ElectroGas Malta Project

Internal Emergency Plan – Scenarios

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ElectroGas Malta Limited

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1 INTRODUCTION

1.1 Objective

The objective of this document is to help the Emergency Controller for assessing the safety distances in the case of emergency scenarios where dangerous materials (mainly LNG and BOG/NG) are released to the atmosphere with potential consequences (Flash fire, VCE, Jet fire and/or Pool fire) and potential domino effects.

These different scenarios have been selected from HAZID and HAZOP reviews and evaluated in the Safety Report. No major accident scenario was identified/evaluated for the CCGT facility (excluding the NG at the D4PP/GRS).

1.2 Reference Documents

The reference documents are tabulated below:

Reference	Designation	Issued by	Date
ENEM-AEC-E0-00-RP-SE-00003	Safety Report - Hazard Identification	AECOM	21/09/2016
ENEM-AEC-E1-00-RP-SE-00001	HAZID worksheets on EPC1 facilities	AECOM	Sept. 2015
ENEM-AEC-E2-00-RP-SE-00001	HAZID worksheets on EPC2 facilities	AECOM	Sept. 2015
ENEM-AEC-FS-00-RP-SE-00002	HAZID worksheets on FSU	AECOM	Sept. 2015
ENEM-AEC-E1-00-RP-SE-00002	HAZOP worksheets on EPC1 facilities	AECOM	Sept. 2015
ENEM-AEC-E2-00-RP-SE-00002	HAZOP worksheets on EPC2 facilities	AECOM	Sept. 2015
ENEM-AEC-FS-00-RP-SE-00001	HAZOP worksheets on FSU	AECOM	Sept. 2015
ENEM-AEC-E0-00-RP-SE-00002	Safety Report - Consequence Analysis	AECOM	21/09/2016

Table 1: Reference Documents

1.3 Abbreviation List

BLEVE	Boiling Liquid Expanding Vapour Explosion
BOG	Boil-Off Gas
CCGT	Combined Cycle Gas Turbine
D3PP/D3PS	Delimara 3 Power Plant/Delimara 3 Power Station
D4PP/D4PS	Delimara 4 Power Plant/Delimara 4 Power Station
FB	Fire Ball
FF	Flash Fire
FLR	Freezing liquid release
FSU	Floating Storage Unit
GRS	Gas Receiving Station
HAZID	HAZard IDentification
HAZOP	HAZard and Operability Study
HP	High Pressure
JF	Jet Fire
LFL	Lower Flammable Limit
LNG	Liquefied Natural Gas
NG	Natural Gas
PF	Pool Fire
RGU	ReGasification Unit
RPT	Rapid Phase Transition
VCE	Vapour Cloud Explosion

2 CONSEQUENCE ANALYSIS

2.1 List of Scenarios

The scenarios as evaluated in the Safety Report are listed in the following table:

Ref.	Equipment	Small leak	Medium leak	Large leak Full bore rupture	Catastrophic rupture	Other
FS-01x	FSU cargo tanks			x		
FS-02x	LNG liquid header	x	x	x		
FS-03x	LNG spray header	x		x		
FS-04x	LNG new liquid line	x	x	x		
FS-05x	LNG loading hoses			x		
FS-06x	LNG unloading arm			x		
FS-07x	Vapour header	x	x	x		
FS-08x	BOG loading hose			x		
FS-09x	BOG unloading hoses			x		
E2-01x	LNG pipeline, on Jetty	x	x	x		
E2-02x	BOG pipeline, on Jetty	x	x	x		
E2-03x	LNG pipeline, Onshore	x	x	x		
E2-04x	BOG pipeline, Onshore	x	x	x		
E2-05x	LNG suction drum, Overpressure				x	
E2-06x	HP LNG pumps suction line	x	x	x		
E2-07x	HP LNG pumps discharge line	x	x	x		
E2-08x	LNG small scale pumps suction line	x	x	x		
E2-09x	LNG small scale pumps discharge line	x	x	x		
E2-10x	Intermediate Fluid Vaporizer (shell side)				x	Release from PSV, BLEVE
E2-11x	LNG suction drum head line	x		x		
E2-12x	BOG compressors discharge line	x	x	x		
E2-13x	NG pipeline from RGU to GRS (tie-in)	x	x	x		
E2-14x	NG pipeline to CCGT GRS	x	x	x		
E2-15x	NG equipment at CCGT GRS	x	x	x		
E2-16x	NG pipeline to Delimara 3 GRS	x	x	x		
E2-17x	NG equipment at Delimara 3 GRS	x	x	x		
E2-18x	NVCC					Loss of flame

Table 2: List of Scenarios

Refer to document **ENEM-AEC-E0-00-RP-SE-00002: Safety Report – Consequence Analysis**.

2.2 Release Sizes

Typical release sizes considered on process equipment (vessel, line) for consequences evaluation are as follows:

Process equipment	Type of release	Size of release	Definition
Process line	Small leak	10 mm hole diameter	Failure of a joint, small instrument connection, or pump seal. May be also a consequence of corrosion.
	Medium leak	50 mm hole diameter	Failure representative of a partial rupture of a pipe or the failure of a small bore connection on a large pipe.
	Large leak Full bore rupture	Pipe diameter	Failure representative of a major accident, i.e. full bore rupture for pipelines.
Process vessel	Catastrophic rupture	-	Catastrophic rupture of process vessels corresponds to the failure of the equipment envelope leading to an instantaneous release of all its contents.
FSU tanks	Large leak	250 mm hole diameter	Considered as maximum tank failure (process/equipment failure).
		500 mm hole diameter	Considered for external scenarios (i.e. ship collision).
		1 000 mm hole diameter	Considered for intentional events (i.e. terrorism/vandalism).
Pressure Safety Valve to atmosphere	PSV release	PSV size	PSV release to atmosphere for related process equipment.

Table 3: Release Sizes on Process Equipment

2.3 Scenario Consequences

Applicable consequences are described in the following table:

Consequence	Definition
Flash Fire (FF)	A Flash Fire, in effect, is a sheet of flame that moves through a cloud of gaseous or vaporised hydrocarbons, without any accompanying shock-wave. It rarely lasts for more than a few seconds, and causes minor damage to equipment and installations, but is fatal to individuals in its path.
Vapour Cloud Explosion (VCE)	A Vapour Cloud Explosion (VCE) - also called Unconfined Vapour Cloud Explosion (UVCE) as it occurs in open area but with obstacles such as equipment and installations. - is similar to a flash fire, except that in addition to the flame front, a pressure front, generated by the fire and due to obstacles, moves through the cloud, at speeds of 100 m/s or greater. Effects calculated for VCE are overpressure.
Pool Fire (PF)	A Pool Fire is a fire on a stationary liquid surface, such as that of a pool of liquid hydrocarbon. Effects calculated for pool fire are thermal radiations.
Jet Fire (JF)	A Jet Fire occurs when a hydrocarbon release from a pressurised source is ignited close to the source of the release. It is a jet of flame that will last as long as the supply of fuel lasts under pressure. Effects calculated for jet fire are thermal radiations.
Boiling Liquid Expanding Vapour Explosion (BLEVE)	A BLEVE occurs when a liquefied, or occasionally a liquid, hydrocarbon is contained in a vessel exposed to an external fire. The fire weakens the shell of the vessel, while also causing the hydrocarbon to boil, thereby pressurising the vessel. Once the vessel's pressure exceeds the threshold limit of the metal, the shell would fail spilling out the rest of the hydrocarbon, which would then undergo an explosion or a fireball. Effects calculated for jet fire are thermal radiations (thermal dose unit) and overpressure.
Freezing Liquid Release (FLR)	If liquid at very low temperature (LNG) is released, direct human contact with the cryogenic liquid will cause freezing fatalities.
Rapid Phase Transition (RPT)	Rapid Phase Transitions (RPT) occur when the temperature difference between a hot liquid and a cold liquid is sufficient to drive the cold liquid rapidly to its superheat limit, resulting in spontaneous and explosive boiling of the cold liquid. When LNG is suddenly heated by contacting a warm liquid such as water, explosive boiling of the LNG can occur, resulting in localized overpressure events. The consequences of this phenomenon will be localized near the spill source and should not cause extensive damage.
Rollover	When LNG supplies of differing densities are loaded into a tank one at a time, they do not mix immediately. Instead, they layer themselves in unstable strata within the tank. After a period of time, these strata may spontaneously rollover to stabilize the liquid in the tank. As the lower LNG layer is heated by normal heat leak, it changes density until it finally becomes lighter than the upper layer. At that point, a liquid rollover would occur with a sudden vaporization of LNG. At some point, without any consideration for the tank pressure release valves, the excess pressure may result in a potential loss of containment.

Table 4: Scenario Consequences

2.4 Consequence Assessment Criteria

In the Safety Report, the evaluation of consequence zones (effects: injury on people and damage on structures) of major accident scenarios used the following criteria for thermal radiation of open continuous fires, thermal radiation dose for fireballs, explosion overpressure and extent of flammable cloud:

Consequence	Threshold values	Effect: Injury	Effect: Damage
Fire (thermal radiation) Jet fire, pool fire	37.5 kW/m^2	99 % fatality	Domino effect to process equipment
	15 kW/m^2	50 % fatality	
	13.4 kW/m^2	40 % fatality Damage to protected person	
	9.3 kW/m^2	5 % fatality High damage to unprotected person	
	7.3 kW/m^2	3 % fatality Low damage to unprotected person	
	5 kW/m^2	1 % fatality	
Fireball (thermal dose unit) BLEVE	3200 $((kW/m^2)^{4/3})$ sec	100 % fatality	-
	2000 $((kW/m^2)^{4/3})$ sec	50 % fatality	
	1000 $((kW/m^2)^{4/3})$ sec	1 % fatality	
Explosion (overpressure) VCE, Vessel bursting, BLEVE Blast	700 mbar	99 % fatality	Domino effect to process equipment
	350 mbar	50 % fatality	
	200 mbar	5 % fatality	
	140 mbar	1 % fatality	
	20 mbar	-	10% window glass broken
Cloud fire / flash fire Flammable gas dispersion	Lower Flammable Limit (LFL) of the gas cloud (Methane in air)	100 % fatality	-
Freezing Liquid Release	Maximum pool spreading	100 % fatality	
Rapid Phase Transitions (RPT)	Maximum pool spreading	100 % fatality	

Table 5: Consequence Assessment Criteria

Note: Damages to buildings and building elements shall be evaluated case by case, depending on the type of structure.

2.5 Results

Consequence results for all scenarios are presented with the following numbering system:

E1	-	011	-	10	-	FF		(F2)
Originator		Scenario identifier		Release size		Consequence		Weather conditions

Where:

Originator	
E1	EPC1 (CCGT)
E2	EPC2 (LNG terminal)
FS	FSU
E0	Other

Scenario Identifier	
01x	Scenario #10 to 19
02x	Scenario #20 to 29
03x	Scenario #30 to 39
…	

Release Size	
10	10 mm
50	50 mm
xx	xx mm
FBR	Full bore rupture
CR	Catastrophic rupture
SV	Safety valve (to atmosphere)
00	None Applicable

Type of Consequence	
FF	Flash Fire
VCE	Vapour Cloud Explosion
PF	Pool Fire
JF	Jet fire
FB	Fire Ball
BB	BLEVE Blast
B	Burst
FLR	Freezing liquid release
RPT	Rapid Phase Transition

Weather Conditions	
F2	F2 Condition
D5	D5 Condition
-	None Applicable

Table 6: Scenario Numbering System

Summary Table for Scenario Effects Distances is provided in **APPENDIX 2**.

The colour code applied for the safety distances drawings is presented in the following table:

Effect	Other		Overpressure	Thermal radiation	Thermal dose
Conse-quence	Freezing liquid release (FLR) Rapid phase transition (RPT)	Flammable dispersion - Flash fire (FF)	BLEVE Blast (BB) Bursting (B) Vapour cloud explosion (VCE)	Jet fire (JF) Pool fire (PF)	Fireball (FB)
(black)	Maximum pool spreading, 100% fatality	LFL, 100% fatality			3 200 $(kW/m^2)^{4/3}$, 100% fatality
(dark grey)			700 mbar, 99% fatality, domino effect (equipment)	37.5 kW/m^2, 99% fatality, domino effect (equipment)	
(dark red)			350 mbar, 50% fatality	15 kW/m^2, 50% fatality	2 000 $(kW/m^2)^{4/3}$, 50% fatality
(red)				13.4 kW/m^2, 40% fatality	
(blue)			200 mbar, 5% fatality	9.3 kW/m^2, 5% fatality	
(light blue)				7.3 kW/m^2, 3% fatality	
(green)			140 mbar, 1% fatality	5 kW/m^2, 1% fatality	1 000 $(kW/m^2)^{4/3}$, 1% fatality
(olive)			20 mbar, 10% window glass broken		

Table 7: Colour Code for Safety Distances Drawings

Effects Envelope (iso-contour) Maps are provided in **APPENDIX 2**: one map for each effect of each type of consequence.

Effects Maps for all scenarios are provided in document ENEM-AECOM-E0-00-DR-SE-00001: Scenario Effects Maps.

3 POTENTIAL DOMINO EFFECTS

As the new CCGT & LNG Terminal is located within the existing Enemalta Power Plant, also classified as a Seveso site, potential domino effects are analysed, from results of the Consequence Analysis.

The scenarios that may cause domino effects are of two types: thermal radiation from jet fire or poll fire, and overpressure from vessel burst or vapour cloud explosion (VCE).

As previously seen, the thresholds for the following domino effects are:

- 37.5 kW/m^2 for thermal radiation (jet fire and pool fire);
- 700 mbar for overpressure (VCE, bursting, BLEVE blast).

Therefore, the domino effects analysis is to identify facilities or equipment within Enemalta Power Plant, where dangerous substances are stored and/or handle, which could be affected by the corresponding distances from the major accident scenarios previously evaluated.

The domino effect matrix is provided in **APPENDIX 3**, where the potential domino effects are classified as follows:

(grey)	Potential domino effect but limited to the closest equipment/facility where the emergency is situated
(orange)	Potential domino effect to adjacent equipment/facility, but operated by same operator
(red)	Potential domino effect to adjacent equipment/facility, operated by other operator

Domino effects are identified between the EGM facilities and Enemalta facilities. No domino effect is identified between the EGM facilities (from FSU to RGU & CCGT, or from RGU to FSU & CCGT), as they are remote enough with comparison to the related safety distances.

APPENDIX 1: CALCULATING LNG AND NG RELEASE RATES

Gas Release (NG)

For gas release, the initial release rate from high pressure equipment is given by:

$$QG = Cd \times A \times \mathrm{P0}\sqrt{\frac{M \times \gamma}{R \times T0}\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{\gamma-1}}}$$

Where:

- $\mathbf{Q_G}$ is the initial gas release rate (kg/s),
- **Cd** is the discharge coefficient,
- **A** is the hole area (m^2),
- $\mathbf{P_0}$ is the initial absolute pressure (Pa),
- **M** is the molecular weight of gas (kg/kmol),
- γ is the ratio of specific heats (-),
- **R** is the universal gas constant (8314 J/kmol.K),
- $\mathbf{T_0}$ is the initial temperature of gas (K).

Rearranging the above and applying ideal gas equation gives:

$$QG = Cd \times \frac{\pi d^2}{4}\sqrt{\gamma\left(\frac{2}{\gamma + 1}\right)^{\frac{\gamma+1}{\gamma-1}}}\, P0\sqrt{\frac{\rho G}{P0}}$$

Approximating the gauge pressure to absolute pressure, substituting γ = 1.31 and **Cd** = 0.85, and converting the units of pressure to bar and noting that the units of the diameter are in mm, the equation can be simplified to:

$$QG = 1.4\ 10^{-4} \times d^2\sqrt{\rho G \times PG}$$

Where:

- $\mathbf{Q_G}$ is the initial liquid release rate (kg/s),
- **d** is the hole diameter (mm),
- $\mathbf{P_G}$ is the initial pressure of gas (bar gauge),
- ρ_G is the initial density of gas (kg/m^3).

Density for NG at process conditions are as follows:

Pressure (barg)	37	36	31	7
Temperature (°C)	15	5	5	10
Density (kg/m^3)	32.1	32.8	27.9	6.4

This equation may be used in order to estimate the initial NG release rate from a hole on high pressure process equipment at the LNG Regasification Terminal (from BOG compressors discharge, NG pipeline to D3PP/GRS and D4PP/GRS).

Liquid Release (LNG)

For liquid release, the initial release rate is given by:

$$QL = Cd \times A \times \sqrt{2 \times \rho L \times [(P0 - Pa) + \rho L \times g \times h]}$$

Where:

- **Q_L** is the initial liquid release rate (kg/s),
- **Cd** is the discharge coefficient,
- **A** is the hole area (m^2),
- **ρ_L** is the liquid density (kg/m^3),
- **P_0** is the initial absolute pressure at the top of the liquid (Pa),
- **h** is the liquid head above the release height (m),
- **P_a** is the atmospheric pressure (101325 Pa),
- **g** is the acceleration due to gravity (9.81 m/s^2).

By neglecting the liquid head (**h**) and replacing the pressure term with the gauge pressure of the liquid (**P_L**), this equation can be simplified to:

$$QL = Cd \times \frac{\pi d^2}{4} \times \sqrt{2}\sqrt{\rho L \times PL}$$

As a simple approximation, substituting **Cd** = 0.61 and assuming ρL 470 kg/m^3 for the LNG liquid density @ -162°C, the equation can be simplified to:

$$QL = 4.6\ 10^{-3} \times d^2\sqrt{PL}$$

Where:

- **Q_L** is the initial liquid release rate (kg/s),
- **d** is the hole diameter (mm),
- **P_L** is the initial pressure of LNG (bar gauge).

This equation may be used in order to estimate the initial LNG release rate from a hole on process equipment at the LNG Regasification Terminal.

APPENDIX 2: SCENARIO EFFECTS DISTANCES

ENEM-AEC-E0-00-RP-SE-00001	Scenario Calculation Sheets (Table)
ENEM-AEC-E0-00-DR-SE-00004	Scenario Effects Maps - Envelope

Also refer to document **ENEM-AEC-E0-00-DR-SE-00001: Scenario Effects Maps** from Safety Report.

APPENDIX 3: DOMINO EFFECT MATRIX