SAFETY OF LNG SUPPLY AT PORTS AREAS, ATHENS, 15.10.2019

SUPER-LNG - SUstainability PERformance of LNG-based maritime mobility

-

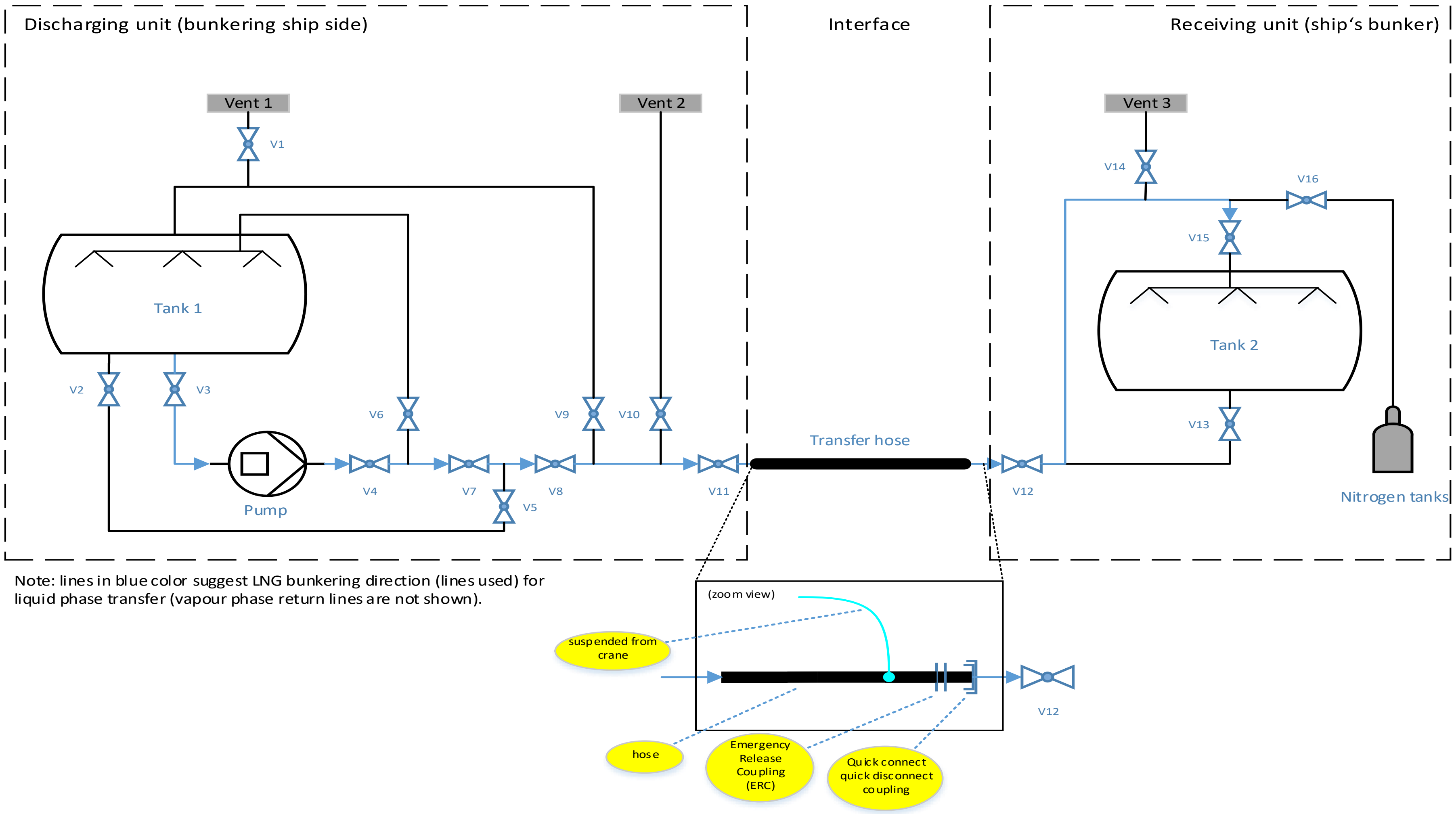
UNCERTAINTIES IN FAILURE RATES IN THE LNG BUNKERING RISK ASSESSMENT

Marko Gerbec, Jozef Stefan Institute, Slovenia
Olga Aneziri, NCSR “Demokritos”, Greece

Contents

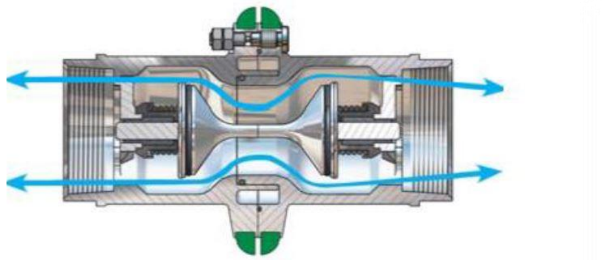
- Introduction to the LNG Bunkering risk assessment
- The bunkering procedure and safety systems
- Generic probabilistic accident model & data needed
- Literature review & results obtained
- Conclusions

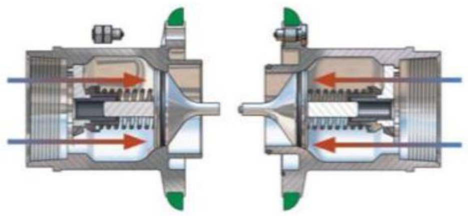
Bunkering installation & procedure



Note: lines in blue color suggest LNG bunkering direction (lines used) for liquid phase transfer (vapour phase return lines are not shown).

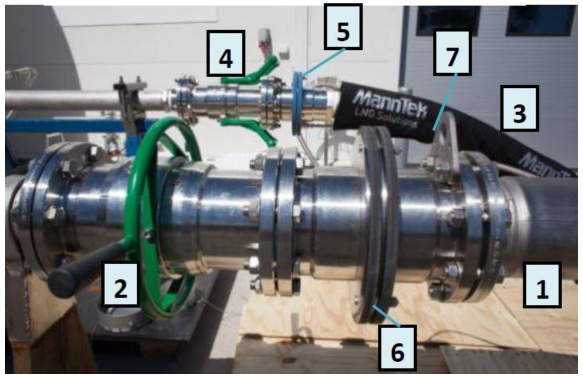
SAFETY SYSTEMS





Safety systems at the bunkering interface

- Manual stop of Loading
- Gas sensors
- Emergency Release Coupling (ERC)
- Emergency Shutdown System (ESD)
- Pressure Safety Valves (PSV)



(BS; CEN) EN 1474-3 : 2008 INSTALLATION AND EQUIPMENT FOR LIQUEFIED NATURAL GAS - DESIGN AND TESTING OF MARINE TRANSFER SYSTEMS - PART 3: OFFSHORE TRANSFER SYSTEMS. Definitions:

ERC - emergency release coupling; device to provide a means of quick release of the transfer system when such action is required only as an emergency measure

ERS - emergency release system; system that provides a positive means of quick release of transfer system and safe isolation of LNG carrier and transfer system. An ERS normally contain one or several ERC's emergency shut down

ESD - method that safely and effectively stops the transfer of LNG and vapour between the LNG carrier and the LNG terminal

1. **LNG bunkering line**
2. Main Quick-Connect/ Dry Disconnect coupling (QC/DC)
3. Vapour return line
4. Return QC/DC
5. ERC main line
6. ERC Vapour Return
7. Pad-eye for LNG bunkering hose crane handling

INITIATING EVENTS IN A PORT HANDLING LNG

SUPER-LNG

✓ **LNG storage tank**

- Boil off removal malfunction, during unloading or storage
- Excess external heat in storage tank area
- Level rise beyond safety height, or overfilling
- Continuation of unloading beyond lower safety level

✓ **Loading arm section**

- Excess external heat in jetty area
- Hydraulic hammer in loading arm, due to inadvertent valve closure
- Inadequate cooling of loading arm
- High winds/move during loading-unloading/stress

✓ **Send out section**

- Inadvertent closure of valve in send out

✓ **Truck**

✓ **Buffer Ship**

✓ **Ship receiving LNG**

General probabilistic model used (1)

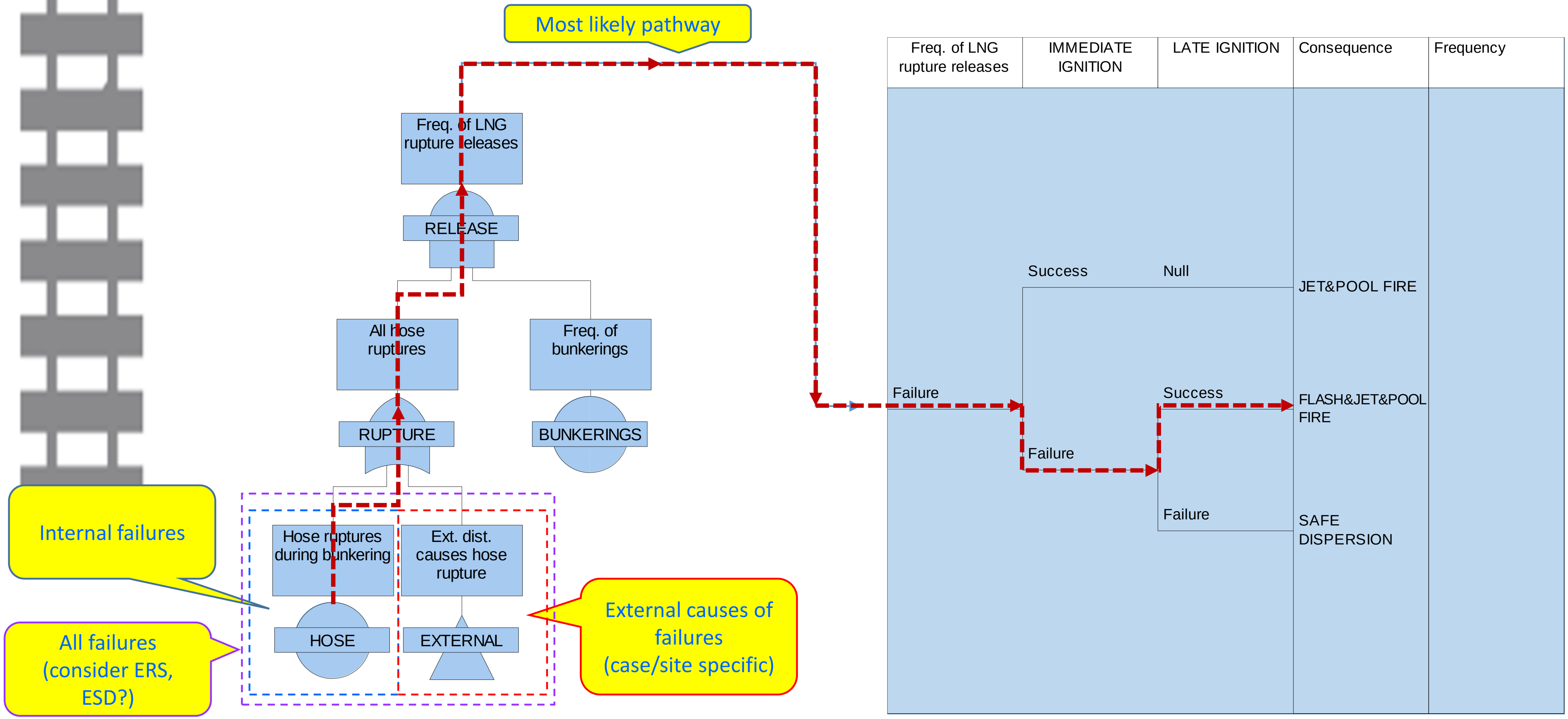
Starting points:

- Bunkering interface & flexible hose/loading arm integrity is of upmost importance
  - There are some LNG bunkering operation specific risk assessment reports
  - How likely it is to fail (threats, safety systems?)
- In a case of lost integrity (leak, rupture) LNG release occurs
  - How likely is it to ignite (immediately/later)?
  - Low long it should take to stop the release (safety systems, humans?)

- Approach (research questions):
  - How did the LNG bunkering risk assessment studies done that?
  - Which literature data did they used?
  - Do they concur in the failure rate data used – uncertainties?

General probabilistic model used (2)

- Fault tree & event tree to be considered



Literature review & results obtained

Interreg ADRION ADRIATIC-IONIAN
European Regional Development Fund - Instrument for Pre-Accession II Fund
SUPER-LNG

Literature reviewed – approach:

- Available specific LNG bunkering RA studies (internet search)
- Tracking to the used data and original sources
- Only few original sources found
  - **Results obtained**
    - ➢ Hoses/arms failure rates (taxonomy and sources)
    - ➢ Ignition models used
    - ➢ Considered safety systems & humans response times

Literature review & results obtained (2)

Interreg ADRION ADRIATIC-IONIAN
European Regional Development Fund - Instrument for Pre-Accession II Fund
SUPER-LNG

- **Seven** specific LNG bunkering case risk assessment studies found

Short	Specific LNG bunkering RA study	Link
Rambøll	RISK ANALYSIS LNG BUNKERING OF VESSELS WITH PASSENGERS ON BOARD. Rambøll; Client DSB, Report type Joint report, 21/08/2013.	https://www.sdir.no/en/shipping/accidents-and-safety/safety-investigations-and-reports/risk-analysis-of-lng-bunkering/
Report Port toolkit	Report Port toolkit risk profile LNG bunkering. Port of Rotterdam, Ministry of Infrastructure & Environment, Port of Antwerp, Port of Amsterdam and Zeeland Seaport. Report No./DNV Reg No.: PP035192-R2 Rev. 2, 28 August 2012	http://www.lngbunkering.org/lng/sites/default/files/2012%2C%20DNV%2C%20Port%20Toolkit%20Risk%20Profile%20LNG%20bunkering.pdf
Energium	Energium GmbH; LNG Hrvatska d.o.o., Quantitative Risk Assessment Report for Liquefied natural gas supply point – distributive LNG station in Rijeka. Doc. No.: O-0077-RPT-0001. Rev. 0, 19.4.2018. Page 77.	(restricted)
M-TECH	Safety Study Chain analysis: Supplying Flemish ports with LNG as a marine fuel Analysis of safety aspects. M-tech, June 2012, final report.	http://www.lngbunkering.org/lng/sites/default/files/2012%20M-Tech%20Supplying%20Flemish%20ports%20with%20LNG%20as%20a%20marine%20fuel%20-%20full%20report.pdf
Gasnor	REPORT QRA: Mongstad LNG Bunkering Station Gasnor. Gexcon, Bergen - 24.01.2017 Ref. No.: Gexcon-16 -F100149-RA-1 Rev.: 02	https://www.dsb.no/globalassets/dokumenter/horinger-og-konsekvensutredninger/mongstadbase-bunkringsanlegg-for-lng/vedlegg-1-risikoanalyse-r2.pdf
Lundevall Arnet	Nora Marie Lundevall Arnet, 2014. LNG Bunkering Operations - Establish probabilistic safety distances for LNG bunkering operations (master thesis). Norwegian University of Science and technology.	https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/235731
WSF	Washington State Ferries; DNV GL, SAFETY RISK ASSESSMENT STUDY BASIS, Appendix 1, Report No. PP061307-02, Rev. 03, Document No.: 167NWYK-13, Date: 2015-03-18.	https://www.wsdot.wa.gov/NR/rdonlyres/4005A4B9-A12D-42C2-B17B-C765846A67F8/104662/UpdatedMarch2015PP061307WSAAppendix1Rev03.pdf

Literature review & results obtained (3)

Interreg ADRION ADRIATIC-IONIAN
EUROPEAN UNION
European Regional Development Fund - Instrument for Pre-Accession II Fund
SUPER-LNG

- Which original failure rate data sources were used by the studies?

Data source	Reference	Link
J.R. Taylor	Hazardous Materials Release and Accident Frequencies for Process Plant, Volume II, Process Unit Release Frequencies, Version 1, Issue 7, September 2006. J.R.Taylor /Taylor Associates ApS. Table 11.3.	https://efcog.org/wp-content/uploads/Wgs/Safety%20Working%20Group/_Nuclear%20and%20Facility%20Safety%20Subgroup/Documents/Reldat%20II%207.pdf
RIVM (BEVI)	Reference Manual BEVI Risk Assessments version 3.2, National Institute of Public Health and the Environment (RIVM), Bilthoven, 2009.	https://www.rivm.nl/documenten/reference-manual-bevi-risk-assessments-version-32
FRED	UK HSE failure rate and event data for use within risk assessments (02.02.2019). Pages 40 and 70.	http://www.hse.gov.uk/landuseplanning/failure-rates.pdf
SHELL	Royal Dutch Shell. LNG Hose Failure Probability Report. Houston : Shell , 2014. SR.14.11417.	
Flemish	Flemish Goverment. Handbook Failure Frequencies (2009)	https://studylib.net/doc/18717910/handbook-failure-frequencies-2009
DNV GL 2013	Failure Frequency Guide -- process equipment leak frequencies data for use in QRA, : DNV Serving the Process Industry.	https://issuu.com/dnv.com/docs/failure_frequency_guidance_process_
NFPA 59A	NFPA 59A. Standard for the production, storage, and handling of Liquefied Natural as (LNG), 2019	https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=59A

No hose/arm data, but sometimes mentioned in

New

Literature review & results obtained (2)

Interreg ADRION ADRIATIC-IONIAN EUROPEAN UNION
European Regional Development Fund - Instrument for Pre-Accession II Fund
SUPER-LNG

- Who used which data/source?

	LNG Bunkering RA studies						
Original sources	Rambøll	Report Port toolkit	Energium	M-TECH	Gasnor	Lundevall Arnet	WSF
J.R. Taylor	✓						
RIVM (BEVI)		✓	✓			✓	✓
FRED			✓				
SHELL					✓		
Flemish				✓			

Literature review & results obtained (2)

Interreg ADRION ADRIATIC-IONIAN
EUROPEAN UNION
European Regional Development Fund - Instrument for Pre-Accession II Fund
SUPER-LNG

- Available failure taxonomy (terminology as stated):
  - leak 5 mm hole
  - leak up to 25 mm
  - leak (10 % diameter, max. 50 mm)
  - leak (25- 50 mm)
  - leak (0.1 cross section area)

  → „Leaks“

  - rupture
  - rupture (guillotine failure)

  → „Rupture“

- Equipment type:
  - Hose (flexible hose) → „Hose“
  - Loading arm (arm) → „Loading arm“

Our terminology used in next slides

Literature review & results obtained (2)

- Taxonomy – usually the target use is mentioned:
  - road tanker/wagon/ship (BEVI, hoses)
  - road tanker transfers (FRED)
  - truck (BEVI)
  - Ship transfers (BEVI, arms)
  - (+ no comment)
- Failure rate units:
  - per hour per hose
  - per hour
  - per year
  - per operation
  - per transhipment

Issue: how to compare data on a common scale?

Answer:

- Let us consider 60 operations per year
- Each operation takes 10 hours
- 1 year is 8760 hours
- Consider time at risk model for „per unit time“ cases

$$p=1 - Exp(- f \times t_{(at\ risk)})$$

- **Thus we compare probability of failure in one year of operations.**

Tabulated data (part 1/2)

#	Equipment	Comment	Failure type	Frequency	Unit	Failure prob. in 1 year	Note	Data source	Related bunkering study
1	Hose	road tanker/wagon/ship	leak (10 % diameter, max. 50 mm)	4,00E-05	per hour per hose	2,37E-02		RIVM	Energium; WSF
2	Hose	road tanker transfers	leak 15 mm hole	4,00E-07	per operation	2,40E-05	Two pullaway prevention systems and pullaway mitigation	FRED	Energium
3	Hose	road tanker transfers	leak 15 mm hole	4,00E-07	per operation	2,40E-05	Two pullaway prevention systems	FRED	Energium
4	Hose	road tanker transfers	leak 15 mm hole	1,00E-06	per operation	6,00E-05	One pullaway prevention system	FRED	Energium
5	Hose	road tanker transfers	leak 5 mm hole	6,00E-06	per operation	3,60E-04	Two pullaway prevention systems and pullaway mitigation	FRED	Energium
6	Hose	road tanker transfers	leak 5 mm hole	6,00E-06	per operation	3,60E-04	Two pullaway prevention systems	FRED	Energium
7	Hose	road tanker transfers	leak 5 mm hole	1,30E-05	per operation	7,80E-04	One pullaway prevention system	FRED	Energium
8	Hose		leak up to 25 mm	4,00E-03	per year	2,74E-04		J.R.Taylor	Rambøll
9	Hose		leak up to 25 mm	8,00E-06	per operation	4,80E-04		J.R.Taylor	Rambøll
10	Hose		leak up to 25 mm	1,50E-06	per hour per hose	9,00E-04	data from study - Table 2, p. 19	(RIVM)	Report Port toolkit
11	Hose		leak up to 5 mm	1,50E-06	per hour per hose	9,00E-04	data from study - Table 2, p. 19	(RIVM)	Report Port toolkit
12	Hose	road tanker transfers	leak (10 % diameter, max. 50 mm)	4,00E-01	per year	2,70E-02		NFPA	
13	Hose	truck	leak (10 % diameter, max. 50 mm)	4,00E-05	per hour	2,40E-02		Purple book	
14	Hose	LPG *	leak (10 % diameter, max. 50 mm)	5,40E-06	per hour	3,24E-03		Flemish	M-TECH
15	Hose		leak (25- 50 mm)	1,90E-07	per transfer	1,14E-05		SHELL	Gasnor
16	Hose		rupture	9,70E-08	per transfer	5,82E-06		SHELL	Gasnor
17	Hose		rupture	1,00E-03	per year	6,85E-05		J.R.Taylor	Rambøll
18	Hose		rupture	5,00E-06	per operation	3,00E-04		J.R.Taylor	Rambøll
19	Hose		rupture	3,40E-07	per hour per hose	2,04E-04	data from study - Table 2, p. 19	(RIVM)	Report Port toolkit
20	Hose	road tanker/wagon/ship	rupture	4,00E-06	per hour per hose	2,40E-03		RIVM	Energium
21	Hose	road tanker transfers	rupture (guillotine failure)	2,00E-07	per operation	1,20E-05	Two pullaway prevention systems and pullaway mitigation	FRED	Energium
22	Hose	road tanker transfers	rupture (guillotine failure)	4,00E-06	per operation	2,40E-04	Two pullaway prevention systems	FRED	Energium
23	Hose	road tanker transfers	rupture (guillotine failure)	4,00E-05	per operation	2,40E-03	One pullaway prevention system	FRED	Energium
24	Hose	road tanker transfers	rupture	4,00E-02	per year	2,74E-03		NFPA	
25	Hose	truck	rupture	4,00E-06	per hour	2,40E-03		Purple book	
26	Hose	LPG *	rupture	5,40E-07	per hour	3,24E-04		Flemish	M-TECH
27	Loading arm		leak (0.1 cross section area)	8,00E-06	per operation	4,80E-04	one arm used; see contributions!)	FRED	Energium
28	Loading arm	road tanker/wagon/ship	leak (10 % diameter, max. 50 mm)	3,00E-07	per hour per arm	1,80E-04		RIVM	Energium
29	Loading arm		leak up to 25 mm	5,00E-05	per year	3,42E-06		J.R.Taylor	Rambøll
30	Loading arm		leak up to 25 mm	8,60E-07	per operation	5,16E-05		J.R.Taylor	Rambøll

Take a note: rarely it is stated what are the boundaries of the system reported – safety devices included or not!
Only FRED provides some data on the contributors (internal and external causes).

Tabulated data (2/2)

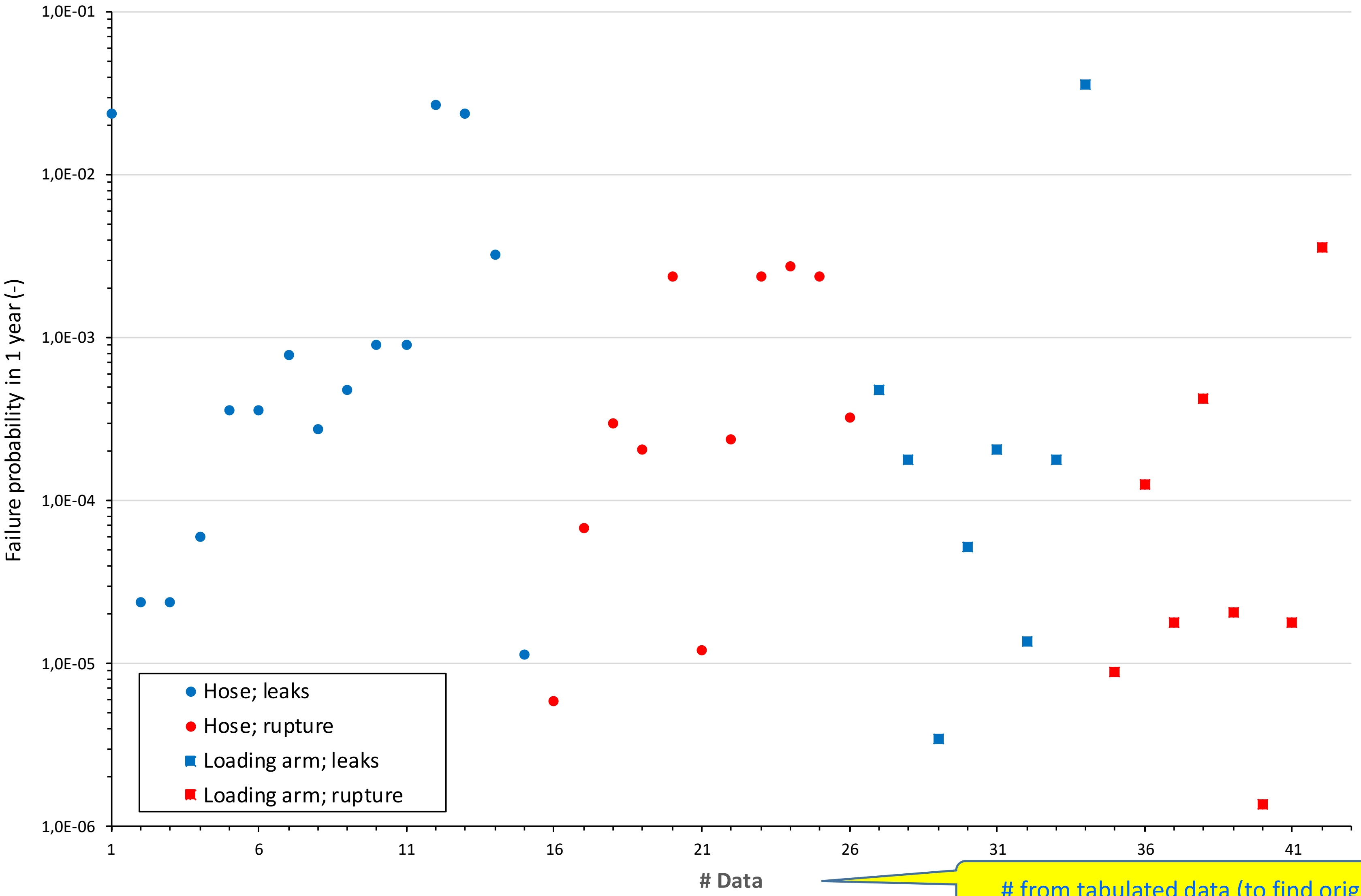
#	Equipment	Comment	Failure type	Frequency	Unit	Failure prob. in 1 year	Note	Data source	Related bunkering study
31	Loading arm	road tanker transfers	leak (10 % diameter, max. 50 mm)	3,00E-03	per year	2,05E-04		NFPA	
32	Loading arm	road tanker transfers	leak (10 % diameter, max. 50 mm)	2,00E-04	per year	1,37E-05		NFPA	
33	Loading arm	Ship transfers	leak (10 % diameter, max. 50 mm)	3,00E-07	per hour	1,80E-04		Purple book	
34	Loading arm	Ship transfers	leak (10 % diameter, max. 50 mm)	6,00E-04	per transhipment	3,60E-02		Purple book	
35	Loading arm		rupture	1,30E-04	per year	8,90E-06		J.R.Taylor	Rambøll
36	Loading arm		rupture	2,10E-06	per operation	1,26E-04		J.R.Taylor	Rambøll
37	Loading arm	road tanker/wagon/ship	rupture	3,00E-08	per hour per arm	1,80E-05		RIVM	Energium
38	Loading arm		rupture (guillotine break)	7,00E-06	per operation	4,20E-04	one arm used; see contributions!)	FRED	Energium
39	Loading arm	road tanker transfers	rupture	3,00E-04	per year	2,05E-05		NFPA	
40	Loading arm	Ship transfers	rupture	2,00E-05	per year	1,37E-06		NFPA	
41	Loading arm	road tanker transfers	rupture	3,00E-08	per hour	1,80E-05		Purple book	WSF
42	Loading arm	Ship transfers	rupture	6,00E-05	per transhipment	3,60E-03		Purple book	WSF

In total 42 data (hoses & loading arms, leaks & ruptures)

let us put the figures on a chart

			Failure probability in 1 year			
Equipment	Failure type	Number of data	Min.	Max.	Max./Min.	Average
Hose	Leak (~10 % diam.)	15	1,14E-05	2,70E-02	2,37E+03	5,48E-03
Hose	Rupture	11	5,82E-06	2,74E-03	4,70E+02	1,01E-03
Loading arm	Leak (~10 % diam.)	8	3,42E-06	3,60E-02	1,05E+04	4,64E-03
Loading arm	Rupture	8	1,37E-06	3,60E-03	2,63E+03	5,27E-04

Results obtained (2) – graphics:



from tabulated data (to find original figures in table)

Results – ignition probabilities

#	Study	Ignition model used - reference	Comments:
1	**Rambøll**	1.) Comparative study on gas dispersion, Scanpower, Report nr. 101368/R!, 24 January 2012 2.) Offshore ignition probability arguments, Report number: HSL/2005/50, Health and Safety Laboratory, 2005	1.) Scanpower study discusses three ignition models (TNO, DNV and Hydro); Rambøll used the TNO model explained on page 42. 30 % conditional ignition probability used for bunkering vessel for immediate ignition prob., and 100 % conditional probability for late ignition. 2.) 6.4 % ignition probability used for non-classified areas, e.g., tank truck with LNG within 60 s.
2	**Report Port toolkit**	Reference Manual Bevi Risk Assessments version 3.2, National Institute of Public Health and the Environment (RIVM), Bilthoven, 2009.	Table 8 data used for category 0 substances. Probability of direct ignition 0.7 was used for continuous release at ship-gas tanker. Late ignition probability was calculated via "free field" (at the max. cloud footprint) or "no free field" (depending on actual ignition sources) methods.
3	**Energium**	International Association of Oil & Gas Producers (OGP), Risk Assessment Data Directory – Ignition Probabilities. Report No. 434 – 6, March 2010.	Table 2.1 Onshore ignition scenario no. 8 is used. Considering the release rate of about 10 kg/s, overall ignition probability is set to 0.025, of which 30 % is immediate and 70 % is late ignition probability.
4	**M-TECH**	Flemish Government. Handbook Failure Frequencies (2009)	Table 15 from Flemish handbook used. Conditional probabilities considering methane (group 0): - cont. rel. <10 kg/s: 2 % immediate ignition; 2 % delayed ign., 20 % explosion. - cont. rel. 10 -100 kg/s: 4 % immediate ignition; 4 % delayed ign., 30 % explosion. - cont. rel. >100 kg/s: 9 % immediate ignition; 10 % delayed ign., 40 % explosion.
5	**Gasnor**	International Association of Oil & Gas Producers (OGP), Risk Assessment Data Directory – Ignition Probabilities. Report No. 434 – 6, March 2010.	Table 2.1/data sheet 3: scenarios 8 -11 are used. Likely a scenario no. 8 curve is used, but no details are given.
6	**Lundevall Arnet**	None	Ignition probability is set to 1
7	**WSF**	International Association of Oil & Gas Producers (OGP), Risk Assessment Data Directory – Ignition Probabilities. Report No. 434 – 6, March 2010.	Table 2.1, data sheet 8, scena - 0.1 kg/s (p=0.001) to 50/10

Summary on the conditional ignition probabilities

Study	Immediate	Late
Ramboll:	30 %	(always)
Report …	70 %	(always; at the max. extent)
Energium	0.75 %	1.75 % (30-70 ratio of 2.5 %)
M-TECH	2/4/9 %	2/4/10 % (+ 20-40 % expl.)
Gasnor	(?; overall 0.1 % - 65 %)	
Lundevall	100 % (likely for the immediate ign.)	
WSF	(?; overall 0.1 – 15 %)	

https://www.dsb.no/globalassets/dokumenter/rapporter/andre-rapporter/final-report-scandpower-2012.pdf
http://www.hse.gov.uk/Research/hsl_pdf/2005/hsl0550.pdf
https://www.iogp.org/bookstore/product/risk-assessment-data-directory-ignition-probabilities/

Results - Considered safety systems & human response times

Study	Considered safety systems, humans and response times?
Rambøll	- rupture-liquid: ESD works in 99 % cases, response time 10 s (otherwise till empty tank) - rupture-gas: ESD works in 90 % cases, response time 10 s (otherwise till empty tank) - leak-liquid: ESD works in 90 % cases, response time 60 s (otherwise till empty tank) - leak-gas: ESD works in 75 % cases, response time 60 s (otherwise till empty tank) - rupture-liquid: Excess flow valve works in 95 % cases (pipe/arm emptied), otherwise ESD works in 99 % cases, response time 10 s (otherwise till empty tank) ESD is to be activated by emergency stop and gas detection. Unclear about excess flow valves and break-away coupling.
Report Port toolkit	Human/operator failure probability = 0.1 , response time 120 s (source BEVI (HARI)). 25 mm hole: ESD PFD is 0.001, response time is 20 s (source BEVI). 5 mm hole: ESD PFD is 0.001, response time is 120 s (source BEVI). Safety breakaway coupling, reaction time 5 s is assumed (should react within 1 s).
Energium	ESD is PERC type (Powered Emergency Release Coupling). Large leaks and rupture close time is 3 minutes. Small and medium leaks close time is 10 minutes.
M-TECH	- PFD of automated ESD is 0.01 and response time 120 s. - PFD of manual (operator) ESD is 0.1 and response time 120 s. The performance criteria for operators as safety measure are defined in detail. Other devices, like break away couplings (ERS) not mentioned.
Gasnor	Human error probability =0.1 (source: UK FRED) for response of the operators. Detection & iso - small and medium leaks: 60 sec. - large and catastrophic leaks: 30 sec. (but no definitions what they are...)
Lundevall Arnet	- Small leak, ESD works: 120 s isolation time. - Medium and large leak, ESD works: 15 s isolation time. - Small/medium/large leak, ESD fails, but operator intervene: 120 s isolation time. - Small/medium/large leak, ESD fails, and operator fails: 1800 s isolation time (maximum outfl - automated ESD PFD: 0.001 (source BEVI); - Operator PFD: 0.1 (source BEVI); - ERC (ERS) PFD:
WSF	During bunkering: up to 60 seconds for the operator to detect and isolate the release. During sailing that depends the release rate (5/15/30 min for large/medium/small, respectively). No reference no the safety systems performance (only hoses).

Summary:
- ESD devices PFD at about 0.01
- Large leak (rupture) closure time:
  - 10 - 60 s (Rambøll, Gasnor, WSF)
  - 120 s (Report Port, M-TECH, Lundevall-Arnet)
  - 180 s (Energium)
- Small leaks closure time:
  - 60 to 600 s
- Human error probability (operators fail to respond) = 0.1

Conclusions

- The boundary of the hose/arm system not always defined
  - only 12/42 failure data specify included safety systems or causes!
- The failure rate figures are within about three order of magnitude
  - largest range (10^4) for loading arm leaks.
  - smallest range (500) for hoses ruptures
- Large differences in ignition probabilities & models used
  - Some consensus in 30 % to immediate and 70 % to late ignition probability
  - For large leaks very high overall ignition probability (=certain!)
- Large leaks duration: 60 to 120 s (180 s) (if everything goes wrong)
  - (modelling show moderate differences for durations over ~60 s)
- Summary: **data used directly impact the risk results obtained!**

Interreg ADRION ADRIATIC-IONIAN
European Regional Development Fund - Instrument for Pre-Accession II Fund
SUPER-LNG

Questions?