ALCOA ALUMINA

Public Safety Risk Assessment - Wagerup Expansion

Final Report

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1. EXECUTIVE SUMMARY

As part of the Environmental approval process for the Wagerup 3 expansion[1], Alcoa Alumina commissioned Qest Consulting to conduct a Public Safety risk assessment, for the existing refinery and changes caused by the expansion. This is part of the full spectrum of risk assessments (EIA, Health, etc.) being undertaken for the expansion, and the public safety risk component is focused on accidental events which may have an acute impact on members of the public (as required by the EPA document "*Guidance for Risk Assessment and Management: Off-site Individual Risk from Hazardous Industrial Plant, July 2000, WA"*). Incidents with only occupational impacts, issues to do with continuous releases and health impacts are excluded from this study and will be addressed separately.

The risk assessment was conducted in accordance with classical risk assessment techniques and is consistent with the EPA requirements.

A range of hazards were identified that had consequences beyond the near field (ie could impact outside the immediate workplace) and these were then analysed to see if they could have adverse consequences outside Alcoa's boundary (ie where the pubic risk criteria apply). The hazards were predominantly of a Hazardous Materials (Chemical/ Fire Hazard) or a process hazard nature (ie digesters which due to the pressures and temperatures have the potential for catastrophic failures). The analysis of the consequences has indicated that none of the events associated with these hazards has the potential to cause serious acute harm to persons outside Alcoa's boundaries and hence the levels of public risk associated with the existing plant (and expansion) comply with all the relevant EPA Off-site Individual Risk from Hazardous Industrial Plant criteria.

During the construction phase there will be an increase in the number of vehicle movement to and from site. At the peak of construction there will be slightly over 1500 additional construction personnel on site, split between shifts. In addition to the community impacts (which are being addressed elsewhere), there is an incremental impact on road safety in the immediate area. While initial plans relating to staggering the construction shifts from operations, pre-start briefings (which will include traffic issues and drug and alcohol policies, etc.), are in place, the detailed planning for the construction is yet to commence. Therefore, while the road safety issues are not typically included in an Off-site Individual Risk from Hazardous Industrial Plant analysis it is recognised that this is a potential impact on the public and appropriate recommendations to ensure management of the issue to As Low As Reasonably Practicable are made.

The maintenance of and performance monitoring of the controls associated with the identified hazards during the life cycle of the risk exposure (expansion and on-going operations) are addressed within the Wagerup Safety Management System (which is consistent with the requirements of AS 4801 "Occupational Health and Safety Management Systems) and the Alcoa Major Hazard Management System.

The management of public safety is an ongoing process for Alcoa and will require an iterative analysis throughout the timeline for the expansion. The following recommendations will help ensure the risk to public safety is minimised:

- Alcoa Wagerup are in the process of implementing a comprehensive Major Hazards Management System (dedicated to equipment whose failure could result in major hazards impacts). This process will provide a robust and systematic approach to

[1] Expansion to 4.7 Mtpa

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identifying the critical equipment controls for managing major hazards and ensuring these are in place and their performance effectively monitored.

The implementation of this process (planned for 2005) should include a review of all the major hazards identified within this report and the routines for monitoring the performance of the relevant critical equipment controls should be established and in place before the commissioning of the proposed expansion

- A traffic management plan for the refinery to help accommodate the increased traffic to the area during construction should be developed and implemented once the construction plan is further developed.
- The on-going design process should include all the normal Hazard review processes (ie HAZID/ Risk Reviews, HAZOP, etc.) typically applied by during good engineering design.
- In order to ensure that additional hazards are not introduced that could adversely impact on the public the existing procedures should be amended to ensure that before any additional Hazardous Material storage is allowed on the site, that the in addition to the normal Dangerous Goods licensing requirements that off-site impact potential is considered.
- The auditing (and monitoring) requirements of the Wagerup Safety Management System, should continue to be utilised to ensure that the relevant control systems (including Dangerous Goods reviews, effectiveness of management systems, etc.) remain effective, beyond the commissioning of the operation.

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2. INTRODUCTION

2.1. BACKGROUND

Alcoa Wagerup is an Alumina refinery, which it is proposed to upgrade to a production capacity of approximately 4.7 million tonnes per annum. The process briefly consists of Bauxite being mined and transported by conveyor to the refinery where it is ground through SAG mills and caustic added to dissolve the alumina (in digesters) various separation processes remove silica and other impurities, the alumina is then precipitated out and separated (and calcining for sale) while the red mud tailings is transported to disposal dams and the caustic is regenerated for recycling.

The proposed expansion to the refinery will see almost a doubling in production, and the following additions in process equipment/ infrastructure is proposed:

- Upgrading of water and power reticulation;
- Additional bauxite stacker and additional bauxite stockpile;
- Additional ore reclaimer;
- On additional grinding mill;
- Three slurry storage tanks;
- Additional digestion unit;
- Two sand removal trains or equivalent;
- 36 precipitation tanks;
- Four assorted evaporation units;
- Upgrade of oxalate removal plant;
- Two additional calciners;
- Additional alumina bin;
- Additional raw water storage facility;
- Additional carbonate removal facility;
- Two additional boilers and two turbo alternators in powerhouse;
- Extension to administration and amenities block;
- Various stock tanks and non-specific upgrades to other sections of the plant (eg oxalate, washers, thickners);
- Expansion of residue drying areas; and
- Upgrade and extension of overland conveyor system.

All of these changes were taken into account when considering potential offsite risks.

2.2. OBJECTIVES

The objectives on this public safety risk assessment for the Wagerup Refinery are:

- To undertake a rigorous and systematic identification, analysis and assessment of the potential for acute Public Safety Hazards associated with the Wagerup 3 Expansion;

- To ensure robust and comprehensive controls to manage the risks (to ALARP standards) have been defined;
- That systems for maintenance of and monitoring the on-going performance of these controls are to be in place during the life cycle of the risk exposure; and
- To communicate the results of the study with all relevant stakeholders (Government, Community, Operator, Designer, workforce, etc.).

In accordance with the EPA criteria for off-site (public) risk [Ref 3] it is required to demonstrate compliance in the following areas:

- A risk level in residential zones of one in a million per year or less, is so small as to be acceptable to the EPA.
- A risk level in "sensitive developments", such as hospitals, schools, child care facilities and aged care housing developments of between on half and one in a million per year is so small as to be acceptable to the EPA.
- Risk levels from industrial facilities should not exceed a target of fifty in a million per year at the site boundary for each individual industry, and the cumulative risk level imposed upon an industry should not exceed a target of one hundred in a million per year.
- A risk level for any non-industrial activity located in buffer zones between industrial facilities and residential zones of ten in a million per year or lower, is so small as to be acceptable to the EPA.

And the purpose of this study is to analyse the potential hazards and risks which can affect public (off-site) safety and assess them against these criteria.

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3. APPROACH

3.1. SCOPE

The scope of this risk assessment covers:

- Public Safety (ie acute accidental effects)
- All phases of the expansion (Engineering, construction, commissioning and operation); and
- Methodology in line with AS4360 “Risk Management” and the EPA “Guidance for Risk Assessment and Management: Offsite individual risk from Hazardous Industrial Plant

3.2. GENERAL STUDY APPROACH

The methodology used in this study is that of classical risk assessment, a systematic approach to the analysis of what can go wrong in hazardous industrial facilities (see Figure 3.1). The conditions are defined and then the following questions asked:

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

These questions correspond to the basic components of a risk assessment. Once a system has been analysed, if the risks are assessed to be too high according to some criteria, the system can be modified in various ways to attempt to reduce the risks to an acceptable 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, QRA enables the most effective measures to reduce risks to be identified.

In its overall scheme, the methodology used follows the "classical" form of quantitative risk analysis involving the following steps:

- System definition, in which information on the facility is collected and assimilated.
- Hazard identification, in which events with the potential for off-site impact are identified, via discussions held with a range of design, operational and safety personnel using the guidewords shown in Appendix A.
- Consequence modelling, in which all the possible consequences of each event are estimated (using appropriate software and other quantitative estimates).
- For each event with a credible off-site impact frequency estimation, in which the frequency (i.e. likelihood or occurrence per year) of each of the accidental events is estimated, based on historical failure data.
- Risk calculation, in which the frequencies and consequences of each event are combined to determine levels of individual fatality risk.
- Risk assessment, in which the risks calculated are compared with the stated criteria.

Figure 3.1 illustrates all these tasks in the context of classical QRA methodology.

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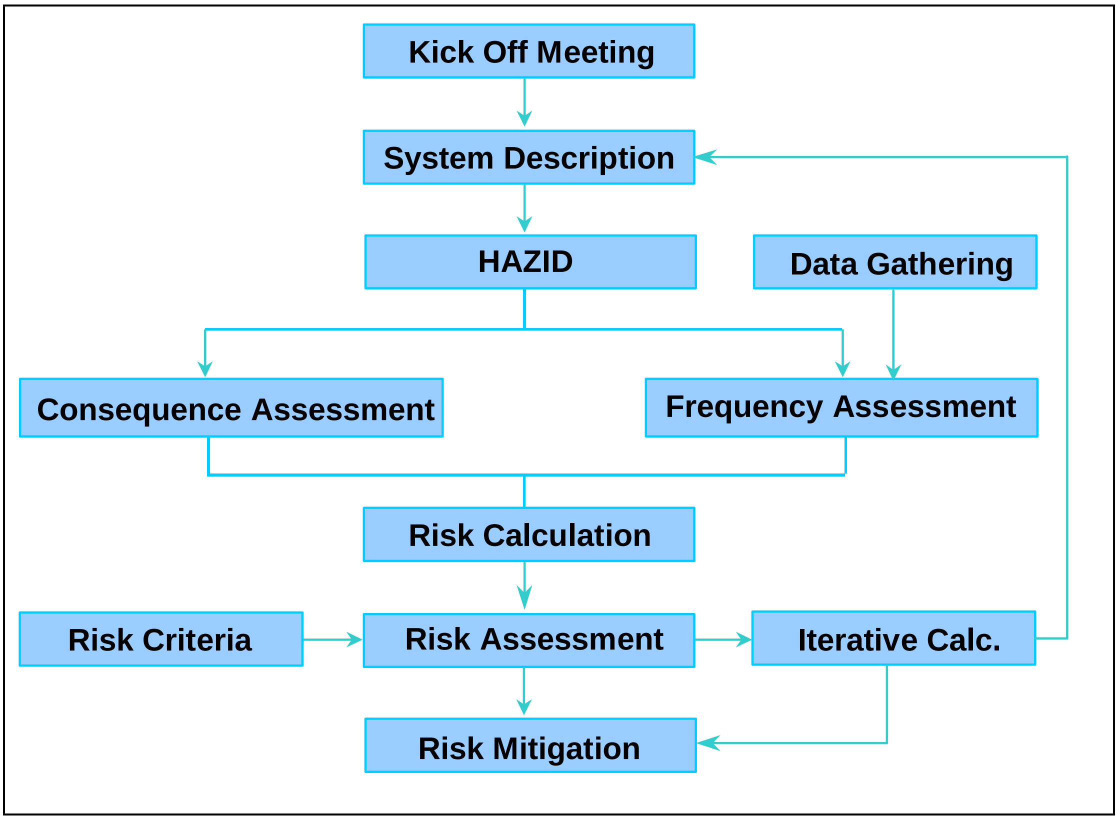
Figure 3. 1 – Risk Assessment Methodology



3.3. SOFTWARE PACKAGES

PHAST Version 6.3 has been used to determine the approximate leak rate (kg/s) for each incident case. PHAST 6.3 is a DNV software tool, which examines the progress of a potential incident from the initial release to far-field dispersion, including modelling of pool spreading and evaporation, and flammable and toxic effects.

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4. FINDINGS

4.1. HAZARDS

The review of all potential major hazards with potential offsite effects identified four areas, with the potential for consequences beyond the near field (ie could impact outside the immediate workplace) that required further quantitative analysis. The major hazardous areas (in term of far field risk potential) are considered to be:

- Chlorine Drums (2 x 920 kg max) which are used for the chlorination of the potable water supply;
- Natural Gas pipeline, which reaches the surface near the site boundary and is used for onsite power requirements;
- Catastrophic Process incidents; Catastrophic failures of the digester (currently 2 are in use – expansion will see another one added) which operate at temperatures and pressures (approx 250 degrees and 20 Bara) where seen as a credible event[2];
- Dangerous goods storage of various hazardous chemicals which are stored in 36 different locations on the refinery.

4.2. CHLORINE BULLETS

The two chlorine drums are located on the East side of the facility near the potable water supply. The chlorine drums were modelled in PHAST [ref 4] as a saturated liquid at atmospheric pressure, the drums were assumed full (ie containing 920kg of chlorine), at weather conditions of 1.5m/s (D), 1.5m/s (F) and 5m/s (D)[3]. The following scenarios were considered and their results were modelled (see Appendix B for modelling graphs).

- 25mm Gas Leak: which in a worst case reaches a distance of 400m downwind before the probability of a fatality effectively reaches zero.
- Vessel Failure: which reaches a distance of 270m downwind before the probability of a fatality reaches zero.

In the case of a vessel failure the dispersion release would have a lesser impact, as there is a sharp loss in pressure behind the dispersion and therefore the effected distances is reduced.

In both circumstances, no impacts outside Alcoa's boundaries(ie offsite) are seen (see Appendix B - aerial map).

4.3. NATURAL GAS PIPELINE

Natural Gas is supplied to the facility via a 10" carbon steel pipeline managed by APT Parmelia, which supplies natural gas at a pressure of 3.44 MPa. The pipeline comes above ground at the entry to site at the southern boundary plant fence. This point is conservatively

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2 *Kaiser Aluminum Corp Gramercy Alumina refinery Louisiana, suffered a Digester Unit explosion in 1999 which caused, 20 injured (all understood to have been on site), released more than 400,000 pounds of sodium hydroxide resulting in residue settling on homes, buildings, and vehicles in the towns of Gramercy and Lutcher, located approximately 3 miles away. The cause of the digester failure included major failures in the maintenance and operational processes at site.*
http://www.msha.gov/minefire/gramercy/report/reportdept.htm#oview

3 *These provide for the range of potentially maximum meteorological conditions*

modelled as the gas being at its highest pressure (ie worst case conditions), is at the closest point to Alcoa's boundary and as it is above ground has the potential for worst-case impact[4]. The entrance into the metering site is through the double gate along the north west fence. Alcoa Security personnel can open all paddocks. The following scenarios were considered and their results were modelled (see Appendix C for modelling graphs).

- Pipeline rupture:
  - A jet fire of 12.5 kW/m^2 reaches a distance of 250m.
  - The prevailing flash fire at the Lower Flammability Level (LFL = 44,000 ppm for Chlorine) reaches a distance of 290m.
  - The maximum concentration at LFL reaches 192m after the flash fire.

These consequence distances do not go outside Alcoa's boundaries (ie have no offsite impacts), as shown in Appendix C.

Natural Gas is used to run the Calciners and it is expected that a release from this area will have a lesser impact than the modelled pipeline rupture and therefore the pipeline consequences can be used as a guide as to the impact from a natural gas release.

4.4. DIGESTER

The possible explosion from the 750kL-digester banks represents a credible potential hazard. At present there are 3 digester banks on-site – this will be increased during the expansion. Each bank contains 5 vessels, the modelling has assumed a full bank rupture, this is rather conservative, as it is probable that not all five vessels will rupture and the vessel are not run at 100% capacity. The extent of the risk was calculated using a TNT equivalency model. The calculations use the *Brode (1955) Equation* [Ref 1] to determine the equivalent weight of TNT, which would cause the same impact as the digester rupture. Once this weight of TNT is known, the overpressure distances were calculated using a TNT Overpressure Excel Spreadsheet. The results can be shown as follows:

	1% Fatality Distance (m) - 21kPag overpressure	**15% Fatality Distance (m) - 35kPag overpressure**	**100% Fatality Distance (m) – 70kPag overpressure**
Digester (750m^3) @ 480kPag, 250° C	149 m	110 m	78 m

It can be seen that at a distance greater than 149m there is no fatality impact on humans. This distance does not reach the site road. Although as noted in the Gramercy incident there is the potential for impact below a fatality level (ie potential health impact, irritation) beyond this.

The resulting impact has no offsite impacts and this is graphically represented in Appendix D.

[4] *Loss of containment events from underground sections of pipe is limited by the shape of the hole excavated by the gas loss.*

4.5. DANGEROUS GOODS STORAGE AND TRANSPORTATION

4.5.1. Dangerous Goods Storage

There are thirty-six (36) dangerous goods location on Alcoa's Wagerup Refinery, all of which are licensed (with DoIR) to store and handle various types and amounts of chemicals. The site has a well-developed drainage system, which will divert any chemical spills to a containment location preventing any loss of containment going off-site.. The drainage system allows the refinery to collect all losses in the tailing dams, which are, located some distance from the process facility.

The dangerous goods license means that the location and method of storage all comply with government specifications and are seen as a well-managed risk. The majority of the dangerous goods are small deposits, which will have no offsite effects.

4.5.2. Caustic Storage

Caustic (50% sodium hydroxide) is stored and handled in significant quantities at the Wagerup site. Caustic is a Class 8 (corrosive) substance and as such poses a hazard to personnel in the immediate vicinity of a spill (ie personnel must come into direct contact to be harmed and as liquid has a very low vapour pressure fumes are not a significant hazard). As the caustic storages are compounded to contain spills and the site has secondary containment available (which would lead spilled caustic to ponds) the potential for a caustic spill to cause significant acute impact off-site is not seen as a credible event[5]. where it can be recovered at a later stage.

4.5.3. Acid Storage

Similar to the Caustic the storage of acids (sulfuric (>51%)) does not present any hazard offsite (ie to the public). It is stored under a dangerous goods license as a Class 8 (corrosive) substance. Any spills would be localised within the compound, which has full containment available, and secondary containment is available which leads the acid to ponds where it can be recovered at a later stage.

4.5.4. LPG Storage

The LPG storage onsite is in small amount (eg 2 x 7.5kL, these tanks are the same size as typically found at petrol stations) and such sized tanks will not have any offsite impacts given their current location. This is consistent with Australian Standard 1596 "The storage and handling of LP Gas" which allows for similar tanks within 20 meters of residential facilities. The Wagerup facilities have 100's of meters separation to the boundary.

4.5.5. Dangerous Goods Transportation

The methods of transport vary depending on the chemical and are all conducted in accordance with the requirements of the Dangerous Goods (Road and Rail) requirements, which includes the requirements for licensed Vehicles, drivers ,etc.. The chemicals can be transported via rail from Bunbury or by road.

4.6. OTHER RISKS

The construction activities surrounding the expansion increase the potential for process incidents at site (due to tie-ins, heavy lifts, etc.), the Wagerup Safety Management System

[5] *Issues relating to environmental impact are addressed under other studies.*

has existing procedures to address these issues and compliance with these (and the completion of appropriate construction safety hazard studies should be conducted) will be an ongoing and iterative process.

During the construction phase a significant potential acute impact on the public will be the increased traffic associated with the construction workforce (slightly over 1500 persons) travel to and from the workplace. While initial plans relating to staggering the construction shifts from operations, pre-start briefings (which will include traffic issues and rigorous drug and alcohol policies), are in place, the detailed planing for the construction is yet to commence. Therefore, while the road safety issues are not typically included in an Off-site Individual Risk from Hazardous Industrial Plant analysis it is recognised that this is a potential impact on the public and appropriate recommendations to ensure manage of the issue to As Low As Reasonably Practicable are made.

5. CONCLUSIONS & RECOMMENDATIONS

The analysis of the consequences has indicated that none of the events associated with the identified hazards has the potential to cause serious acute harm to persons outside Alcoa's boundaries and hence the levels of public risk associated with the existing plant (and expansion) comply with the all the relevant EPA Off-site Individual Risk from Hazardous Industrial Plant criteria.

The expansion of the Alcoa Wagerup refinery presents a greater potential for hazards to occur onsite and continued focus will be required to ensure that the construction and on-going operational risks are appropriately managed.

The management of public safety is an ongoing process for Alcoa and will require an iterative analysis throughout the timeline for the expansion. The following recommendations will help ensure the risk to public safety is minimised:

- Alcoa Wagerup are in the process of implementing a comprehensive Major Hazards Management System (dedicated to equipment whose failure could result in major hazards impacts). While such major hazard control programs are mandatory at Major Hazard Facilities (MHF)[6], Aloca Wagerup falls well below the threshold for being classified a MHF (ie would require 25 tonnes of chlorine or 200 tonnes of LPG on site) and the development of the Major Hazards Management System is a proactive approach by Alco to ensure that at all times major hazards are understood, communicated and that the controls are of a high integrity.

  This process will provide a robust and systematic approach to identifying the critical equipment controls for managing major hazards and ensuring these are in place and their performance effectively monitored.

  The implementation of this process (planned for 2005) should include a review of all the major hazards identified within this report and the routines for monitoring the performance of the relevant critical equipment controls should be established and in place before the commissioning of the proposed expansion.

- A traffic management plan for the refinery to help accommodate the increased traffic to the area during construction should be developed and implemented once the construction plan is further developed.

- The on-going design process should include all the Normal Hazard review processes (ie HAZID/ Risk Reviews, HAZOP, construction safety studies, etc.) typically applied by during good engineering design.

- In order to ensure that additional hazards are not introduced that could adversely impact on the public, the existing procedures should be amended to ensure that before any additional Hazardous Material storage is allowed on the site, that the in addition to the normal Dangerous Goods licensing requirements that off-site impact potential is considered.

- The auditing (and monitoring) requirements of the Wagerup Safety Management System, should continue to be utilised to ensure that the relevant control systems

[6] *Sites, which store and/or handle specific Hazardous materials in such quantities as to poss a major hazard to workers and the community, as defined by the National Standard for Control of Major Hazard facilities.*

(including Dangerous Goods reviews, effectiveness of management systems, etc.) remain effective, beyond the commissioning of the operation.

6. REFERENCES

1. Lees FP, *Loss Prevention in the Process Industries*, 2nd Edition, Volume 2, 1996.
2. Health and Safety Incident Classification, Document Number 18.32.2, Feb 2003.
3. Guidance for the Assessment of Environmental Factors (in accordance with the Environmental Protection Act 1986) – Guidance for Risk Assessment and Management: Off-site Individual Risk from Hazardous Industrial Plant, July 2000, WA.
4. PHAST 6.42, DNV, 2004.
5. Natural Gas Emergency Procedure (WGP), Document Number 42099, Dec 2002.
6. Construction Tie-in / Modification Work Procedure (WGP), Document Number 26683, May 2002.
7. Project Safety Review – Document Number 18.17, June 1996.
8. Process Safety Management – Worksheet, Document Number 18.17.2, June 1996.
9. Major Hazard Management System – An Overview.
10. Major Hazard Control Plan for Wagerup Refinery Emergency Response Controls (GWP), Nov 2004.
11. Withers, R.M.J. and Lees F.P., "The Assessment of Major Hazards. The Lethal Toxicity of Chlorine, Part 2. Model of Toxicity to Man", J. Haz. Materials, 12 (1985), 283 – 302.
12. Zwart, A. and Woutersen R.A., "Acute Inhalation Toxicity of Chlorine in Rats and Mice: Time – Concentration Mortality Relationships and Effects on Respiration", J. Haz. Mats., 19 (1988), 195 – 208, Elsevier Science Publishers B.V., Amsterdam.
13. van Heemst V., "Estimating Chlorine Toxicity Under Emergency Conditions", Chlorine Safety Seminar, Brussels, November 14 – 15, 1990.
14. Matheson, *"Matheson Gas Data Book"*, Sixth Edition, December 1980.

APPENDIX A: GUIDEWORDS MAIN CATEGOIRES

External and environmental hazards

- Natural and Environmental Hazards
- Created (Man-made) Hazards
- Effect of the Facility on the Surroundings
- Infrastructure
- Environmental Damage

Facility hazards

- Control Methods/Philosophy
- Fire and Explosion Hazards
- Process Hazards
- Utility Systems
- Maintenance Hazards
- Construction/Existing Facilities

Project implementation issues

- Contracting Strategy
- Hazards Recognition and Management
- Contingency Planning
- Competency

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APPENDIX B: CHLORINE MODELLING RESULTS

MODELLING

The consequences of each scenario were modelled in PHAST. PHAST is a fully integrated software package that allows detailed hazard assessment of toxic and flammable substances. The consequences models in PHAST employ the Unified Dispersion Model (UDM), which has been validated against a wide range of experimental tests. It has been accepted by companies and government worldwide, and is the most widely used package of its kind in the world.

The two LoC event sizes were analysed as follows:

- 25mm vessel leak size typical for a Small Bore Fitting (SBF) failure; and
- Vessel Rupture.

Three wind speeds were analysed in PHAST and the worst-case scenario results were used. The three weather conditions were:

1.5 F	Wind at 1.5m/s, still night conditions
1.5 D	Wind at 1.5m/s, still day conditions
5 D	Wind at 5m/s, windy conditions

The following information in used in PHAST for the modelling on the Chlorine consequences.

Probit Number

The probability of fatality at a point is calculated via the probit equation. The toxicity of a material is defined by three parameters: n, a, b.

PHAST first calculates the toxic load L received at a given point:

$$L = \int_0^T C^n dt = C^n T$$

where C is the concentration in ppm, and T is the duration of the exposure in minutes.

Next the probit number Y is calculated:

$$Y = a + b\ln(C^n T)$$

The probit function used in this study for chlorine is that of van Heemst (1990), with:

a = -10.1
b = 1.11
n = 1.65

Probability of a Fatality

The probability of fatality at a given point under a given toxic exposure is calculated from the probit number as follows:

$$P(\,fatality) = 0.5 + \frac{1}{\sqrt{\pi}} \int_0^{\frac{Y-5}{\sqrt{2}}} e^{-x^2} dx$$

For chlorine, the fatality probabilities can be calculated to be:

The following table illustrates the effects likely to be experienced by humans exposed to various concentrations of chlorine [Ref. 14]. It is recognised that the concentrations for fatalities may not agree with those predicted using the probit, they are, however, useful as a general guide.

HUMAN RESPONSE TO CHLORINE EXPOSURE

Chlorine Concentration (ppm)	Effect
1	Minimum concentration causing slight symptoms after several hours.
3.5	Minimum concentration detectable by odour.
4	Minimum concentration that can be breathed for 1 hour without damage.
15	Minimum concentration causing throat irritation.
30	Minimum concentration causing coughing.
40-60	Concentration dangerous in 30 minutes.
1000	Concentration likely to be fatal after a few deep breaths.

RESULTS

Figure B. 1 – 25mm Chlorine Leak

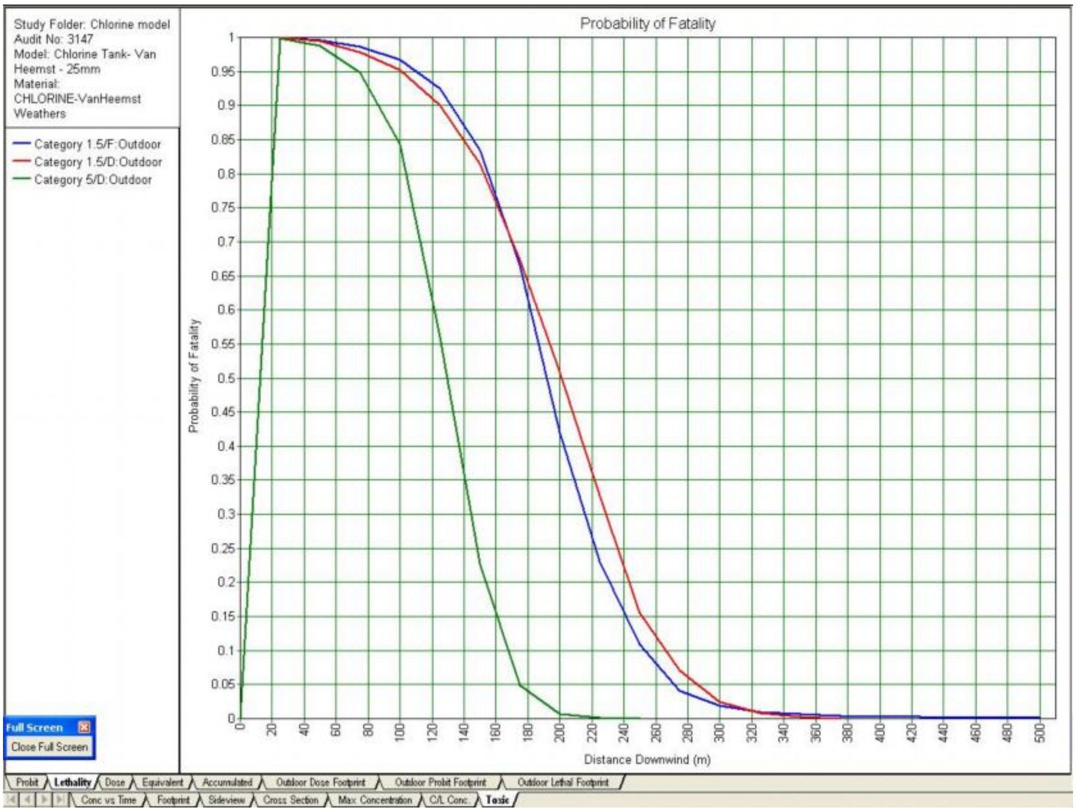

Figure B. 2 – Rupture – Chlorine Release

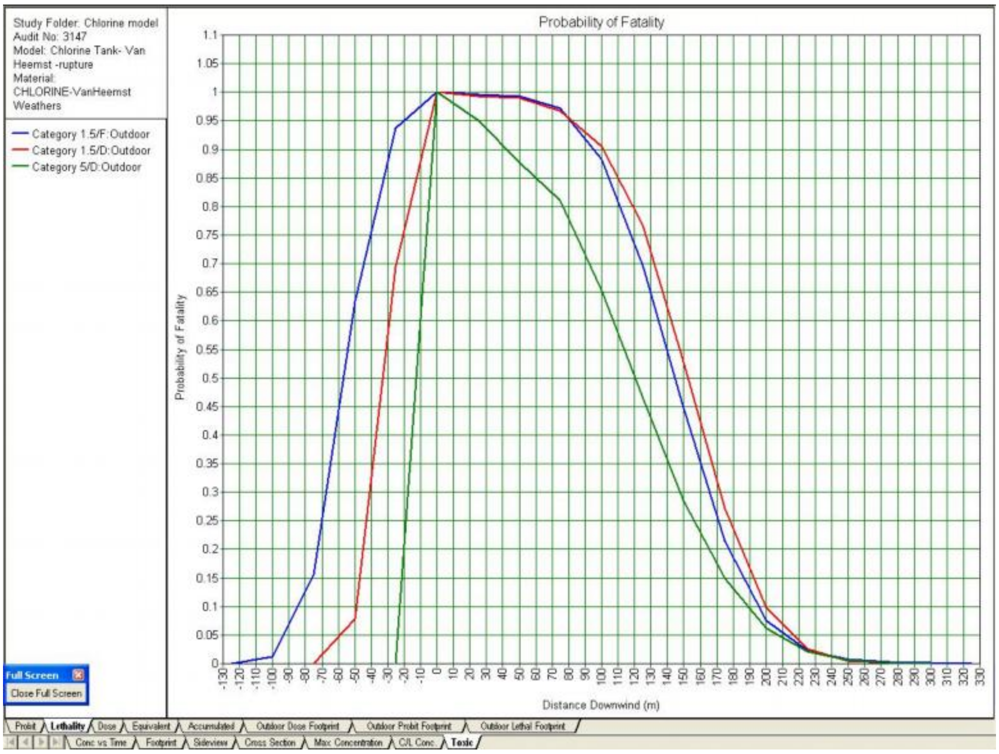

Figure B. 3 – Aerial Map with Consequence Distance

INTERPRETATION OF RESULTS

A 25mm Chlorine vessel leak can propagate to a toxic distance of approx. 400m until the probability of fatality falls to a negligible level. From the different weather conditions it can be seen that the two slower wind speeds create a more hazardous scenario as the chlorine is relatively dense gas and can therefore be carried further at slower wind speeds.

A rupture of the chlorine bullet would amount to a toxic distance of approx. 270m until the probability of fatality falls to negligable. The reasoning behind the lesser consequence distance for a full rupture of the vessel, compared to a 25mm leak, is that in the occurance of a rupture pressure from the vessel is immediately lost and there is less of a force behind the propagation of the chlorine.

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APPENDIX C: NATURAL GAS MODELLING RESULTS

MODELLING

The natural gas pipeline was modelled in PHAST as a vessel with a large amount of inventory (10E4 kg). The pressure was specified as 34.4bar and at a temperature of 25ºC. Under these conditions PHAST calculated the length of a Jet Fire, flash fire and maximum concentration at the three weather conditions. These weather conditions were:

1.5 F	Wind at 1.5m/s, still night conditions
1.5 D	Wind at 1.5m/s, still day conditions
5 D	Wind at 5m/s, windy conditions

Worst-case scenarios were selected from these three wind conditions.

The Jet Fire model used in PHAST uses the Shell model which bases it's calculations on the following preliminary equations:

Jet Velocity

The jet velocity, v_J is calculated as:

$$v_J = \frac{M}{\rho_{Jet}\,\pi r^2_{expanded}} = \frac{\text{Mass discharge rate}\left(\text{kg s}^{-1}\right)}{\left(\text{Mass density}\left(\text{kg m}^{-3}\right)\right)\times\left(\text{Cross-sectional area}\left(\text{m}^2\right)\right)}$$

The density of the jet is calculated using the Properties Library.

Expanded Radius

The expanded radius is calculated as:

$$r_{expanded} = \left(\frac{m}{\rho_{Jet}\,\pi v_j}\right)^{\frac{1}{2}}$$

The flame is modelled as a cone frustum, where the base of the frustum is lifted off a distance B from the release point, and is tilted an angle a from the axis between the release point and the base.

The flame is defined by four circles. The first and second have the same centre and inclination, but the first has zero radius. The third and fourth have the same centre and inclination but the fourth has zero radius. The first and fourth circles, with their radii of zero, are added to complete the surface of the flame; the radiation calculations treat the flame as a set of conical surfaces, where each conical surface is bounded by two circles, and these two circles ensure that the entire flame is treated as a radiating surface.

The worst-case scenario for a jet fire was taken at weather condition 1.5/D and the result is shown in Figure C.1.

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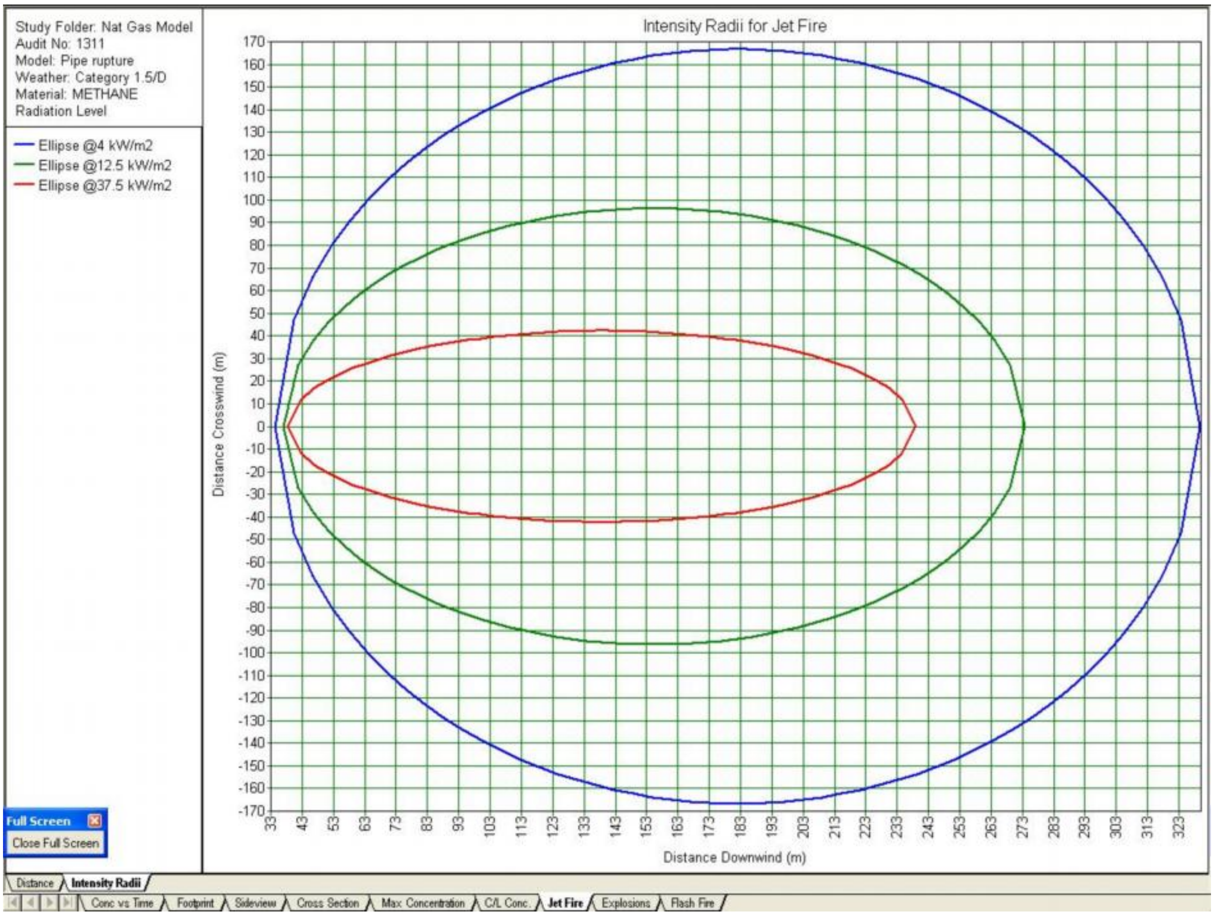
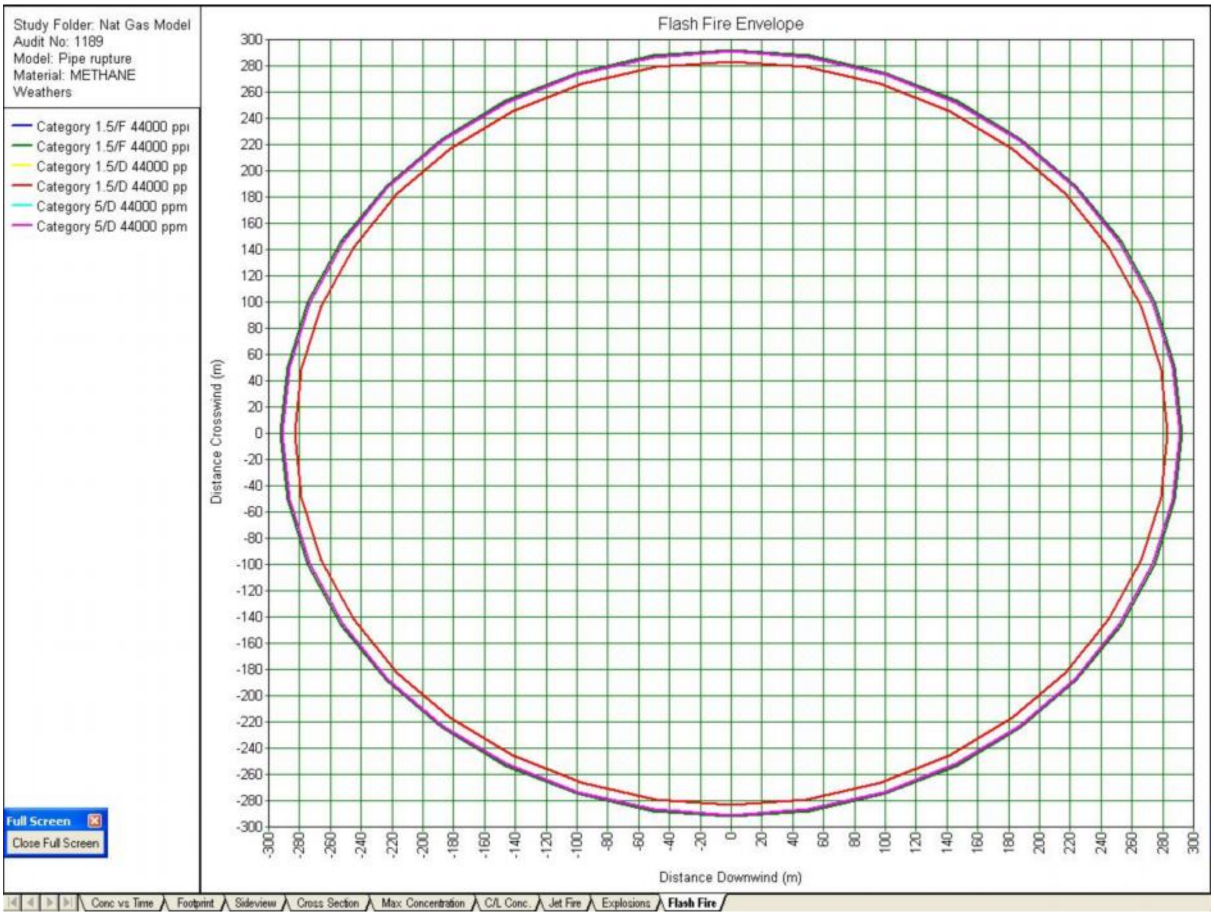
Figure C. 1 – Natural Gas Pipeline Rupture – Jet Fire



The Flash Fire calculation uses flammable parameters in PHAST to calculate the distance potential of a flash fire at the substances lower flammability limit. The flash fire graph (Figure C.2) shows the maximum area covered by the flash fire envelope, i.e. the area swept out by the flash fire footprint, through all wind directions.

Figure C. 2 – Natural Gas Pipeline Rupture – Flash Fire



The maximum concentration graph (Figure C.3) is achieved in PHAST by modelling the distance to which the LFL is reached. The graph shows the contours of the maximum concentration reached at a given location during the course of the release at the three different weather conditions used.

Figure C. 3 – Natural Gas Pipeline Rupture – Max. Concentration

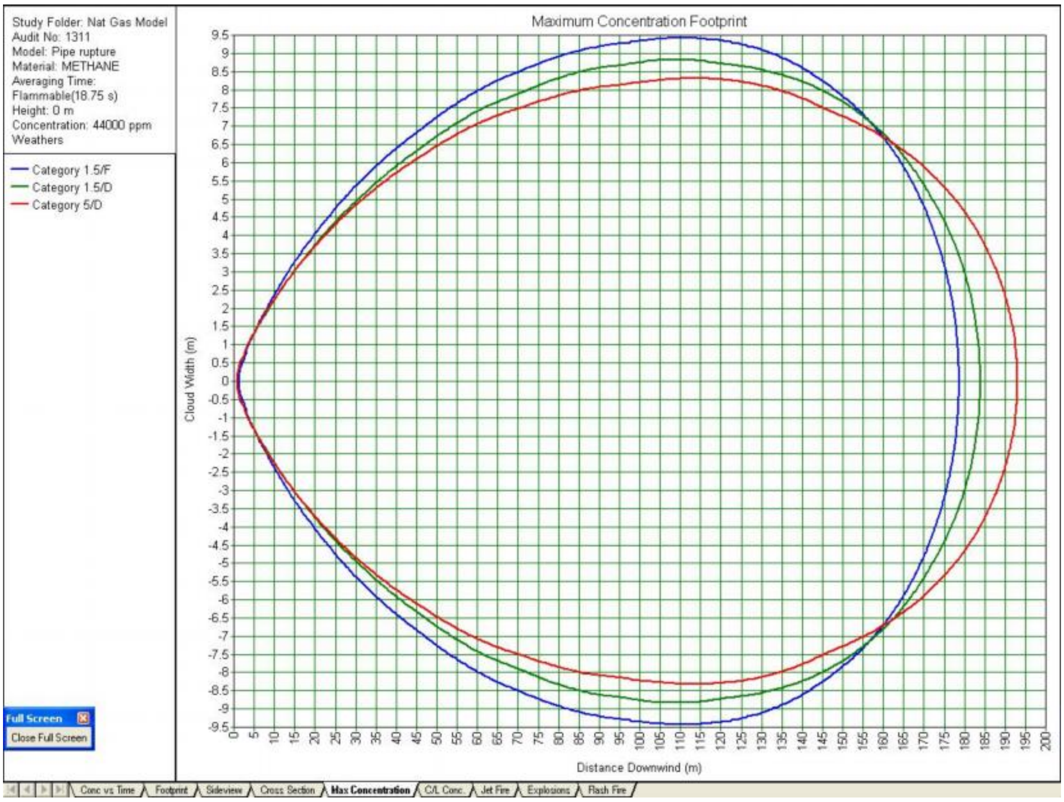


Figure C. 4 – Aerial Map with Consequence Distances

INTERPRETING RESULTS

A 10” pipeline rupture can propagate to a distance of approx. 250m by a jet fire. From the different weather conditions it was determined that the slower wind speed of 1.5/D created a more hazardous scenario as the natural gas is relatively light gas and can therefore be carried further a slower wind speeds.

The rupture will also produce a flash fire to a distance of 290m at a wind speed of 1.5/F. This is an initial fire release and it is most likely that following the flash fire the jet fire will continue to burn until the pressure in the pipeline is lowered enough to prevent any further damage.

The probability of ignition is present for this rupture up to 192m from the initial release point, this is shown through the maximum concentration graph which shows the distance to where the flammability limit falls below the LFL of methane.

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APPENDIX D: DIGESTOR MODELLING RESULTS

MODELLING

The calculations use the *Brode (1955) Equation* [Ref 1] which determines the TNT equivalent tonnage for an explosion in the digester. This calculation uses the input of the pressure of the digester, the volume and the specific heat capacity ratio for the material contained within the digester. An Excel model, which determines the effected distance for different TNT explosions, was then used to determine the distance of impact at different overpressures. The results were as follows:

	1% Fatality Distance (m) - 21kPag overpressure	**15% Fatality Distance (m) - 35kPag overpressure**	**100% Fatality Distance (m) – 70kPag overpressure**
Digester (750m^3) @ 480kPag, 250° C	149 m	110 m	78 m

At a distance greater than 149m from the digester explosion, the overpressure level is too low to have any impact on humans.

Figure D. 1 – Aerial Map with Consequence Distances