A Best Practice Approach to Shelter-in-Place for Victoria

MFB

Victoria

CFA

Australian Government

Chem Centre

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A Best Practice Management Model for Protective Action Decision-Making has been developed by the MFB, CFA, DH and ChemCentre. This research project was made possible with the financial support of the Australian Government through the Victorian Emergency Management Grants Program. The project incorporated an extensive review of world's best practice in this area, including scientific research to validate that shelter-in-place (i.e. to take shelter in your home) can provide community protection.

Key outcomes of the project include:

- decision guides for emergency services, industry and the local government sectors; and
- support tools to assist incident controllers on how best to manage public safety.

Shelter-in-Place Report
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Guide Definitions

ACH	Air Changes per Hour
AEGL	Acute Exposure Guideline Level
AIHA	American Industrial Hygiene Association
ALOHA	Areal Locations of Hazardous Atmospheres
CALD	Cultural and Linguistically Diverse Groups
CFA	Country Fire Authority
CSEPP	Chemical Stockpile Emergency Preparedness Program
Concentration	Concentration is the amount measured in parts per million (ppm) or milligram per cubic metre (mg/m^3), of a substance present in the atmosphere resulting from a release.
DH	Department of Health
ERPG(s)	Emergency Response Planning Guideline(s). Values intended to provide estimates of concentration ranges above which one could reasonably anticipate observing adverse health effects.
USEPA	United States Environmental Protection Agency
Evacuation	Evacuation is the timely and effective relocation of exposed persons or persons having the potential of being exposed to a toxic or chemical agent, to an alternate location having no potential for exposure to the same toxic or chemical agent.
Incident Controller	An incident controller is the person in charge of the overall incident management at site.
NEWS	National Emergency Warning System
NOHSC	National Occupational Health and Safety Commission
Protective Action Zones	This is the area downwind from the release point within which the airborne concentration of the vapour is high enough to necessitate a protective action.
SEWS	Standard Emergency Warning Signal
SIP	Shelter-in-place, is a protective action to provide public safety by going indoors and following the recommended shelter, shut and listen actions as instructed by the first responders.
STEL	Short Term Exposure Limit, 15 minute occupational exposure limit
Toxic	A substance that is poisonous and/or hazardous to life or health
TWA	Time-weighted average, 8 hour Occupational Exposure Limit

Executive Summary

Following the review of best practice decision making during outdoor hazardous atmospheres, a strategy has been developed for the Australian Fire Services, to provide an effective and expedient response. This strategy was validated for Australian residential houses under Australian conditions using scientific testing.

In this report an outdoor hazardous atmosphere incorporates toxic loads from accidental or deliberate chemical releases, or smoke and products of combustion from fires.

A protective action decision guide has been developed for emergency services to use during outdoor hazardous atmospheres where there may be a risk to public health (refer to ***Protective Action Decision Guide for Emergency Services during Outdoor Hazardous Atmospheres***). This guide details best practice principles for planning and implementing community protective actions during hazardous atmospheres. A standard approach to protective action decision making is provided and includes the recommendation of issuing shelter-in-place (SIP) as a default protective action to avoid potential public exposure, followed by a more detailed analysis process utilising a flow chart.

An atmospheric modelling integration tool was developed to assist first responders in this decision making process. This tool can rapidly identify affected areas as a plume dispersion display on Australian mapping systems. Generated reports provide additional information on potentially affected population demographics and housing data, as well as impacted features of interest (e.g. schools, hospitals, etc.).

A protective action guide has also been developed for local government and industry (refer to ***Protective Action Guide for Local Government and Industry during Outdoor Hazardous Atmospheres***). This guide provides information on a standard approach to community protective actions during hazardous atmospheres. The main purpose of this document is to ensure that local government and industry are using consistent terminology with emergency services when providing public information related to a chemical incident to ensure public confidence and compliance. Community education templates have been developed using a descriptive catch phrase for the public to implement when instructed to SIP.

1. Introduction

1.1 Background

Emergency management of chemical incidents is the responsibility of emergency services. There are many industries within populated residential areas with large quantities of toxic hazardous chemicals. There is also an increased volume of chemicals being transported through residential areas. Accidental outdoor chemical releases can cause severe health effects or even death in nearby residences. It is therefore essential to have emergency protective action plans in place to manage the public health risk and for rapid official and public response. Two protective action options are used in the event of an accidental chemical release – evacuation, or sheltering inside a building, also know as shelter-in-place (SIP). Evacuation is very resource intensive for emergency management agencies and not always the safest option for a short term release of toxic chemicals.

Terminology for sheltering varies from country to country. The term shelter-in-place is commonly used in the United States as an emergency response action in which people are advised to take shelter indoors and seal their building. This is usually done by closing doors and windows, and turning off ventilation systems. In Australia, SIP is referred to as “protect-in-place” (AS HB76:2004 Dangerous Goods – Initial Emergency Response Guide) and is largely based on U.S. data and management models. The terminology shelter-in-place has been adopted in this report for the relevance of its meaning and associated public perception with sheltering, as described by Higgins (2006).

SIP is an effective emergency response action used worldwide in a short-term chemical release situation when the outdoor atmosphere is too toxic for evacuation. Extensive studies have shown that the air inside a building provides temporary protection until the vapour cloud has passed (Blewett et al. 1996, Engelmann, 1992, and Siren, 1993). The effectiveness of SIP is determined by a number of factors. One important factor is the rate at which outside air enters the house, this is measured as the air exchange rate. Air exchange rate is a measure of airflow (m^3 h^{-1}) per volume (m^3) and is usually expressed as air changes per hour (ACH). Air exchange rate is a measure of three processes:

- infiltration – air leakage through cracks and openings in the building envelope,
- natural ventilation – airflow through open windows and doors,
- mechanical ventilation – forced air movement by fans.

Computer modelling software such as ALOHA (Areal Locations of Hazardous Atmospheres), developed jointly by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (USEPA), is able to estimate indoor air concentrations during an atmospheric chemical release, however, this software assumes a typical air exchange value for all low-rise buildings. Studies in the U.S. and Australia have shown large variability in residential building air exchange rates (Chan et al. 2005, Brown 1997). This variability can have a significant effect in reliably estimating the level of protection provided by buildings.

Very little data has been obtained on air exchange rates for house type in Australia. This data is essential to estimate indoor exposure time in residential houses during a chemical release. By measuring air exchange rates for a variety of house types in Australia, and incorporating these values into computer modelling software, a much more accurate estimate of indoor chemical concentration and the level of protection provided by SIP can be determined.

There appear to be gaps in the overall process of initiating and implementing SIP within emergency services in Australia. Inadequate procedures for protective action decision making and community engagement were highlighted during a chemical incident at Westpoint in Victoria in December 2007 (OESC, 2008). Emergency preparedness areas identified as lacking, included a delayed decision making response and lack of inter agency co-ordination in managing the protective strategies for the community.

The effectiveness of SIP not only relies on the protective action decision making process but procedures and systems in place on how to communicate this decision to the public, and then for the public to accept this information and enable it. Public warning systems and telephone ring-down systems are required to inform residents of an emergency situation. And finally, for any management model to be successful, the public need to to be educated through community and industry education programs.

1.2 Project Aim

The aim of this research project is to develop a management model to assist emergency services in its decision making process during outdoor hazardous atmospheres that may require evacuation or SIP. To develop such a model for Australian conditions, an understanding of air exchange rates for a variety of different house types, coupled with new decision making tools (e.g. plume modelling integration software) and targeted education is paramount to its success.

This project is limited to validating SIP for residential houses only. Further research would be required for validating the level of protection provided by other structural types, such as commercial and industrial buildings.

1.2.1 Air Exchange Rates

Air exchange rates were derived for different house types using the tracer gas decay method. A partnership was formed with the ChemCentre in Western Australia to share data on air exchange rates for Australian houses. Testing was performed on a number of different house types in each state of Australia.

The values for air exchange rates can be averaged for each house type (e.g. brick veneer, weather board) and age, and allocated to residential areas, particularly those in high risk areas. A more accurate indoor air concentration can be calculated during a chemical incident using known air exchange rates, which would allow emergency services to more confidently instruct SIP as a safe alternative to evacuation.

1.2.2 Development of More Practical Modelling Platforms

A number of plume modelling software programs are available for predicting the downwind hazard from the release of hazardous materials. The take up and utilisation of these models by Fire Services within Australia has been mostly hap-hazard and disjointed. Whilst a few fire services actively use plume modelling at incidents, most have only limited knowledge or experience, or in some case do not conduct any modelling at all. A number of factors have contributed to this situation including the complexity of some programs, time and space to produce useful outputs, poor quality Geographic Information System (GIS) data and integration or the need for GIS expertise.

This project has included the development of a modelling integration tool, to allow trained personnel to rapidly produce plume predictions from chemical releases with Australian GIS mapping data, for assessment by emergency managers and other stakeholders. This tool also integrates Census Data analysis, providing instant reports (including Threat Zone Area Assessment) on potentially affected population demographics and housing data, as well as reports on impacted features of interest.

This additional information will assist emergency managers to make timely decisions, direct resources and prioritise tasks as well as pre-empt potential problems relating to exposed communities. Whilst of primary use during an incident, this additional information will be of benefit during any pre-planning activities, as well as post incident, for agencies such as Health and Local Councils involved in recovery operations.

It should be noted that, at present, plume modelling cannot be used to predict downwind concentrations of products of combustion caused by fires. However, there is a capability in this modelling integration software tool to manually highlight an area that is thought to be affected according to the meteorological conditions or from visual or odour observations. This feature will then provide the same report information as the prediction outputs with additional 'all hazards' capability.

1.2.3 Development of Management Models for Emergency Services

The *Protective Action Decision Guide for Emergency Services during Outdoor Hazardous Atmospheres* was developed to allow for effective emergency planning for a chemical release, and includes simplified decision tools to minimise time delays in selecting the appropriate protective action. Making this decision tool available across all emergency agencies will provide a more coordinated response when required.

The best practice model will be easily transferable to other Australian States and should be considered in updating Australian Standards (HB76:2004 Dangerous Goods – Initial Emergency Response Guide). A modified version of this guide was developed for local government and industry to provide information on the decision making process used by emergency services during a chemical release, as well as providing consistent terminology and community education information on how to SIP (see *Protective Action Guide for Local Government and Industry during Outdoor Hazardous Atmospheres*).

1.2.4 Community Education Models

Community fact sheets and programs to educate the community on SIP actions have been developed to give the public the understanding behind SIP. These education materials promote a slogan for SIP called "shelter, shut and listen", which are the necessary actions required when applying this protective action.

2. Review of Shelter-in-Place as a Public Protective Action

2.1 Effectiveness of Shelter-in-Place

SIP refers to sheltering inside a building and closing all doors and windows, and turning off ventilation systems. SIP only offers a temporary protective measure during an outdoor hazardous atmosphere because the outdoor air infiltrates the building as the plume passes, however, for short term chemical releases (less than 4 hours) it can provide substantial protection from toxic doses.

The effectiveness of SIP has been validated through modelling and experimental research (Chan et al. 2004, Sorensen et al. 2002, Blewett and Arca 1999). There is also real data from a comparative study of evacuation versus sheltering during an incident in southwest England by Kinra et al. (2005). The results support SIP over evacuation as a public protective action during a hazardous release accident. No other comparative studies of evacuation against sheltering can be found, however, there are many documented case studies in the U.S. by the National Institute for Chemical Studies for incidents involving chemical releases (NICS, 2001). Findings from these incidents reported no fatalities associated when sheltering in place.

Several towns in the U.S. advise SIP as the first and immediate response when alerted to a chemical emergency. Contra Costa County in California has successfully used this approach for the past ten years. They promote a three stage response of ‘shelter, shut and listen’. This immediate action provides protection for the community while authorities assess the situation and develop the appropriate response strategies.

2.1.1 Shelter-in-Place Factors

The amount of protection provided by SIP varies mainly with the air infiltration, or air exchange rate of the building and the length of time the building is exposed to the toxic plume. This is because the outdoor air gradually infiltrates the building through small gaps and cracks. The more gaps in a building, the greater the infiltration rate and the faster the outdoor air contaminant enters the house. However, indoor air concentrations do not increase in a linear relationship to ACH, that is, an airchange rate of 1.0 does not mean that all the indoor air will be replaced with 100% of outdoor air in one hour. This is partly due to the interior mixing of the air, also, some of the contaminants that enter the house will also exit the house, ie. ACH is a balanced flow of air into and out of a building. Fletcher and Saunders (1994) calculated the length of time taken to replace 95% of the air inside a house with outdoor air, at an air change rate of 0.5 h^{-1}, to be 6 hours.

Indoor air concentrations are also reduced by filtration from the building envelope and by sorption on indoor surfaces, resulting in a reduced peak indoor concentration. Depending on the chemical, sorption can occur by absorption into materials, or by a chemical reaction with the material. Sorption can be effective in reducing the indoor air concentration during a chemical release, however, desorption (e.g. off-gassing) can lead to low levels of exposure after the plume has passed. Not a lot of data can be found for sorption, but a study using ammonia has shown a 15 to 35% reduction in peak indoor air concentration (Chan, 2006). A larger reduction in peak concentration was found for lower infiltration rates.

Another significant factor that affects the success of SIP is the time lines that emergency services use for public warning and the protective action processes used. Delays in SIP implementation or termination can greatly increase indoor air concentration (Chan et al. 2007).

The most important and difficult task when issuing SIP has often been found in public compliance. Previous incidents where SIP has been advised have shown a low response to this action (Vogt and Sorensen, 1999). Research has shown that effective communication with the public is essential for the SIP protective action to be followed when issued in an emergency. Poor communication and lack of understanding of the reasoning behind SIP may lead people to ignore official recommendations if they perceive that this is not an effective means of protection.

2.1.2 Air Exchange Rates

The level of protection offered by sheltering-in-place is determined by the outdoor air infiltration rate into the building. The rate of infiltration is determined by the pressure differences between outside and inside a building. These pressure differences drive air across the building envelope. The pressure is directly related to wind speed and temperature differences. Higher wind speeds increase the pressure difference and the infiltration rate, but also disperse hazardous plumes more quickly. Greater temperature differences between indoors and outdoors (also known as the stack effect) also increase infiltration rates.

Infiltration rate is a measure of the rate of air movement through doors, windows and gaps in the building, and determines the number of times fresh air replaces the indoor air, also known as air change rate or air changes per hour (ACH). Buildings with lower air change rates will have less vapour intrusion than buildings with higher air change rates. A house would be considered tight if it had an air exchange rate of 0.5 h^{-1} or less. A goal in the U.S. is to achieve a rate of 0.25 h^{-1} (Vogt et al. 1999).

Houses with higher air infiltration rates (e.g. 1 ACH) will have a faster rise in indoor air concentration, however, once the plume has passed, the concentration will rapidly decay much faster than the tighter houses due to the rapid exchange with the outdoors. If residents sheltered for a long time, the indoor concentration would eventually approach the outdoor concentration, therefore it is important to terminate sheltering once the hazardous plume has passed.

Meteorological conditions can have a significant effect on indoor air change rates. The higher the wind speed the more quickly the chemical will infiltrate a building (Chan, 2006). In the U.S., air change rates have been reported as 0.1 ACH for a tight house during mild weather conditions to 1.5 ACH for a leaky house under severe weather conditions (Chan et al. 2005). A year long study by Wallace et al. (2002) reported that a typical temperature difference of 10°C between indoors and outdoors was recorded to have an increase of 0.2 air changes per hour. Relative humidity and atmospheric stability also affect infiltration rates; an inversion layer causes a chemical plume to travel closer to the ground, where it is less likely to dissipate.

Air change rates are much lower for modern, energy efficient buildings than older, pre 1980's homes before housing standards changed (Sherman and Dickerhoff, 1998). Increased energy costs have lead to changes in building codes for reduced energy consumption and more stringent weatherisation requirements for new houses. A study in the U.S. by Vogt et al. (1999) used house age as an indicator for air infiltration rates as a result of these changed building codes.

Studies by Biggs and Bennie (1988) on houses in Melbourne and Sydney, found that infiltration rates in older houses with fixed wall vents were double when compared to newer houses with sliding aluminium windows, exterior doors with weather-stripping, on a concrete slab, with no wall vents. A U.S. study by Sherman and Dickerhoff (1998) also found that timber houses and houses on stumps generally have a much higher air change rate than houses on a concrete slabs.

Socioeconomic status has also been found to be related to high air exchange rates in residential buildings. A study by Chan et al. (2005) on single residential buildings found that houses occupied by low-income households had significantly higher air exchange rates than those occupied by higher income households. This has significant importance because normally lower income households are situated closer to industries.

Biggs et al. (1987) estimated the average natural filtration rate for 32 test houses located in major Australian cities using fan pressurisation testing and empirical equations, to account for wind speed. The values were 0.44 ACH in Canberra, 0.55 ACH in Sydney and Hobart, and 0.57 ACH in Melbourne. In comparison, Ferrari (1991) tested the living rooms in 41 Sydney houses using tracer gas decay. Results varied from 0.2 to 2.3 ACH, with an average of 0.9 ACH, with the newer houses (less than five years old) measuring an average of 0.33 ACH.

Houses in colder climates appear to have lower air change rates, with a minimum standard of 0.5 ACH, a legal requirement in Norway, Sweden, Finland, Denmark and Iceland, 0.8 in Germany and 0.5-1.0 in the U.K. No minimum ACH standards are enforced in Australia and there are limited studies on residential housing air change rate measurements.

2.1.3 Time Lines

There are a number of time constraints involved when implementing SIP. Once the decision has been made to SIP, there may be a delay in the time taken to notify the public of this instruction. Past studies by Rogers (1994) have found that residents can take a long time to respond to emergency warnings. People may not respond immediately to a warning. Studies have found that people often seek additional advice from relatives, friends and the media before making a decision. A further time delay occurs for the population to implement the protective action.

A time delay for initiating SIP can have a significant impact on its effectiveness, as high concentrations of a toxic plume may have already entered a building if doors and windows are not closed before the plume arrives. The decision to end SIP is just as important, and must be made before the air concentration inside is greater than the outdoor air concentration. Hazardous vapours that enter tight buildings during a hazardous plume will leave the structure very slowly once the plume has passed over. Also, chemicals that have sorbed onto building surfaces will gradually desorb, creating a continuous exposure and increased dosage to the occupants. Therefore, once the toxic plume has passed, notification must be made for residents to open up all doors and windows, to allow fresh air in and to flush or remove any hazardous vapours.

2.1.4 Dose/Exposure and Health Effects

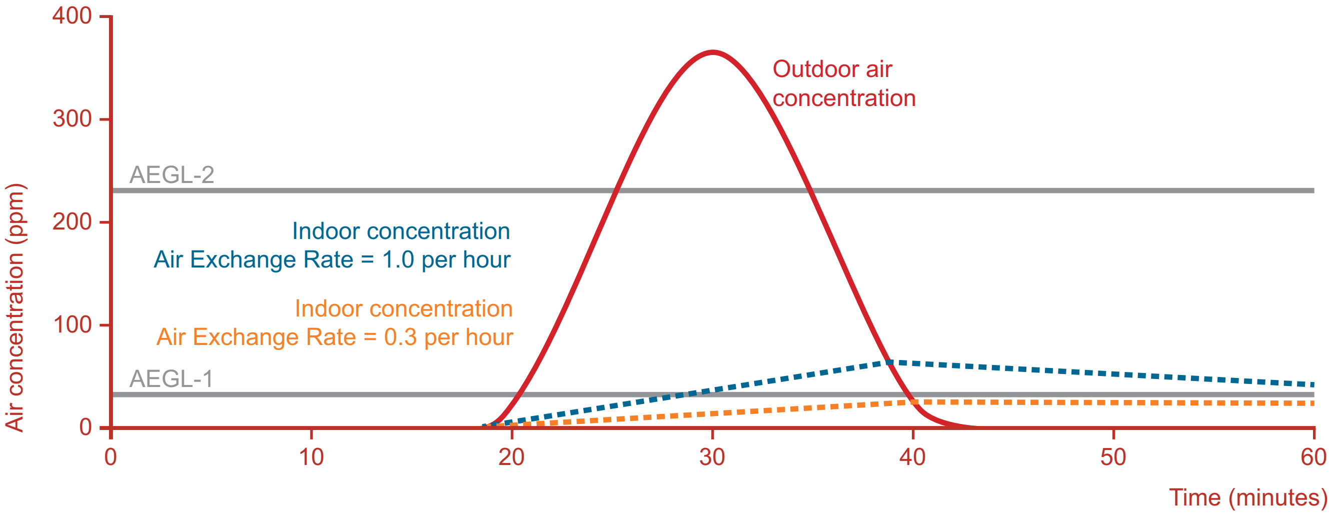
SIP effectiveness has often been considered in terms of the dose reduction achieved by sheltering indoors. The dose of a chemical is a measurement of how much a person is exposed to a chemical over a period of time, and the higher the dose the greater the likelihood of illness, disease or death. A common misconception by the general public has been found that exposure to a toxic material will lead to harmful or fatal consequences. This lack of understanding may be related to the lack of compliance associated with sheltering during a chemical release. It is therefore very important to include the dose and exposure concept in the education models for both the community and emergency services.

The protection provided by sheltering is usually much greater than that calculated by the dose reduction value. Health effects, unlike dose, do not necessarily vary linearly with concentration. For some toxic chemicals such as hydrogen sulphide, a short-term exposure at high (peak) concentrations is much worse than exposure to low concentration for a longer time. Figure 1 shows an example where sheltering provides protection from the peak outdoor air exposure and is very effective in preventing serious injuries or fatalities for those chemicals with a high toxic load. Since the goal of SIP is to minimise adverse health affects caused by the toxic plume it is essential to consider the dose-response relationship for the toxic chemical.

2.1.5 Community Exposure Standards

The level of risk to the community varies with the outdoor air chemical concentration and its related health effects. The level of public safety has previously been measured in terms of Occupational Exposure Standards, developed to protect the worker for an 8 hour day, over a working lifetime. These limits, however, do not provide protection for the

Figure 1. Computer modelling of airborne concentration of ammonia, outdoors and indoors at a point 2 km downwind for two building air exchange rates



general public, particularly the sensitive population, including infants, the elderly and people with respiratory diseases. We recommend a hierarchy based approach for selecting air quality reference values that are appropriate for protecting the public from short-term exposure(s) to chemicals in air. The hierarchy of values follows three exposure levels: the Acute Exposure Guideline Levels (AEGL's) (US EPA), the Emergency Response Planning Guidelines (ERPG), and the Australian Occupational Exposure Standards (Table 1). These exposure standards will be used by scientific and health professionals to feed into the decision making process during a chemical emergency.

2.1.6 Chemical Characteristics

The physical properties and characteristics of a chemical needs to be considered when implementing protective actions. The state (gas, liquid, vapour), density and vapour pressure of the chemical will determine the rate and concentration that it is released into the atmosphere and how far the plume will travel, and where the affected areas will be. Furthermore, an understanding of the amount of chemical released, release type (e.g. continuous, instantaneous) and expected duration of the release is essential in the decision making process.

SIP is not recommended for chemical releases that are highly flammable or explosive in the atmosphere.

2.1.7 Community Education

Effective communication with the public is essential for a SIP protective action to be followed when issued in an emergency (Vogt and Sorensen, 1999). Poor communication and lack of understanding the reasoning behind SIP may lead people to ignore official recommendations if they perceive that this is not an effective means of protection. Studies following incidents where residents were

Table 1. Order of selection for short-term community exposure standards

Hierarchy	Air Quality Exposure Standards	Selection Guide
↓	Acute exposure guideline levels (AEGL's)	Use AEGL's first. Values for 227 chemicals currently available
	Emergency response planning guidelines (ERPG's)	Use ERPG if no AEGL. Values for 136 chemicals available
	Australian occupational exposure standards	Use 8 hr TWA or 15 min. STEL if no AEGL or ERPG available

instructed to shelter in their homes such as the Three Mile Island, West Helena explosion in the U.S. (Cutter and Barnes, 1982), have found that many people will often defy official recommendations and evacuate.

Compliance rates were studied for a chemical explosion in West Helena, Arkansas, in the U.S. (Vogt and Sorensen, 1999). Authorities ordered residents in a two mile area downwind of the plant to evacuate and those in the two to three mile zone to SIP. A survey reported that 90% of residents told to evacuate complied as instructed, but only 27% of residents advised to shelter, did so, and 68% opted to evacuate instead. These findings indicate that people are more likely to evacuate when both warnings to evacuate and SIP are issued to residents in close proximity to each other.

Several community education programs have been successfully operating in the U.S. for the past decade. These programs use simple messages for the public to follow when the community warning system is activated. This allows for immediate protection while assessment and response strategies are developed. Communication can also be established when people are inside with the radio emergency alert system, where authorities can issue further instructions using this system. One of these successful programs is found in Contra Costa County in California, where they promote a "Shelter, Shut and Listen" slogan. This program has been in place for almost ten years and has been very effective with no reported fatalities. An education program includes regular community meetings and emergency preparedness fairs that are organised by a designated Community Outreach team. The education programs are extended into schools where an animated turtle called "Wally the Wise Guy" is used to promote SIP.

Extensive research by the U.S. Department of Defence, Chemical Stockpile Emergency Preparedness Program, (CSEPP, 2001) reported a number of Best Practices for public education on SIP. The report outlines information required for effective SIP community education, including the need for an explanation on vapour intrusion and the effectiveness of sheltering when termination is made at the appropriate time. They advise that the education program should include detailed information on how the public will be advised to shelter and when to end sheltering. SIP protective action messages must be consistent with the education program to avoid confusion.

Other countries, including the U.K., U.S. and Singapore promote sheltering inside a building during a chemical release as an effective protective action through the distribution of information packets to residents in the mail. A "Go in, Stay in, Tune in" slogan has been adopted in the U.K. and the EU commission.

In Australia, some community education is provided to local residences on what to do during a chemical emergency, by many Major Hazards Facilities, and/or their local councils (e.g. Maribyrnong City Council, Melbourne). This information is distributed to nearby communities on fridge magnets and information brochures.

One region of Melbourne that incorporates several large industries has established a group called the Altona Complex Neighbourhood Consultative Group. This group provides a communication and education process between industry and local community through regular meetings and newsletters. The group also provide a warning system Community Alarm, which is regularly tested, and a dedicated telephone network for incident notification to local schools and the local council.

2.1.8 Sheltering Summary

Overall, the decision process whether to SIP requires:

1. An understanding of building type and age, within the area of interest (e.g. infiltration rate of 0.6 air changes per hour).
2. Environmental conditions such as wind speed and direction, and air temperature.
3. Understanding of the nature and cause of the toxic release and how long it will last.
4. Assessment of the chemical characteristics and level of toxicity. Sheltering is effective at reducing peak

concentrations for a limited time, but may be less effective at reducing the cumulative dose over a longer period (Wilson, 1987).

5. Education of the public.

2.2 Levels of Shelter-in-Place

A number of levels of SIP have been developed in the USA for houses surrounding the 8 Chemical Stockpile sites by the Oak Ridge National Laboratory (Rogers et al., 1990). The levels have been defined by their risks to the community and level of public education provided:

Normal Sheltering – taking refuge in an existing residence, closing all doors and windows and turning off all heating, ventilation and air conditioners.

Expedient Sheltering – in addition to normal sheltering, applying plastic sheeting and tape to windows, doors and vents, and taping over electrical outlets.

Enhanced Sheltering – install permanent barriers such as weather strips and storm windows to reduce infiltration.

Pressurised Sheltering – requires a designated sealed room and positive pressure, created with large fans. These shelters are expensive to set up and use and are not typically used for the general public.

Normal and expedient sheltering are most commonly used because they are easy to do and fast to implement. The effectiveness of expedient sheltering in residential buildings was tested by Jetter and Whitfield (2005). Results showed that proper sealing with plastic sheeting and duct tape can significantly reduce chemical infiltration. A reduction in air exchange rates was also shown, however, the time taken to implement the taping and sealing varied from 20 min. – 1 hour. Rogers et al. (1990) found that for large releases under moderate atmospheric conditions, "expedient sheltering" resulted in higher indoor air concentrations than "enhanced sheltering" due to the longer implementation time.

Other SIP strategies

Recent studies by Tarkington et al. (2009) have shown that SIP protection can be greatly improved from highly water soluble reagents, such as ammonia, by sheltering in a bathroom with the shower running, and by breathing through a damp washcloth. Limitations associated with using a damp cloth were found to be saturation of the cloth and leakage around the edges; however these can be overcome by frequent rinsing of the cloth and using a stretchy material such as pantyhose or a bandage to secure the material. The data collected from simulated experiments demonstrated that running a shower during an ammonia release was very effective as a SIP strategy and reduced exposure to ammonia by 98% after 30 minutes. Unlike other reducing factors for sheltering, it is possible to maintain this increased level of protection for as long as the running water is continued. This strategy should be considered for other water soluble gases such as hydrogen chloride, hydrogen fluoride and ethylene oxide, but would be less effective for chlorine and relatively insoluble gases such as phosgene.

In Australia, the benefits of expedient sheltering may be outweighed by the likelihood of residents having a supply of plastic and duct tape, and the ability to complete this task before the toxic plume arrives.

Normal sheltering has been shown to be very effective from outdoor air contaminants, providing people enter the building before a toxic plume arrives and leave the shelter as soon as the cloud passes over.

2.3 Current Shelter-in-Place Management Models in Australia

There are currently no management models in Australia for SIP based on Australian conditions for emergency responders. The SIP strategy is already an emergency response procedure used Australia wide, and is detailed under the Australian Standards (AS) HB76: 2004 "Dangerous Goods – Initial Emergency Response Guide" (Emergency Management Australia, 2008). This guide is supplied in various emergency response vehicles around the country; however the information provided on SIP is very limited with no advice on the level of protection it provides in relation to the Australian housing and climate. There are also no decision tools to assist first responders in making evacuation versus SIP decisions.

Emergency Management Australia (EMA) has produced a booklet for the public "Preparing for the Unexpected, 2008." This booklet provides information on what to do in the event of a hazardous chemicals release and includes sheltering information on what to do inside your home such as: close all windows and doors, turn off all ventilation systems, close all vents, gather emergency kits and make sure the radio is working, go to an internal room that ideally has no windows and is on the ground floor. EMA provides information on the national warning signal used in Australia called the Standard Emergency Warning Signal (SEWS). The SEWS is a distinctive sound used by emergency services to alert the community when an urgent safety message is about to be played on radio, television, public address system or mobile siren. The SEWS tone will only be used during major emergencies. To our knowledge, the EMA have not provided management models to assist emergency services.

Victoria has strict regulations that promote the safe operation of major hazard facilities (MHF) under the Occupational Health and Safety (Major Hazards Facilities) Regulations (2007). The onus is on facility operators to develop comprehensive Safety Cases that detail the safe operation of their facilities in accordance with Major Hazards Facilities Regulations. This includes a requirement for offsite emergency notification, such as sirens, phone calls and fridge magnets, as part of their Emergency Plan. The ability to estimate offsite impact in the case of an emergency must also be in place as part of the MHF regulations. Plume modelling prediction software is commonly used for this compliance.

2.4 International Best Practice Shelter-in-Place Models

2.4.1 First Responder – Emergency Response in the U.S.

An initial procedure for the first responders in the case of a chemical incident is to establish a protective action distance from the source. This distance is based on when the airborne chemical concentration reaches below a certain level. The distance is also used to decide which protective action should be initiated. Several techniques are used to determine the protective action distance. When minimal information is available, the 2008 "Emergency Response Guidebook" (ERG 2008) can be consulted.

The ERG guidebook lists initial isolation and protective action distances for hazardous chemicals depending on the size of the spill (small or large) and the time of the spill (day or night). When the amount of the chemical involved is known, some emergency response agencies use gas dispersion modelling such as the ALOHA, developed by NOAA and US EPA. It should be noted that both the ALOHA model and the 2008 ERG are limited for airborne concentrations at distances greater than 10km from the source, and ALOHA cannot predict for release durations greater than 60 minutes, or during fires.

2.4.2 National Institute for Chemical Studies (NICS)

Extensive SIP programs have been developed in the U.S. following the Bhopal disaster in 1984 (Joseph et al. 2005). A large toxic gas release from a methyl isocyanate storage tank at a Union Carbide pesticide plant in Bhopal, India, killed thousands and injured hundreds of thousands in the densely populated residential town adjacent to the plant. This tragedy initiated a sequence of legislative and industrial changes to the chemical industry in the U.S. Following the Bhopal incident, and a subsequent chemical release at a local Union Carbide plant in Charleston, West Virginia in the U.S., a non-profit organisation was formed, called The National Institute for Chemical Studies (NICS). Members of the board of directors included representatives from the chemical industry, labour, education and government as well as advice from a former administrator of the US EPA. NICS provides sheltering advice for the US EPA and work on projects in conjunction with the Oak Ridge National Laboratory on sheltering for Chemical Stockpile Sites.

The NICS has been involved in various studies relating to the health and safety of residents in their Kanawha valley, including the best way for emergency responders to protect the public in a chemical emergency. Outcomes from these studies have led the NICS to be a strong advocate for SIP in chemical emergencies. This information is detailed in a report prepared for the US EPA on "Sheltering in Place as a Public Protective Action" (NICS, 2001). NICS have instructors who provide training to emergency services around the country on "Protective Action Decision-Making". Current workshops are based on the program, "Protecting the Public in a Hazardous Materials Emergency." NICS promote sheltering-in-place to the community with videos and information leaflets.

Existing best practice SIP models are used in many U.S. states, including: California - emergency response SIP guidance 2008, and Contra Costa County – "shelter, shut and listen" Sugiyama et al. (2004).

2.4.3 U.S. Department of Homeland Security (DHS)

DHS have a 'Ready' campaign for preparing the community for emergencies with online publications available to the public at no cost (Ready, 2009). 'Ready' consists of three key preparation requirements: get an emergency supply kit, make a family emergency plan, and be informed about the different types of emergencies that could occur and their appropriate responses.

2.4.4 U.S. Chemical Stockpile Emergency Preparedness Program

For decades the U.S. Army has stored its chemical warfare agents at eight U.S. Army installations around the country. In 1985 an order was made for these weapons to be destroyed. An order was also made for the nearby public to be protected until the chemical weapons were gone, and the Chemical Stockpile Emergency Preparedness Program (CSEPP) was created. The CSEPP incorporates several agencies, including the Federal Emergency Management Agency (FEMA), Department of the Army and the American Red Cross.

CSEPP are strong advocates of SIP and have comprehensive guidance material and best practices on this protective action, prepared by experts in emergency management from Argonne National Laboratory (ANL), Oak Ridge National Laboratory (ORNL) and NICS. The Shelter-in-Place Work Group (SIPWG) for the Chemical Stockpile Emergency Preparedness Program (CSEPP) have developed an extensive and comprehensive guide book on SIP as a protective action (Yantosik, 2006). Dispersion modelling is primarily used by hazard analysts following an accidental chemical release to determine which protective action (evacuation or SIP) is issued to minimize public exposure.

2.4.5 Canada

The Canadian Association of Fire Chiefs (CAFC) has a Decision Flow Chart for determining whether SIP or the evacuation of people during an outdoor toxic gas release is required (Wilson and Morrison, 2000). The CAFC also have a guide, called the LCMAO SHIP Mini Guide, which assists incident commanders and first responders with planning for chemical emergencies, and in making the most appropriate public protective decisions during a chemical emergency.

One downfall in this decision tree is the infiltration/air change rates are not known and are difficult to estimate by just looking at the building. Therefore first responders have to rely on a best guess based on typical ACH for Canadian houses.

2.4.6 United Kingdom

The U.K. acts under the Civil contingencies Act 2004 for emergency planning and preparedness. In response to calls from local responders and planners, a non statutory "Evacuation and Shelter Guidance (2006)" was prepared by the Civil Contingencies Secretariat of the Cabinet Office (U.K.

resilience, 2009). The Guidance provides information to initially take shelter inside during a chemical release. Emergency preparedness is co-ordinated between local response organisations and local resilience forums.

The Government worked with emergency services to produce advice for householders on what to do in the event of an emergency. This advice was published in the booklet "Preparing for Emergencies" (Preparing for Emergencies, 2004). The Preparing for Emergencies booklet was sent to every household in the U.K. in August 2004. The general advice for a nearby chemical incident is: "go in, stay in, and tune in."

The "Go in, Stay in, Tune in" advice is recognised and used around the world. It was developed by the independent National Steering Committee on Warning and Informing the Public as being the best general advice to give people caught up in most emergencies.

2.4.7 Singapore

Singapore Civil Defence Force (SCDF) has an extensive emergency preparedness and readiness program. A Community Emergency Preparedness Program was launched in 2003. The public are educated on emergency procedures and readiness for 'In-Place Protection' or sheltering in their homes. This Civil Defence and Education program aims for at least one member of every household to be trained in emergency exercises, in food and water rationing and sheltering. Sheltering has also been incorporated into building design since 1997, where all new residential developments must have apartment shelters.

3. Protective Action Decision Making

When a chemical release occurs in a residential area it is essential that the appropriate protective action is selected quickly, so that the public can be notified and act upon this action before the arrival of the toxic plume. However, protective action decision making is a very time consuming and complex process. Emergency planning can reduce time delays in the decision making process by identifying the variables associated with the best protective action for a given range of conditions.

The choice of protective action options for protecting the public from exposure to a chemical plume is limited to evacuation and sheltering-in-place. The emergency decision process is complicated by identifying the wide range of conditions under which each option is appropriate. For example, a continuous, long term release under low wind and low inversion conditions could lead to a long duration, low lying hazardous plume. Under these conditions preference should be given to evacuation. Other considerations in the decision making process should include population characteristics, such as the distance between the release point and the density and distribution of the populated areas, to determine the number of people affected.

There are a number of factors that must be considered when deciding the appropriate protective action. These factors can be considered in several ways. Current processes available to help make protective action decisions include: checklists, decision matrices, decision trees, decision tables and quantitative risk assessments.

3.1 Protective Action Tools

3.1.1 Protective Action Checklist

A SIP protective action checklist itemises various decision attributes and their related values. Consideration of each attribute will lead to either sheltering or evacuation. A protective action checklist was demonstrated by Sorenson et al. (2004) (refer to Table 2). The first column lists the variables that require consideration. The second and third

Table 2. Protective Action Checklist

Attribute	Shelter	Evacuation
Infiltration	Tight housing	Leaky housing
Plume duration	Short	Long
Time of day	Night	Day
Population density	High	Low
Road geometry	Closed	Open
Road conditions	Poor	Good
Population mobility	Immobile	Mobile
Traffic flow	Constrained	Unconstrained
Public perception of shelter effectiveness	High	Low
Toxic load	High	Low

Source: Adapted from Sorensen et al. 2004 columns list the associated conditions that favour either sheltering or evacuation.

Checklists have the advantage that they are easy to develop and follow. However, this checklist is too simplistic with many disadvantages, including conflicting outcomes, such as if there was a short plume duration during the day. Also, the importance of each attribute and the influence on other attributes is not considered.

3.1.2 Decision Trees

Decision trees provide a series of yes/no questions for the user to follow down the branches to one of the required outcomes. It is often necessary to have a third outcome 'conduct a detailed analysis' when there is not enough information to chose evacuation or sheltering. Decision trees work toward a main objective, such as to avoid fatalities or minimize number of people exposed, or to reduce exposure below a threshold level. The limited number of branches and yes/no answers can leave out a large number of variables and their impact on SIP.

3.1.3 Quantitative Risk Assessments

Quantitative risk assessments can be prepared in a table. Factors that impact SIP are weighted with a number according to their effectiveness. The values are added to give a number that is used to determine whether to evacuate or shelter according to a pre-determined scale. This process allows first responders to review protection action decision making using all SIP related attributes, however, determining a weighting value for each attribute can be difficult and could lead to a biased outcome.

4. Deriving Australian Air Exchange Rates

4.1 Methodology

Air exchange rates were measured for 73 houses in all states of Australia during 2008 and 2009 using the tracer gas decay method. Air exchange rate is the unit of ventilation that measures the amount of air moving through a space to the volume of the space. Air changes per hour (ACH) is the most commonly used unit, and is the volume of air per hour divided by the room volume.

4.1.1 Tracer Gas Decay

Tracer gas testing involves releasing a small concentration of non toxic gas (e.g. Sulphur hexafluoride) into the building and then measuring how much the tracer gas is diluted by outdoor infiltrating air over a period of time. The decay rate over time of the tracer gas concentration is used to calculate the air change rate for a given room volume.

Tracer gas testing was performed by scientists from the ChemCentre of Western Australia as part of a collaborative study. The test method used is based on ASTM E 741 – 00; Determining Air Change in a Single Zone by Means of a Tracer Gas Dilution (2006). The tracer gas selected for this project was sulphur hexafluoride (SF_6) at an initial concentration of approximately 5 ppm. All doors and windows were shut and oscillating fans were placed in each room or open space to achieve thorough mixing of the air in the house. The air volume of each room or open space in a house was measured and the calculated amount of neat sulphur hexafluoride gas was injected into each room with an air-tight syringe.

Several representative air sampling locations were selected in each house and concentrations of tracer gas were measured in these locations using portable infrared gas analysers (Miran Sapphire), alternating between different sampling sites. Each location was monitored for five minutes and three sampling cycles. The decay rate over time of the tracer gas concentration was used to calculate air exchange (ACH) values for each location monitored. The air exchange for the whole house was then calculated as the average of each monitored location.

Indoor temperatures were monitored on North, South, East and West walls of the house using data logging temperature sensors. Outdoor temperature, wind speed and direction were monitored with a Davis weather station.

Table 3. Statistical distribution of air exchange rate values for different house types

Construction Material	Sample Number	Mean	Standard Deviation
Brick Veneer	19	0.5	0.3
Cement Sheeting	5	0.5	0.5
Corrugated Metal	2	1.9	1.2
Double Brick	28	0.5	0.4
Stone	2	0.6	0.1
Weatherboard/Timber	17	1.0	0.7
Total	73	0.7	0.5

4.2 Air Exchange Results

A number of building types were examined, including weatherboard, brick veneer, double brick, corrugated iron and cement sheet, over a range of building ages, from 2 to 130 years. House types were grouped for statistical analysis into double brick, brick veneer, cement sheeting, corrugated metal, stone and weatherboard/timber. Measured air exchange values varied between 0.1 to 2.7 h^{-1}. Descriptive statistics on these data are given in Table 3.

The mean ACH values vary from 0.5 h^{-1} for brick homes to 1.0 h^{-1} for weatherboard/timber homes. At first glance, these values suggest that air exchange rates are affected by construction type. However, when the air exchange results are separated into construction type and grouped by age, it can be seen that the air exchange rates correlate with the age of homes within each construction material group (Figure 2).

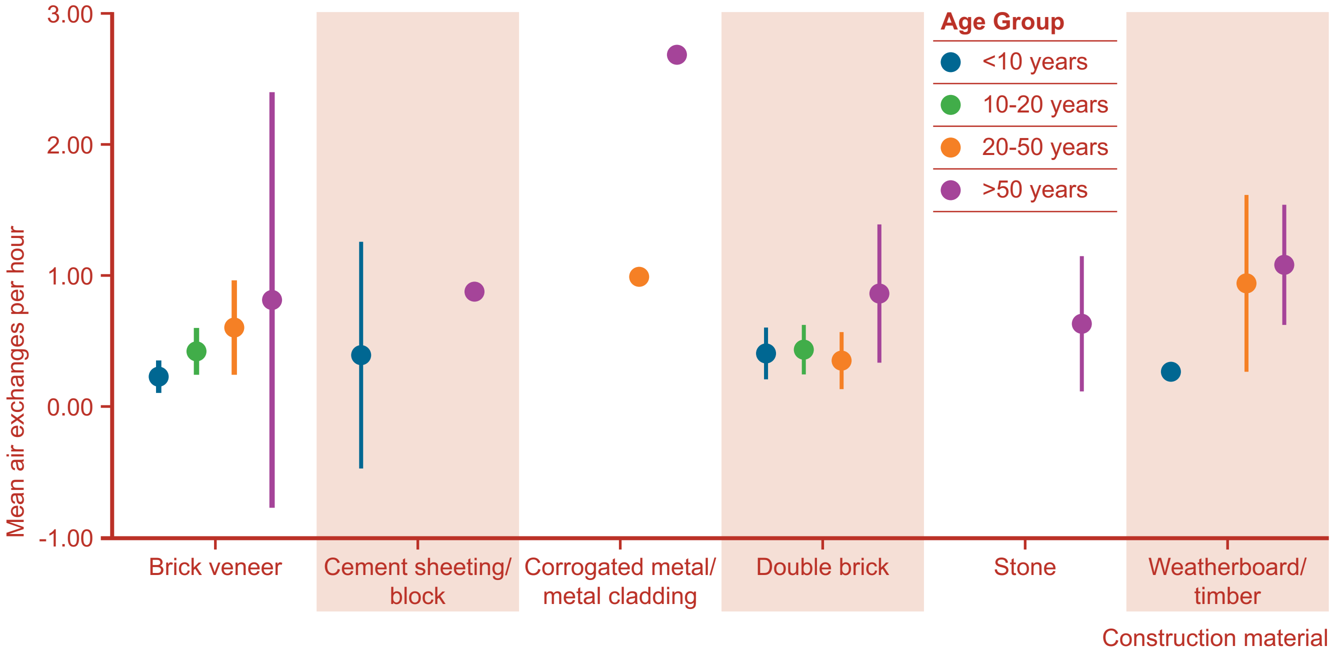
Clearly, the air exchange rates for older houses are considerably higher than those for houses built more recently irrespective of the construction material. Further statistical tests (ANOVA) support this conclusion, demonstrating that overall the exchange rates for houses built within the last 50 years are distinct from houses constructed earlier. A pattern for reduced air exchange rates in newer homes can be explained by changes in housing standards over the years (Building Codes Australia, 1990). A requirement for increased energy efficiency in houses has resulted in modified designs and techniques for producing 'tighter' homes.

The principal building material used in the construction of the home appears to have a lesser impact on exchange rates. From the above figure it can be seen that all weatherboard and timber homes tested were older than 20 years, compared to a full age range of double brick and brick veneer homes tested. A deeper analysis of the data demonstrates that there may be some statistical difference between brick/brick veneer and weatherboard/timber homes, however it is by no means as clear cut as for the age dependence.

4.3 Selection of a Representative ACH for Australian houses

Using a single ACH value in plume modelling simplifies the decision making process during emergencies. The houses tested have a mean ACH value of 0.7 h^{-1}. However, measurements of central tendency do not provide adequate coverage of the

Figure 2. Mean Air Exchange Rate with 95% Confidence Intervals vs Building Construction Material Grouped by Building Age (years)



population. Generally the 95th percentile is used in exposure studies and is what we initially considered for input values into plume modelling. Figure 3 demonstrates that the difference in air exchange rates between the 90th and 95th percentiles is relatively large due to the spread of data with high exchanges rates. Based on these findings the 90th percentile ($1.3h^{-1}$) was chosen as the default ACH parameter for our model. The 90th percentile covers most structures including all buildings up to the age of 50 years (Figure 3). In the present study the sampling points were chosen to represent the range of different construction materials and building ages but do not necessarily represent the distribution of house types and age in a typical suburb. Further understanding of age class within an affected area will allow for adjusting the ACH to better represent the specific situation. For example, a lower ACH value would be used in new housing estates where houses are less than 10 years old.

4.4 Estimated Air Exchange Rate Effects

The ALOHA equation (Equation 1) was used to calculate ACH values (Reynolds, 1992). Wind speed values from the tested homes were used in Equation 1 to derive a set of estimated air exchange rates for comparison with the actual air exchange rates.

Equation 1

$$E = \frac{\sqrt{Q_s^2 + Q_w^2}}{V_s}$$

E = air exchange rate (h^{-1})

V_s = total structure volume (m^3)

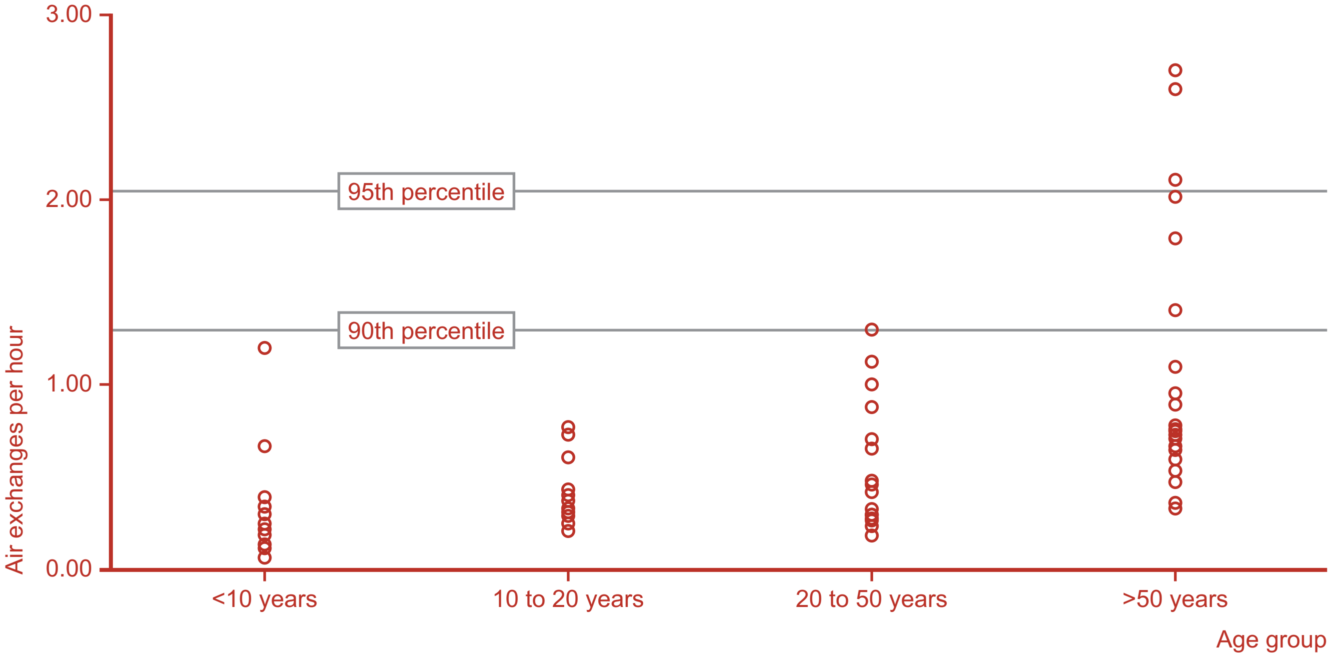
Q_s = infiltration rate from temperature differences (m^3s^{-1})

Q_w = infiltration rate from wind (m^3s^{-1})

The above ALOHA equation is based on the assumption that the air exchange rate depends on the pressure differences created by wind and temperature. Several approximations are made by ALOHA to calculate the ACH, i.e. a single storey building floor area is set to 160 m2, leakage area = 0.00059 x floor area and indoor temperature is 20°C. Certain parameters were forced constant when calculating ACH, including an outdoor air temperature (20°C), medium humidity, sheltered, partly clouded with no inversion.

From the current data set, there was no significant correlation between wind speed

Figure 3. Air Exchanges per Hour Grouped by Building Age with Overall 90th & 95th Percentiles



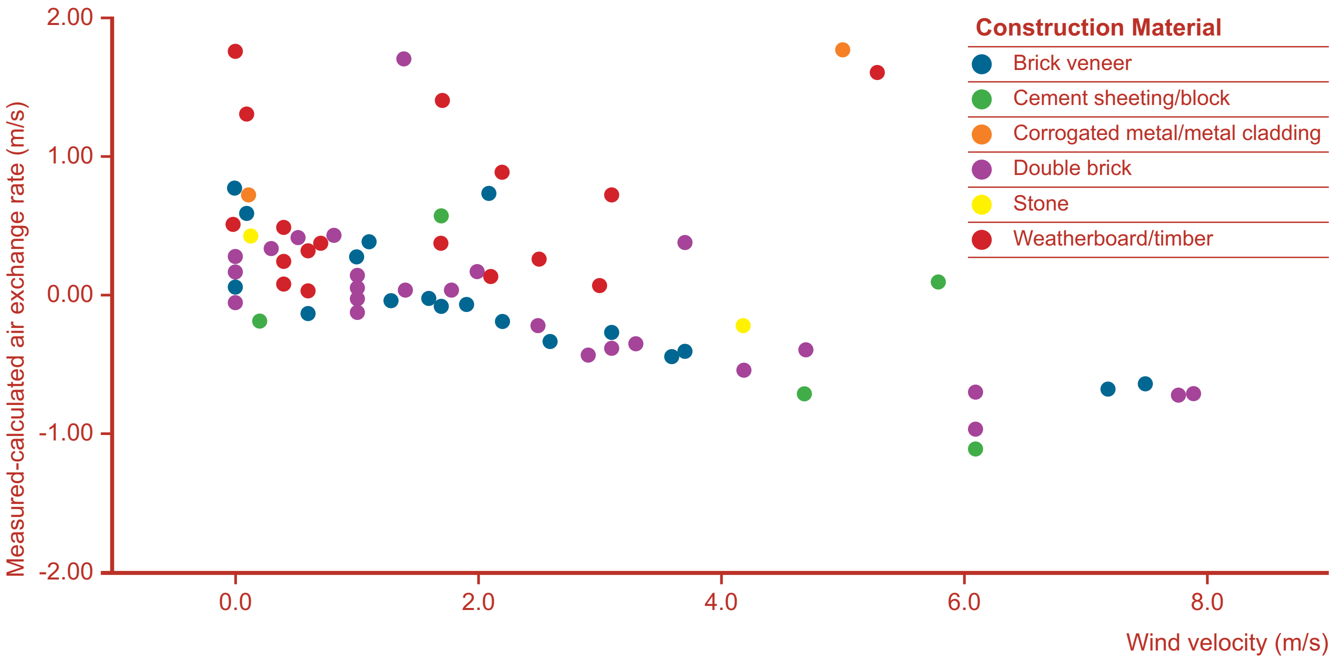
or temperature and air exchange rates. Future testing should include repeated measurements on a single house under different atmospheric conditions to assess the impact of wind speed on ACH. The difference between the measured and calculated air exchange rates was examined at various wind speeds and is illustrated in Figure 4. This graph shows that ALOHA underestimates air exchange rates at low winds speeds, particularly for weatherboard houses. A difference can also be seen for higher wind speeds where calculated air exchange rates are overestimated, in one example up to 1.0 air change per hour. The differences between measured and calculated values appear to be due to the high sensitivity of the modelled air exchange rates to the wind speed parameter, and also the leakage area is more representative of brick rather than weatherboard homes.

The difference in the ACH data from tracer gas measurements and the default ALOHA values has a considerable impact on the level of protection provided by sheltering indoors during a chemical release. Figure 5 illustrates the significant effect air exchange rate has on indoor air concentration during an outdoor chemical release. ALOHA predicts the indoor air concentrations at two different air change rates, compared to the community exposure standards (AEGL's). This graph highlights the importance of using locally-derived ACH values when estimating indoor air concentrations during a chemical release, because underestimated air exchange rate values could lead to over exposure of the sheltered occupants.

The effect of underestimated air exchange rates on termination time was also considered, since a delay in terminating SIP has the potential for prolonged exposure. This is because the indoor concentration continues to rise after the peak of the plume has passed, and it also takes a considerable amount of time for the indoor concentration to decrease and re-equilibrate with the outdoor atmosphere.

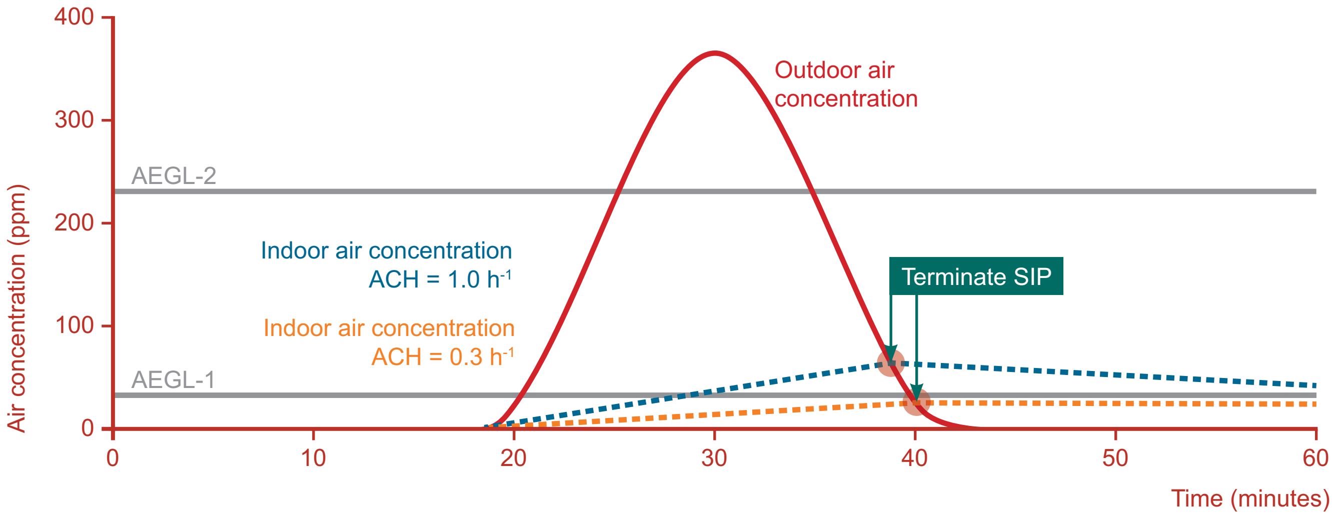
Determining termination time for SIP is critical in minimising occupant exposure to atmospheric contaminants. The best time to depart the shelter is the point where outdoor concentration drops to and below indoor air concentration. Figure 5 suggests that the relationship between air exchange rate and ending SIP appears to be minimal, with the time difference for air exchange of 1.3 and 0.5 h^{-1} to be only a couple of minutes. Therefore decisions on when to end sheltering could be made with default ALOHA estimated ACH values with little impact on

Figure 4. Difference between Measured and Calculated Air Exchange Rate at Various Wind Speeds



termination time. This finding may be useful for decision makers in the field during a short term chemical release where SIP termination time could be estimated quickly using default ALOHA ACH values.

Figure 5. Graphical Representation of an Instantaneous Ammonia Leak at a Point 2 km Downwind Using ALOHA



5. Management Model for Best Practice Decision Making During a Chemical Release

Following the review of best practice decision making during a hazardous atmosphere, a strategy has been developed for the Australian Fire Services, to provide an effective and expedient response that has been recently validated.

The *Protective Action Decision Guide for Emergency Services during Outdoor Hazardous Atmospheres* has been developed for emergency services to use during an outdoor hazardous atmosphere. This guide details best practice principles for planning and implementing community protective actions during hazardous atmospheres. A standard approach to protective action decision making is provided and includes the recommendation of issuing SIP as the initial protective action to avoid potential public exposure, followed by a more detailed analysis process utilising a flow chart. An atmospheric modelling integration tool was also developed to assist first responders in this decision making process, and a community education program has been prepared for the successful implementation of this protective action approach with the public.

The *Protective Action Guide for Local Government and Industry during Outdoor Hazardous Atmospheres* has been developed for local government and industry. This guide provides information for local government on a standard approach to community protective actions during hazardous atmospheres.

The main purpose of this document is to ensure that local government and industry are using consistent terminology with emergency services when providing public information related to hazardous atmospheres to ensure public confidence and compliance. Community education templates have been developed using a descriptive catch phrase for the public to implement when instructed to SIP.

5.1 Preparing a Shelter-in-Place Strategy

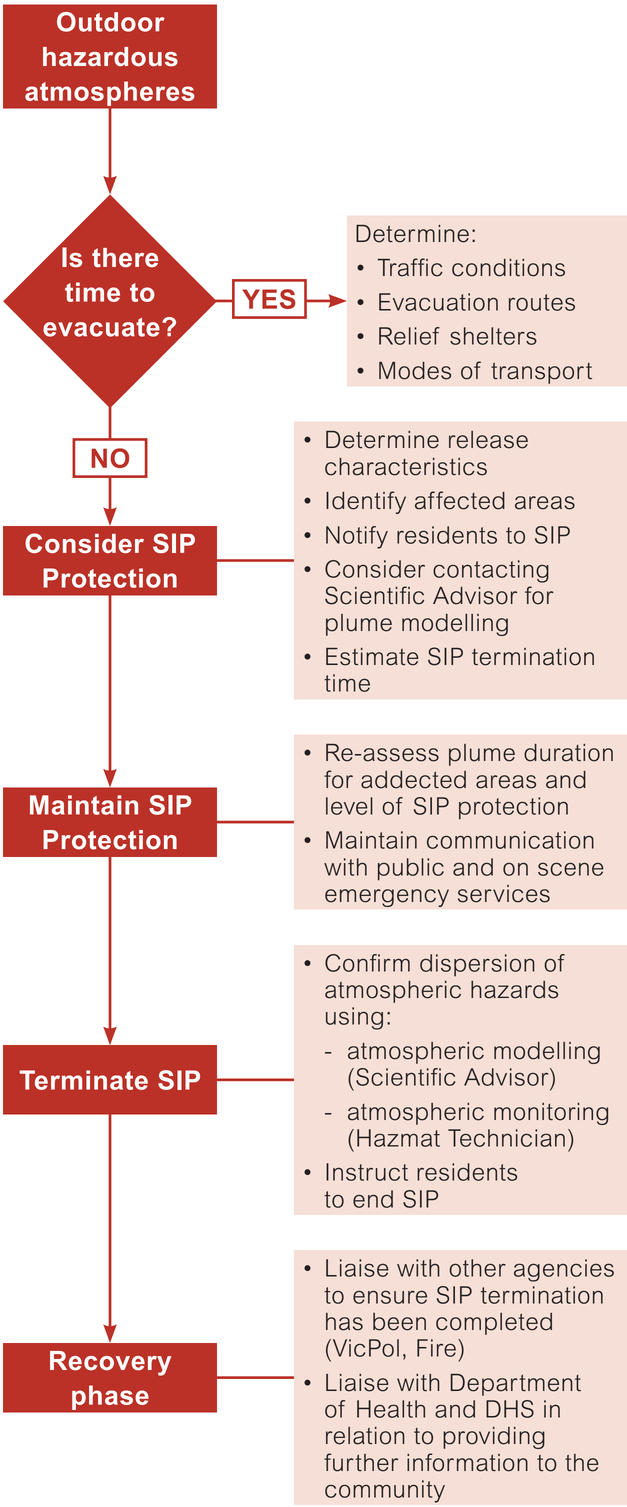
A comprehensive protective action strategy consists of three options as outlined in Table 4.

Plans should provide for quickly determining the preferred protective actions and the areas expected to be affected, based on information that should be available minutes after the event. In most cases, the initial

Table 4. Protective Action Strategy

Protective Action	Conditions
No Action	• If outdoor air concentration is believed not to pose any community health risk
Shelter-in-place	• Consider as initial action • Requires early notification to residents • Must include best time to end SIP • Communication to community essential
Evacuation	• If have sufficient time and resources before arrival of the plume (min. 2 hrs) • Consider if release is flammable or explosive • Consider potential for atmospheric exposure during evacuation

Figure 6. Shelter-in-Place Flow Chart



protective action response will be to SIP until further information is gathered for the decision-making process.

A decision to SIP must always include requirement for terminating SIP. SIP should always be considered as a two-part process that is not complete until the "terminate SIP" recommendation is made, and a terminate SIP instruction is announced.

Protective actions will be made for affected communities where estimated airborne concentrations are predicted to exceed an AEGL-1. These high risk areas are labelled and isolated as protective action zones according to the airborne concentration.

The best practice strategy includes the SIP flow chart (Figure 6) as a reference tool to be used by first responders at a chemical incident. This flow chart outlines the important factors to consider during such an incident and will require some input from specialist advice for plume modelling, and atmospheric monitoring.

5.2 Atmospheric Modelling Integration Tool

A new integrated modelling platform has been developed to assist incident controllers with the decision making process by:

- Identifying affected areas with predicted plume areas and concentrations displayed on different mapping systems (refer to Figure 7).
- Identifying number of buildings and residents affected, including features of interest (such as hospitals, schools, day care centres) in a downwind plume (refer to Table 5 and Figure 8).
- Introducing a new default air exchange rate value into modelling software to better represent the majority of Australian house types and provide a more accurate estimate of indoor air concentrations. This representative air exchange rate value measured for Australian house types is 1.3 h^{-1}.
- Identifying the termination time for SIP, as the time where the outdoor air concentration drops to or below the indoor air concentration.

Dispersion modelling systems transform incident information, for major chemical releases, into actionable information. First responders to a chemical incident utilise emergency response software modelling to determine the safest protective action (Sugiyama et al. 2004). Emergency response models incorporate a number of data and real time information. Many fire departments in Western Society use the CAMEO/ALOHA system model because it is free and readily accessible from the internet. This system was jointly developed by the NOAA (National Oceanic and Atmospheric Administration) Ocean Service's Office of Response and Restoration and the Environmental Protection Agency (EPA), and incorporates Gaussian plume dispersion modeling with an extensive chemical property database and source term models for a variety of chemical releases (National Oceanic and Atmospheric Administration, 2009).

The models mainly used within Australia include ALOHA, Hazard Prediction and Assessment Capability (HPAC), Queensland Fire Rescue Service (QFRS) UNI program. Whilst HPAC was widely distributed by Emergency Management Australia (EMA), it is no longer supported, difficult to use, has poor GIS integration and most users acknowledge they are not proficient in it. Although Aloha does have a time limitation of one hour for estimating airborne concentrations, it does have the ability to calculate indoor air quality. It is also easy and quick to use, however, its main drawback is its GIS integration, as the MARPLOT program used for displaying Aloha footprints is only available with US GIS data.

Accident Reporting and Guidance Operation System (ARGOS) is a Danish developed modelling platform that is now available to Australian users. It has improved GIS and information sharing abilities, Numerical Weather Prediction, as well as Puff model calculation and extended time frame calculations. It is however far more complex to operate and will require some work before it will meet the needs of Fire Services who are used to working with programs such as Aloha. It does, however, provide a positive opportunity for future developments in Hazmat plume modelling.

Time is an important consideration for SIP decision making. For time critical decisions, users preferred the simpler models as they could be produced in time for the decision making process. For these reasons as well as its ease of use, current utilisation within Australia and free availability, the Aloha model was chosen for the development of the integration tool.

The developed modelling integration tool has been designed to import models from the Aloha program into a GIS environment (ArcMap). The focus was on developing a simple "button click" interface to dispense with the need for GIS expertise as well as to increase the usefulness of the plume model through spatial data integration.

Operation of this tool requires the users to first create the model within the Aloha package, then using the specially designed toolbar in ArcMap, they can point and click a point of origin for the release and the tool will automatically import and orientate the model in the correct scale. More than one plume can be imported into the one map document.

The tool will import the three threat zones and the outer confidence lines with standard colours and labels, which can be changed by the user if they wish. From here users can display these footprints over a number of different layers such as Melways, road network maps, topographical maps and aerial photography (Figure 7). The current view can be easily exported and shared with other stakeholders through a variety of formats as well as exported to Google Earth (KML).

Figure 7. Predicted Plume Dispersion in Three Different Atmospheric Concentrations for a Simulated Chemical Release

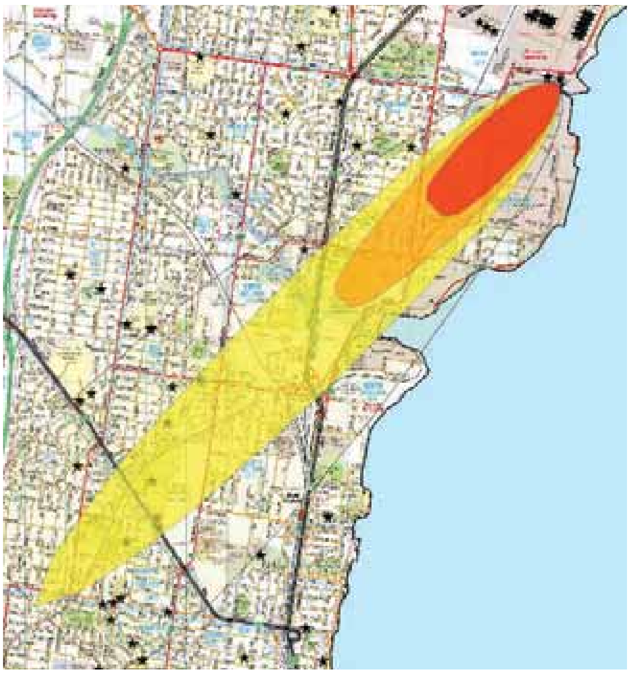


Table 5. ALOHA integration Tool Threat Zone Assessment Report

Threat Zone	Footprint Red	Footprint Orange	Footprint Yellow	Confidence Limit Yellow
Value (ppm)	3000	1200	250	250
Length Downwind (km)	1.7	3.0	7.2	7.2
Area (ha)	73	160	571	1281
Dwellings				
Semi Detatched	6	10	63	251
Separate House	592	971	3962	6878
Flats Units	34	98	551	1063
Other Dwellings	0	0	16	29
Total Dwellings	632	1079	4592	8221
People				
Age 0 - 4	308	410	1298	2433
Age 5 - 14	105	174	579	1078
Age 15 - 19	353	410	927	1557
Age 20 - 24	79	138	681	1320
Age 25 - 34	199	287	1385	2499
Age 35 - 44	203	329	1372	2636
Age 45 - 54	225	350	1385	2589
Age 55 -64	156	261	1119	2097
Age 65 - 74	128	225	1128	1920
Age 75 - 84	112	176	1110	1741
Age 85+	25	43	370	559
Persons Working	620	886	4440	8620
Persons Not Working	779	1184	4233	7100
Total Persons	1895	2805	11360	20436

A significant additional feature is the integration of census data available from the Australian Bureau of Statistics (ABS). By selecting the required plume and pressing the report button, the tool will provide a Threat Zone Assessment including incident summary information including a snapshot of the model (Table 5).

For each Zone (Footprint) The Threat Zone Assessment will indicate:

- Value/Threshold Modelled
- Downwind distance
- Total Area of the Zone
- Dwellings information (Type and Number)
- Population numbers
- Population Age Breakdown
- Population Working
- Population Not Working (Indicative of Day/Night Populations)

Census data is available for parcels of land known as Census Collection Districts. The census collection district (CCD) is the ABS's standard geographic unit of collection. On average there are about 150-250 dwellings per CCD, however there may be more in some urban CCDs, and in rural areas a CCD may contain fewer dwellings yet cover an extensive area. As this is the smallest data set used, where a threat zone intersects with a CCD, the report will include that CCD's full data even if only some of it falls within the threat zone limiting the opportunity for under-assessment.

Similarly to the census data, the new VicMap Features of Interest data has also been incorporated into the tool. This is a Spatial Information Infrastructure dataset containing a dynamic database of features and sub features such as education centres, community centres, care and emergency facilities, power facilities, locality points, towers and landmarks (refer to Table 6).

For each Zone (Footprint) The Threat Zone Assessment will indicate a number/type summary as well as names of:

- Hospitals
- Care Facilities
- Health Facilities
- Education Centres (Schools)
- Residential Buildings (Retirement home)
- Emergency Facilities (Police, Fire, Ambulance, SES)
- Community Centres
- Places of worship
- Sports Facilities
- Reserves

This information may be critical in determining incident priorities such as hospitals and schools, identifying unsafe areas people may congregate or evacuate to, as well as for assessing impacted critical community infrastructure during response and recovery operations.

5.2.1 Custom Area of Interest

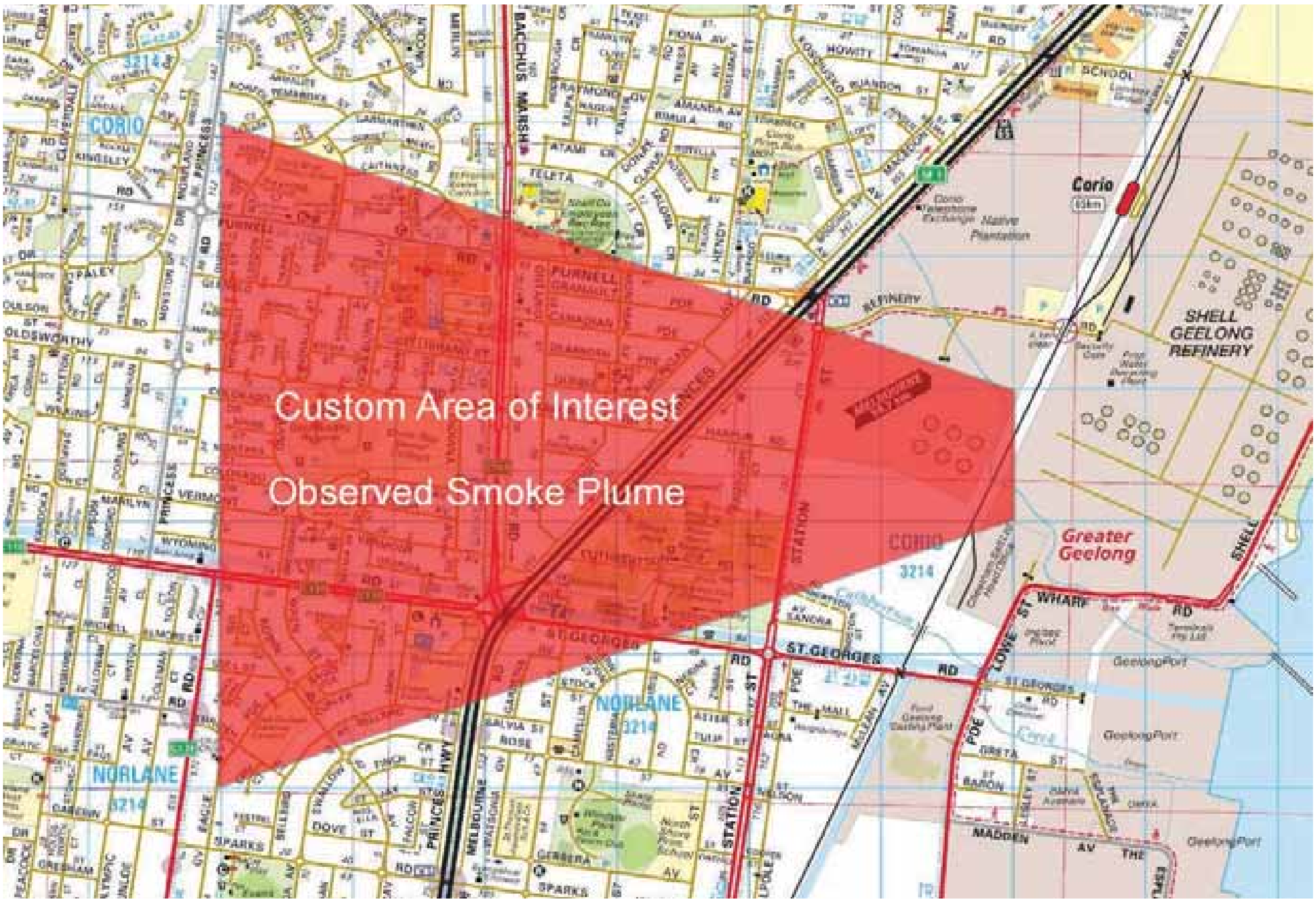
It is not possible to provide a predictive model for all situations. Threat Zone Impact Assessments on the other hand can be undertaken for almost any incident provided there is a designated area of interest. This could be through results from field monitoring, observations of smoke plumes, past history or simply concern for a particular area.

As the impact assessment relies only on a designated area it can also be considered useful in an 'all hazards' approach. This has provided an unforeseen benefit beyond the scope of the project in that the area of interest can not only be for a fire or chemical spill, but other hazards such as a wildfire, storm, wind, earthquake or flood event, in fact any incident where agencies want to know who may be affected.

Table 6. ALOHA Features of Interest Report Features of Interest Report

Feature Type	Feature Subtype	Address	LOC: 1000ppm = ERPG-3 Colour: Red		LOC: 150 ppm = ERPG-2 Colour: Orange	LOC: 50 ppm ERPG-1 Colour: Yellow
			Footprint	CFD Limit	CFD Limit	CFD Limit
Barrabool CFA	fire station	15 Wheat Sheaf Rd Ceres 3221			✓	
Ceres Primary School	primary school	40 Cochranes Rd Ceres 3221				✓
Geelong West CFA	fire station	67B McCurdy Rd Herne Hill		✓		
Herne Hill Primary School	primary school	194 Church St Hamlyn Heights	✓			
Belmont Grange	aged care	Church St Hamlyn Heights	✓			
Manifold Heights Primary School	primary school	20 Strachan Ave Manifold Heights		✓		

Figure 8. Custom Area of Interest for an All Hazards Impact Assessment



To utilise this feature a separate "Custom Area" feature (refer Figure 8) has been incorporated into the modelling tool. This allows users to simply point, click and drag an area of interest over a map layer. This custom area is then displayed and reported on in the same way as an imported Aloha plume.

5.2.2 Plume Models for Structure Fires

Research into the availability of plume models for structure fires has revealed very little available in this area. In fact, at the time of this research a simple off the shelf package to model releases from structure fires was not able to be located.

In the case of plumes resulting from structure fires, additional factors need to be considered above that for a chemical spill or release. Plumes from fires are strongly buoyant and the plume rise equation will first need to be solved before the normal downwind dispersion can be modelled. Whilst equations for solving plume rise do exist (Briggs, 1984 and Weil, 1988) the source data required for these calculations is not readily available.

In particular the main issue facing model developers is the definition of the source term or products of combustions. Unlike a chemical spill where many details are known or can be researched, the products contributing to a fire plume are often unknown as they go beyond the basic materials being stored but also include the packaging materials, building materials and other contents. The products released are also chemically altered and changed by their exposure to heat and consumption within the fire, resulting in additional unknown products being released. Given many of the plume rise models are designed for stack emissions, additional factors such as the rate of fire spread, effect of suppression methods, building design, ventilation and heat of combustion (or Heat Term) become often difficult to establish variables that have a significant effect on release rate and therefore plume generation.

In some specific situations there is scope for fire modelling. The ALOFT software has the ability to model downwind combustion products from large outdoor fires, however this is predominantly suited to liquid hydrocarbons pool fires where the source term can be accurately entered. The blast and heat from Boiling Liquid Expanding Vapour Explosions (BLEVE's) can also be modelled using a number of programs including ALOHA.

Aside from these limited situations, it can be seen that there are many hurdles to overcome for the modelling of plumes from structure fires. Like any dispersion model, accurate definition of the Source Term is critical to producing an accurate model (garbage in equal's garbage out). Given the complete uniqueness of structure fires and their unknown variables, it is unlikely that modelling software capable of providing the answers to what is it, how much and where is it going will be available in the near future.

There is, however, some hope that modelling the particulate released from fires may provide answers to the "where is it going?" question. The ARGOS platform was initially developed for dispersion modelling of nuclear incidents such as the Chernobyl Accident in 1983. Its ability to model buoyant radioactive particulate releases from these types of incidents (fire/explosion) is equally applicable to non radioactive particulate releases. It is also a more complex model with real-time and forecast weather data, puff model calculation and extended time frames.

As discussed previously, ARGOS is a far more complex model to operate and further work including research to validate source term entry requirements for fires will be required to bring a model such as this online in a response scenario. However, given the current capabilities of the software, the availability of the program and the ability for future developments, it provides the most likely way forward at this time and there is continuing work in this area.

5.2.3 Modelling Tool Utilisation

Whilst primarily seen as a response phase tool, modelling and impact assessment also have valuable application in the preparedness and recovery phases. For example, it also has application in preparing preplans, conducting exercises and post incident analysis.

The integration tool developed allows Models and Impact Assessments to be produced in minutes, this provides early advice to Incident Management well before ground observations can be obtained or field impact assessment conducted. Other significant benefits apply to rural sectors where response expertise may be some hours away. The tool is capable of being deployed remotely on laptops which allows models and impact assessments to be undertaken either onscene or remotely from any other location.

5.3 Public Education to Support a Shelter-in-Place Strategy

SIP community education programs that allow for an understanding and awareness of this protective action are essential for public compliance for when official instructions by emergency services are made. SIP protective action messages must be consistent with the education programs to avoid confusion.

There are various community emergency response information leaflets and fridge magnets currently distributed from major hazard facilities and local government. We recommend adopting and promoting the Shelter-Shut-Listen catch phrase so consistent terminology and awareness can be provided across emergency services, industry, local government and the community.

We have developed a generic set of templates for Councils, Industry and Emergency Response agencies to adopt and incorporate. These templates are included at the back of the *Protective Action Guide for Local Government and Industry during Outdoor Hazardous Atmospheres* and consist of:

- Community Emergency Response Information Brochure
- Shelter-in-Place fridge magnet, and
- Shelter-in-Place Community Education Fact Sheet

This combined approach using common phrasing reinforces the SIP message, providing an emergency preparedness plan for households during outdoor hazardous atmospheres.

6. Conclusion

Tracer gas studies have provided validation of SIP as an effective protective action through the determination of a representative air exchange rate value for Australian house types under Australian conditions. This representative value was chosen to protect the majority of Australian house types during a short-term chemical release, and will be used to improve current atmospheric modelling systems. Outputs from this modelling will assist incident controllers in their protective action decision making and SIP processes, where the level of atmospheric exposure to residents can be considered and the best plan of action determined.

Our studies found that measured air exchange rate values were higher than estimated values previously calculated by atmospheric modelling practices. This finding provides an overall improvement of current modelling practices for estimating indoor air quality, and expected level of exposure to sheltered occupants.

Other findings include the significant effect that building age has on the air exchange rate for residential houses, and structural type, i.e. brick or weatherboard homes, has a lesser contribution. This factor may allow decision makers to more accurately determine the level of protection residential housing may provide during a hazardous atmosphere. Whereby new housing estates where houses are less than 10 years old (ACH $\leq 0.5\ h^{-1}$) can provide indoor protection for twice as long as older housing estates.

An extensive review of best practices for managing chemical incidents was undertaken to achieve the development of a standard approach to protective action decision making for emergency services. An emergency services guide (*Protective Action Decision Guide for Emergency Services during Outdoor Hazardous Atmospheres*) was developed to outline the protective action process and includes tools to assist decision makers. A protective action decision making flow chart was prepared for quick reference by first responders at a chemical incident and follows a step by step process.

An atmospheric modelling integration tool was also developed to assist first responders and incident management personnel in this decision making process. The modelling tool, coupled with a hierarchy-based community exposure standard protocol, can facilitate early identification of impacted, or at risk, communities and provide both combat and support agencies with valuable information. The remote operation capability of this tool allows for the ability to produce incident predictions and/or impact assessments with map overlays in a timely manner.

A Protective Action Guide has also been developed for local government and industry (refer to *Protective Action Guide for Local Government and Industry during Outdoor Hazardous Atmospheres*). This guide provides information on a standard approach to community protective actions during a chemical incident. The main purpose of this document is to ensure that local government and industry are using consistent terminology with emergency services when providing public information related to a chemical incident to ensure public confidence and compliance. Community education templates have been developed using a descriptive catch phrase for the public to implement when instructed to SIP.

This project has developed a Best Practice Management Model for protective action decision making applicable to Australian conditions and emergency arrangements. This management model has been developed through funding from the Australian Government administrated by the Office of the Emergency Services Commissioner (OESC).

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