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Terminals Pty Ltd

Quantitative Risk Assessment for the Addition of Butadiene Facilities at the Geelong Terminals Site

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1. INTRODUCTION

QEST Consulting have been commissioned by Terminals Pty Ltd to complete a Quantitative Risk Assessment (QRA) for the addition of Butadiene storage facilities at the Terminals Geelong site. This QRA builds upon previous Quantitative Risk Assessment work, conducted at the facility, by DNV.

The Qest Consulting Group merged with DNV Australia in 2003. The completion of this QRA by the Qest Consulting Group ensures a consistent understanding of the hazards and risks associated with the Geelong facilities.

1.1. Background

Terminals Pty Ltd are proposing to build a new (4000 m^3) butadiene storage sphere at their Geelong terminal. The sphere will provide storage of butadiene for use by Dow. The sphere will receive product via sea tanker and the existing VCM road tanker facilities will be modified to allow export via road tanker.

This report includes an assessment of the proposed facilities following the construction of the sphere. An assessment of the risk results has been undertaken with reference to the Victorian "Interim" Risk Criteria[1] for hazardous facilities.

1.2. Aims and Objectives

The aim of this QRA study is to assess the level of risk associated with the proposed facilities. The specific objectives of the study are to:

- Identify the hazardous incidents that relate to the operation of the facilities.
- Assess the significance of each incident in terms of its potential off-site impact.
- Assess and quantify the off-site levels of risk to people, property and the environment due to the proposed plant and its operation, using iso-risk levels only (individual risk contours).
- Compare the level of associated risk of the butadiene facilities with existing risk levels.
- Provide a clear, concise report of the analysis.

1.3. Terminals Geelong Risk Assessment History

The first risk assessment of the Geelong VCM Storage Terminal was undertaken by DNV in 1987. More recently, in 1997 DNV Consulting investigated and commented on the impact of some additional flammable / combustible liquid storage tanks on the individual and societal risk profiles generated in the 1987 risk study.

In 1999, DNV Consulting undertook a risk assessment of the site including the development of the proposed MIPA storage facility (2200m^3 API 620 type storage tank). A number of principal hazard scenarios in VCM, MIPA and flammable liquids storage were considered.

In 2001 DNV Consulting updated the risk assessment of the site for the proposed development of a propylene storage facility (1767m^3 sphere). Propylene hazardous scenarios were added to the 2002 Safety Case QRA risk model. This risk assessment was accepted and approved by the local Geelong council.

In 2004 QEST Consulting are updating the risk assessment for the installation of a proposed butadiene storage facility (4000m^3) sphere.

For the detailed results of each previous QRA conducted, reference should be made to the relevant QRA report.

[1] Victorian WorkSafe Authority: The Requirements for "Demonstration" Under the Occupational Health & Safety (Major Hazard Facilities) Regulations, MHD GN-16 Rev. 0, September 2001.

2. DESCRIPTION OF BUTADIENE FACILITIES

A description of the proposed butadiene development at the Geelong site is as follows.

2.1. Ship Unloading Operation

It is expected that 3 shipments of butadiene will be received at the refinery pier each year and transferred via pipeline to the butadiene sphere. Each ship will deliver 2000 tonnes of butadiene and it is anticipated that a ship will take 10-12 hours to fully discharge its load into the butadiene storage sphere.

The unloading operation is based on vapour return to avoid emissions of butadiene to atmosphere. The deliveries will typically be refrigerated to minimise pressure, however the tank has been designed to allow un-refrigerated butadiene to be received and stored.

2.2. Product Storage Sphere

The product will be stored in a sphere 4000m^3 sphere that will be operated to a maximum capacity of 90%. The new facility is to be installed at the east end of the existing plant in the same location as the previously proposed propylene sphere.

The maximum operating pressure of the sphere is 300kPa and the normal operating pressure is 100-150kPa.

2.3. Product Pump Out

From the sphere product will be transferred to a road tanker at 11kg/s in order to fill the tanker over a 30 minute period. Two load out pumps are provided.

It is envisaged that there will be 365 tanker deliveries throughout the year transporting 18 tonnes of butadiene per load.

2.4. Miscellaneous

The existing VCM loading station (near pump pit 1) will be modified to incorporate the butadiene loading facilities.

It will have a "dead man" security system (driver tapping button) and be under camera surveillance.

Terminals currently require the driver to stay inside the station hut during the loading operation and to press a button at regular intervals to inform the control room operator of his well being. The facility has gas detectors installed.

Key process parameters such as tank level, pressure, temperature, actuated valve position and pump-running status will be remotely displayed in the Terminals control room. Tankers have additional connections for vapour return and air supply (for emergency shutdown valves on truck).

2.5. Design Basis

In summary, the new butadiene storage facility will have the following design basis for this study.

- Operating 24 hrs/day, 365 days/year.
- 3600m^3 sphere operating storage capacity.

- Unloading of ships 3 times a year at 166 tonnes/hr.
- Loading of 365 tankers a year at a rate of 11 kg/s.
- System has to be fail safe and adequately instrumented for remote operation under driver control.
- Driver security system to be included.

2.6. Comparison of Butadiene versus VCM Operations

To assess the impact of the proposed butadiene facilities, current VCM operations are compared to proposed butadiene operations, as shown in Table 2.1.

Table 2.1 Comparison of VCM Vs Proposed Butadiene Facilities

Item	VCM Facilities	Butadiene Facilities
Class	2.1	2.1
Flash fraction at 25 C	Near 18%	12%
Storage pressure at 25 C	500 kPa absolute	100-150 kPa absolute
Number of imports by ship per year	18	3
Size of imports by ship	10,000 tonnes	2,000 tonnes
Total imports per year	180,000 tonnes by ship	6,000 tonnes by ship
Number & size of storage vessels	3 x 3,840 m^3, 1 x 5,575 m^3	1 x 4000 m^3
No & size of road tanker movements per year (Exports)	7,500 x 24 T / year	365 x 18T / year

3. SCOPE AND METHODOLOGY

3.1. Study Scope

The study assesses the risks to the public arising from both normal operations and typical occurrences associated with the storage and handling of hazardous materials at the site after the installation of the butadiene sphere. The transportation of hazardous materials to the site by road was limited to the analysis of incidents within the site boundary.

3.2. Study Methodology

The methodology used in this study is that of classical risk assessment. This is a systematic approach to the analysis of what can go wrong in complex industrial systems. The normal conditions of operation of the system are defined and then the following questions asked:

- What accidental events can occur in the system?
- How frequently would each event occur?
- What are the consequences of each event?
- What are the total risks (frequencies x consequences) of the system?
- What is the significance of the calculated risk levels?

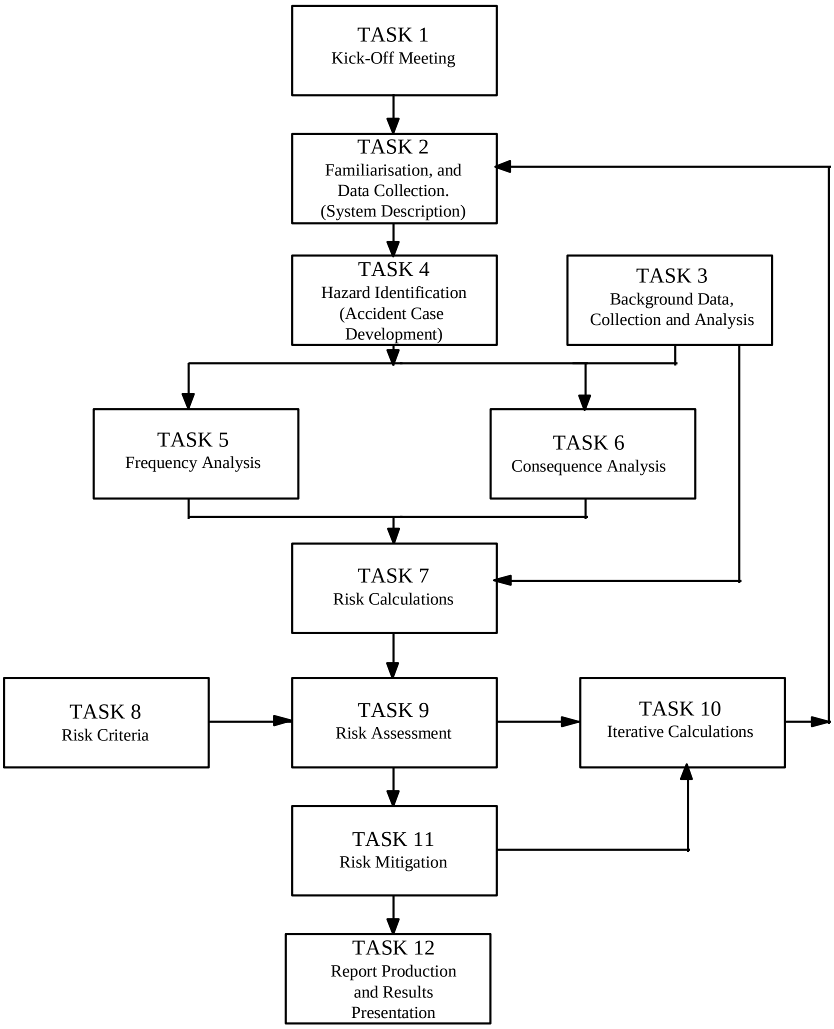
These questions correspond to the five basic components of a QRA. Once a system has been analysed, if the risks are assessed to be too high according to the selected risk acceptance criteria, the system can be modified in various ways to attempt to reduce the risks to a tolerable level, and the risk levels recalculated. The process may therefore be viewed as iterative, where the design of the system may be changed until it complies with the needs of society. By objectively quantifying the risks from each part of the system, a quantitative risk analysis enables identification of the most effective measures to reduce risks.

The methodology involves the following steps: -

- System definition, in which information on the facility is collected and assimilated.
- Hazard identification, in which site events and external events are identified, which may lead to the release of hazardous material.
- Frequency estimation, in which the frequency (i.e. likelihood per year of occurrence) of each of the accidental events is estimated, based on historical failure data.
- Consequence modelling, in which all the possible consequences of each event are estimated.
- Risk calculation, in which the frequencies and consequences of each event are combined to determine levels of fatality risk.
- Risk assessment, in which the risks calculated are compared with the Victorian "interim" risk criteria.

Figure 3.1 shows the project flow by task. SAFETI (Software for the Assessment of Fire, Explosion, and Toxic Impact) is used to complete the risk assessment. This package is used by many chemical and petrochemical companies and government agencies in different countries around the world.

Figure 3.1 Typical Risk Analysis Methodology



There are a number of ways of presenting risk. However this study uses a measure of individual risk per annum in order to establish an increase in risk for the Terminals Geelong facility.

4. HAZARD IDENTIFICATION

4.1. Hazard Scenarios

The hazard identification process has been undertaken based on a review of the activities undertaken at the Geelong terminal through the addition of the proposed butadiene sphere. These hazards are reviewed and modified for their applicability using butadiene instead of propylene. As a result the primary hazards associated with the storage and handling (import and export) of butadiene are summarised in Table 4.1.

Table 4.1 Hazard Scenarios – Butadiene Storage and Handling

Hazard Series	Description	Consequences
A	Loss of containment from road tanker loading hose/arms during unloading or loading.	Flammable vapour cloud leading to potential flash fire, jet fire and pool fire. Knock-on to road tanker, potential BLEVE.
B	Loss of containment from road tankers (loading activities)	Flammable vapour cloud leading to potential flash fire, jet fire and pool fire or BLEVE.
C	Loss of containment from butadiene storage sphere.	Flammable vapour cloud leading to potential flash fire, jet fire and pool fire or BLEVE.
D	Loss of containment from import pipelines and load out piping.	Flammable vapour cloud leading to potential flash fire, jet fire and pool fire. Knock-on to storage facilities potential VCM or butadiene BLEVE.

This section of the report considers the potential hazards that might arise at the Geelong terminal due to the operation of the butadiene storage and handling facilities. In addition external hazards are reviewed to determine if they can cause hazardous release incidents at the butadiene storage facilities.

4.2. Potential Consequences

4.2.1. Flash Fires

Flash fire risks can arise due to the late ignition of butadiene vapours from liquid spills (Class 2.1 Flammable Gas). Flash fires may pose an offsite hazard to surrounding populations, but are unlikely to cause a knock-on effect at the VCM storage spheres. Butadiene flash fire risks are considered and modelled in this study.

4.2.2. Fire Balls

Pressurised storage of butadiene can result in a fireball under certain circumstances; the credible mechanisms for this are a fire beneath the vessel or impingement of a jet fire on unprotected metal above the liquid level in the sphere.

Even though these events are rare, they are a large consequence event and have been modelled in this analysis.

The detailed design process will specify the protection systems (sloping bund, deluge, pressure relief) fitted to such vessels to prevent incidents of this type.

For a fireball (due to hot rupture) to occur a number of separate conditions/failures have to take place:

- A large sustained VCM / butadiene release;
- Ignition of a VCM / butadiene release resulting in a sustained jet fire;
- Fire orientation towards the butadiene sphere; &
- Failure to isolate a VCM / butadiene jet fire.

4.2.3. Pool Fires

In the event of a release of butadiene from the handling or storage facilities a pool fire is possible as the butadiene is stored as a liquid. A release of butadiene will collect in a pool and undergo rapid boiling off to vapour. The heavier than air vapour could then either result in a flash fire at an ignition source flashing back to the source and forming a pool fire or disperse safely. Depending on the size and duration of the release escalation on to the butadiene sphere, VCM sphere or MIPA tank are possible. Butadiene pool fire risks are considered and modelled in this study.

4.2.4. Jet Fires

In the event of a release of butadiene from the handling or storage facilities a jet fire is possible. Depending on the size and duration of the release escalation on to the butadiene sphere, VCM sphere or MIPA tank are possible. Butadiene jet fire risks are considered and modelled in this study.

4.2.5. VCE (Vapour Cloud Explosion) Risks

Theoretically, at least, butadiene and VCM, both DG Class 2.1 materials, can result in a VCE if a large flammable of either vapour cloud is ignited. In reality there is a growing appreciation of the need for considerable confinement of the vapour cloud before the overpressures that characterise these types of explosions can develop.

While it is noted that the Terminals site is essentially an “unconfined” area it was judged appropriate, partly as a precautionary measure, partly out of the need to provide evidence of “due process”, to model VCE events in this analysis.

Within SAFETI a lower limit of 1,000 kilograms of material must be within the flammable limits in a vapour cloud in order for explosion modelling to take place. In the event that a flammable cloud of greater than 1,000 kg is produced, a probability of explosion of 10 percent of all delayed ignitions has been taken. All other delayed ignition cases are modelled as flash fires.

4.2.6. Toxicity of Combustion Products

Vinyl chlorine monomer (VCM) may generate relatively small quantities of high toxicity combustion products (e.g. hydrogen chloride and phosgene).

However, the combustion products from a fire involving butadiene are [1] CO_2 - harmless unless encountered in a high enough concentration to be an asphyxiant, and [2] CO - when there is some incomplete combustion - which is an asphyxiant.

Previous QRA and consequence modelling work performed locally by DNV has shown that these toxic combustion products would rise in the thermal plume of a fire of the types modelled here and disperse to very low concentrations prior to any return to ground level. The surrounding population would not be exposed to acutely, or chronically, harmful concentrations or doses of these materials.

Therefore, the decision was made that toxic combustion products are not an issue for butadiene or VCM storage since they would not contribute to off-site injury or fatality risks and offsite populations are extremely unlikely to suffer significant adverse health effects from the base event (itself very unlikely). The toxic impact of butadiene and VCM combustion products is excluded from further consideration.

4.2.7. Toxicity of Unignited Releases

Butadiene is an irritant to the eyes with dizziness, drowsiness, blurring of vision and nausea occurring from moderate concentration exposure in the gaseous form. At large concentrations it becomes a simple asphyxiant. When exposed to liquid, butadiene can cause skin burns due to the refrigeration effect. It is thought to be a likely carcinogenic.

Therefore the acute risk due to exposure of toxic vapours generated from butadiene spills are excluded from further consideration. The longer terms effects of a carcinogen are impossible to quantify in quantitative risk terms. A QRA only deals with immediate acute toxic effects for the duration of the loss of containment scenario. Longer-term toxic effects are also influenced by many other factors after the exposure. As a result carcinogenic effects are excluded from further consideration.

4.3. Knock-On Effects

This study is particular concerned with knock-on effects between the existing VCM facilities and the proposed butadiene facilities. Of all potential events, a VCE or sustained jet fire associated with these facilities may cause a knock-on effect, manifesting itself as a fireball (cold rupture) or a BLEVE (hot rupture).

5. KEY MODELLING ASSUMPTIONS

In the process of undertaking the quantitative risk assessment of the proposed additional butadiene sphere at the Geelong site, a number of key modelling assumptions are identified, which are critical to the risk results. This section lists the key modelling assumptions along with their assumed operating parameters.

The following assumptions are applicable to the risk modelling of all facilities.

1. The study focus is on release events capable of producing an offsite fatality risk: events that can only pose an on-site risk are not modelled.
2. All pumps will have double mechanical seals with a pressurised liquid barrier to prevent the possibility of butadiene leaks through the sealing system.
3. The time to detect, investigate and isolate a process liquid leak (using ROVs) has been (conservatively) assumed and modelled as 2 minutes. (This time period is defined as the "Limit Duration" in the failure cases tables.) The two-minute response time has been estimated based on the following: within 2 minutes a relevant leakage is detected by the gas detection system which is interlocked to automatically shutdown and isolate the process and automatically call the CFA.
4. The maximum operating pressure of the butadiene is 300kPa, normal operating pressure is between 100-150 kPa. All releases are conservatively modelled at the maximum operating pressure.
5. Butadiene will be delivered to Terminals via a ship delivering 2000 tonnes 3 times a year. Each delivery will take 10-12 hours to unload. For conservatism it is assumed that the ship unloading facilities are in use for 24hrs to ensure safe loading (ensures adequate cooling of the unloading equipment).
6. Butadiene is exported from the site using 18 tonne road tankers. The analysis assumes that there are 365 tanker loading operations per year.
7. The time to unload a road tanker is assumed to be 30 minutes but for conservatism 1 hour is assumed. Based on 365 deliveries per year, a road tanker is assumed to be present at the loading bay [(365 x 1) / (365 x 24)] 5 % of the year.
8. The butadiene sphere is assumed to be operating at 3600m^3 90% of capacity (4000m^3). It is assumed that the sphere will operate at half capacity for 330 days in an average year and for the remaining 35 days the sphere is assumed to be full. Two cold rupture and BLEVE scenarios are modelled based on the assumed sphere inventories.
9. BLEVE frequencies for the proposed butadiene sphere are referenced from the VCM sphere BLEVE frequencies contained within the existing SAFETI model.
10. For the storage sphere and road tankers, leaks continue until the whole inventory is lost, but subject to a maximum time limit of 60 minutes. Within a 60 minutes period all releases will have reached a steady state in term of hazard distance and potential fatal impacts. Therefore the modelling of consequences beyond the 60-minute period is not required. This assumption is not critical to the risk analysis.
11. The butadiene failure cases included in the risk model are detailed in Appendix A.

6. RISK CRITERIA

There are a number of ways of presenting risk; individual risk and societal risk.

Individual risk is defined formally by the IChemE (1992) as the frequency at which an individual may be expected to sustain a given level of harm from the realisation of specified hazards. It is usually taken to be the risk of death, and usually expressed as a risk per year.

Societal (or group) risk is the risk experienced in a given time period by the whole group of personnel exposed. It reflects the severity of the hazard and the number of people exposed to it. It is expressed in terms of annual fatality rate FN curves.

However this study uses a measure of individual risk per annum in order to establish an increase in risk for the Terminals Geelong facility.

6.1.1. Individual Fatality Risk Criteria

The primary measure from this study is Individual Risk. This is the risk experienced by a hypothetical individual assumed to be continuously present at a specific location. Individual risk is presented in this report in the form of individual risk of fatality contours over a map of the Terminals site and surrounds.

Individual risk criteria are best at establishing exclusion zones or defining an area of limited desirable population density: in other words in relatively high-risk areas.

Table 6.1 provides an overview of the individual risk criteria that are generally applied to residential populations / areas in Victoria, as well as in various other States.

Table 6.1 Individual Risk Criteria, Residential Areas

STATE	ACCEPTABLE RISK, per year [3)]	
	NEW PLANT	EXISTING PLANT
Victoria, maximum acceptable Risk level in residential areas	1×10^{-7}	1×10^{-7} [1)]
Victoria, risk level not to be Exceeded at plant boundary	1×10^{-5}	1×10^{-5} [2)]
Western Australia	1×10^{-6}	1×10^{-6}
New South Wales	1×10^{-6}	1×10^{-6}

1) *For risk levels between 1×10^{-5} and 1×10^{-7} per year all practicable risk reduction measures to be taken, but a restriction on residential development is applicable to new proposals.*

2) *When outside the plant boundary risk reduction measures must be taken.*

3) *1×10^{-5} per year = one chance in a hundred thousand per year.*
1×10^{-6} per year = one chance in one million per year.
1×10^{-7} per year = one chance in ten million per year.

The individual risk levels shown on contours are calculated for the 'most exposed person'. This means that the individual risk levels are calculated for the risk of death of an individual present 100% of the time and in the open (i.e. not in a building), without any allowance for them escaping.

It is observed that where the offsite population involved might be categorised as industrial workforce it is conventional to relax the criteria by a factor of 10. In this instance the majority of the offsite population is working on the Shell Refinery and at the Basell Petrochemical Plant.

7. RISK RESULTS

7.1. Individual Risk Contours

The risk results presented in Figure 7.1 and Table 6.1 are Location Specific Individual Fatality Risk contours for the existing Terminals facility and with the addition of the proposed Butadiene facilities.

Figure 7.1 Existing Development Fatality Risk Contour

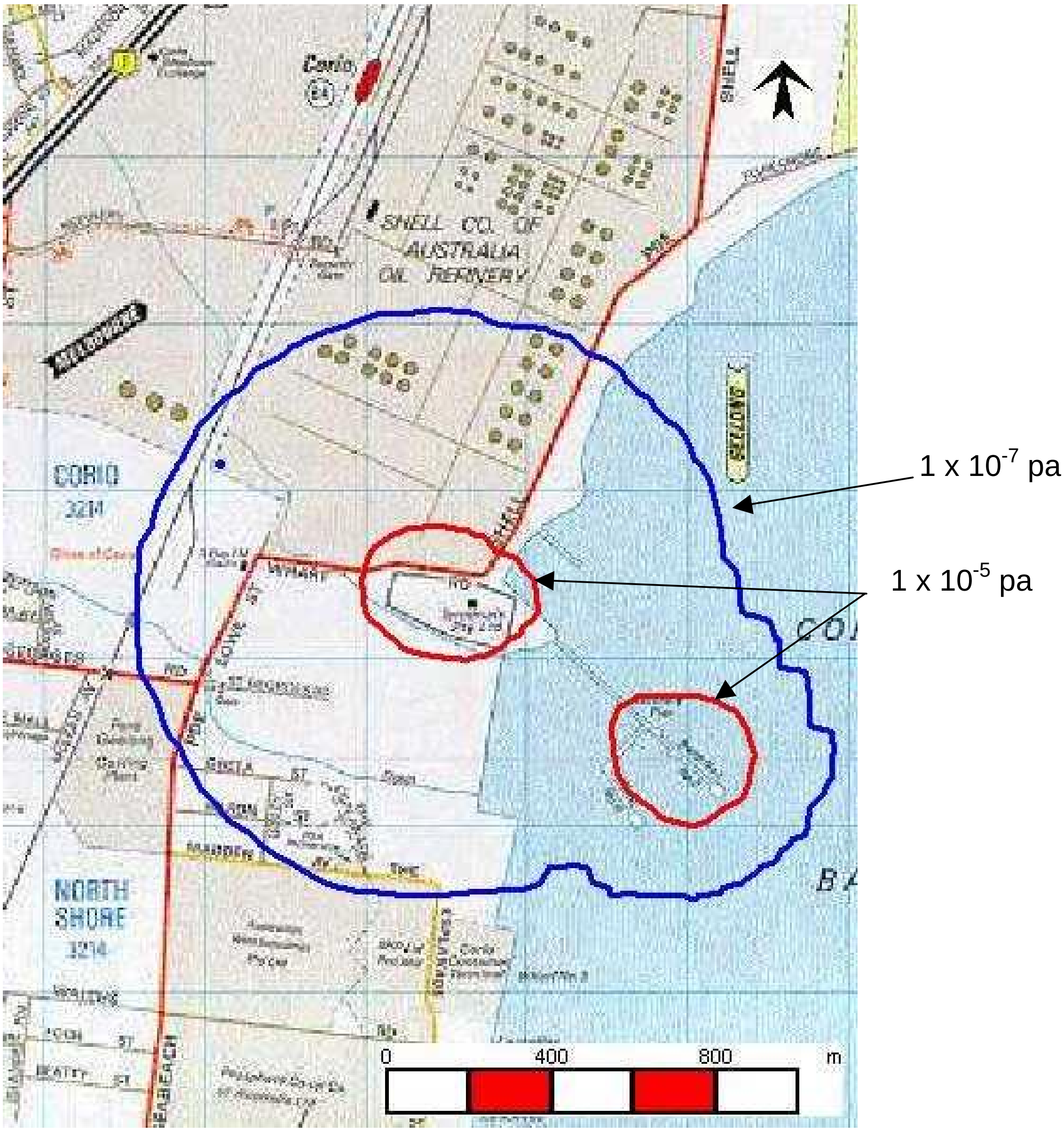
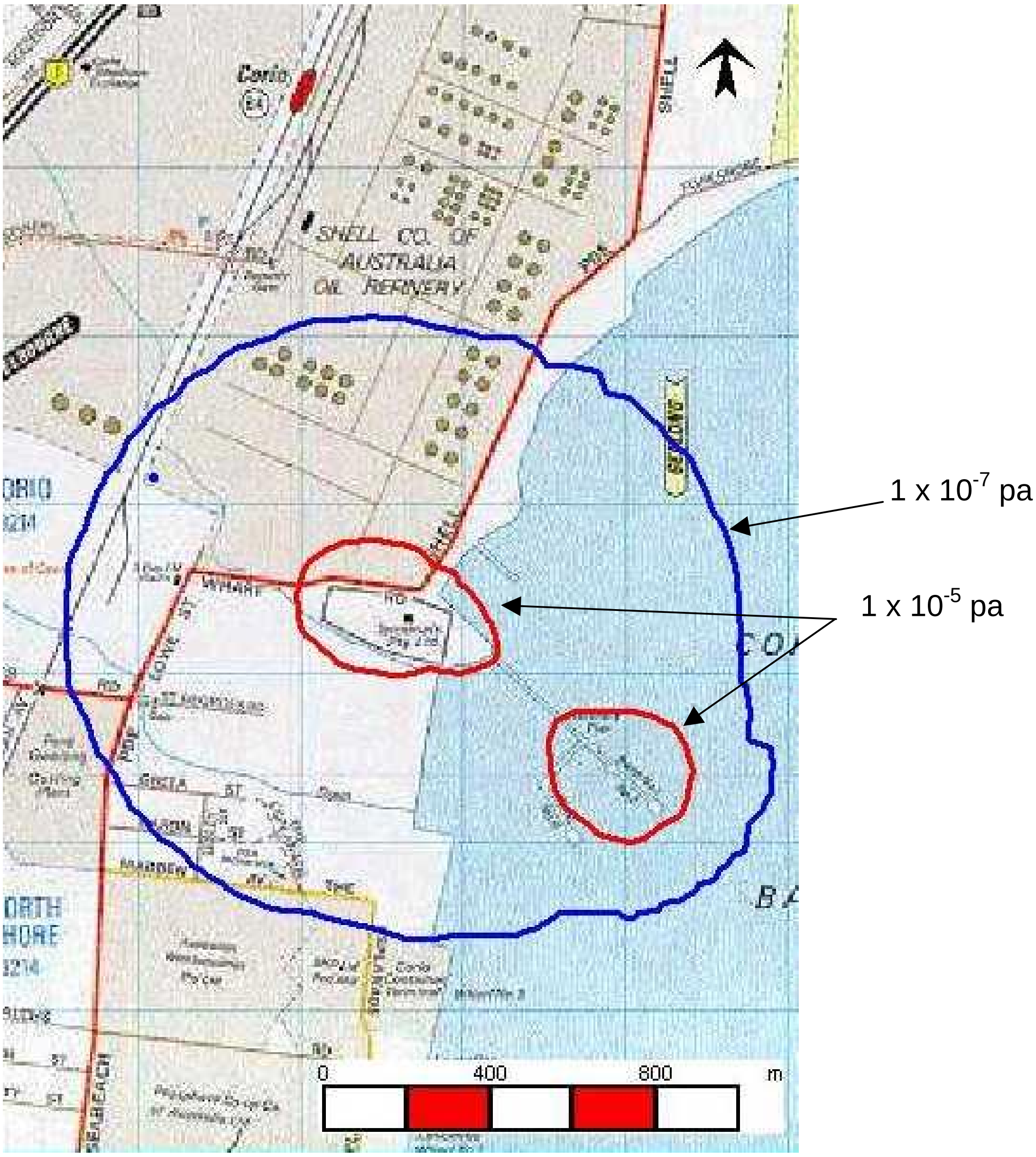


Figure 7.2 Proposed Butadiene Development Fatality Risk Contour



A comparison with the revised Terminals risk profile shows that with the addition of the butadiene facilities onto the Terminals site there is no significant change in the risk level at the site boundary. This can be understood by consideration of the comparison of VCM and butadiene operations described in Table 2.1.

According to the risk criteria presented in Table 6.1 the 1 x 10^{-5} per year (1 chance in a hundred thousand per year) contour should be confined to the site boundary. Review of Figure 7.1 shows that the individual risk contours for the site exceed the “Interim” site boundary criteria set in Victoria (1×10^{-5} fatalities per annum). The 1 x10^{-5} per year risk contour is enlarged as it encompasses the new butadiene facilities. The 1 x10^{-5} per year risk contours around the jetty end remain constant.

QEST Consulting considers that the individual risk for the additional facilities should not be considered to be unacceptable since the increase in risk is not significant when considered against the existing levels of risk on the site.

The 1 x 10^{-7} per year (one chance in ten million per year) contour is confined to the industrial zoned land surrounding the Terminals site. Compared to the existing facilities there is a slight difference in the size of the 1 x 10^{-7} per year contour over the sea only driven by the BLEVE of the butadiene sphere. The 1 x10^{-7} per year (land based) circular risk contour remains unchanged as the land risk levels are still dominated by the VCM spheres.

As the risk contours are confined to the surrounding industrial land the individual risk results should be considered acceptable.

The proposed butadiene facilities at the time of the analysis were in the early stages of preliminary design. QEST recommends that consideration of potential safeguards that may reduce the risk from the primary risk driver of a storage sphere BLEVE are reviewed and assessed in suitable detail to ensure that the risks due to the proposed expansion are reduced *so far as reasonably practicable*.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. Conclusions

From the results of the risk assessment the following conclusions can be made:

- There is no statistically meaningful increase in the risks characterised at the Terminals Pty. Ltd. Geelong facility attributable to the addition of a competently designed butadiene storage vessel and its associated transport systems.
- The risks from the proposed facilities are assessed to be acceptable against the Victorian Interim Risk Criteria established for judging such facilities.
- Detailed design activities shall provide the appropriate forum to demonstrate that risks have been reduced so far as practicable with regard to the reduction in likelihood of events that are to a large degree inherent to these activities (i.e. bulk storage of pressure liquefied gases).

The critical aspect of the results of this Quantified Risk Assessment is the frequency with which the butadiene and VCM storage vessels assessed are predicted to fail catastrophically. The BLEVE frequencies were specifically reviewed by DNV for Terminals in a Technical Note (VCM Storage Sphere – Escalation to BLEVE) in August 2002 and the cold rupture frequencies reviewed by DNV in a QRA of a Proposed Propylene Sphere in December 2001.

QEST have reviewed the data and find it still to be from the best available worldwide data sources.

8.2. Recommendations

BLEVE events from the butadiene vessel drive the risk increment associated with the planned expansion – because of their far-field impacts. It is recommended that the potential for such events is subject to scrutiny during detailed design and that the design makes best use of some of the available mechanisms for considerably reducing the likelihood of such events.

9. REFERENCES

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APPENDIX A - FAILURE CASE SCENARIOS

This QRA model was built on the existing Safety Case QRA model. This appendix presents a summary (Table A1.1) of the additional butadiene failure cases entered into the SAFETI risk model.

Table A1.1 Additional Butadiene Failure Case Scenarios

Item Description	Event ID	Temp C	Press (bar abs)	Phase V/L/T	Limit Rate kg/s	Limit Mass kg	Limit Duration secs	BD Exposure Factor	BD Frequency (per year)
Import Pipeline From Ship	INP-BUTE-25L	30	-	T	46	15000	600	0.0082	1.4E-6
	INP-BUTE-100L	30	-	T	46	15000	600	0.0082	1.8E-7
Butadiene Storage Tank	ST-BUTE-25L	20	Sat Liq	T	n/a	2340000	n/a	1	9.3E-6
	ST-BUTE-100L	20	Sat Liq	T	n/a	2340000	n/a	1	6.6E-6
Cold Rupture	ST-BUTE-RUPT	20	Sat Liq	L	n/a	2340000	n/a	1	7.1E-9
(vessel unwraps)	ST-BUTE-RUPT-50%	20	Sat Liq	L	n/a	1170000	n/a	1	6.5E-8
BLEVE	ST-BUTE-BLEVE Full	20	Sat Liq	L	n/a	2340000	n/a	1	4.9E-8
	ST-BUTE-BLEVE-50%	20	Sat Liq	L	n/a	1170000	n/a	1	4.5E-7
Butadiene Transfer Pumps	PUMPS-BUTE-25L	30	-	T	11.1	1000	120	0.042	3.7E-5
	PUMPS-BUTE-100L	30	-	T	11.1	1000	120	0.042	4.0E-6
Road Tanker Unloading	ARM-BUTE-25L	20	-	T	11.1	700	120	365	3.3E-4
Arms	ARM-BUTE-100L	20	-	T	11.1	700	120	365	6.6E-5
Storage Feed to Road	RTNK-P-BUTE-25L	20	-	T	11.1	700	120	0.042	2.8E-6
Tanker	RTNK-P-BUTE-100L	20	-	T	11.1	700	120	0.042	3.7E-7
Road Tanker Exports	RTNK-BUTE-25L	20	Sat Liq	T	n/a	20000	n/a	0.042	4.0E-6
	RTNK-BUTE-100L	20	Sat Liq	T	n/a	20000	n/a	0.042	4.0E-7
	RTNK-BUTE-RUPT	20	Sat Liq	L	n/a	20000	n/a	0.042	2.7E-7
								Total	1.4E-3