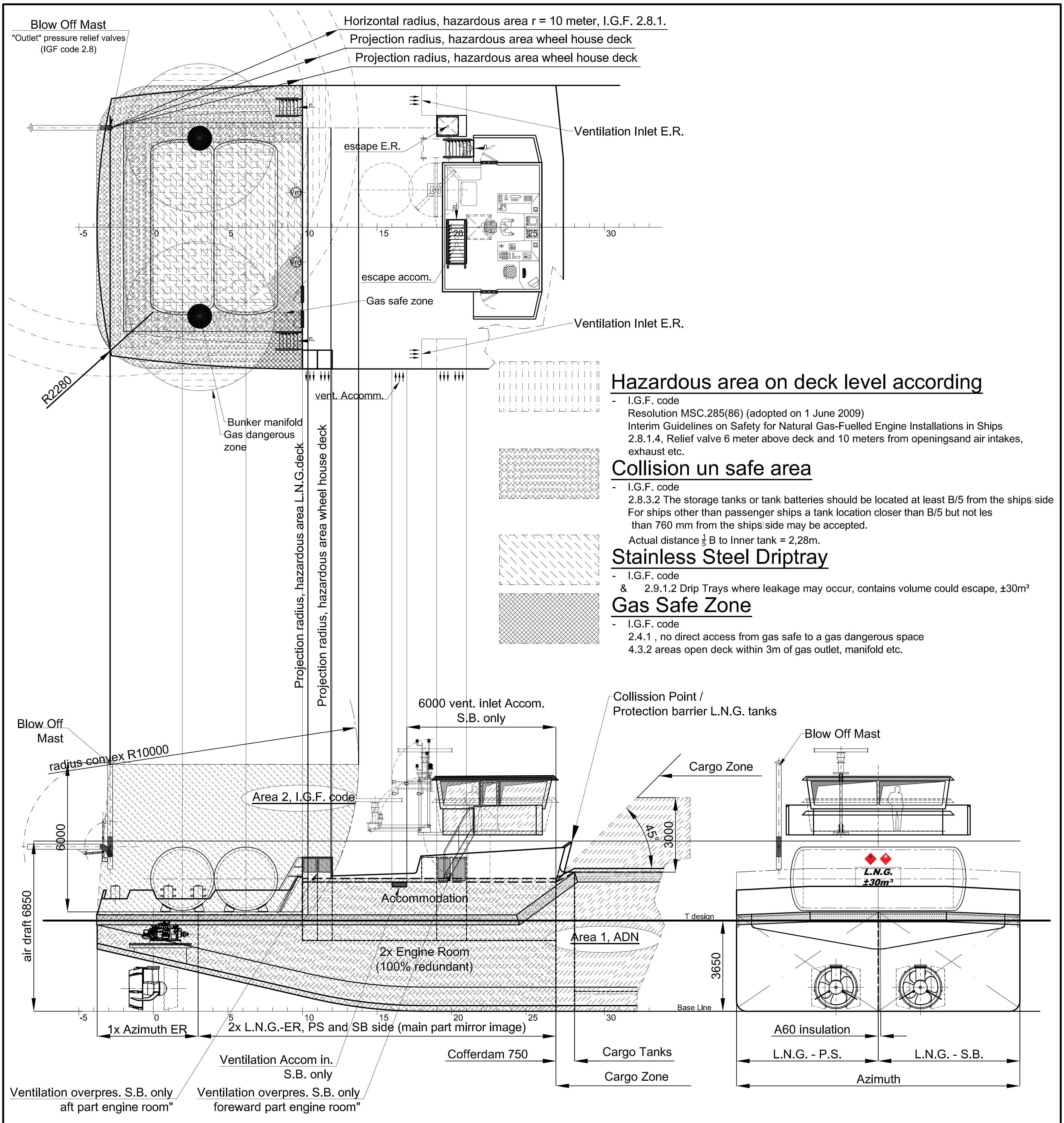

Area 1 according

- A.D.N.
- 30.12.2006 EN Official Journal of the European Union
  DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
  of 12 December 2006
  laying down technical requirements for inland waterway vessels and repealing Council Directive 82/714/EEC
  (2006/87/EC)
  Area 1 Cargo Zone / Area
  2 Wheel House
  3 Accommodation
  4 2x L.N.G Engine Room (P.S. & S.B.)
  5 1x Azimuth Engine Room

Area 2 according

- I.G.F. code
  Resolution MSC.285(86) (adopted on 1 June 2009)
  Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships
  Area 1 Accommodation
  2 2x L.N.G Engine Room (P.S. & S.B.)
  3 1x Azimuth Engine Room
  4 Aft Deck / L.N.G. Area

Combination Area 1 & 2

Area 1 Accommodation
2 2x L.N.G Engine Room (P.S. & S.B.)
3 1x Azimuth Engine Room

Area Divisions according:

1. **I.M.O.: Resolution M.S.C. 285 (86) (adopted om 1 June 2009) (I.G.F. guidelines, Interim Guidelines On Safety for Natural Gas-Fuelled Engine Installations in Ships)**
2. **European Regulations: Code 2006 / 87 / EC**
3. **European Regulations: Code 2008 / 68 / EC**

Drw.Nr. 000-003 (1of 3)

rev.	date	inspected
REV1	DATE	INSPECT

☐ For approval
☐ For information
☐ For construction
☐ Stamped approved by class

BODEWES MILLINGEN a/d RIJN Nederland
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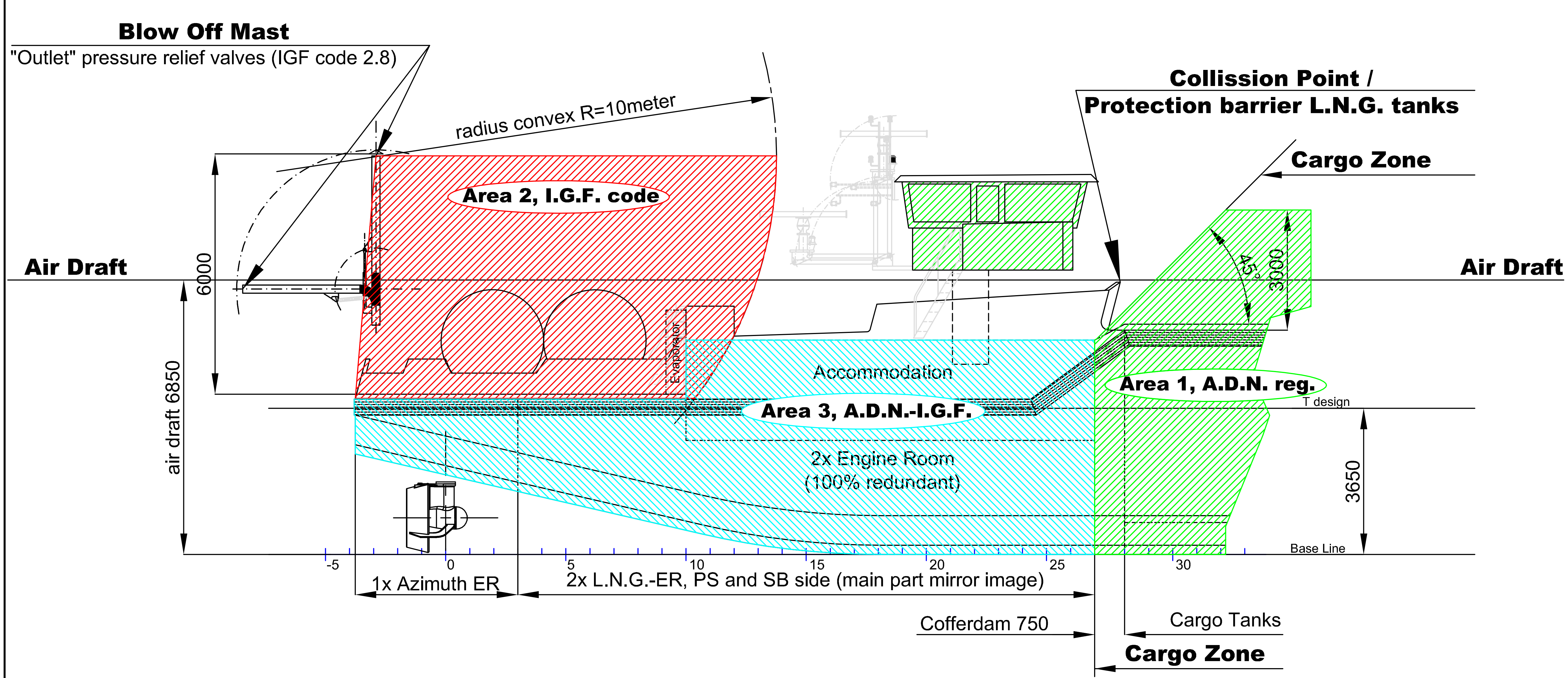
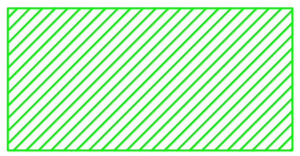
Damen River Tanker
Safety Division with regard to IMO & European Regulations

drawn: WK — date: 2012-07-07 — scale: ....
proj. no.: Sneekes — ident. to drw. no.: ....
yard no.: .... — derived fr. drw. no.: ....
 — drw. no.: 000-003 (1of3), 2012-07-07

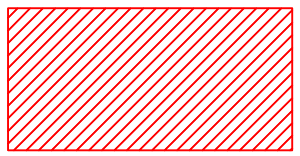
Cargo Zone (E.U. / A.D.N.regulations) 100% separated from the L.N.G.-N.G. Zone (I.G.F.code)





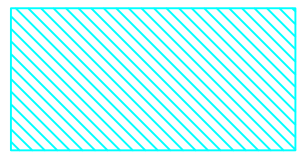
Area 1 according

- A.D.N. regulations
- 30.12.2006 EN Official Journal of the European Union
  DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
  of 12 December 2006
  laying down technical requirements for inland waterway vessels and repealing
  Council Directive 82/714/EEC (2006/87/EC)
  Area 1 Cargo Zone / Area
  2 Wheel House
  3 Accommodation
  4 2x L.N.G Engine Room (P.S. & S.B.)
  5 1x Azimuth Engine Room



Area 2 according

- I.G.F. code (guidelines)
  Resolution MSC.285(86) (adopted on 1 June 2009)
  Interim Guidelines on Safety for Natural Gas-Fuelled Engine
  Installations in Ships
  Area 1 Accommodation
  2 2x L.N.G Engine Room (P.S. & S.B.)
  3 1x Azimuth Engine Room
  4 Aft Deck / L.N.G. Area

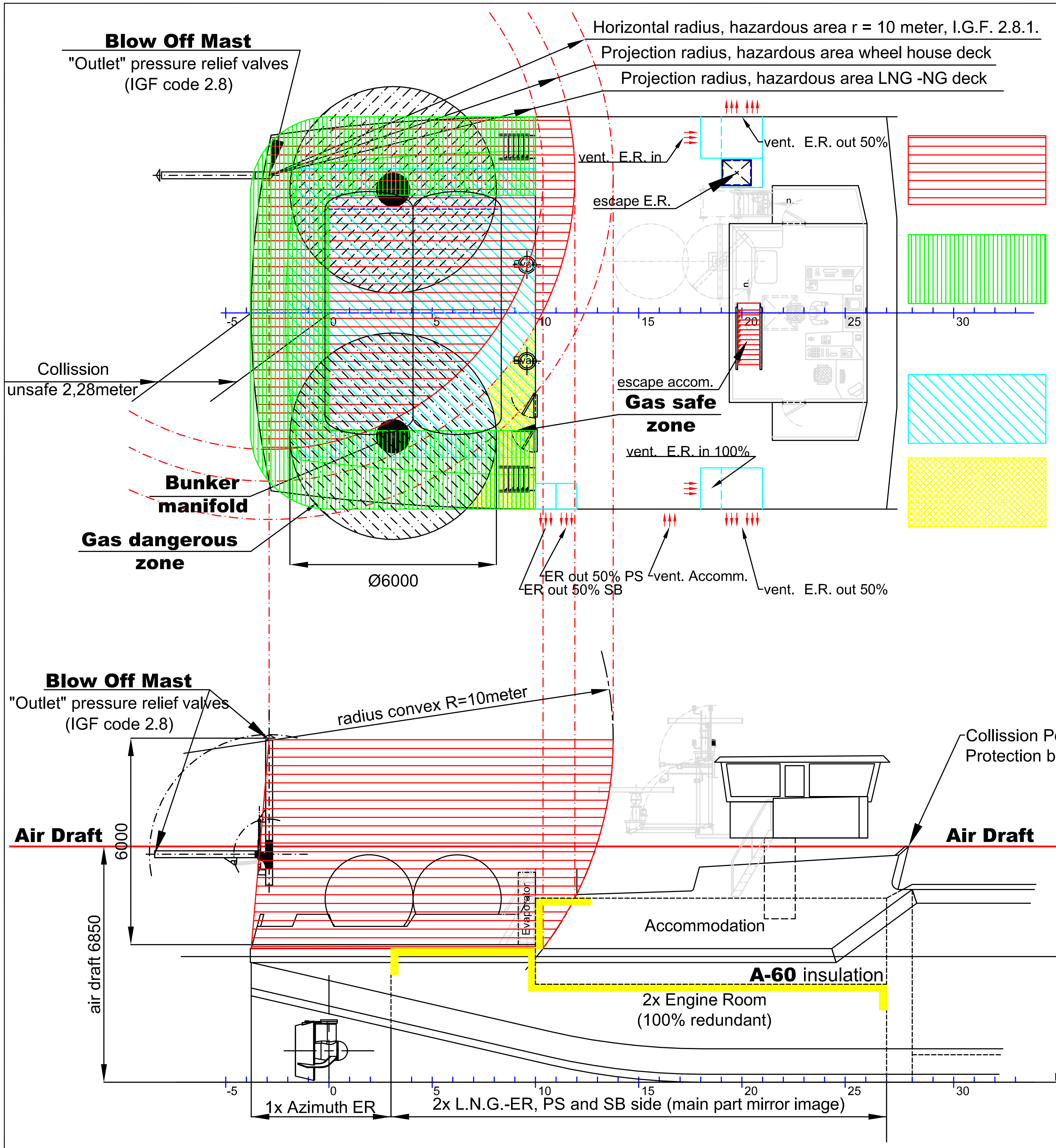


Area 3 combination 1 & 2

(in compliance with A.D.N. regulations and I.G.F. code)
Area 1 Accommodation
2 2x L.N.G Engine Room (P.S. & S.B.)
3 1x Azimuth Engine Room

Drw.Nr. 000-003-a (2 of 3), 2012-07-07

Safe Storage L.N.G Tanks and Gas Safe Zone Aft Ship



Hazardous area on deck level according

- I.G.F. code
  Resolution MSC.285(86) (adopted on 1 June 2009)
  Interim Guidelines on Safety for Natural Gas-Fuelled Engine Installations in Ships
  2.8.1.4, Relief valve 6 meter above deck and 10 meters from openingsand air intakes, exhaust etc.

Collision un safe area

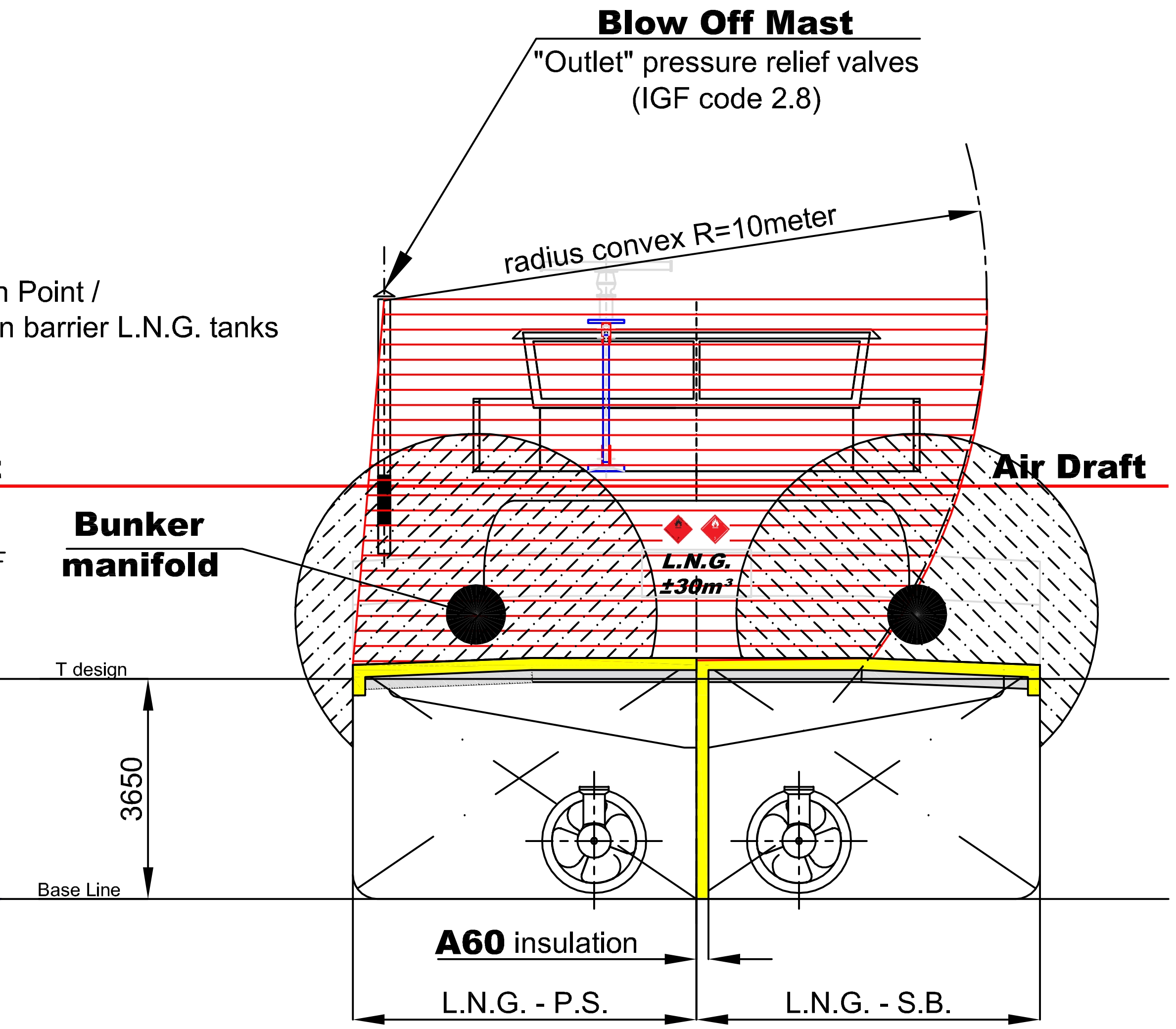
- I.G.F. code
  2.8.3.2 The storage tanks or tank batteries should be located at least B/5 from the ships side
  For ships other than passenger ships a tank location closer than B/5 but not les
  than 760 mm from the ships side may be accepted.
  Actual distance $\frac{1}{5}$B to Inner tank = 2,28m

Stainless Steel Driptray

- I.G.F. code
& 2.9.1.2 Drip Trayswhere leakage may occur, contains volume could escape, ±30m³

Gas Safe Zone

- I.G.F. code
  2.4.1 , no direct access from gas safe to a gas dangerous space
  4.3.2 areas open deck within 3m of gas outlet, manifold etc.



Drw.Nr. 000-003-b (3 of 3), 2012-07-07

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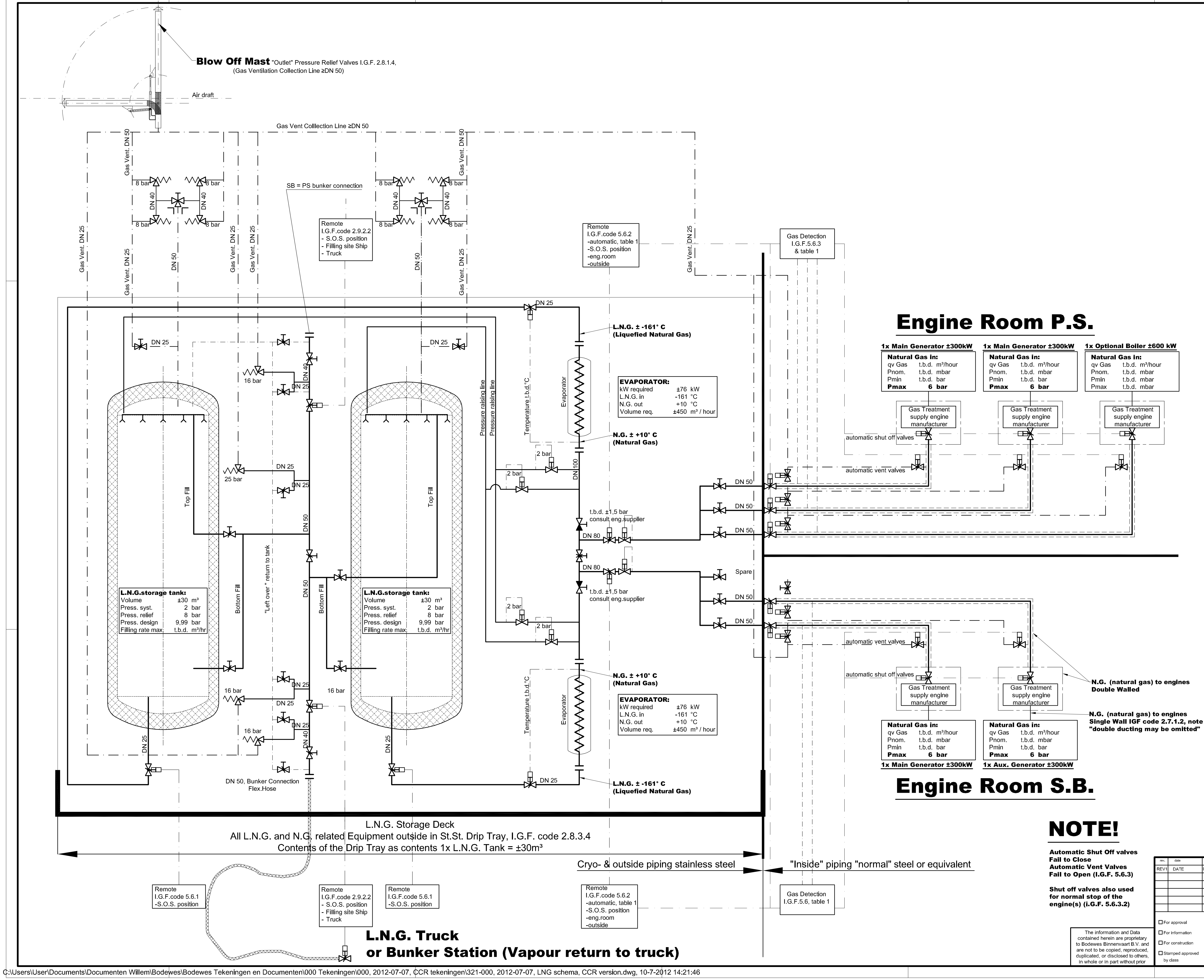

L.N.G. TANKS

Cryogenic tank constructed following the
E.N. 13530 (T.P.E.D.) code
Approved according to the
A.D.G.and I.M.O. - I.M.D.G. code

SYTEM DESIGN PRESSURE 2 bar

100% LNG-NG COMBUSTION; REDUNDANT SYSTEM

Total Installed power

4x Gen.Set 300 kW	=	1.200	kW
1x Boiler 600 kW	=	600	kW
Power total per system	=	1.800	kW

Max. Fuel consumption

Gasoil	=	42,50	MJ/kg
LNG	=	49,51	MJ/kg
Fuel consumption gasoil	=	± 190	g/kW/hour (gasoil)
1.800 kW	=	± 342	kg/hour gasoil
		± 295	kg/hour LNG
specific gravity LNG	=	430	kg/m³
295 kg LNG	=	± 690	liter/hour LNG
specif gravity NG	=	0,68	kg/m³
295 kg NG	=	± 435	m³/hour NG

Maximum velocity piping

Velocity LNG Filling	=	± 7	m/sec
Velocity LNG Combustion	=	± 2	m/sec
Velocity NG (gas)	=	± 15	m/sec

Filling

DN	Filling rate		
DN 50 mm	=	± 50	m³ LNG / hour

Combustion LNG

690 liter LNG / hour = 0,01 m (diameter)

Combustion NG (at 1 bar)

435 m³ NG / hour = 0,10 m (diameter)

Required capacity Evaporator

Heat of Evap. LNG-NG = 510 kJ/kg
Specific heat NG = 2,2 kJ/kgK
Evaporation of LNG-NG
295kg x 510 kJ/kg = 150.500 kJ = 43 kW
Heating NG of -161°C up to NG of ±10°C
295kg x 2,2kJ/kgKx171° = 111.000 kJ = 31 kW
Required capacity = 74 kW

NOTE!

Automatic Shut Off valves
Fail to Close
Automatic Vent Valves
Fail to Open (I.G.F. 5.6.3)

Shut off valves also used for normal stop of the engine(s) (i.G.F. 5.6.3.2)

rev.	date	inspected
REV1	DATE	INSPECT

☐ For approval
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Principal One Line LNG Diagram

drawn: WK	date: 2012-07-07	scale:	
proj. no.: Sneekes	ident. to drw. no.:		
yard no.:	derived fr. drw. no.:		
Copyright by willemkroon@home.nl	drw. no.: 321-000, 2012-07-07		

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