Formal Safety Assessment - LNG
-IMO/MSC86 Review

London June 1st 2009

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Hazid:
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Review: E Grønstøl (LMG), R Skjong (WPL)
Participants from Høegh, DNV, LMG, Navantia, LMG

Risk Analysis Report:
Authors: E Vanem (DNV), I Østvik (LMG), P Antao (IST)
Review: S Valsgård (DNV), J Juhl (DMA), R Skjong (WPL)
One Dephli Session with experts

Data fully documented: LRFP, QUEST, Houston Law Center, Colton, IZAR, DNV, Various Technical Papers & reports

Note: This FSA do not rely on LRFP…
Authors, Reviewers, Partners, Data, Etc

RCO+ CBA:
Authors: AM Cimadevila (Navantia), E Vanem (DNV)
P Antao (IST)
Review: JR Chacon (Navantia), R Skjong (WPL)
Participation: 3 RCO meetings

Final Submission:
Prepared by E Vanem (DNV)
Review J Juhl (DMA), R Skjong (WPL)
Review: SAFEDOR STC
Review: DMA (Denmark)

Note: The correct FN diagram in Annex (wrong in main report):
Editing error
Outline

Background and introduction

- **Formal Safety Assessment**
- **Liquefied Natural Gas and LNG shipping**

Definition of scope
Risk acceptance criteria
Review of LNG accident statistics
Risk analysis and assessment

- **Risk models and event trees**
- **Frequency and consequence assessment**
- **Individual and societal risk**

Risk control options
Conclusions
Background

LNG carriers normally considered to be among the safest vessels in the merchant fleet

- **Safety record of LNG fleet among the best in the world**
- **Generally well designed, constructed, maintained and operated vessels**
- **High focus on safety within LNG industry**

This study initiated in order to quantify the risk level of LNG carriers

- **Applying the Formal Safety Assessment approach**
- **Identifying high risk areas and evaluating measures for improving safety**
- **Recommendations reported to IMO**
Introduction: Formal Safety Assessment

Standard risk assessment with the aim of developing maritime regulations (IMO)
Introduction: LNG – Basic properties

Liquefied Natural Gas

- Cryogenic liquid at -162 °C
- Mostly consist of Methane (> 90%)
- Volume 600 times less than natural gas
- LNG weights less than water
- Flammability range (vaporized): 5 – 15%
Introduction: LNG – Hazards

Hazards associated with LNG
- Pool fires
- Ignition of drifting vapor clouds
  - Autoignition temperature above 540 °C – need ignition source
- Cryogenic temperatures
- Asphyxiation
- Rollover
  - Design condition – LNG tanks should withstand such pressure
- Rapid Phase Transition (RPT)
  - Minor hazard to people and structures – may shatter windows/glass

Hazards NOT associated with LNG
- Explosion: LNG is not explosive (in liquid form)
  - LNG vapor will only explode in a mixture with air within the flammability range and within an enclosed (or semi-enclosed) space
- BLEVE (Boiling Liquid Expanding Vapor Explosions)
  - BLEVE only associated with pressurized liquids. LNG tanks are not designed for pressure and cannot pressurize to such levels
- Pollution: LNG is neither toxic nor persistent
  - Limited environmental impact
Introduction: LNG shipping

First LNG shipment by sea in 1959, and first purpose built LNG tanker in 1964

Relatively small fleet: 233 as of August 2007

- Steadily increasing with another 134 vessels in the order books

LNG carriers typically on long-term contracts
Introduction: LNG carriers

LNG fleet dominated by two designs: membrane tanks and spherical tanks (Moss tanks)

- Each constituting about half the fleet, but membranes are dominant among the newbuildings.
Scope definition

High-level generic FSA of the entire fleet
Shipping phase
Operational phase of LNG vessels
Only Safety of LNG crew and people on other vessels
Only unintended accidents
Accidents of a certain scale
Risk acceptance criteria

Individual risk acceptance criteria (fatality risk)

- Intolerable risk: $> 10^{-3}$ per year
- ALARP area: $10^{-6} - 10^{-3}$ per year
- Negligible risk: $< 10^{-6}$ per year

Societal risk acceptance criteria expressed in FN curves
Operational experience

158 identified events involving LNG carriers
- with and without spillage
- accident frequencies assumed independent on shiptype

Broken down on generic accident categories:

<table>
<thead>
<tr>
<th>Accident category</th>
<th>Accidents (#)</th>
<th>Frequency (per shipyr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>19</td>
<td>$6.7 \times 10^{-3}$</td>
</tr>
<tr>
<td>Grounding</td>
<td>8</td>
<td>$2.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Contact</td>
<td>8</td>
<td>$2.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Fire and Explosion</td>
<td>10</td>
<td>$3.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Equipment/machinery</td>
<td>55</td>
<td>$1.9 \times 10^{-2}$</td>
</tr>
<tr>
<td>Heavy weather</td>
<td>9</td>
<td>$3.2 \times 10^{-3}$</td>
</tr>
<tr>
<td>Loading/unloading</td>
<td>22</td>
<td>$7.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Containment system</td>
<td>27</td>
<td>$9.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Total</td>
<td>158</td>
<td>$5.6 \times 10^{-2}$</td>
</tr>
</tbody>
</table>
Critical accident scenarios

Main risk from 5 generic accident categories:

Collision
Grounding
Contact
Fire and explosion
Incidents while loading/unloading of cargo

These will be subject to further risk modeling and analysis

- Frequency assessment
- Consequence assessment
Frequency estimation

Frequencies estimated based on accident statistics

- Vent riser fires excluded
- Only loading/unloading incidents with leakage included

Compared to statistics for other vessels types

- Reasonable agreement

**Accident frequencies for LNG tankers generally lower**

<table>
<thead>
<tr>
<th>Accident category</th>
<th>Frequency (per shiyr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>$6.7 \times 10^{-3}$</td>
</tr>
<tr>
<td>Grounding</td>
<td>$2.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Contact</td>
<td>$2.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Fire and Explosion</td>
<td>$1.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>Leakage of LNG; loading/unloading</td>
<td>$3.2 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
Consequence estimation

Step 1: Establish conceptual risk models
  - One for each critical accident scenario

Step 2: Construction of event trees
  - Based on conceptual risk models

Step 3: Quantification of event trees
  - Utilizing best available source of information for each branch in the event tree
Collision risk model

ACCIDENT STATISTICS

50 / 50

DAMAGE STATISTICS

EXTENT OF DAMAGE

Collision frequency

Loading condition model

Damage extent model

Cargo leakage frequency

Collision frequency

Probability of being loaded/in ballast

Probability distribution of damage

Probability of cargo release

DATA NOT AVAILABLE:

EXPERT OPINION

Consequence
Grounding and contact risk models

EVENT TREES QUANTIFIED SIMILARLY AS FOR COLLISION SCENARIO
Fire and explosion risk model

Fire/Explosion frequency model
- Engine room fire
- Accommodation area fire
- Compressor room fire

Loading condition model

Fire protection model

Cargo leakage model

LNG hazard model

Survivability model

Evacuation model

Consequence

FIRE STATISTICS FOR OIL TANKERS

STATISTICS FOR HSC AND PASSENGER SHIPS

Probability of being loaded/in ballast, at sea/port
Probability of fire protection system failing
Probability of cargo release
Probability of LNG hazards materializing
Probability of sinking
Number of fatalities
Loading/unloading risk model

Probability of loading/unloading incident with spillage

Probability distribution of spillage extent

Probability distribution of LNG hazards materializing

Number of fatalities, LNG crew, terminal workers

Consequence

EVENT TREE QUANTIFIED BASED ON REASONABLE ASSUMPTIONS ON TYPICAL LNG TRADING PATTERNS AND NORMAL CARGO TRANSFER OPERATIONS

ASSUMED THAT ONLY SMALL SPILLAGES WOULD OCCUR DURING LOADING/UNLOADING
Potential Loss of Lives (PLL) from LNG shipping (per shipyear)

<table>
<thead>
<tr>
<th>Accident category</th>
<th>PLL (crew)</th>
<th>PLL (passengers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision</td>
<td>$4.42 \times 10^{-3}$</td>
<td>$1.59 \times 10^{-3}$</td>
</tr>
<tr>
<td>Grounding</td>
<td>$2.93 \times 10^{-3}$</td>
<td>0</td>
</tr>
<tr>
<td>Contact</td>
<td>$1.46 \times 10^{-3}$</td>
<td>0</td>
</tr>
<tr>
<td>Fire and Explosion</td>
<td>$6.72 \times 10^{-4}$</td>
<td>0</td>
</tr>
<tr>
<td>Loading/unloading</td>
<td>$2.64 \times 10^{-4}$</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$9.74 \times 10^{-3}$</td>
<td>$1.59 \times 10^{-3}$</td>
</tr>
</tbody>
</table>
Individual risk

Contribution from critical accident scenarios:

\[ 1.6 \times 10^{-4} \text{ per personyear} \]

Contribution from occupational accidents:

\[ + 4.9 \times 10^{-4} \text{ per personyear} \]

Total individual risk to LNG crew:

\[ = 6.5 \times 10^{-4} \text{ per personyear} \]

Individual risk within ALARP area!

Observation: Individual risk dominated by occupational accidents
Societal risk – FN curves

Societal risk within the ALARP area
## Risk Control Options (RCO)

<table>
<thead>
<tr>
<th>RCO description</th>
<th>GCAF</th>
<th>NCAF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk based maintenance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Navigational systems</td>
<td>2.2</td>
<td>&lt;0</td>
</tr>
<tr>
<td>- Steering systems</td>
<td>7.4</td>
<td>&lt;0</td>
</tr>
<tr>
<td>- Propulsion systems</td>
<td>57</td>
<td>&lt;0</td>
</tr>
<tr>
<td>- Cargo handling systems</td>
<td>159</td>
<td>118</td>
</tr>
<tr>
<td>Strain gauges</td>
<td>394</td>
<td>351</td>
</tr>
<tr>
<td>Increased crashworthiness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Increase double hull width</td>
<td>74</td>
<td>71</td>
</tr>
<tr>
<td>- Increase double bottom height</td>
<td>60</td>
<td>54</td>
</tr>
<tr>
<td>- Increase hull strength</td>
<td>60</td>
<td>55</td>
</tr>
<tr>
<td>Redundant propulsion system</td>
<td>61</td>
<td>55</td>
</tr>
<tr>
<td>Improved navigational safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- ECDIS</td>
<td>3.1</td>
<td>&lt;0</td>
</tr>
<tr>
<td>- Track control system</td>
<td>0.4</td>
<td>&lt;0</td>
</tr>
<tr>
<td>- AIS integrated with radar</td>
<td>0.06</td>
<td>&lt;0</td>
</tr>
<tr>
<td>- Improved bridge design</td>
<td>2.3</td>
<td>&lt;0</td>
</tr>
<tr>
<td>Restrictions on crew schedule</td>
<td>6.3</td>
<td>0.7</td>
</tr>
<tr>
<td>Simulator training</td>
<td>12</td>
<td>5.8</td>
</tr>
<tr>
<td>Increased fatigue design life</td>
<td>High</td>
<td>&lt;0</td>
</tr>
<tr>
<td>Thermal image scanning</td>
<td>28</td>
<td>20</td>
</tr>
<tr>
<td>Redundant radar sounding</td>
<td>236</td>
<td>232</td>
</tr>
</tbody>
</table>

Cost-effectiveness criteria:

- GCAF < USD 3M
- NCAF < USD 3M

Cost-effective RCOs exist – all related to navigational safety

- **Risk based maintenance**
- **ECDIS**
- **Track control system**
- **AIS integrated with radar**
- **Improved bridge design**
Safety critical trends and developments

Current trends that may influence future safety level of LNG shipping:

- Lack of qualified LNG crew
- New LNG trades – e.g. cold climate
- New LNG operators
- New trading patterns – e.g. more short-term contracts
- Bigger and faster ships
- New propulsion systems – with on-board reliquefaction systems
Conclusions and recommendations

Prior perception – LNG vessels associated with high level of safety – substantiated by this FSA:

- **Risk levels within ALARP area**
- **Most RCOs not cost-effective**

However, cost-effective RCOs identified

- **All related to navigational safety (also other ships)**
- **Should be implemented to make risk ALARP**
MSC 86/17 Terms of Reference

1 Consider whether the methodology was applied in accordance with the FSA Guidelines and the Guidance on the use of HEAP and FSA.

2 Check the reasonableness of the assumptions and whether the scenarios adequately addressed the issues involved.

3 Check the validity of the input data and its transparency (e.g., historical data, comprehensiveness, availability of data, etc.).

4 Check whether risk control options and their interdependence were properly evaluated and supported by the assessment.

5 Check whether uncertainty and sensitivity issues have been properly addressed in the FSA study.

6 Check whether the scope of the assessment was met in the FSA study.

7 Check whether expertise of participants in the FSA study was sufficient for the range of subjects under consideration.

8 Provide a report on the above issues, which should include a discussion on any strengths and weaknesses, the lessons learned regarding the FSA Guidelines and the Guidance on the use of HEAP and FSA, and their application and the evidence used to support the conclusions.
Consider whether the methodology was applied in accordance with the FSA Guidelines and the Guidance on the use of HEAP and FSA

The LNG FSA used the steps prescribed in the IMO Guidance
Standard Techniques used
Experienced Persons
Data search far beyond use of LRFP
Primary data from HARDER
Etc
Check the reasonableness of the assumptions and whether the scenarios adequately addressed the issues involved.

Main Scenarios:

1 - Collision
2 - Contact
3 - Grounding
4 – Fire/Explosion

1-3 represents 90 % of risk

Scenarios developed in one event tree for each scenario.

Initiating event frequencies taken from reviewed historic data.

Branch probabilities from data, previous referenced studies and expert judgement.

Detailed review of all available data.

Events that has never happened predicted.
Check the validity of the input data and its transparency (e.g., historical data, comprehensiveness, availability of data, etc.)

Data fully documented: LRFP, QUEST, Houston Law Center, Colton, IZAR, DNV, Various Technical Papers & reports

Personnel involved included Operator, Designer and Classification personnel that have been in the LNG business since the 70ties...
Check whether risk control options and their interdependence were properly evaluated and supported by the assessment.

There are no strong interdependencies that are not easy to check.
Check whether uncertainty and sensitivity issues have been properly addressed in the FSA study

Optimistic and conservative assumption discussed in great detail
Interpretation of data is discussed in detail
Consensus or Average estimates presented
FSA is a framework for including better research results if available
Check whether expertise of participants in the FSA study was sufficient for the range of subjects under consideration

The project team were drawn primarily from DNV, IST, Navantia/IZAR, LMG, Høegh

1 Hazid workshop
1 Delphi Session
3 RCO meetings

Review (Int)
Review (ext)
Review (STC)
Review (DMA)
Other Specific Issues

- The FSA was carried out between April 2005 and January 2007
- The FSA was issued by IMO in July 2007 for MSC83 (October 2007)
- During the period: Many requests for report – positive feedback

- Please suggest that FSA Review is speeded up at IMO
- Experience:
  - Many of those involved have new jobs (unavailable for a review)
  - One of the companies involved reorganized/new owners
  - Etc…
Other Specific Issues

MSC 86/17/2 comments on the recommendation of a RCO even though its GCAF is estimated to (slightly) above USD 3 million.

It is argued that the NCAF criterion renders this RCO cost-effective. In fact, the estimated NCAF is negative, and it is based on this criterion that the RCO is recommended. In general, it is argued that NCAF is a valid criteria that is fulfilled, and this is in accordance with the FSA guidelines. In MSC 86/17/2 only the GCAF criteria has been considered, and this criteria alone, as MSC 86/17/2 points out, does not by itself render this RCO cost-effective.

It is in agreement with the FSA guidelines (MSC 83/INF.2) to consider both GCAF and NCAF as criteria, which was done in this FSA. It is also stated explicitly in the FSA that one of the criteria that was used was NCAF < USD 3 million.
Other Specific Issues

MSC86/17/2 stated that the interdependencies of the different RCOs have not been studied and quantified.

True

In practice, this interdependencies would not alter the conclusions, and therefore, which RCOs that are cost-effective are not affected by the interdependencies of the various RCOs.

Regarding the five RCOs that was found to be cost-effective in this FSA, it can quite easily be shown, using only the information that is contained in the FSA report, that a study on the interdependencies does not change the conclusion – i.e. all five RCOs are still cost-effective when the interdependencies are taken into account.

In conclusion, therefore, it is agreed that in principle the interdependencies should be taken into account, but it can be demonstrated that in practice, this does not change the conclusions and the recommendations. To illustrate this, below is the updated GCAF/NCAF values for the five RCOs in question (Values can easily be derived from the information in the FSA report) under the assumption that they will all be implemented.
Other Specific Issues

<table>
<thead>
<tr>
<th>RCO number (ref. FSA report)</th>
<th>Updated GCAF (USD million)</th>
<th>Updated NCAF (USD million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1c</td>
<td>3.44</td>
<td>-2.66</td>
</tr>
<tr>
<td>5a</td>
<td>3.88</td>
<td>-2.9</td>
</tr>
<tr>
<td>5b</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>5c</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td>5d</td>
<td>3.6</td>
<td>-2.1</td>
</tr>
</tbody>
</table>
Other Specific Issues

It is also commented that some assumptions need further justification.

It is stressed that effort has been made to highlight all assumptions that has been made in the FSA report, so that these can be examined and also so that the sensitivity of the results with regards to these assumptions can investigated.

Anyone who reviews the FSA study is invited to challenge the assumptions, and if scientific evidence suggests so, to alter the assumptions and update the assessment with updated information, as available.
Other Specific Issues

Regarding the particular assumptions that were mentioned in MSC 86/17/2:

- It is assumed that the probability of penetration of the outer hull in a collision with another vessel (LNG carrier being the struck ship) is comparable to that of other ship types. This assumption has been made in concordance with experts and is believed to be conservative. Also, there is no reason to believe that this assumption is very wrong, since most of the important factors here are independent of the LNG vessel itself, e.g. the speed and size of the other vessel, collision angle, etc.

- The assumptions that the fire fighting systems' reliability is comparable to that of other ship types have been verified by a group of experts (among them experts on fire protection on LNG carriers) and found to be reasonable.

- The assumptions 15% of fire/explosions in the engine room could be avoided and 20% of all drift groundings due to unavailability of the propulsion system could be avoided are based on discussions with experts, and are compared to previous studies. However, due to limited data for Risk Based Maintenance, it is acknowledged that these estimates should be considered uncertain. However, given the data and information currently available, it is still believed that this would be the best available estimate as of today. It is also noted that the conclusions and recommendations regarding this RCO is not sensitive to this assumption, so even notable changes in these assumptions would not alter the recommendations from this FSA study.
Other Specific Issues

HAZIDS results different from RA.

There is a tendency to see the same perception bias amongst experts as non-experts:

Example: In the description of the HAZID session in MSC78/INF.6, page 75, Table 50, the highest ranked risk for DSS is ‘Failure in survey and inspection (Failure to detect and prevent wastage and fatigue defects)’. This single hazard received the risk ranking RI=10.4, based on the severity SI= 3.7 and frequency FI=6.7. This converts to a frequency of 5.011 annually and a consequence of 5.011 fatalities, or a risk of about 25.12 fatalities per ship year. In a fleet of 6,000 ships this corresponds to 150,720 fatalities annually. This was one hazards, there are also a couple of other hazards with RI at or above 10! The total risk from all hazards adds up to 47 fatalities annually per ship, or the entire crew 2.5 times annually!
Thank You

Q:

A: