ENVIRONMENTAL & SOCIAL IMPACT ASSESSMENT (ESIA) FOR PRINOS OFFSHORE DEVELOPMENT PROJECT

Chapter 10 Emergencies and Risks

TABLE OF CONTENTS

TABLES

DIAGRAMS

MAPS

FIGURES

ABBREVIATIONS

ALARP	As Low As Reasonable Practicable
CBA	Cost Benefit Assessment
DTL	Dangerous Toxic Load
EBRD	European Bank for Reconstruction and Development
EIS	Environmental Impact Study
ENERGEAN	Energean Oil & Gas S.A.
ESIA	Environmental & Social Impact Assessment
EU	European Union
HAZID	Hazard Identification
HSE	Health, Safety and Environment
IRPA	Individual Risk Per Annum
LFL	Lower Flammable Limit
LSIR	Location Specific Individual Risk
OGP	(International Association of) Oil & Gas Producers
PLL	Potential Loss of Life
POB	Persons on Board
QRA	Quantitative Risk Assessment
SIP	Self Installing Platform
SLOD	Significant Likelihood of Death
SLOT	Specified Level of Toxicity
TAD	Tender Assist Drilling

10 EMERGENCIES AND RISKS TO THE ENVIRONMENT AND PEOPLE – QUANTITATIVE RISK ASSESSMENT (QRA)

10.1 PURPOSE, SCOPE AND OBJECTIVES OF THE RISK ASSESSMENT

This section of the Environmental and Social Impact Assessment (ESIA) describes the Quantitative Risk Assessment (QRA) studies performed to date in order to determine the level of risk (to groups of individuals) associated with the existing and proposed new facilities.

Whilst the current QRA work was undertaken to demonstrate that individual and total facility risk levels have been managed to ALARP as part of Energean's work to prepare a Safety Case for the new and existing facilities (in line with European and Greek legislation) it has also been employed to define a number of oil spill scenarios that have subsequently been modelled deterministically to assess potential environmental impacts. This work is described in further detail below (see section 10.8.2 Oil Spill Dispersion Modelling) and the full Oil Spill Modelling report is included as Annex 08. For completeness, calculated IRPA levels for worker groups are presented and discussed in this report even though they have no direct relationship to the potential environmental impact of the described facilities. The safety of Energean staff working offshore clearly influences the socio-economic wellbeing of the wider project area.

The purpose of the QRA is to provide a numerical estimate of the level of risk to people, associated with identified and defined Major Accidents. Risk is normally presented as IRPA (Individual Risk Per Annum – the chance each worker has of suffering a fatal accident per year of work) and PLL (Potential Loss of Life: the number of staff that might be killed in a defined period). QRA provides a means to compare the derived risk levels against industry accepted tolerability criteria and also provides a baseline against which potential risk reduction measures can be assessed. For new facilities potential design modifications can be implemented to allow risk levels to be reduced to a level that is demonstrated to be ALARP. For facilities already in operation (such as the Prinos complex which this ESIA also covers), it is clearly more difficult to implement design changes. However risk levels can be reduced, principally by introducing enhancements to the way the facility is operated and/or the response measures to prevent failures from escalating.

The scope of the QRA was to provide an integrated risk profile, which considers the level of risk associated with the existing Prinos production facilities and the new Self Installing Platforms (SIPs). Drilling and workover/intervention, using the 'Energean Force' Tender Assist Drilling (TAD) facility is also considered within the QRA. However, the Major Accidents that are associated with the Energean Force itself (e.g. loss of stability) are not considered in the scope of the risk assessment. The risks associated with the Kappa platform, located at the South Kavala field and its associated pipeline, have not been formally assessed. The future of this field is currently uncertain. It is currently operated for approximately a week every month, with crew in attendance for just a few hours at the start and end of a production cycle. The platform processes sweet gas at very low pressures (maximum of 12 bar) with little liquid inventory and so the risk levels will be orders of magnitude lower that those associated with sour crude production at Prinos and Epsilon (both to the workers and to the environment).

No QRA work was completed for the onshore facilities as part of this scope. QRA analyses for onshore facilities are not currently required under applicable legislation (Serveso). Historically risks and controls applicable to onshore facilities including oil loading facilities have been determined Qualitatively based upon a comprehensive HAZID exercise.

Whilst the primary objective of the QRA is to assess the level of risk to personnel; it also allows the scenarios, which could adversely impact the environment to be defined in a systematic and auditable manner. Clearly one of the key risks that staff working on an offshore oil and gas installation are exposed to, is the unplanned and uncontrolled release of hydrocarbons, particularly if those hydrocarbons either contain poisonous components such as hydrogen sulphide or if the released hydrocarbon stream is subsequently ignited causing fires and explosions. Clearly the uncontrolled release of a hydrocarbon stream has the potential to not only affect the safety of the staff on the facility but also the environment in which the facility is located. Unignited oil spills clearly present the most significant hazard to the environment of any upstream oil and gas operation. To define risk to humans the size and frequency of potential hydrocarbon leaks has to be calculated. This data can then be used to define the key threats to the environment.

10.2 DEFINITION OF A MAJOR ACCIDENT

The QRA is focused on deriving an estimate of the numerical level of risk associated with the major accidents. According to article 2 of EU Directive 2013/30 on the Safety of Offshore Oil and Gas Operations (currently being transposed into Member State legislation), Major Accidents are defined as:

a. *an incident involving an explosion, fire, loss of well control, or release of oil, gas or dangerous substances involving, or with a significant potential to cause, fatalities or serious personal injury;*

b. *an incident leading to serious damage to the installation or connected infrastructure involving, or with a significant potential to cause, fatalities or serious personal injury;*

c. *any other incident leading to fatalities or serious injury to five or more persons who are on the offshore installation where the source of danger occurs or who are engaged in an offshore oil and gas operation in connection with the installation or connected infrastructure; or*

d. *any major environmental incident resulting from incidents referred to in points (a), (b) and (c).*

e. *for the purposes of determining whether an incident constitutes a major accident under points (a), (b) or (d), an installation that is normally unattended shall be considered attended.*

10.3 FACILITY AND OPERATIONS OVERVIEW

The current and planned hydrocarbon production infrastructure in the Prinos offshore area has been fully described in the previous sections. For the Prinos complex itself the QRA model was based upon the situation following the tie back of the Lamda and Omicron platforms, i.e. all planned modifications including new pipework, risers, flanges, storage tanks etc. were included in the model. The composition of fluids in the defined surface and sub-sea pipework network changes with time as new wells and fields are brought on stream and gas lift rates are increased or decreased. The scenario which models the early period of production from Epsilon was used as this combined a high net production rate with a low gas lift rate and thus results in hydrogen sulphide concentrations that are considered on the "high" side of average. As will be demonstrated hydrogen sulphide levels are the key contributors to personnel risk (IRPA) whilst net oil production rates (and associated pressures) are the largest contributor to environmental risk.

The new facilities were modelled "as currently designed". By necessity this EIS is prepared early in the detailed design phase and hence the risks calculated will be higher than the final risk levels obtained. The opportunity to implement further risk reduction measures will be taken over the course of detailed design and in doing so ALARP demonstrated before construction contracts are awarded. Some of these potential risk reduction measures are discussed.

10.4 THE RISK ASSESSMENT PROCESS

The risk assessment process is summarised in diagram below and consists of the following key stage activities:

- Systematic and structured identification and definition of the scenarios giving rise to the Major Accidents
- Assessment of the likelihood or frequency of the defined scenarios

- Assessment of the consequences, to people, associated with the defined scenarios
- Combining the frequency and consequences to derive estimates of the numerical levels of risk
- Comparison of the estimates of risk against risk tolerability criteria.

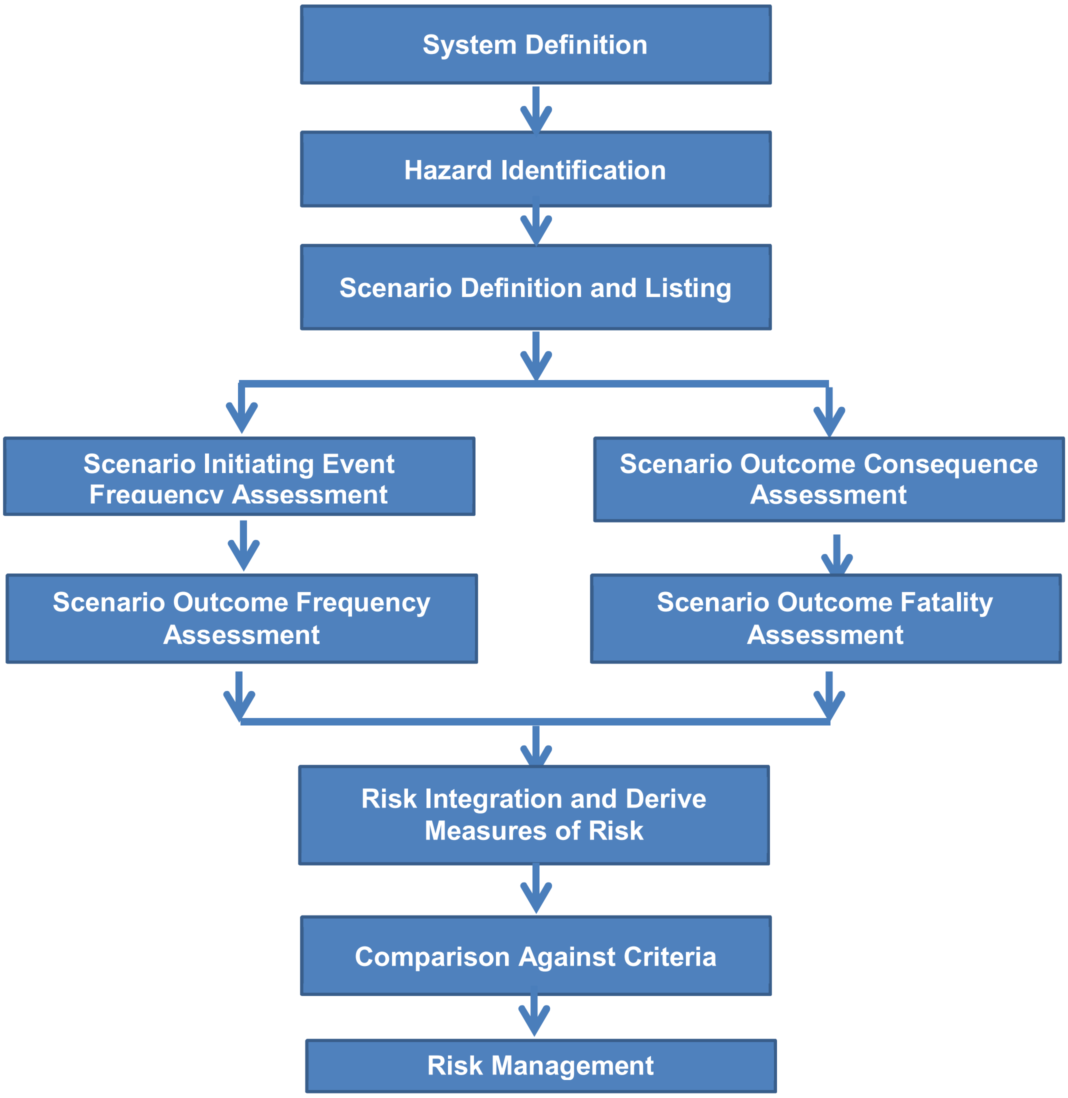


Diagram 10-1: Risk assessment process

10.5 IDENTIFICATION OF MAJOR ACCIDENT SCENARIOS

The Major Accidents for the Prinos QRA were derived based on a review of existing Hazard Identification (HAZID) and risk assessment studies and by review of the processes and activities.

The Major Accidents associated with the new SIP facilities are based upon the safety studies performed during the engineering phase. The diagram below summarizes the approach adopted for the identification of the major accidents.

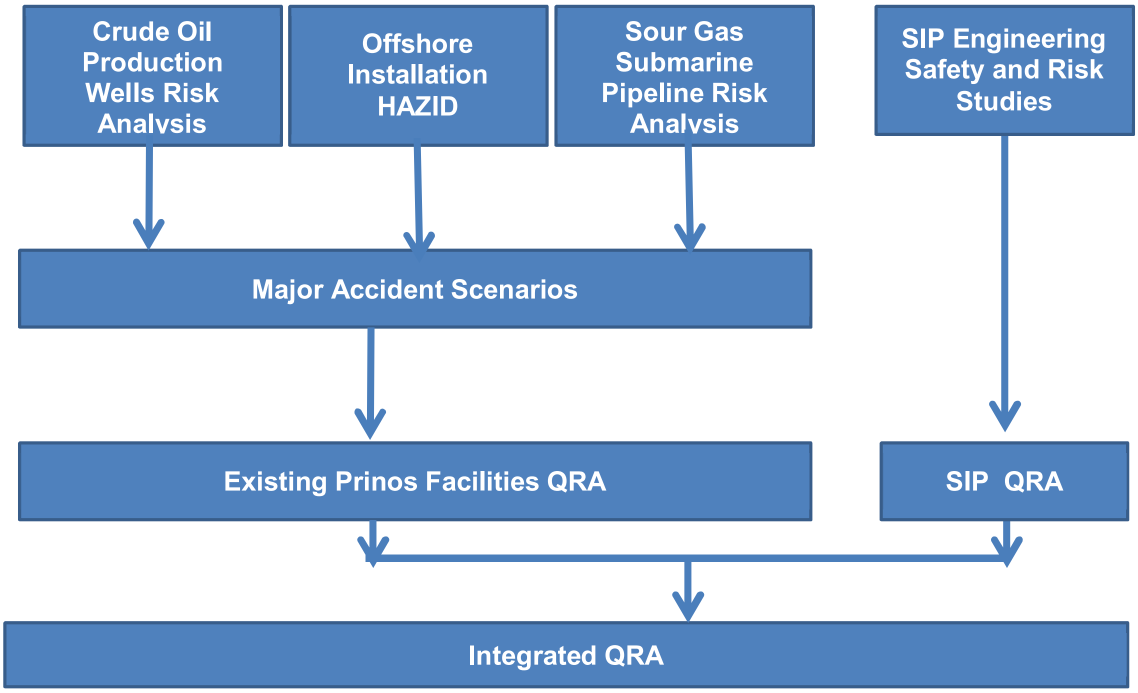


Diagram 10-2: Identification of major accidents scenarios

10.6 MAJOR ACCIDENT SCENARIOS

The Major Accident scenarios considered for the Prinos and Lamda/Omicron QRA can be broadly summarised as follows:

- Release of well fluids, from the wells, during drilling, workover/intervention, production activities. Sources include Alpha, Beta, Lamda, and Omicron platforms. These have the potential to result in fire/explosion/toxic gas effects and/or environmental impact due to oil spillage.
- Release of well fluids, sour gas, sour liquid or sweet gas from the production, export and gas lift subsea pipeline infrastructure. Such releases could result in fire/toxic gas/explosion effects (depending on the location of the release and proximity to platforms). Pipelines containing liquid hydrocarbons have the potential to result in environmental impact.
- Structural failure/collapse, which in addition to the immediate injury/fatality effects, could also result in loss of hydrocarbon containment and hence environmental impacts.

- Ship collision. Impact from attendant or passing vessels have potential to cause immediate injury/fatality effects and also result in loss of hydrocarbon containment
- Loss of control during crew boat operations. A major loss of control (e.g. capsize could result in injury/fatalities. It is noted that personnel logistics activities are conducted by a crew boat, helicopters are not used to support the offshore operations.

Table below, summarizes the major accidents associated with Prinos offshore activities.

Table 10-1: Major accidents summary

Location	Hazard Source	Prinos Major Accidents		
		Ref	Event	Potential Consequences
Wellhead Platforms	Alpha / Beta Platforms	AB-01	Loss of Containment: Well Fluids	• Injury/fatality due to fire/explosion/toxic gas effects • Oil spill/environmental impact
		AB-02	Loss of Containment: Sweet Gas (Gas Lift)	• Injury/fatality due to fire/explosion effects
		AB-03	Blowout: Well Fluids (Drilling/Intervention)	• Injury/fatality due to fire/explosion/toxic gas effects • Oil spill/environmental impact
		AB-04	Structural Failure	• Injury/fatality due to structural collapse effects • Injury/fatality due to fire/explosion/toxic gas effects (in the event if subsequent loss of containment) • Oil spill/environmental impact
		AB-05	Ship Impact	• Injury/fatality due to structural collapse effects • Injury/fatality due to fire/explosion/toxic gas effects (in the event if subsequent loss of containment) • Oil spill/environmental impact
	SIPs (Lamda / Omicron)	LO-01	Loss of Containment: Well Fluids	• Injury/fatality due to fire/explosion/toxic gas effects • Oil spill/environmental impact
		LO-02	Loss of Containment: Sweet Gas	• Injury/fatality due to fire/explosion effect

Location	Hazard Source	Prinos Major Accidents		
		Ref	Event	Potential Consequences
			(Gas Lift)	
		LO-03	Blowout: Well Fluids (Drilling/Intervention)	• Injury/fatality due to fire/explosion/toxic gas effects • Oil spill/environmental impact
		LO-04	Structural Failure	• Injury/fatality due to structural collapse effects • Injury/fatality due to fire/explosion/toxic gas effects (in the event if subsequent loss of containment) • Oil spill/environmental impact
		LO-05	Ship Impact	• Injury/fatality due to structural collapse effects • Injury/fatality due to fire/explosion/toxic gas effects (in the event if subsequent loss of containment) • Oil spill/environmental impact
Production Platform	Delta Production Platform	D-01	Loss of Containment: Sour Crude	• Injury/fatality due to fire/toxic effects • Oil spill/environmental impact
		D-02	Loss of Containment: Sour Gas	• Injury/fatality due to fire/explosion/toxic gas effects
		D-03	Loss of Containment: Sweet Gas	• Injury/fatality due to fire/explosion effects
		D-04	Structural Failure	• Injury/fatality due to structural collapse effects • Injury/fatality due to fire/explosion/toxic gas effects (in the event if subsequent loss of containment)

Location	Hazard Source	Prinos Major Accidents		
		Ref	Event	Potential Consequences
				• Oil spill/environmental impact
		D-05	Ship Impact	• Injury/fatality due to structural collapse effects • Injury/fatality due to fire/explosion/toxic gas effects (in the event if subsequent loss of containment) • Oil spill/environmental impact
Pipelines	12 ins Wellfluids from Alpha, Beta to Delta	PL-01	Loss of Containment: Wellfluids	• Injury/fatality due to fire/explosion/toxic gas effects • Oil spill/environmental impact
	10 ins Wellfluids from Lamda, Omicron to Delta	PL-02	Loss of Containment: Wellfluids	• Injury/fatality due to fire/explosion/toxic gas effects (in the event subsea release effects are able to impact Delta, SIP platform/manned areas) • Oil spill/environmental impact
	6 ins Gas Lift from Delta to Alpha, Beta	PL-03	Loss of Containment: Sweet Gas	• Injury/fatality due to fire/explosion effects (in the event subsea release effects are able to impact Delta, SIP platform/manned areas)
	6 ins Gas Lift from Delta to Lamda, Omicron	PL-04	Loss of Containment: Sweet Gas	• Injury/fatality due to fire/explosion effects (in the event subsea release effects are able to impact Delta, SIP platform/manned areas)
	8 ins Sour Crude to Shore	PL-05	Loss of Containment: Sour Crude	• Injury/fatality due to fire (sea surface pool fire) /toxic effects • Oil spill/environmental impact

Location	Hazard Source	Prinos Major Accidents		
		Ref	Event	Potential Consequences
	12 ins Sour Gas to Shore	PL-06	Loss of Containment: Sour Gas	• Injury/fatality due to fire/explosion/toxic gas effects (in the event subsea release effects are able to impact Delta, platform/manned areas)
	5.3 ins Sweet Gas Recycle From Shore	PL-07	Loss of Containment: Sweet Gas	• Injury/fatality due to fire/explosion effects (in the event subsea release effects are able to impact Delta, platform/manned areas)
Prinos Field	Logistics Activities	CB-01	Loss of Control (Crew Boat)	• Injury/fatality due to loss of control of the crew boat (e.g. capsize)

10.7 NATURE OF CONSEQUENCES

In general, major accidents are associated with loss of containment from the primary hydrocarbon systems. Release of pressurised hydrocarbon fluids can result in a range of physical effects (consequences) that can affect personnel. Table below summarizes the nature of the consequences that are associated with the major accidents.

Table 10-2: Major accidents consequences

Consequence	Summary	Potential Impacts on People
Jet Fire	Upon release, the gas can form momentum driven jets several tens of meters in length. Should ignition occur, high heat levels could be experienced at some distance away from source. Sustained jet fire impingement can result in structural failure and escalation.	Injury/fatality due to exposure to high heat radiation levels.
Pool Fire	Ignition of large quantities of released flammable liquids can form a pool fire. Equipment and structures exposed to the effects of pool fires can subsequently fail, resulting in escalation.	Injury/fatality due to exposure to high heat radiation levels.
Flash Fire	Flash fires generally occur as a result of delayed ignition of flammable gas clouds. Ignition of the cloud results in “burn back” to source and subsequent fire.	Injury/fatality due to being engulfed in a flammable gas cloud.
Explosion	Typically there is potential for explosions in those areas of plant where there is a high degree of congestion and confinement. Increased levels of congestion and confinement serve to both reduce ventilation rates, and hence provide conditions conducive to the accumulation of flammable mixtures. The congestion and confinement also services to increase the level of overpressure associated with the rapid combustion of the flammable gas cloud.	Explosions can result in injury/fatality via the following mechanisms: • Direct physical effects of the overpressure • Overpressure physically moving a person • Overpressure causing missiles/ structural collapse

Consequence	Summary	Potential Impacts on People
Hydrogen Sulphide (H_2S)	There are a number of areas of the process where H_2S is present in the hydrocarbon stream. Loss of containment from the hydrocarbon envelope can result on the formation and dispersion of a toxic plume.	Fatality due to the exposure to the toxic effects of H_2S

10.8 OIL SPILL SCENARIOS

10.8.1 Scenarios identifications & description

In addition to the potential impacts on personnel, which as explained above, are the primary focus of the QRA, the major accidents can also affect the environment via the release of quantities of liquid hydrocarbons to sea. The QRA process served to inform a range of credible oil spill cases for which trajectory modelling and impact assessment has been performed (Paragraph 10.8.2).

Table below summarises the oil spill scenarios. They cover all relevant parts of the production infrastructure, i.e.:

- Well head platforms (new and existing) and release of well fluids;
- Release of well fluids during drilling and workover/intervention activities;
- Release from liquid topsides processes; and
- Releases from the pipeline systems.

Estimates of credible oil spill sizes have been derived within the Prinos Complex oil spill contingency plan and these have been adopted and supplemented with spill size estimates for the new planned facilities.

Oil spill modelling has been performed on the spill scenarios considered to be the most threatening to the marine and coastal environments. This work and the results and implications are discussed below. The full oil spill modelling report is attached as Annex 08.

Table 10-3: Oil spill scenarios

Ref	Scenario	Release Size	Release Locations	Sub Scenario	Notes/Justification
P1	Blowout	475 m^3 (largest credible blowout)	1. Prinos Complex 2. Lamda 3. Omicron	Blowout- Alpha, Beta during drilling, workover using Energean Force. Release of well fluids	The Prinos Oil Spill Contingency Plan proposes 120m^3 as a representative oil spill size for the wells associated with the Prinos reservoir. The Prinos reservoir is highly depleted and the wells will not self-flow, in addition the reservoir fluids have a high water cut. The oil spill contingency plan suggests a 24 hr response time, this is assumed to be representative of the time take to initially respond, access the well head, kill the well and initiate oil spill response. During this period it is assumed the volume spilled is as per the oil spill contingency plan scenario (i.e, 120 m^3). The 24 hr duration is of the order of blowout durations experienced historically. The impact assessment prepared for the new EU Offshore Safety Directive, which is based on historic blowout data, suggested 56% likelihood that a blowout would persist for < 2 days before being controlled/naturally bridging. This assessment suggested only small proportion of blowouts result in major spills (e.g. 15% likelihood of blowout lasting > 2 weeks).
L1				Blowout- Lamda during drilling, workover using Energean Force. Release of well fluids	The wells to be drilled and completed from the Lamda platform serve to develop the Epsilon reservoir. The pressure of the Epsilon field well fluids is approximately 2,000 to 3,000 psi higher than for Prinos/Prinos North reservoir. The water cut is also very low. It is assumed that the 24 hr response time (refer to the above discussion) is representative of the time taken to secure a well. The Basis of Design (Rev

Ref	Scenario	Release Size	Release Locations	Sub Scenario	Notes/Justification
					B) states the maximum production rate is 3,000 bbls/day. Hence the spill scenario is 3,000 bbl (approximately 475m^3)
O1				Blowout- Omicron during drilling, workover using Energean Force. Release of well fluids	The wells to be drilled and completed from the Omicron platform serve to develop the Prinos North reservoir, which has similar characteristic s to the Prinos reservoir, hence (as per Prinos) 120m^3 is adopted for the representative oil spill scenario.
P2	Topside Leak	150m^3 (worst case topside leak)	1. Prinos Comple x 2. Lamda 3. Omicron	Process release – release of liquid hydrocarbons from topsides hydrocarbon envelope	From Oil Spill Contingency Plan – Estimate of maximum credible topside spill size. This scenario is assumed to represent/bound Prinos topsides process release scenarios
L2				Process release – release of liquid hydrocarbons from topsides hydrocarbon envelope	Full bore release from production header considered (production riser release covered in LO1 case below). Max anticipated HC liquid flowrate is 90m^3/hr. Detection / Isolation assumed to occur within 60 seconds. Inventory size for production header is estimated to be about 3 m^3.
O2				Process release – release of liquid hydrocarbons from topsides hydrocarbon envelope	Assume topsides production system inventory is identical to Lamda
LO1	Release from	205 m^3	Vicinity of the subsea	Release of well fluids from production	Estimate based on pipeline volume plus maximum production rate (12,150 stdbpd, based on SIP basis of design) assumed to continue for 30 minutes

Ref	Scenario	Release Size	Release Locations	Sub Scenario	Notes/Justification
	Production Pipeline		tie-in	pipelines – Lamda/Omicron to Delta	prior to shut down. Assuming: • 12,150 stdbpd (SIP Basis of Design, Rev B) • Approx. $80m^3$/hr throughput • Assume 30 mins to shutdown = 40 m^3 released, in addition volume released by reverse flow/draining from Delta end of the pipeline is assume to be 40 m^3, hence released amount prior to shutdown is 80 m^3 • Inventory of the pipeline approximately 250 m^3 (assume 5 km of pipeline) • Assume 50% of the pipeline inventory is released = 125 m^3 • Assumed total volume released is therefore 125 m^3 + 80 m^3 = 205 m^3
PL1	Release from Export Pipeline	$410m^3$	Vicinity of Prinos, Mid-point between Prinos and Sigma Onshore, Near Sigma Onshore	Release of sour crude from export pipeline Delta to Sigma	Assuming: Pipeline volume is 580 m^3 Assume 50% of pipeline inventory is released = 290 m^3 Assume 30 mins to shutdown, yields an additional 60 m^3 (throughput assumed as 17,000 bopd). In addition, volume released by reverse flow/draining from sigma end of the pipeline prior to shutdown is assumed to be $60m^3$, hence total release prior to shutdown is 120 m^3. Assumed total volume released is 290 m^3 + 120 m^3 = 410 m^3 *This includes estimated future output including Lamda and Omicron Platforms.*

10.8.2 Oil Spill Dispersion Modelling

10.8.2.1 Introduction

The offshore oil and gas facilities covered by the current ESIA (both existing as well as the planned and potential new facilities) are located in close proximity to the coast lines of the Greek mainland and the Greek island of Thasos. Hydrocarbons are currently produced from 3 drilling locations (Alpha, Beta and Kappa) that contain 26 wells between them. These fluids are initially treated at the Delta platform. From here partially stabilised oil at approximately 1% BS&W and dry sour-gas are sent by two independent pipelines to the onshore facilities (Sigma). Fully treated crude oil is stored at Sigma and periodically loaded in 250,000 bbl parcels to crude tankers through a loading buoy located 3 km from the shore. The planned and potential extension projects will add two further drilling centres (Lamda and Omicron) that will each hold up to a maximum of 15 wells. These new facilities will be tied back to the existing facilities by short-length, small-bore, multiphase pipelines.

Leaks of oil from this offshore infrastructure (including the marine loading buoy) clearly present a significant hazard to the immediate environmental and socioeconomic wellbeing of the area surrounding it. Oil entering the sea from loss of integrity of the existing or extended facilities will form a slick on the surface which will then be moved by the wind, waves and current until it is either:

- Recovered by Energean using its oil spill response facilities,
- Washes up onto the coastline or
- Dissipates due to the combined effects of evaporation and biodegradation.

In this section, the modelling work commissioned by Energean to calculate risks to the most vulnerable receptors on the surrounding coastlines is discussed.

10.8.2.2 Definition of leak sources and leak scenarios

A QRA investigation has been undertaken that allowed potential, non-routine (failure), events to be modelled. This work was described above. Based upon this analysis three worst case scenarios were defined and from these corresponding oil spill modelling scenarios developed and then used as inputs to the oil spill modelling work described in this section.

The three worse case leaks considered were:

- **<u>A blow out from one of the new wells being drilled on the Lamda platform</u>:** analysis indicated that a blowout would create a larger potential release than any other scenario that could take place on the existing or new facilities. Whilst a blowout releases crude from only one well (rather than other topside scenarios that could release production from all wells simultaneously) it takes longer to recover from such an incident. Simulation work indicated that unconstrained flow for a period of 24 hours at a rate of up to 3,000 bbl/day could occur. The Lamda platform was selected as the blowout location. A blowout whilst drilling into a virgin reservoir has a higher likelihood (and also a more significant consequence) than when sidetracking an existing well in a depleted field. Lamda was selected rather than Omicon as the Epsilon field has the highest bottom-hole reservoir pressure and it is fractionally closer to the island of Thasos from this location.

- **A leak from the main oil line transporting semi stabilised crude from Delta to Sigma:** a leak in this existing line can generate a larger spill due to its long length and higher throughput than either of the new multiphase lines installed in the extension projects. The new lines have a low potential for failure as they will be buried over their whole length (protecting them from external damage) and will be designed for full wellhead shut-in pressures (giving them a very large corrosion allowance compared with normally rated lines). The main export line runs on the sea bed for the first 4.2 nautical miles (approximately 7km) after it leaves Delta. Although fishing is prohibited over the line, pipeline inspections have shown that trawling does occur. In the unburied sections damage from trawl boards has been noted to the external concrete coating. In the buried sections seabed scour from trawl boards has been noted – but never to a depth where the pipeline is impacted. Leaks in the buried section are more likely from internal corrosion than external impacts. Internal events normally result in pin-hole leaks that lead to a sheen developing on the sea surface above or close to the pipeline routing. Sheens are easy to spot in the Kavala Gulf as for 40 to 50% of the year the water surface is calm. Energean also has its divers' swim the pipeline routes regularly looking to see if any oil seeps can be seen from the sea bed. Seeps of this kind have little potential for environmental damage. A major leak can only be caused by an external impact and hence in an unprotected section of the line. Hence the second leak scenario takes the modelled leak on the export pipeline (410 m3 released over an 8.5 hour period) and positions it at the point where the pipeline first becomes buried, i.e. places it as close as feasible to shore.
- **A leak whilst loading processed crude to an oil tanker:** leaks in this system were not considered during the QRA as the onshore facilities were not included in this review. The onshore facilities are not modified by the planned or potential expansions and are already covered by valid environmental permits. However as loading operations represent the closest location to shore where a large leak could potentially occur it appeared prudent to model the worse possible leak in this location. Oil is loaded to tankers at approximately 12,000 bbls/hr. All subsea connections are checked by divers prior to loading commencing and every 4 hours after loading starts and hence these is little to no chance of a full bore rupture subsea. Loading is not undertaken in high wind conditions where the tanker could move. Three anchor points are used in any case to prevent movement during loader. The only feasible (but unlikely) event is that the hose is not properly fixed to the hard piped system on the tanker and suddenly breaks loose.

At all times there are 2 tanker staff observing this point. They are in permanent radio communication with the Sigma control room, from where the loading operation can be remotely stopped. A rupture at this point would not be detected by the low-pressure trip system installed, as the pressure close to the ships tanks is very low anyway under normal conditions. This incident is a scenario used when response systems are tested. It normally takes 2 minutes for the shipping pumps to be stopped and the pressure energy in the loading line to be dissipated. In this period 400 bbls would be spilt. Hence a spill of 400 bbls over 2 minutes, period 3km from shore is assumed for this scenario.

Using these leak scenarios for a range of oil spill scenarios were developed as described below.

10.8.2.3 Development of oil spill modelling scenarios

10.8.2.3.1 Introduction

The quantity of oil released to the sea and the time in which the releases take place are two critical parameters for defining oil spill scenarios that can be used within a simulation model representing the Gulf of Kavala. Oil spill modelling can be undertaken on either a deterministic basis of stochastic (probabilistic) basis. Clearly the final location of a spill of oil and the time it takes to arrive at that location depends on factors such as wind direction, wind strength, wave height, current strength and direction, water and air temperature, type of crude spilled etc. These parameters vary minute by minute, day by day, month by month etc. In stochastic modelling the probability of a defined amount of oil reaching the shore is calculated based upon knowledge of how these properties change with time. Commonly 100 runs for each spill will be undertaken and from this mean, minimum and maximum data generated. Stochastic modelling can simulate events on a particular day, for a particular month or for the average properties over a particular year. This type of modelling gives a good picture of where oil might occur and how its likelihood of appearing at a particular defined location changes with month, season etc. It does not however allow specific worst case (or best case scenarios) to be studied and hence the effectiveness of planned response measures to such worst cases to be determined.

Deterministic modelling is used where specific combinations, normally the “worst” case, or the “most likely” case are to be investigated. At the request of EBRD Energean has developed a series of deterministic scenarios rather than running a stochastic analysis. These have been used to predict how quickly winds blowing in a specific direction, at a certain speed, would carry oil to the most vulnerable sections of shoreline at different times of a typical year. The basis of the data used in these scenarios is outlined below.

10.8.2.3.2 Selection of sensitive receptors

When performing deterministic modelling not all onshore locations can be studied in the same amount of detail. To keep the number of scenarios to a manageable level the areas of particular sensitivity need to be identified and scenarios that look at how these areas could be impacted defined. For the sake of the current work the following locations have been defined:

- **The coast between the Kavala and Nea Karvali** – this coast line contains the historic port of Kavala, a number of tourist beaches (to the west and east of Kavala), the commercial port at Fillipos, small industrial based marine facilities (Fertiliser plant, Sigma water intake and loading buoys, Refined product intake buoys). Oil spills in this area would have an impact on the tourist industry – particularly in the summer months and on a number of significant socio-economic activities (fishing, car ferry to Thasos, commercial port activities, etc.) year round. Winds from the south would carry spilled oil towards this coastline from all three leak points defined.
- **The coast between the Sigma plant and the mouth of the delta of the Nestos river** – this coast falls under numerous protection provisions (part of Natura 2000, SPA, National park, Ramsar wetlands, IBA). Moreover, it holds a number of small-scale fish farming enterprises. The impact on this coastline would be most significant from the late spring through to the end of summer. Tourism would be disrupted particularly in the summer whilst fauna would be impacted from late spring. Fish farming would be disrupted year round. Winds blowing from the southwest would bring oil towards this stretch of coast from leak points 1 and 2. Clearly leak point 2 is closer to this coastline than leak point 1. Spills from leak point 1 have more chance of being blown to the north of Thasos.
- **The north and North West coast of the island of Thasos** – Thasos is a major tourist destination. Whilst many of the main beaches are on the east and south of the island there are a number of popular tourist locations on the coast immediately adjacent to Energean's offshore facilities (Rachoni, Prinos, Kalarachi etc.). Clearly oil spills during the summer would be of greater significance than those in the winter due to the impact on the dominant tourist industry. Oil would be blown to this coast from spills at locations 1 and 2. Location 1 is clearly closer than location 2

10.8.2.3.3 Metocean data

Energean has collected detailed met-ocean data for the Kavala Gulf area to allow it to design the new facilities. This data has been described in Chapter 8. The same data has been used to define a range of appropriate deterministic oil spill modelling scenarios. Oil spill movement in shallow water environments is largely driven by wind direction. In deep water environments leaks originating below the sea surface can move for considerable distance dictated by current before they surface. In shallow waters such as the Gulf of Kavala this is not an issue. Oil from the main oil line leak reaches the surface less than 20 minutes after the leak occurs whilst for the other two events the oil is spilt from above the sea into it. Understanding wind direction and strength is therefore the most critical parameter when defining deterministic scenarios.

As can be seen from the annual wind data tabulated below, conditions in the Gulf of Kavala can be split into two main seasons, i.e. summer (running from May through to September) and winter (running from October to April). Wind strengths are relatively low throughout the year. The most likely weather condition in winter is a dead calm, with wind speeds being "gentle breeze" or below for around 60% of the time. In summer there are less dead calm days but on average winds are classified as a gentle breeze or lower for around 72% of the time. Hence for the majority of the time spills in the Gulf of Kavala would move relatively slowly from their starting points.

Legend

Common occurrences

red - 12 most common
yellow - next 24 most common
orange - next 24 most common

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	All
29	30	0	0	0	0	0	0	0	0	0	0	0	0	0
28	29	0	0	0	0	0	0	0	0	0	0	0,018	0	0,002
27	28	0,018	0	0	0	0	0	0	0	0	0	0	0	0,002
26	27	0	0	0	0	0	0	0	0	0	0	0	0	0
25	26	0	0	0	0	0	0	0	0	0	0	0	0	0
24	25	0	0	0,018	0	0	0	0	0	0	0	0,018	0	0,003
23	24	0	0,077	0	0	0	0	0	0	0	0,018	0	0	0,007
22	23	0,018	0,039	0	0	0	0	0	0	0	0	0,018	0,035	0,009
21	22	0,035	0,058	0,018	0	0	0	0	0	0	0,035	0,036	0,053	0,019
20	21	0,070	0,077	0,035	0	0	0	0	0	0	0,018	0,036	0,018	0,021
19	20	0,140	0,077	0,105	0,036	0	0	0	0	0	0,035	0,073	0,175	0,054
18	19	0,193	0,231	0,245	0,036	0,018	0	0	0,018	0	0,035	0,181	0,193	0,095
17	18	0,351	0,173	0,386	0,018	0	0	0	0	0	0,193	0,217	0,281	0,135
16	17	0,456	0,269	0,298	0,054	0,018	0	0	0	0,018	0,158	0,254	0,684	0,185
15	16	0,684	0,673	0,579	0,109	0,053	0	0	0	0	0,263	0,471	0,947	0,314
14	15	1,157	0,865	0,579	0,163	0,053	0	0,018	0	0,163	0,403	0,652	1,368	0,451
13	14	1,192	1,519	0,947	0,236	0,140	0,036	0,123	0,018	0,236	0,561	0,707	1,666	0,612
12	13	1,736	2,192	1,262	0,670	0,456	0,127	0,123	0,158	0,598	1,280	1,721	2,139	1,033
11	12	2,332	2,558	1,841	1,069	0,754	0,127	0,210	0,421	0,978	2,367	2,681	2,753	1,503
10	11	3,471	3,385	3,103	1,540	1,069	0,417	0,544	0,912	1,775	3,471	3,333	3,138	2,175
9	10	4,453	4,673	3,401	1,938	1,911	1,178	1,280	1,964	2,518	4,453	3,986	5,137	3,070
8	9	6,434	5,673	4,628	3,388	2,980	1,685	2,279	2,770	4,130	5,645	5,036	6,101	4,226
7	8	7,433	6,500	6,364	4,783	3,594	3,116	5,645	5,242	5,634	6,311	5,797	7,100	5,629
6	7	8,555	7,077	6,452	5,924	5,908	5,580	8,275	8,240	6,902	6,925	7,138	7,749	7,068
5	6	7,714	7,404	7,696	8,116	8,310	8,859	11,799	11,729	9,801	8,012	7,917	8,310	8,817
4	5	7,889	8,115	9,537	10,815	11,606	13,279	15,305	14,919	12,428	8,994	8,351	8,292	10,810
3	4	9,081	9,135	11,325	13,696	14,008	16,069	15,761	15,077	14,294	10,256	9,746	9,274	12,321
2	3	9,730	11,865	11,553	14,348	14,884	16,522	14,043	13,517	14,004	12,272	10,996	10,063	12,811
1	2	11,957	12,154	13,377	14,819	16,567	16,033	12,290	12,062	13,297	12,658	12,663	11,325	13,265
0	1	14,902	15,212	16,252	18,243	17,672	16,975	12,307	12,956	13,225	15,638	17,953	13,201	15,366
		100	100	100	100	100	100	100	100	100	100	100	100	100

blue - all remaining

Diagram 10-3: Wind speed distribution over a typical year

The following "wind rose" shows wind speed by direction and strength over an entire year. As can be seen the predominant wind direction is from the northeast. These winds prevail for almost 40% of the time. Wind roses showing monthly variations are available. These show northeasterly winds predominate in all months. Together with winds from the east and north, winds that would generally blow oil slicks away from the critical coastlines identified, dominate for more than 60% of the year. Spills would therefore normally slowly drift out to sea towards the Kappa platform and then into open sea beyond.

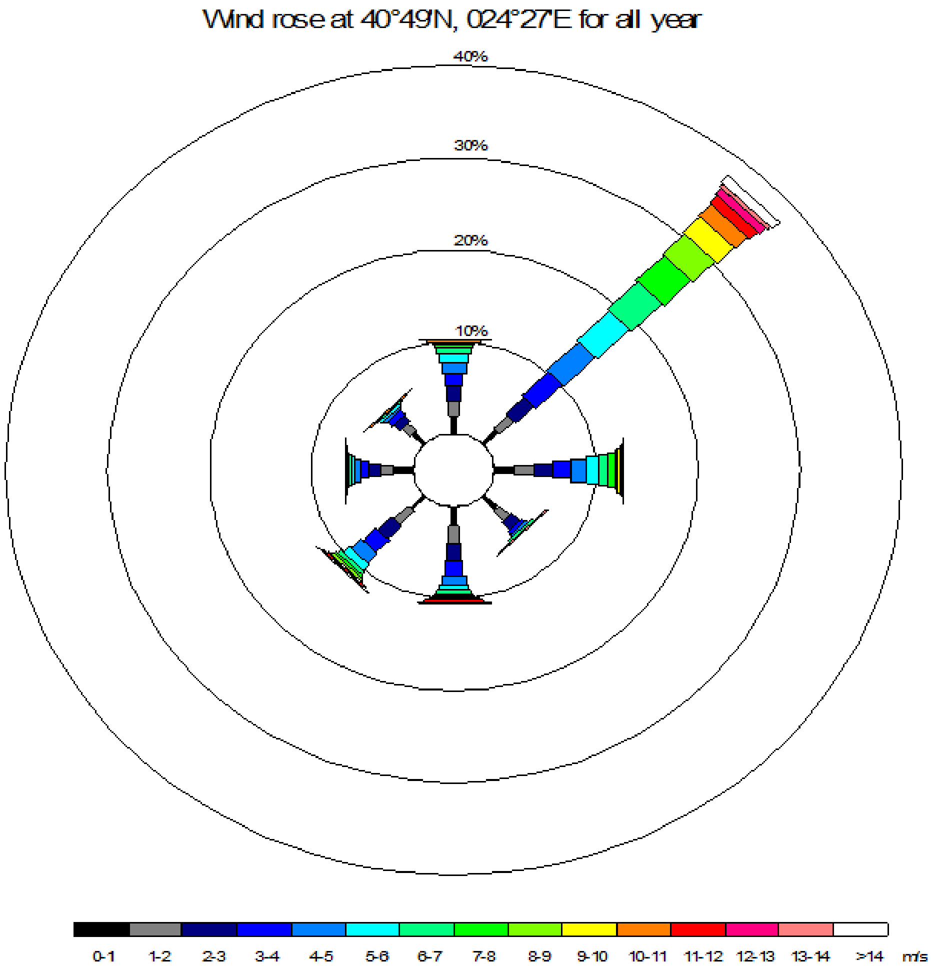


Diagram 10-4: Wind rose showing predominant wind directions

Winds blow about 10% of the time from the south. These winds can be relatively strong in the winter but are infrequent and generally short lived. Winds classified as a strong breeze or above occur for about 7 hours a month in the winter and don't occur in the summer. These short lived southerly storms therefore represent the worst-case scenario for bringing oil onto the coastline between Kavala and Nea Karvali.

Winds blow from the southwest, potentially blowing crude into the Nestos delta wetlands around 12% of the year. Strong winds blow for a maximum of 3 hours per month in the winter and not at all in the summer.

Winds from the North West, which would take spilled crude towards the Thasos island coast are the least frequent occurring only 5% of the time and never at strong conditions. The mean wind speed in this direction in the winter is 2.1 m/s (a light breeze) and in the summer they are slightly fresher at 2.4 m/s. High winds virtually never occur.

Wave heights in the Gulf of Kavala are below 1m height for 95% of the year. The only circumstances where significant waves cab be generated is where winds are from the south (from the open sea) when heights of up to 6m can be very rarely reached. Almost 50% of waves greater than 1m are associated with southerly winds. As a result of the low wave activity, spills are not dispersed over wide areas as they are blown by the wind. Waves also do not hamper oil spill recovery efforts. Energean's boats are capable of responding for more than 99% of the year. Clearly when responding to spills blown by strong southerly winds towards the Kavala coast line oil response activities could be hindered, but spills tend to be broken up rapidly by these significant waves. This has greatest significance for leaks from location 3 (loading point) which is just 3km from shore. Loading operations are not attempted during periods of strong winds from the south as divers cannot function in this weather to perform required safety checks. These winds are so infrequent and last for such a short time that this is not a significant issue. As a result the coincident leak at location 3 with a major southerly storm is not considered a valid scenario.

		337,5	22,5	67,5	112,5	157,5	202,5	247,5	292,5	Total
		22,5	67,5	112,5	157,5	202,5	247,5	292,5	337,5	
6,5	7,0	0	0	0	0	0	0	0	0	0
6,0	6,5	0	0	0	0	0,001	0	0	0	0,001
5,5	6,0	0	0	0	0	0,001	0	0	0	0,001
5,0	5,5	0	0	0	0	0	0	0	0	0
4,5	5,0	0	0	0	0	0,006	0	0	0	0,006
4,0	4,5	0	0	0,001	0	0,025	0	0	0	0,027
3,5	4,0	0	0	0,001	0	0,043	0	0	0	0,045
3,0	3,5	0	0	0	0	0,079	0	0	0	0,079
2,5	3,0	0	0	0,001	0	0,104	0,006	0	0	0,112
2,0	2,5	0	0,010	0,010	0,003	0,222	0,025	0	0	0,271
1,5	2,0	0	0,164	0,065	0,016	0,475	0,158	0,001	0	0,879
1,0	1,5	0,077	1,890	0,382	0,109	1,085	0,439	0,024	0	4,005
0,5	1,0	0,894	13,574	3,108	0,394	4,310	1,806	0,354	0,095	24,537
0,0	0,5	5,032	15,891	17,746	3,397	18,940	4,440	2,467	2,123	70,036
Total		6,004	31,529	21,317	3,919	25,292	6,874	2,846	2,218	100,000

Legend
Common occurrences
red - 12 most common
yellow - next 24 most common
orange - next 24 most common
blue - all remaining

Diagram 10-5: Wave heights and distribution by direction

10.8.2.3.4 Physical property data

As discussed above, oil spill scenarios have been developed for a typical winter month (February) and a typical summer month (July). HYSIS has been used to determine the physical properties of the spilled crude. Crude properties at leak point 1 are based upon Epsilon PVT Data. Crude properties for leak points 2 and 3 represent a point where equal volumes pf crude are being produced from Prinos and Epsilon.

Water and air temperature data have been obtained from the same source as the wind and wave speed data for the area:

- Crude properties: Epsilon
  - ⇨ Oil viscosity 9 cp
  - ⇨ Oil gravity 36 API
  - ⇨ Oil wax content 3.9%
  - ⇨ Oil pour point: -36'C
- Crude properties: Mixed blend
  - ⇨ Oil viscosity: 8 cP
  - ⇨ Oil gravity: 34.5 API
  - ⇨ Oil wax content: 1.7%
  - ⇨ Oil pour point: -24'C
- Summer properties
  - ⇨ Air temperature: 25.2'C
  - ⇨ Water temperature: 24.0'C
- Winter properties
  - ⇨ Air temperature: 7.5'C
  - ⇨ Water temperature: 12.0'C

10.8.2.3.5 Oil spill scenarios

Based upon the above analysis the following scenarios have been defined.

- **Winter – based upon February as a typical month**
  - ⇨ **1A:** Wind from the S at a mean speed of 3.95 m/s. This represents 8.3% of potential outcomes in a typical winter month. This takes oil towards Kavala/Nea Karvali
  - ⇨ **1B:** Wind from the S at 10 m/s for 7.5 hrs, followed by 3.95 m/s after this. This represents 1.0% of potential outcomes in a typical winter month. Simulates the worst case of a single continuous storm blowing directly towards Kavala/Nea Karvali. It is expected that for leaks at location 1 and 2 this will potentially represent the "worst case" scenario.
  - ⇨ **1C:** Wind from the SW at a mean speed of 3.38 m/s. This represents 12.2% of potential outcomes in a typical winter month. This takes oil towards the protected wet lands east of Nea Karvali
  - ⇨ **1D:** Wind from the SW at 10 m/s for 3.5 hours followed by 3.38 m/s after this. Simulates a worst case storm at the same time the leak starts. This represents 0.5% of potential outcomes in a typical winter month. It sends oil towards the protected wetlands east of Nea Karvali. It is possible that for leak point 2 this would represent the "worst case" scenario.
  - ⇨ **1E:** Wind from the NW at a mean speed of 2.1 m/s. There is no storm conditions recorded with wind from this direction. This represents 6.3% of potential outcomes for a typical winter month. This would take oil towards the island of Thasos.
  - ⇨ **1F:** Wind from the NE at a mean speed of 7.5 m/s. This represents 33.1% of potential outcomes in a typical winter month. This is the predominant wind direction

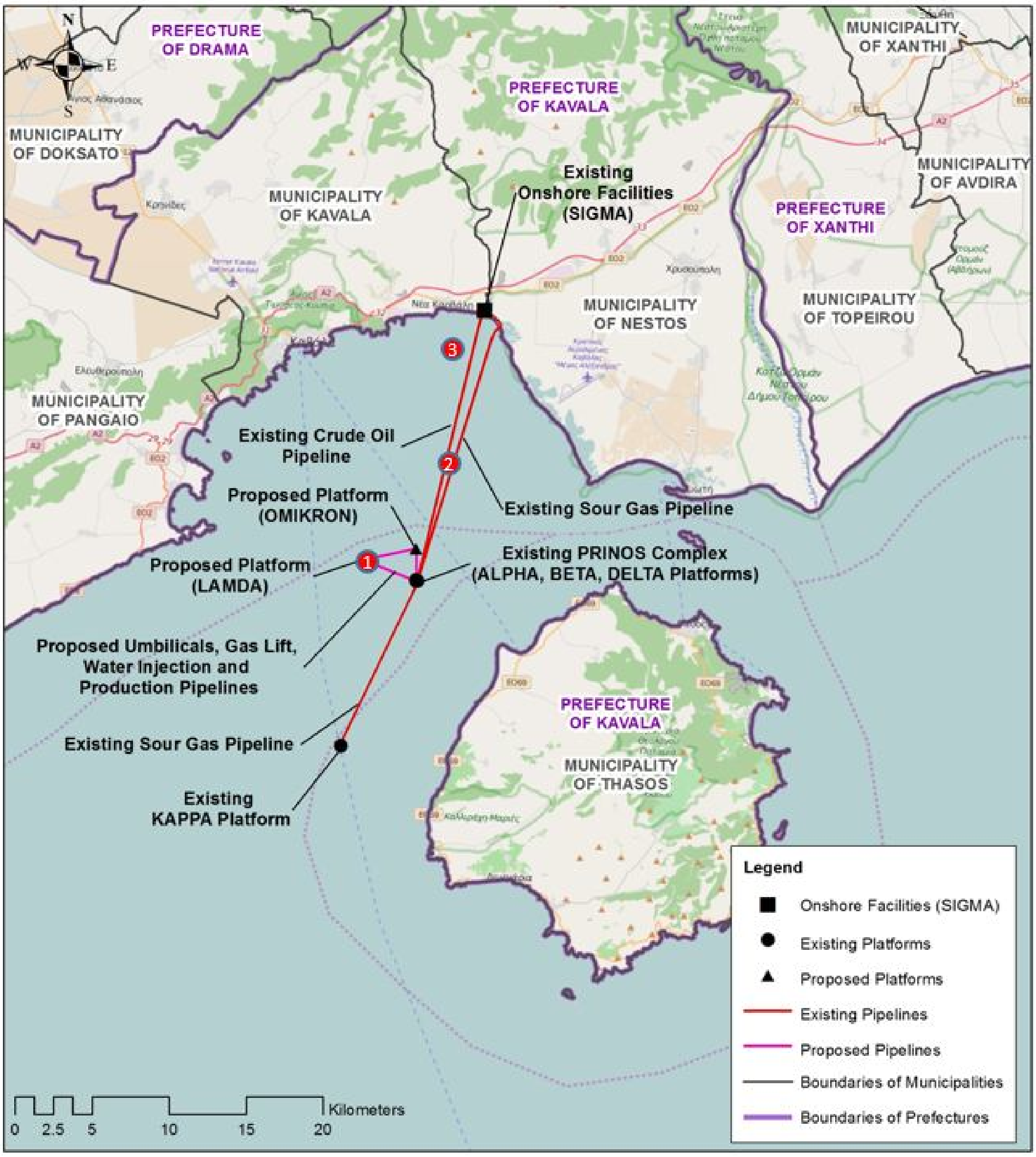
taking oil generally offshore. This and the subsequent scenario represent the "most likely outcome" when applied to all leaks.

- ⇨ **1G:** Wind from the NE at a speed of 13 m/s for 48 hours followed by 7.52 m/s after this. This simulates a typical storm with winds from the predominant direction. This represents 6.6% of potential outcomes. It would take oil generally offshore

- **Summer – based upon July as a typical month**
  - ⇨ **2A**: Wind from the S at a mean speed of 2.7 m/s. This represents 7.3% of outcomes. There are no winds greater than strong breeze and hence no storm scenario in the summer. This takes oil towards Kavala/Nea Karvali. When applied to leak point 3, this would be the likely "worst case".
  - ⇨ **2B**: Wind from the SW at a mean speed of 3.4 m/s. This represents 10.9% of the potential outcomes during a typical summer month. There are no winds greater than strong breeze in the summer in this direction and hence no storm scenario. This takes oil towards the protected wet lands east of Nea Karvali
  - ⇨ **2C**: Wind from the NW at a mean speed of 2.4 m/s. This represents 6.8% of potential outcomes in a typical summer month. Again there are no storms in this direction in summer. This takes oil towards Thasos. It is likely that this scenario represents the "worst case" for oil spills reaching Thasos when applied to leaks in position1.
  - ⇨ **2D**: Wind from the NE at a mean speed of 5.0 m/s. This represents 37% of the potential outcomes in the summer months. This is the predominant wind direction that takes oil generally offshore. This combined with the storm scenario below, represent the "most likely" outcome
  - ⇨ **2E**: Wind from the NE at 10 m/s for 7 hours followed by 5.0 m/s. This simulates a typical summer storm from the predominant wind direction. It occurs around 2% of the time.

All of the twelve above scenarios will be applied to each of the leak points 1 and leak points 2. Scenario 2A will also be applied to leak point 3. There is no merit in simulating this leak point for other wind directions or in the winter. As discussed above loadings are not undertaken in the winter when winds are blowing from the south as the concurrent high waves disrupt safety procedures. Average winds in the summer and winter (if storms are ignored) are similar. As this point is so close to the shore the impact of winds from the southwest are very similar to those from the south.

The leak points are shown on the following map for clarity.



Map 10-1: Potential leak points

10.8.2.4 Modelling

Energean contracted BMT Cordah (Aberdeen, UK) to develop an oil spill model for the Kavala Gulf and to use this to simulate the 25 deterministic runs defined above. BMT Cordah has performed many similar studies for operators and fields located in the UK North Sea as well as elsewhere in the world. It uses OSIS modelling software. OSIS can simulate the fate and dispersion of surface oil slicks in 2D. 3D modelling was not considered necessary due to the low water depths and small waves sizes prevailing in this area. OSIS was jointly developed by BMT and AEA Technology plc and is a particle-tracking model that represents an oil slick as a collection of free moving particles that simulate the spreading slick. The weathering model and associated algorithms within OSIS have been validated against controlled actual spills at sea and real spill events, supported with laboratory calibration. The model combines:

- Weathering algorithms that determine physical change to the slick as it spreads;
- Transport processes acting on the oil due to the current, wind, waves, diffusion and buoyancy in the ocean surface layer; and
- Change due to evaporation, emulsification and natural dispersion; and prediction of physical properties (density, viscosity and flash point changes)

Hydrodynamic and bathymetric data are available in the OSIS package for most locations in the world, including the North Aegean. These standard inputs have been checked for validity and retained. BMT separately has prepared met-ocean (wind and wave data) for the project and these surveys have been used within the oil spill modelling work. Hence met-ocean data used across the whole project is consistent.

As in all deterministic modelling the outcomes are relatively simplistic. Oil generally moves in straight lines (in the direction of the modelled winds). Only where currents are strong do trajectories change from the wind direction. Lateral spread of oil is similarly limited. To better replicate lateral spreading time series data can be used. In these models wind speeds are varied around a defined mean based upon actual weather data measured. Whilst this type of model provides more realism it can make the results harder to interpret than a more simplistic deterministic approach. In a deterministic model OSIS tends to give more weight to the wind than the current conditions. Results vary from the geographic location on the globe and are a function of the current data available in the area of interest. OSIS has been found generally in trials to slightly over estimate the volume of oil that beaches. In this way it gives a worst-case volume of oil beached under specific and fixed wind conditions.

For each scenario defined above BMT Cordah has run the corresponding model until no significant amount of oil remains on the sea surface (significant in this context means that 99% of the spilled oil has either arrived at a coast line, or has been removed by weathering effects – evaporation and/or biodegradation). As output they have provided image files that show:

- The size and orientation of the oil slick approximately 3 hours after the spill occurs. In around 99% of wind and weather conditions Energean will be able to have its oil spill response facilities mobilised to site and booms deployed at this point. Having an estimate of spill size at this point provides a check that the length of booms currently available are sufficient to contain the predicted slick.
- The size and orientation of the slick at the point in time when oil first arrives at a coastal location. In the model it is assumed that no oil is removed by the emergency response system mobilised, i.e. the system is either 100% ineffective, or it is not actually mobilized.

In addition to these figurative outputs the OSIS model also generates the following data:

- The time taken from the spill occurring until the first droplet of oil arrives at the coast;
- The coordinates of the predicted beaching location assuming the deterministic

parameters applied;

- The time at which no significant amount of the slick remains on the sea surface;
- The volume of oil that has reached the coast between these two times.

As the models are deterministic, there is no output that identifies the likelihood of this event from occurring. Wind and wave data used is summarised by compass point direction (i.e. North, North East etc.) representing angles O', 45' etc. from north. Each data point represents data gathered in a range of -22.5' to +22.5' from the selected compass point. Hence when a specific coastal coordinate is defined (e.g. from a wind blowing directly from the south) the actual extent of the coast potentially contacted could be anywhere on a bearing of -22.5' to +22.5' from the modelled point. Deterministic modelling does not attempt to predict actual landing points based upon real data, but simulates the time in which response measures need to be deployed given an assumed fixed weather direction. As discussed above this type of model tends to somewhat overestimate the amount of oil beached and underestimate the amount of time to the beaching incident (in reality the spill would meander to the coast rather than travel there directly).

10.8.2.5 Modelling results

The results of the oil spill modelling work as undertaken by BMT Cordah are summarised in the table below. To the data generated by the deterministic modelling has been added the likelihood of the defined case representing the prevailing weather conditions when the spill occurs. As can be seen for leak points 1 and 2, approximately 67% of potential weather events have been modelled (with winds orientated from 4 of a potential 8 compass directions). With weather from the non-modelled directions the tendency would be for slicks to move away from the coast (i.e. act like the scenarios that model weather from the predominant North Easterly direction).

For leak point 3, only 7.3% of potential outcomes have been modelled. As discussed previously only winds from the southerly direction have been considered for this leak point, considering is relative closeness to shore. Wind in all other directions would result in significantly longer durations before a beaching event occurs.

The data representing the “worst case” scenarios for each of the three defined sensitive coasts are highlighted. For these scenarios (case 1B for the coastline between Kavala and nea Karvali) case 1D (for the coast along the Nestos Delta wetlands) and case 2C (for the north western coast of Thasos island) the illustrations showing positions of the slick after 3 hours and the shape and orientation of the slick when beaching first occurs have been included. Data for the prevailing wind condition is also presented and discussed.

The worst case scenarios seem to be:

- **Coast between Kavala and Nea Karvali:** Case 1B, oil is forecasted to beach after 7 hours
- **Coast between Nea Karvali and the mouth of the Nestos River:** Case 1D, oil is forecast to beach after 9 hours
- **North West Coast of Thasos Island:** Case 2C, oil is forecast to beach after 48 hours

The worst case scenarios for the mainland areas are those simulating the winter months when short lived storms can occur. They also are both associated with a leak from the main oil export pipeline. Although this leak is smaller than the modelled blow out scenario, the fact that the leak point is closer to shore gives a higher probability for significant volumes of oil arriving at the shore.

The worst case scenario for Thasos is the summer scenario following a blow-out from Lamda. Storm force winds do not blow towards Thasos in the winter and summer winds are slightly fresher.

The three identified worst case scenarios are discussed in further detail below. Clearly scenario 1B applied to the pipeline leak is the most critical. The single scenario applied to the loading line leak is similarly discussed. Under the modest winds of the Kavala Gulf, oil beaches after this incident after approximately 10 hours.

10.8.2.5.1 Worst Case Scenario for the Kavala-Nea Karvali shoreline

As simulated, oil beaches after a major leak from the oil export pipeline on the shore somewhere between Kavala and the Sigma Plant after approximately 7 hours. All released oil has come ashore after 30 hours. The time to reach shore is short relative to other scenarios because 1B assumes that a storm commences at exactly the same time as the leak occurs and blows at a constant 13 m/s from the south for 7.5 hours before then subsiding to average winter wind conditions. These high southerly winds carry the oil slick rapidly to the coast. Southerly winds also bring with them high waves. These high waves are significant. Firstly they break up the oil spill creating an emulsion. Hence the volume of “emulsified oil” arriving at the shore is greater than the volume of “oil” released (1,042 m^3 compared with 410 m^3). Secondly, the high waves would prevent Energean from deploying its oil spill rescue system. Normally this system takes a maximum of 3 hours to deploy and can prevent the slick moving to the coast whilst the oil is skimmed from the surface.

Whilst the potential impact of scenario 1B is significant, largely because existing oil spill response measures cannot prevent such a leak escalating into a coastal pollution event, the likelihood of it occurring is very remote. Southerly storms such as that modelled occur for just 0.6% of the year. Scenario 1B assumes that all winds over 10 m/s in a winter month occur as a single storm of 7.5 hour duration. Frequently high winds blow multiple times in a month for a shorter duration. Any storm of 5 hours or less would have significantly less impact as after it passes wave levels quickly dissipate and oil spill equipment would be mobilised prior to the oil reaching shore. No statistical data is available to determine how frequent a “maximum” storm occurs, but from local experience it is probably the case twice per winter. This would reduce the probability of this scenario to 0.2% (i.e. by a factor 3).

The other aspect to consider when judging significance is the likelihood of the leak occurring at the same time a major storm occurs. Clearly if the modelled failure was caused by high winds or waves then the probability of the two events cannot be multiplied as there would be a degree of dependency. As it is, in this instance, there is a significant degree of independence; that is, during a storm such a failure is less likely to occur than at any other time of the year. As discussed above, a major failure of the export pipeline is likely caused by the impact of the trawl board of a fishing boat. Southerly storms of this magnitude are forecast accurately a number of days in advance. During this weather the small fishing boats that make their living in the Gulf of Kavala are not fishing. Hence the chance of such a leak occurring during a storm is considerably lower than in calm weather.

If we take the chance of such a major leak occurring in the first place as a relatively probable event, say 1 x 10^{-2} (once per hundred years) and then multiply this by the probability of scenario 1B occurring (2 x 10^{-3}) and reduce the probability that both events occur simultaneously by a modest factor 10, then this gives a likelihood of an oil spill reaching this shore, in the magnitude calculated, as 2 x 10^{-6}. This clearly is a very low incident frequency. Whilst the existing response measures do not allow this level to be reduced further the fact that the likelihood is so low anyway would likely not warrant further mitigation measures from being considered. As oil skimming operations cannot be made effective in high seas the only alternative to further reduce risk levels would be to reduce the size and probability of a failure. This could be achieved by burying the sections of the pipeline that are currently exposed.

10.8.2.5.2 Worst case scenario for the coast line between Nea Karvali and the Nestos river Delta

Scenario 1D represents the worst case scenario for an oil spill arriving at this vulnerable stretch of coastline. Under modelled winter storm conditions it takes 9 hours for oil from a spill in the oil export line to reach the shore. Whilst this is only 2 hours longer than the worst case scenario for the northern coast (discussed above), the potential severities of these two incidents are very different.

Available data clearly shows that high winds from the southwest are less common than those from the south, and they are not accompanied by significant waves. Although the modelled pipeline leak is closer to this shore than the northerly shore it takes 2 hours longer to travel this shorter distance because storm force winds last only for 3 to 4 hours maximum per winter month. As high waves are not associated with winds from this direction the oil response vessel owned by Energean can be deployed with no issue and have booms deployed and skimming operations underway at least 6 hours before any oil reaches the shore. Whilst such operations are not 100% effective they would dramatically reduce the calculated volume of “emulsified oil” (567 m^3) reaching the shore. These operations would also slow the passage of oil to shore further. Southwesterly winds are uncommon and short lived. If the passage of an oil slick can be slowed it gives time for the wind to swing back to the predominant north westerly direction, which would blow the slick back out to sea, or for the wind to fall to calm conditions which is the most common situation in winter.

Met-ocean data shows that storms from the southwest occur for about 0.3% of the year. If again we assume that the pipeline failure frequency from ship impact is 1 x 10^{-2}, the frequency of a spill reaching the shore can be calculated. In this case it is possible that a storm from the south west of this length and magnitude could occur each month, hence the probability is not reduced as in scenario 1B. Also in this case it is less certain that fishing would cease, hence the frequency is reduced by 2 rather than 10 as was previously the case. As wave conditions allow for effective use of oil spill rescue equipment 99% of the year in the Gulf of Kavala then there is only a 1% or 1 x 10^{-2} chance they fail to contain the spill. Hence the probability of a spill of the calculated magnitude reaching the coast is 1.5 x 10^{-7}. This is a lower probability than for scenario 1B because in this case there is time and capacity to implement design oil spill response measures.

10.8.2.5.3 Worst case scenario for oil arriving on the north western coast of Thasos Island

As storm winds never blow from the North West towards the coast of Thasos and wave heights are always modest, oil spills floating in this direction move slowly. The worst case modelled (scenario 2C) predicts that oil from a blowout at Lamda takes approximately 48 hours to arrive at the coast. In an average month winds blow in this direction for just 36 hours in total. The probability that they blow continuously for 48 to 81 consecutive hours (as simulated) in this direction is therefore highly improbable. In reality the slick is likely to move part of the way towards the coast before being either becalmed or blown from the northeast towards open sea (see section 10.8.2.5.5 below for a description of the impact of winds from the north east). A deterministic model cannot simulate this type of behaviour. Clearly where travel times are longer than a few hours the chances are that weather conditions will shift to predominant strengths (i.e. calm) and direction (northeasterly).

According to North Sea OGP data the probability of a blowout occurring whilst drilling a normally pressured development well is 4.8 x 10^{-5}/well. A side track would have a lower probability. However if all 17 wells are assumed to have this probability then the chance of a blowout happening during the planned extension project is 8 x 10^{-4}. The probability of the modelled worst case scenario is 2.8% or 2.8 x 10^{-2}. There is no dependency or independency between the event and the weather assumed in the scenario. Weather conditions are ideal for oil recovery operations using booms and spills. Although waves from this direction are minimal it will be assumed that response efforts fail 1 in 100. Hence the probability of a slick of the calculated magnitude calculated arriving on Thasos is 2.3 x 10^{-7}.

10.8.2.5.4 Oil spill from the loading buoy

As discussed earlier in this section, loading operations cannot take place during storm conditions. If a storm is forecast it is allowed to blow through before loading commences. If a storm develops unexpectedly loading ceases. Hence the worst case for a spill from the loading system is normal average winds from the south. Whilst these wind speeds are modest (3 m/s) a spill reaches the shore approximately 10 hours after it occurs. All oil has beached after 11 hours. Although there is sufficient time for the Energean oil spill response system to be mobilised in this period, operational requirements are for a boom to be deployed around the front of the vessel prior to loading commencing. If a leak occurs oil is captured by the boom and prevented from passing to shore. This is effective as inshore wave sizes are even smaller than the already small wave sizes seen more generally and the maximum volume of such a leak is relatively small. Because such a leak could have major consequences the integrity of the system is checked before each operation and monitored during the entire operation. Clearly if oil is seen passing the fixed boom the oil spill response vessel would be mobilised. It would be mobilised in any regard to skim collected oil from the surface.

10.8.2.5.5 Impact of winds blowing from the predominant northeastery direction

As discussed above, winds blow predominantly from the northeast. Winds from this direction have been modelled even though they would not constitute a worst case for any of the identified sensitive coastal areas in the Gulf of Kavala. Considering the relatively long durations it takes for an oil slick to reach shore (in all but two of the modelled cases the time is above 10 hours), it is reasonable to conclude that nearly all oil spilled in the Gulf of Kavala would end up being blown eventually in the direction of this predominant wind.

Hence analysis of these cases (1F, 1G, 2D and 2E for either leak point) is important. As can be seen from the attached drawings oil blown in this direction would eventually beach, if not removed using the oil spill response facilities, in Iersissos Bay, Akti peninsular, Halkidiki. This stretch of coast has similar features and sensitivity to the North West coast of Thassos. It contains stretches of rocky cliffs and sandy beaches with many tourist resorts.

The minimum time for oil to reach this coast would be following a blowout in the winter. The time period would be between 34 and 71 hours, the shorter time being if the blowout occurred during the early part of a major winter storm. Whilst a storm from the south brings high winds and high waves a storm from the northeast only brings high winds. Waves do not develop because of the very limited fetch area. Energean's oil spill response vessel can operate easily in these conditions and hence with such long transit times most oil could be removed from the sea before reaching the coast. In summer conditions transit times are more than 4 days to this location. The potential for a significant spill would be greater than on Thasos because for a large part of the year slicks would move in this direction.

Table 10-4: Modelling outcomes for the three leak cases

Leak Point	Scena-rio #	Wind Direction (from)	Storm (yes/no)	Impact Location (place)	Time to Coast (hrs)	Time to End slick (hrs)	Volume Beached (m^3)	Annual Likelihood (%)
1	1A	S	No	Kavala	32	63	319	4.8

Leak Point	Scena-rio #	Wind Direction (from)	Storm (yes/no)	Impact Location (place)	Time to Coast (hrs)	Time to End slick (hrs)	Volume Beached (m^3)	Annual Likelihood (%)
1	1B	S	Yes	Kavala	16	64	546	0.6
1	1C	SW	No	Protected area	36	65	228	7.1
1	1D	SW	Yes	Protected area	28	66	322	0.3
1	1E	SE	No	Thasos	53	83	214	3.7
1	1F	NE	No	Open Sea	71	129	469	19.3
1	1G	NE	Yes	Open Sea	34	106	809	4.4
1	2A	S	No	Kavala	56	85	128	3.0
1	2B	SW	No	Protected area	36	66	237	4.5
1	2C	NW	No	Thasos	48	81	215	2.8
1	2D	NE	No	Open Sea	111	183	503	15.4
1	2E	NE	Yes	Open Sea	99	184	540	0.8
Total deterministic scenarios for leak point 1 (Lamda blow out)								**66.7 %**
2	1A	S	No	Kavala	22	30	291	4.8
2	1B	S	Yes	Kavala	7	30	1,042	0.6
2	1C	SW	No	Protected area	17	25	257	7.1
2	1D	SW	Yes	Protected area	9	25	567	0.3
2	1E	SE	No	Thasos	59	67	185	3.7
2	1F	NE	No	Open Sea	81	89	498	19.3
2	1G	NE	Yes	Open Sea	38	46	812	4.4
2	2A	S	No	Kavala	38	46	162	3.0
2	2B	SW	No	Protected area	17	26	246	4.5
2	2C	NW	No	Thasos	57	65	193	2.8
2	2D	NE	No	Open Sea	126	134	488	15.4
2	2E	NE	Yes	Open Sea	114	134	562	0.8
Total deterministic scenarios for leak point 2 (main pipeline)								**66.7 %**

Leak Point	Scena-rio #	Wind Direction (from)	Storm (yes/no)	Impact Location (place)	Time to Coast (hrs)	Time to End slick (hrs)	Volume Beached (m^3)	Annual Likelihood (%)
3	2A	S	No	Kavala	10	11	36	7.3
Total deterministic scenarios for leak point 3 (Tanker loading point)								**7.3 %**

Selected results are graphically presented in the below figures. The full Oil Spill Modelling Report is presented as an annex:

Figure 10-1: Pipeline 1B scenario. Deterministic results 3 hrs after release (max response time); 7 hrs after release (min arrival time until beaching) and 30 hrs after release (end of simulation)

Key: Red cross for the release point, track and beaching locations (red); final particle positions (black)

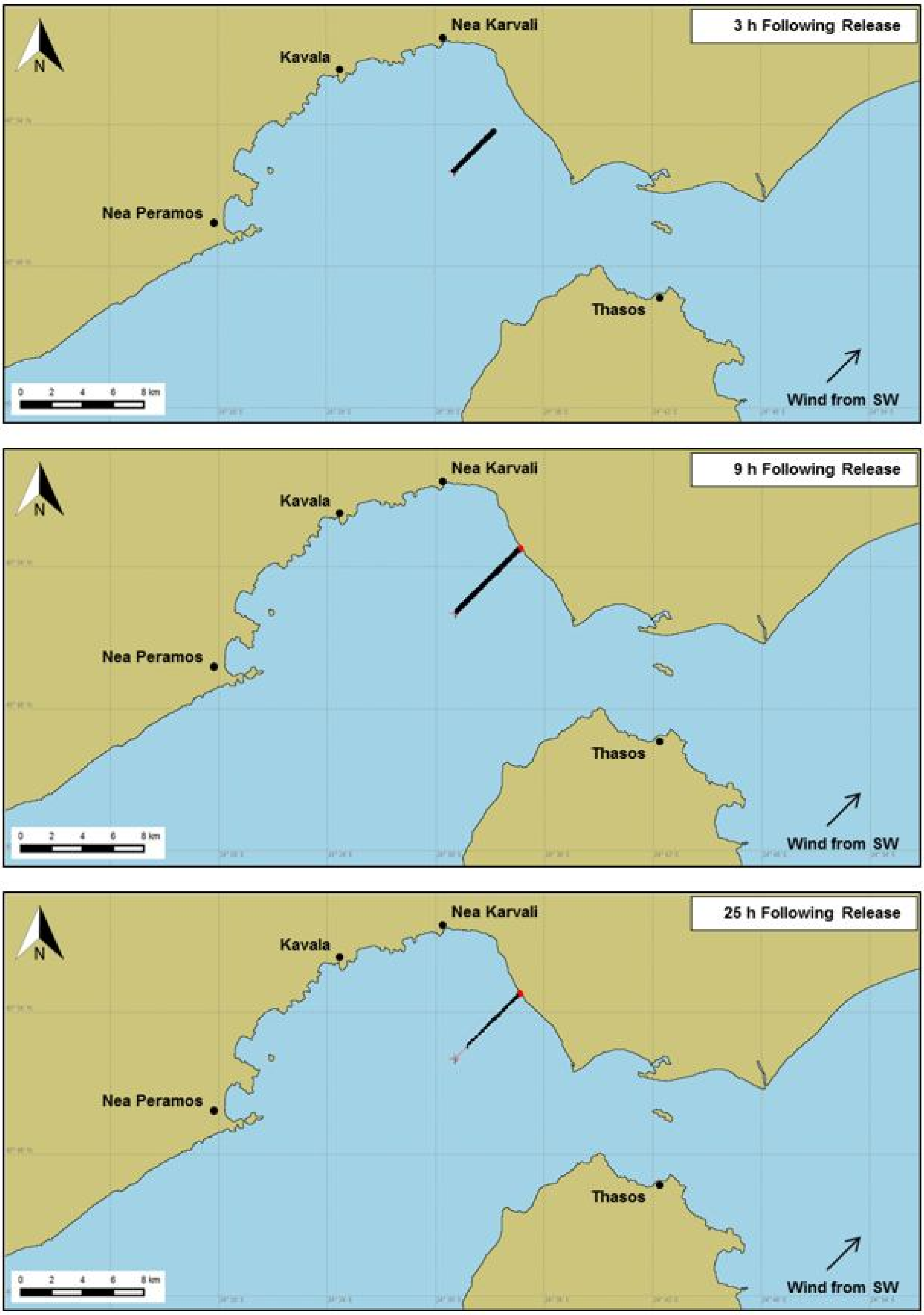


Figure 10-2: Pipeline 1D scenario. Deterministic results 3 hrs after release (max response time); 9 hrs after release (min arrival time until beaching) and 25 hrs after release (end of simulation)

Key: Red cross for the release point, track and beaching locations (red); final particle positions (black)

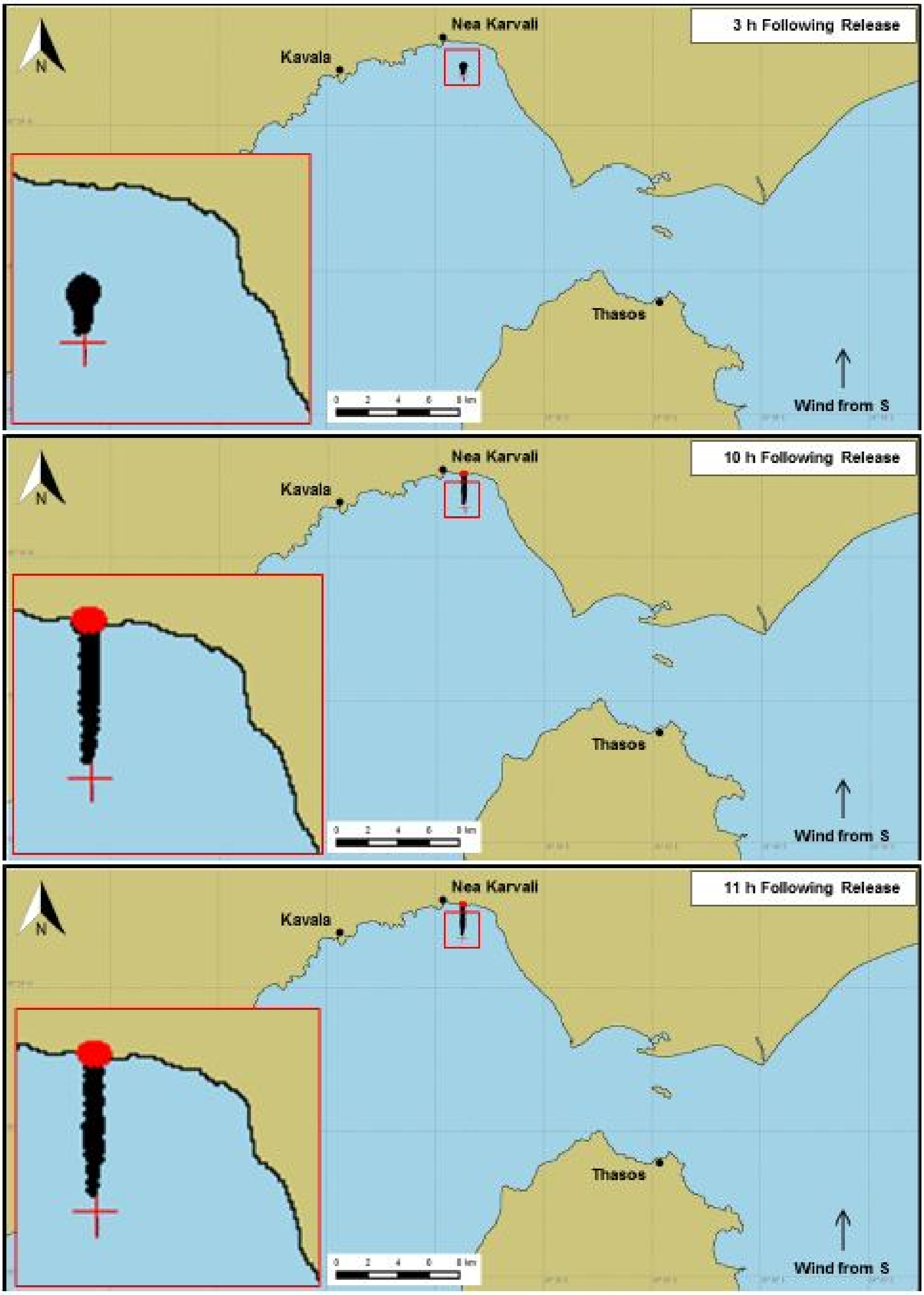

3 h Following Release
Nea Karvali
Kavala
Thasos
Wind from S
N
10 h Following Release
Nea Karvali
Kavala
Thasos
Wind from S
N
11 h Following Release
Nea Karvali
Kavala
Thasos
Wind from S
N

Figure 10-3: Loading buoy scenario. Deterministic results 3 hrs after release (max response time); 10 hrs after release (min arrival time until beaching) and 11 hrs after release (end of simulation)

Key: Red cross for the release point, red square: zoom; track and beaching locations (red); final particle positions (black)

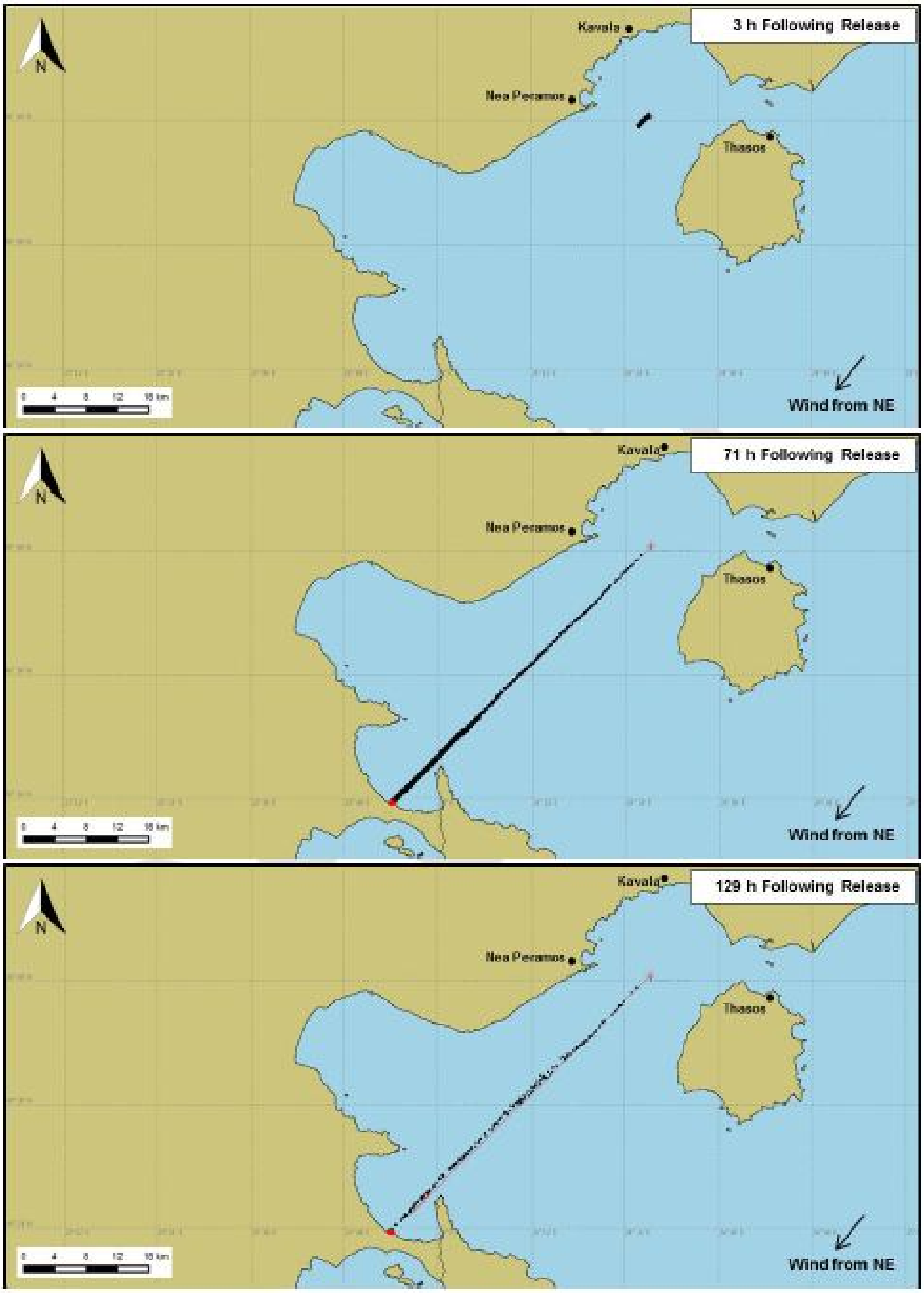


Figure 10-4: Well blow-out 1F scenario. Deterministic results 3 hrs after realease (max response time); 71 hrs after release (min arrival time until beaching) and 129 hrs after release (end of simulation)

Key: Red cross for the release point, track and beaching locations (red); final particle positions (black)

10.8.2.6 Conclusion and discussion

10.8.2.6.1 Introduction

A deterministic analysis of the potential impacts of worst-case oil spills from the existing and future offshore oil facilities operated by Energean in the Gulf of Kavala has been undertaken. These scenarios modelled a spill of 475 m^3 over a 24 hour period originating from a well blow-out on the planned new Lamda platform, a spill of 410 m^3 over an 8.5 hour period originating due to the impact of a trawling board striking and rupturing the main export line at the point just before the line becomes buried and a spill of 64 m^3 over a 2 minute period due to a failure of the hose connection to a tanker being loaded with crude at the tanker loading point.

The deterministic scenarios developed were used to model wind directions in the summer and winter months, under normal (mean) and maximum (storm) conditions, that would push the surface slick towards the most sensitive coastlines in the study area (the commercially sensitive coast line between Kavala and Nea Karvali, the environmentally sensitive coastline of the Nestos river delta wetlands and the tourist sensitive coastline of north western Thasos).

Metocean data has been prepared and analysed to assess the likelihood of the modelled weather directions being dominant when a leak occurs.

Deterministic modelling tends to overestimate the amount of oil arriving at the coast as it is assumed that the spilled oil moves uniformly in the chosen weather direction. In realty oil would spend more time drifting in multiple directions before reaching the coast. In the Gulf of Kavala where wind speeds are generally low or zero and dominated by stronger winds that blow to offshore, it is probable that winds taking crude onshore never blow for long enough to actually satisfy the time predicted in the deterministic models.

10.8.2.6.2 Detailed discussion

The worst case scenario is a result of a winter storm bringing oil to the shore between the Sigma plant and the port of Kavala following a major rupture of the main oil export line. Under such circumstances oil would arrive at the coast about 7 hours after release and continue for a further 23 hours. Weather from the south produces significant waves. These would prevent the immediate deployment of Energean's oil spill response vessel. Before it could be at site first oil would have reached the coast. As a result of the high waves the leaked oil is emulsified. The volume of emulsified oil arriving at the coast is almost three times the volume of oil spilled.

Whilst such a scenario would have a significant impact to the commercial and tourist activities of the area the chance of such an event occurring is remote. Assuming that oil spill response vessels are not mobilised at all the calculated probability of such a severe event is calculated as 2 x 10^{-6} (i.e. twice per million years). In the 20 year life span of the described project the probability would be 4 x 10^{-5}. In reality the volume of oil would never reach the level calculated. Although the oil spill response system could not prevent some oil reaching the shore it should be in place 4 hours after the beaching commences. Hence if oil arrives at a uniform rate around 83% of the spilled volume should be recovered. It is also highly unlikely that southerly winds would blow continuously for 30 hours. On average southerly winds occur for about 10% of the time on average, with the worst month being April (20%). Thus 40% of southerly winds would have to blow in one continuous period for all oil to be beached. In reality during this period either calm weather or winds from the northeast would occur.

In all other cases there is sufficient time to allow oil spill response vessels to be mobilised. The Kavala Gulf is characterised by low waves heights (for 95% of the time wave heights are less than 1m) and hence skimming operations are very effective. Taking into account the availability of this system the chance of oil arriving on the other two sensitive coasts examined is an order of magnitude lower.

It is therefore concluded that the prolongation of oil production from the existing and planned oil infrastructure does not present significant risk with regards to unplanned/failure events.

10.8.2.6.3 Existing mitigation measures applied

As discussed above there is a relatively low chance of oil spilt to the sea from Energean's facilities reaching the coastline of the Kavala Gulf. The location that has the highest likelihood of seeing spilled oil is Ierissos Bay on the Akti peninsula. Predominant winds would likely carry most slicks formed towards this coastline, unless the spill occurred during heavy southerly winds that blow for limited duration in the Winter months.

The likelihood (probabilities) calculated assumes that:

- A leak actually occurs and
- No response measures are taken to remove the pool of oil before it reaches the shore.

In reality Energean has developed structured controls that create "barriers" to both prevent incidents such as these from occurring and if such incidents do occur, preventing them from escalating to a point where significant damage occurs. Clearly oil spills need to be avoided, but if they do occur, their consequence is relatively limited if the spilt oil is contained offshore and recovered prior to drifting to coast.

The following "barriers" have been defined by Energean and effectively implemented over the last 35 years of operation. The additional facilities to be installed do not significantly change the size and complexity of the offshore assets or increase the likelihood of a spill from occurring or the potential size of such spills. The biggest consequence is on oil loading operations as the frequency of these events will increase with growing production.

Barriers to prevent spills occurring:

Blow out prevention – As the consequence of a well blowout is significant strict controls are applied during the drilling process to ensure such an event occurs very infrequently. Like all oil and gas operators Energean has a suite of well design and well operations manuals that dictate the precautions to be taken to avoid loss of well control. These are built on available international standards and embrace good oilfield practice. At all times multiple barriers between the live reservoir and the atmosphere are maintained. These barriers change as a drilling operation progresses and comprise elements such as: drilling “mud” and “brine” to provide hydrostatic pressures greater than reservoir pressures, cement, plugs and of course a blow-out preventer mounted at surface. This critical device is subject to detailed certification on a 5-yearly basis and is function and pressure tested every 28 days. Data collected by OGP for normally pressured oil development wells drilled to North Sea standards indicates the chance of an accidental well release is 3.9 x 10^{-4}/well drilled. Such a release would necessitate use of a well control device. Such events result in a blow-out 4.8 x 10^{-5}/well drilled. Hence the chance of a blowout occurring whilst Energean drills and side-tracks the 17 firm wells covered by this project is 8x10^{-4}. This is well within the ALARP region.

Pipeline integrity management – Precautions to ensure oil pipelines do not leak commence with the selection of the correct materials so as to avoid excessive corrosion, in the design phase. The line that represents the largest risk is one that was designed more than 35 years ago and which inspection has shown over the intervening period has not suffered excessive corrosion. Internal inspection using intelligent pigs is the key method of ascertaining pipeline condition and verifying integrity. Corrosion rates are not expected to increase due to the implementation of the planned field extension. Crude properties will not change and the main oil line will remain essentially free of water. Hence the chance of internal damage leading to a significant leak will remain low. External impacts do have the potential to cause failures. This is why the lines are protected with a concrete coating and largely buried. Fishing activities are banned over the pipeline corridors. External corrosion is avoided by using cathodic protection systems. The only area of potential exposure is in the part of the main oil export line that is not buried if fishing vessel activities are not adequately controlled. Consideration will be given to burying this line when the new pipelines are buried. This will have a short-term localised negative impact to the environment (disruption of the sea bed) but would further reduce the probability of a large pipeline leak.

Loading Operations – specific precautions are taken when tanker loading operations are undertaken. The tanker loading system comprises a fixed pipeline approximately 3km long (buried) connected to 200m of flexible heavy-duty hose. This hose is picked up by a crude tanker. A blind flange removed and then connected to the inlet manifold of the vessel. Prior to each loading all sub-sea components are inspected by Energean’s divers. The divers stay on location and re-inspect the hose every 4 hours. Small leaks would therefore be identified rapidly. The hose itself is replaced completely every 5 years. At surface 2 staff are deployed to monitor the connection between the hose and ship at all times. These staff can radio the Sigma control room and request pumping to stop. Loading does not take place in the winter months when high winds are blowing from the south bringing significant waves to shore.

Recovery measures – as described elsewhere in the ESIA Energean has developed an oil spill response system comprising booms and skimmers for containing surface slicks and recovering them to a dedicated barge. This system can be mobilised offshore day and night in a maximum of 3 hours. Deployment is regularly practised. Sea states are conducive to immediate mobilisation for 99% of the year. When storm force winds are blowing from the south deployment could be delayed by up to 7 hours. The results of the oil spill modelling work undertaken in support of the ESIA would indicate that the size and deployment time achievable are suitable. When loading tankers a boom is installed at all times around the loading point. With a location so close to shore 3 hours is considered too long to be able to mobilise a boom following a spill.

10.9 MAJOR ACCIDENT FREQUENCY ASSESSMENT

10.9.1 Hydrocarbon release scenarios

The frequency assessment part of the QRA serves to estimate, numerically, the likelihood of the defined major accident occurring in the first instance (e.g. a release of hydrocarbons) and the outcome frequency (e.g. jet fire). The hydrocarbon release frequency assessment consists of two key components:

- Derivation of the initiating event frequency; and
- Derivation of the outcome frequency.

The initiating event frequency is derived by combining a “parts count” with generic, industry recognised, equipment leak data. This approach yields a statistical leak frequency for defined isolatable sections of the process. These leak frequencies are further modified by applying a hole size distribution to generate the frequencies of “small”, “medium” and “large” releases.

To model the development of the scenario after release, event trees are prepared for each isolatable section and for each hole size. The event tree provides a framework for the frequencies of the possible outcomes associated with the release of hydrocarbons (e.g. jet fire, pool fire, flash fire, explosion, unignited toxic release). The nodes on the event tree consider factors such as:

- Does the release ignite immediately?
- Does the release ignite after a delay?
- Is detection and isolation effective?
- Are active and passive mitigation measures effective?

The success or failure of these factors dictates the outcomes.

The frequency assessment part of the QRA relies on the use of a range of datasources, databases and assumptions. These are further detailed in the QRA Reports (Annex 07). Table below provides a summary of the main frequency assessment data sources.

Table 10-5: Hydrocarbon Release Scenarios: Frequency Data Sources Summary

Aspect	Description	Data Source
Equipment Leak / Release Frequencies	The generic release frequencies for equipment items such as pumps, valves, flanges, vessels etc.	OGP, based on UK Hydrocarbon Release Database.
Pipeline Release Frequencies	The generic release frequencies for pipelines and risers.	OGP, based on "PARLOC"
Blowout / Well Release Frequencies	The generic frequency of blowout/well releases during drilling or workover/intervention activities.	OGP, based on "SINTEF"
Hole / Release Size Probabilities	The hole size distribution, probability of "small", "medium", "large", "full bore" releases.	OGP based on UK Hydrocarbon Release Database.
Ignition Probabilities	The probability that the release ignites at an early stage (yielding jet or pool fire) or delayed (resulting in flash fire/explosion).	OGP, based on Energy Institute Review
Detection / Isolation / Shutdown Probabilities	The probability that the release is detected and isolated	CMPT

10.9.2 Non-hydrocarbons release scenarios

In addition to assessing the risk to people associated with the hydrocarbon release major accidents, the QRA also considers the levels of risk due to non-hydrocarbon release major accident Scenarios.

Typically for offshore installations, non-hydrocarbon release major accidents include:

- Loss of control during personnel marine or aviation logistics transfer (helicopters are not used to support Prinos operations, personnel transfer is via crew boat);
- Structural failure;
- Loss of stability (not relevant for the Prinos complex as the platforms are fixed jacket/tower design) nor for the proposed satellites;
- Loss of station keeping/position
- Ship impact (impact by attendant or errant passing vessel)

The frequency assessment for the Prinos and Lamda non-hydrocarbon release major accidents also uses industry data sources as a basis for estimating frequency of occurrence.

Table 10-6: Non-Hydrocarbon Release Scenarios: Frequency Data Sources Summary

Aspect	Description	Data Source
Crew Boat Loss of Control Frequency	The frequency of a Major Accident associated with marine logistics / personnel transfer by crew-boat.	OGP, based on global data
Ship Impact Frequency	The frequency associated with a vessel impacting the offshore structures	OGP
Structural Failure Frequency	The frequency of severe structural failure.	OGP

10.10 MAJOR ACCIDENT CONSEQUENCE ASSESSMENT

10.10.1 Overview

The consequence assessment process of the QRA serves to assess the magnitude of the physical effects associated with the major accidents (e.g. hazard ranges due to jet fires, toxic gas plume dispersion). Subsequent to determining the levels of physical effects, the vulnerability assessment is performed to translate levels of harm, to people, into probabilities of fatality.

10.10.2 Physical effects assessment

The physical effects assessment serves to estimate parameters such as:

- Initial release rates, for the defined hole sizes;
- Heat radiation and profiles associated with jet fires and pool fires;
- Overpressures associated with explosions;
- Extent of flammable and toxic gas dispersion hazard ranges.

A number of software packages (described below) have been used for this assessment.

In particular subsea releases have been modelled using guidance outlined by the CMPT [1999]. The guidance in CMPT [1999] indicates that subsea releases can be modelled as a bubbling cone reaching the surface, as illustrated below.

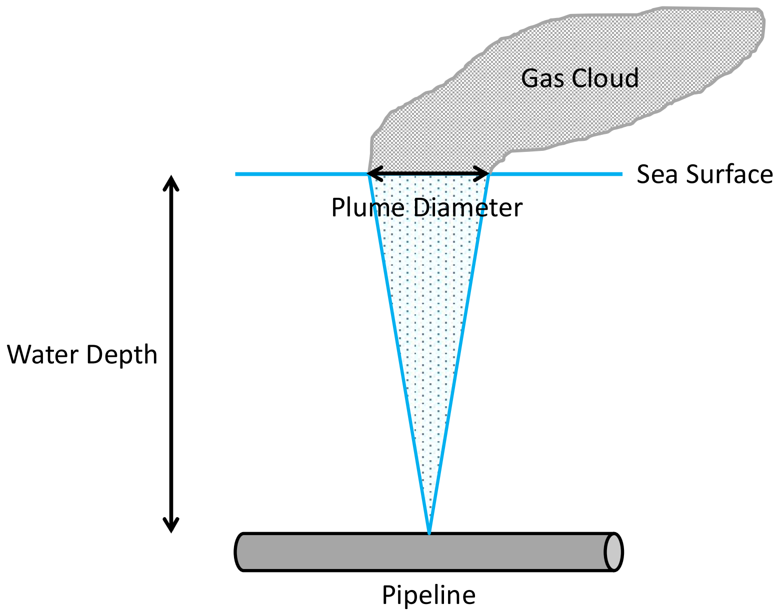


Figure 10-5: Illustration of subsea release (bubbling cone)

CMPT [1999] outlines an industry standard assumption that the diameter of the plume at the surface can be approximated as 20% of the depth to the release point, regardless of the rate of material being released. The average sea depth at Prinos is around 40 m; as such a plume surface diameter of 8 m was used for modelling subsea releases. Pipelines going to shore have also been modelled at 20 m depth and at sea surface to account for variations in water depth in the route of these pipelines.

The consequence modelling has been carried out using DNV Phast (an industry leading consequence modelling software package).

Release rate analysis was carried out using DNV Phast. Multiphase streams use a representative material to approximate the mass release rate based on the molecular weight of the mixture. This is to account for errors that can arise when modelling multiphase fluids due to the simplification of mixtures modelled by DNV Phast. However for gas streams, pure methane or a representative mixture was used.

The gas fraction of the stream was calculated based on the Heat and Material Balance sheets. The calculated release rate was factored according to the gas mass fraction. It has been assumed the gas would reach the surface uniformly and form a 'pool' with the gas composition at the surface taken as the same as in the pipeline (i.e. no benefit was taken to account for gas absorption into the sea whilst bubbling up to the surface).

Preliminary modelling indicated that the worst-case consequence results were found using the average gas release rate over the 2 first minutes of discharge; as such this was used as the basis of the analysis.

Flammable results are given for the LFL and half LFL, which is respectively 44,000 ppm and

22,000 ppm for methane. Toxic results are given according to the UK HSE SLOT (Specified Level of Toxicity) and SLOD (Significant Likelihood of Death) for a 10 minutes exposure, i.e. at 669 and 1,107 ppm. The concentrations are in line with the analysis carried out for the QRA.

10.10.3 Vulnerability assessment

To translate the physical effects into a numerical estimate of harm to people, vulnerability assessment is performed. There are a number of industry recognised data sources and approaches available for translating varying levels of fire, explosion and toxic gas consequences into the estimates of probability of fatalities that are required for the QRA.

Table below summarises the harm criteria adopted for the QRA.

Table 10-7: Harm Criteria

Consequence	Criteria – Level of harm to people	Reference
Jet Fire	100% fatality – 35 kW/m^2 70% fatality – 12.5 kW/m^2 Escape route impeded – 6 kW/m^2 Muster Area inaccessible - 4 kW/m^2	OGP
Pool Fire	Escape route impeded – 6 kW/m^2 Muster Area inaccessible - 4 kW/m^2	
Flash Fire	100% fatality – within the gas cloud Lower Flammable Limit (LFL) envelope	OGP
Explosion	100% fatality - 0.3 bar	OGP
Hydrogen Sulphide (H_2S)	100% fatality – 1107 ppm 50% fatality – 669 ppm	HSE Assessment of Dangerous Toxic Load (DTL)

10.11 RISK INTEGRATION AND MEASURES OF RISK

The frequency, consequence and vulnerability data, for each scenario, are combined to generate the numerical measures of risk, which can then be compared against the appropriate risk tolerability criteria. Table below summarises the measures of risk derived by the QRA.

Table 10-8: Measures of risk

Measure of Risk	Description	Presentation
Location	The risk at a particular location for a	For offshore the LSIR essentially

Measure of Risk	Description	Presentation
Specific Individual Risk (LSIR)	hypothetical individual who is positioned there for 24 hours per day, 365 days per year.	represents the zones of risk, it can be represented in tabular format.
Individual Risk Per Annum (IRPA)	The level of risk (of death) experienced by an individual person. This measure of risk takes into account the amount of time a person is exposed to the major hazards. The individual risk therefore includes both the proportion of time onsite and also the proportion of time in specific locations on the facility where they may be exposed to the effects of potential hazards. IRPA is independent of the number of people exposed.	Typically presented in tabular format, which presents IRPA for a range of worker groups. This allows distinction to be made between the most exposed (e.g. operators, maintenance) and least exposed (e.g. accommodation) personnel. For Prinos the IRPA will consider proportion of time individual spends in various platform areas and the time they spend offshore.
Potential Loss of Life (PLL)	The level of risk (of death) experienced by the whole group of people exposed to the major accidents. Since this measure of risk is related to the total exposed group, it is therefore dependent on the total number of people onsite and in each worker group.	Generally tabular format summarising the PLL for each worker group. The total PLL is also derived, which is useful since it presents a single “rolled up” measure of risk. For this reason PLLs are used as a basis for Cost Benefit Analysis (CBA).

10.12 RISK TOLERABILITY CRITERIA

The offshore oil and gas sector and Major Hazard industries in general have tended to adopt the risk tolerability framework proposed by the United Kingdom Health and Safety Executive (UK HSE). This framework is presented in the below figure and uses the IPRA as the prime measure of risk.

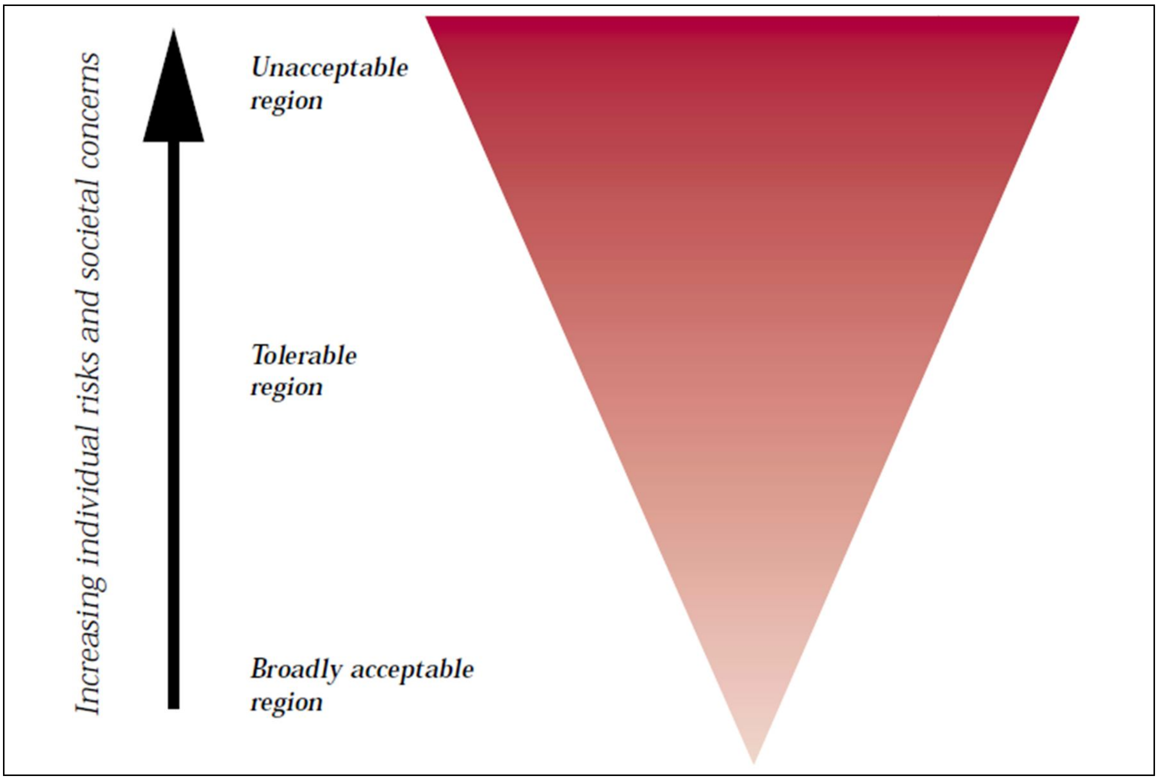


Figure 10-6: Risk tolerability criteria (UK HSE)

The risk tolerability criteria adopted for the QRA aligns with and is based up the UK HSE criteria (refer to table below).

Table 10-9: Individual risk tolerability criteria

IRPA (/yr)	Description	Expectation
>1 x 10^{-3}	Intolerable	Fundamental improvements needed to reduce risk
1 x 10^{-4}	Target for Worker	Energean “target” for a worker. Aim to reduce risks to this level,
1 x 10^{-6} to 1 x 10^{-3}	ALARP Region	Look for opportunities to reduce risk to As Low AS Reasonably Practicable (ALARP)

Note that there are no tolerability criteria for Potential Loss of Life (PLL), since the PLL is related to the total number of exposed personnel. A platform with a high number of Persons on Board (POB) will have a higher PLL than a platform with a lower PLL hence numerical PLL tolerability criteria cannot be established. PLL is a useful, rolled up measure of the level of group risk and aids in the understanding of risk contributors and assists risk based Cost Benefit Assessment (CBA).

There is no measure equivalent to IRPA or PLL to represent the potential for damage to the environment due to the failure of an oil and gas installation. Hence no tolerability criteria have been defined and therefore an exercise equivalent to ALARP cannot not be performed for environmental risks as it can for personnel safety risks.

10.13 RISK ASSESSMENT RESULTS

10.13.1 Individual risk per annum (IRPA)

The Individual Risk Per Annum for installation workers is presented in the following table.

The worker groups listed are those defined for the existing Prinos complex. Separate worker groups were defined for the Lamda platform and IRPA levels for these groups calculated. Energean does not however intend to employ dedicated Lamda staff. Lamda staff will be drawn from the existing Prinos crew and hence whilst on Lamda they will not attract risk on Prinos.

The Prinos staff that will be exposed to risks at Lamda are:

1. Alpha Operator
2. Beta Operator
3. Safety representative
4. Maintenance lower deck (crane operator)
5. Maintenance Instrumentation and
6. Maintenance Electrical

The Alpha or Beta operator will visit Lamda every month to launch a pig to Delta. He will be accompanied by the crane driver and an electrical and instrument technician who will undertake any routine maintenance activities required. Every two weeks the Alpha and Beta operator together will visit for a process walk round. During Coiled Tubing interventions an Operator will be in attendance with routine visits of the crane operator and safety officer.

LSIR levels for Lamda (based on full year occupancy) are lower than either Alpha or Beta platforms. However staff assigned to Lamda sees a small increase in their IRPA as when on the satellite they spend all of their time on the process deck, i.e. the Alpha operator attracts less risk whilst on Lamda than Alpha but because he spends none of this time in the Delta restroom or control room his risk level rises slightly. His risk level remains below $1x10^{-3}$.

The values shown for Prinos/Lamda workers are for a representative year of normal operations, the values for a year of simultaneous operations during a drilling campaign are also shown to ensure the worst case operating conditions are considered.

Table 10-10: Individual risk per annum

Worker Group	IRPA per year (normal operations)	IRPA per year (drilling campaign)
Instrumentation	4.49E-04	4.72E-04
Control Room Operator	2.29E-04	2.49E-04
/ Safety Representative	5.48E-04	5.74E-04
Alpha Operator	5.73E-04	6.29E-04
Beta Operator	5.40E-04	5.96E-04
Upper Deck Operator	8.02E-04	8.13E-04
Lower Deck Operator	5.51E-04	5.62E-04
Maintenance Upper Deck	6.95E-04	7.06E-04
Maintenance Lower Deck	4.73E-04	4.84E-04
Maintenance Electrical	2.73E-04	2.87E-04
Maintenance Instrumentation	3.99E-04	4.18E-04

10.13.2 Potential loss of life (PLL)

The total potential loss of life for Prinos is $4.86x10^{-2}$ per year the contribution from various hazard types is shown in the following diagram. This level of risk means that statistically there should be 1 fatality every 20 years on the Prinos complex. Introduction of the Lamda satellite makes no material change to PLL as no additional workers will be introduced.

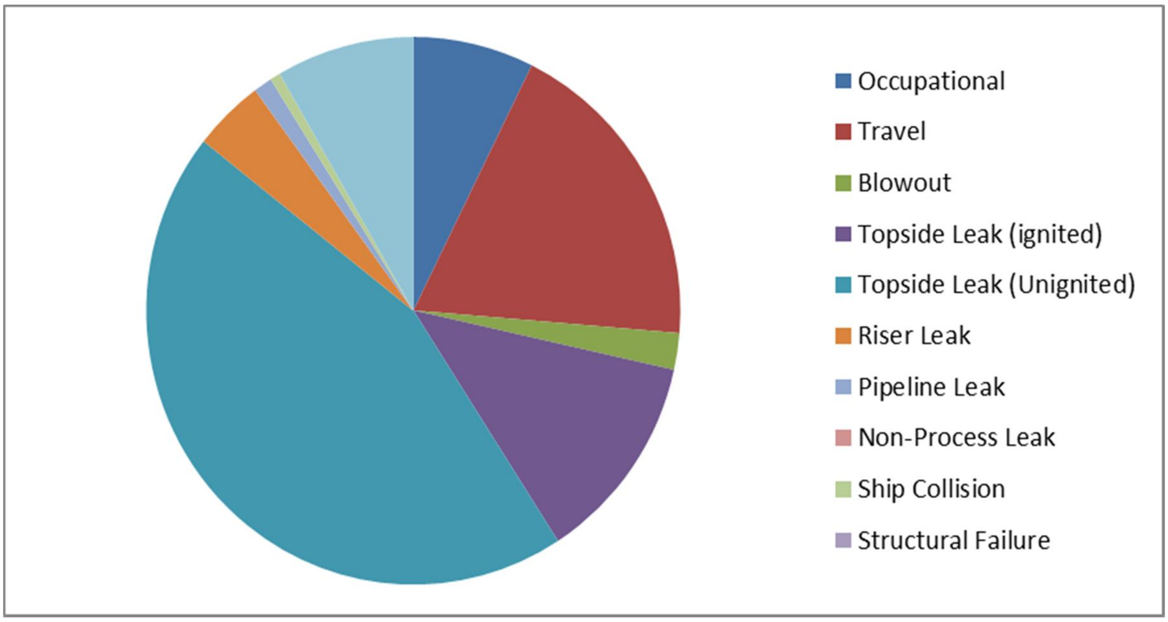


Diagram 10-6: Breakdwon of risk contributirs on Prinos and Lamda platforms

10.14 DISCUSSION

10.14.1 Comparison against risk tolerability criteria

The Individual Risk Per Annum (IRPA), for the existing facilities can be seen to reside within the "Tolerable if ALARP" region of the risk management framework. The risk levels are predominantly driven by the sour/toxic nature of the well fluids and hence the process streams present widely over the complex. The main Delta process platform is of an older type of design and layout, with less segregation between the higher and lower risk areas, than would be found on a more modern processing facility.

This lack of segregation tends to result in personnel being exposed to the risks associated with sour/toxic gas whenever they are offshore unless they are in enclosed locations with a pressurised atmosphere. Energean largely mitigates the toxic hazards associated with high H_2S levels by proactive use of procedural controls, particularly the installed breathing air system that can be accessed at all positions on the platform. Without the use of this system risk levels for individuals would be intolerable.

In contrast to the risk associated with toxic gas the calculated risks associated with fire and explosions are in line with or lower than levels for comparable installations. Whilst the design of the existing facilities is somewhat outdated, the small size of the facility, the low operating pressures coupled with the high water content of most streams, minimises the contribution of fire and explosions to IRPA. Effectively the relative probability of a substantial leak is low because of the small size of the complex and the consequences are limited because of the low pressures and high water content. Toxic hazards are in contrast substantial because although leaks are predicted to occur with a low frequency the presence of very high H_2S levels means substantial areas of the platform are impacted when even moderate leaks occur.

Whilst overall IRPA levels are below that considered intolerable they remain high and actions to identify options to reduce individual risk are in the process of being identified. Clearly these actions will focus on the hazards that have the largest contribution to risk, i.e. unignited toxic gas releases. As leak frequencies are low focus will clearly have to be on identifying additional barriers to prevent released toxic gasses harming the offshore work force.

It is recognised that significant risk reduction has already been achieved by not using helicopters for personnel transfer, helicopter transportation is typically one of the main contributors to a platforms risk profile. In addition, personnel do not reside on the platform/in the field (there is no accommodation module on Delta), instead they day trip to the offshore location from Kavala.

Although IRPA does not equate directly to environmental risk understanding the source of risk to humans can also be used to assess the potential threat to the environment. As has been illustrated and discussed the underlying frequency of leaks that have the potential to impact the environment is low. Risk reduction measures will focus on reduction of the consequences of toxic gas releases rather than oil spills as oil spills current are seen to contribute negligibly to worker risk. Risk reduction activities are therefore unlikely to significantly change environmental risk levels.

10.14.2 QRA reviews and risk reduction

Given the risk levels estimated by the QRA, a process of risk reduction reviews has been initiated. The risk reduction review process consisted of the following elements:

- Determination and understanding of the key contributors to the risk profile
- Detailed review of the QRA assumptions, rule sets and inputs to confirm these aspects are representative and not overly conservative
- Identification of possible risk reduction strategies that can be passed forward for more detailed evaluation and feasibility assessment as part of the ENERGEAN risk reduction forward plan.

Following this process, the QRA was revised to ensure it was representative of actual operational arrangements in a number of key areas including:

- Shift patterns, area manning and occupancies: this data was developed and reviewed in conjunction with operations.
- Appropriately reflecting how the risks of sour/toxic gas are managed on a day to day basis via strategies such as:
  - ⇨ All personnel being provided with escape Breathing Air (BA) sets and receiving the required training.
  - ⇨ Maintenance work, e.g. breaking into the hydrocarbon envelope, being performed with all personnel under air and all non - essential personnel being made aware and kept away from such work areas.
- Appropriately reflecting the level of protection afforded to occupants of the control room.
- Appropriately reflecting the composition and nature of process streams, in particular those with high sour/toxic gas content.

10.14.3 Risk reduction strategies – existing facilities

The QRA review and risk reduction process served to identify a number of additional potential risk reduction strategies that will be passed forward for more detailed evaluation, these include:

- Upgrading the upper deck restroom/toilet/change room block area. It is proposed that this area and structures be upgraded such that occupants are protected from the effects of fire, smoke, toxic gas, explosion overpressure, for sufficient time to plan and make their escape to place of safety. The risk benefits of implementing this risk reduction are shown in Table below. This project already been accepted by management and included in the 2016 budget.
- Reviewing the control room upgrade project to determine whether there are opportunities that could reduce the amount of time personnel spend in the process areas. For example could information be relayed to control room panels, thereby removing the requirement for gauges, readings to be taken locally, in the process areas.

This project was already scheduled for implementation in 2016. The scope is being revisited to ensure maximum benefits to IRPA levels are achieved.

- Upgrading the main escape route from the upper deck restroom area to the Delta boat landing or lifeboats so that staff is protected whilst evacuating from an escalating emergency. This opportunity has yet to be quantified to determine whether on a cost to avert a fatality basis it can be justified.

Table 10-11: Risk benefit to worker groups from protecting the upper desk restroom

Worker Group	IRPA per year (Upper deck restroom protected)	Risk Reduction
Instrumentation	3.59E-04	9.05E-05
Control Room Operator	2.29E-04	Negligible
Shift Supervisor / Safety Representative	4.35E-04	1.14E-04
Alpha Operator	4.56E-04	1.18E-04
Beta Operator	4.23E-04	1.18E-04
Upper Deck Operator	6.79E-04	1.23E-04
Lower Deck Operator	4.28E-04	1.23E-04
Maintenance Upper Deck	6.17E-04	7.76E-05
Maintenance Lower Deck	3.96E-04	7.69E-05
Maintenance Electrical	2.25E-04	4.79E-05
Maintenance Instrumentation	3.27E-04	7.18E-05

10.14.4 Risk reduction strategies – new facilities

An integrated risk based design process will be followed to prioritise inherently safe design principles. This includes risk reduction workshops that will be carried out to identify measures to further reduce the risk to personnel. Current measures being considered include:

- The reduction of leak sources (which is investigated as a sensitivity case of the QRA, where manual valves on headers containing toxic fluids would be welded). The risk benefits of implementing this risk reduction are shown in table below.
- Full process shutdown during maintenance and inspection campaign – already confirmed as being accepted.
- Protection of escape routes.

Table 10-12: Risk benefit to worker groups from welding manual valves on headers containing toxic material

Worker Group	IRPA per year (Upper deck restroom protected)	Risk Reduction
Instrumentation	4.49E-04	Negligible
Control Room Operator	2.29E-04	Negligible
Shift Supervisor / Safety Representative	5.48E-04	3.80E-10
Alpha Operator	5.70E-04	3.61E-06
Beta Operator	5.37E-04	3.61E-06
Upper Deck Operator	8.02E-04	Negligible
Lower Deck Operator	5.51E-04	Negligible
Maintenance Upper Deck	6.95E-04	5.68E-10
Maintenance Lower Deck	4.73E-04	2.43E-09
Maintenance Electrical	2.71E-04	1.74E-06
Maintenance Instrumentation	3.98E-04	1.74E-06