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USING PREDICTIVE RISK ASSESSMENTS TO DEVELOP USER-FRIENDLY TOOLS FOR ON- AND OFF-SITE EMERGENCY PLANNING

Jo Fearnley and SreeRaj R Nair
Aker Solutions, Phoenix House, 3 Surtees Way, Surtees Business Park, Stockton on Tees, UK, TS18 3HR;
Tel: +44 (0) 1642 334053; e-mail: jo.fearnley@akersolutions.com

Chemical plants which could cause major accident hazards in the UK carry out predictive risk assessments (PRA) to comply with COMAH regulations. Typically PRA is used to identify the worst case consequence contours for representative safety and environmental scenarios which are then used to determine if the prevention, control and mitigations available are sufficient to reduce the risk to as low as reasonably practicable (ALARP).

However the worst case consequence assessment will not always help in understanding the development of the scenario over time, and hence what effect that has on emergency response options both on- and off-site. This is particularly true with toxic releases where the cloud will travel over time, compared to a fire where the key emergency response is to prevent the fire from spreading to limit the radiant effect and potential for escalation.

For a toxic release the development of the hazardous scenario over time (both before and after isolation of the leak) needs to be considered in advance as there is limited time / personnel available to run models during an emergency. It is therefore advisable that the site has a document prepared which can be directly used for emergency planning, both for exercises and for a real emergency situation, covering a range of potential scenarios, of differing severity.

This should enable typical questions to be answered, for example:

– How far has the toxic cloud travelled by the time emergency services are mobilised, and how far will it travel in the next period of time?
– What is the toxic effect on people from the cloud at various downwind distances of interest, and how is this changing over time?
– What type of mitigation is needed: e.g. is there a need to evacuate people? / is there time to do so?
– How much time does the site emergency team have to isolate the leak before it reaches a vulnerable population?

This paper looks at the need for a detailed emergency plan, developed in advance considering a range of scenarios. The important aspects which need to be considered in the plan include:

– User friendly output for use with minimal specific knowledge of the scenarios
– Scenario specific hazard extent
– Relevant criteria for the output which is easily understood by non-experts
– Explanations of usage and criteria in simple terms

KEYWORDS: emergency plan, emergency response, consequence assessment

INTRODUCTION

Chemical plants which could cause major accident hazards in the UK carry out predictive risk assessments (PRA) as a basis for compliance with regulations. Typically, the assessments identify the range of potential consequences from a representative set of hazardous scenarios (safety and environmental). This is then used to determine if the prevention, control and mitigations available are sufficient to reduce the risk to as low as reasonably practicable (ALARP).

Even with the best controls, major accidents will never be totally eliminated so understanding the effects of any that do occur is critical to being able to deal with them. Emergency planning and response is the principal means to mitigate the effects in the event of loss of containment.

STATUTORY REQUIREMENT

The Control of Major Accident Hazards (COMAH) Regulations 1999, implement the Seveso II Directive (96/82/EC), and are important for controlling major accident hazards involving dangerous substances in the UK. The COMAH Regulations aim to prevent major accidents involving dangerous substances and to limit the consequences to people and the environment if accidents do occur. COMAH requires on-site and off-site emergency plans to deal with potential major accidents for those sites identified as top tier, i.e. with the greatest hazards.

Schedule 5, Part 1 of COMAH describes the objectives of emergency plans and one of them is '*communicating the necessary information to the public and to the emergency services and authorities concerned in the area*' (HSE, 2003).

EMERGENCY PLANNING

Emergency planning is part of an overall strategy for controlling and minimising the effects of major accidents to people and the environment. One of the key components of the emergency planning is identification of the significant sources, types, scales and consequences of potential major accidents, including malicious acts (HSE, 2003).

Some of the general issues in understanding the release events and severity are:

- What are the possible consequences of a release of dangerous substances to people and to the environment?
- Over what distances can these hazards create harmful effects, i.e. how far from the sources will these substances be dangerous to people and to the environment?
- What level of harm will they pose and under what circumstances?
- Is the harm immediate or delayed?

The answers to the above are required for emergency preparedness. This helps in determining:

- The public information zone for awareness communications on potential risks and mitigating actions to be taken
- Who needs to be informed and when in an actual emergency (based on the extent of the potential impact on on-site personnel, emergency response personnel, off-site industrial and domestic populations)
- What advice should be communicated (e.g. close doors and windows, stay indoors, evacuate or other mitigation measures)
- What immediate actions to be taken (e.g. isolate leak, other control measures, evacuate, cordon-off, search and rescue, etc.)

INFORMATION FROM COMAH PREDICTIVE RISK ASSESSMENTS

One element of the top tier site COMAH safety reports is the background information that can be used for emergency planning and preparedness. This includes:

- The process hazard review identifying the significant release sources and hence the set of representative scenarios for PRA
- The consequence modelling data (including dispersion models) from PRA
- Data on the potential harm from the substances concerned
- Information on mitigation measures to be taken/available on-site.

Although one of the reasons for completing PRA is to provide information for emergency planning the results of assessment for risk estimation will not always provide practical support for emergency response. This is because the PRA tends to identify the resultant effects after a period of time (e.g. one hour) rather than information to understand the development of the scenario over time, and hence what effect that has on emergency response options. This is particularly true with toxic releases where the cloud will travel over time, compared to a fire where the key emergency response is to prevent the fire from spreading to limit the radiant effect and potential for escalation.

Table 1. Dangerous toxic load criteria

Abbreviation	Definition
DTL	Dangerous Toxic Load Describes the exposure conditions, in terms of airborne concentrations and duration of exposure, which would produce a particular level of toxicity in the general population. DTL is expressed as an equation, which allows the calculation of the concentrations which relate to any chosen time period. UK HSE has defined SLOD and SLOT DTLs.
SLOD	Significant Likelihood of Death Corresponds to the exposure conditions which are predicted to cause mortality of 50% of an exposed population
SLOT	Specific Level of Toxicity Corresponds to the exposure conditions which are predicted to cause • Severe distress to almost every one in the area • Substantial fraction of exposed population requiring medical attention • Some people seriously injured, requiring prolonged treatment • Highly susceptible people possibly being killed.

The Dangerous Toxic Load (DTL) criteria set by the Health and Safety Executive (HSE, 2008) for fatalities, Significant Likelihood of Death (SLOD), and injuries, Specific Level of Toxicity (SLOT), are generally used for predictive risk assessments in the UK. These are explained in Table 1.

Direct use of the SLOD and SLOT criteria is often not sufficient for emergency planning purposes. This is because vulnerable populations such as the young, old or sick may have a higher mortality or injury rate than estimated, and because, dependent on the material considered, even very low concentrations may cause distress. For some materials the concentration which leads to distress/awareness may extend well beyond the SLOT contour, and hence the emergency services need to understand the implications and response necessary. For some people this could mean medical attention is required, and for others just further information and reassurance. This should be acknowledged when considering emergency response and hence appropriate toxic criteria need to be selected for emergency planning.

TOXIC ASSESSMENT CRITERIA FOR EMERGENCY PLANNING

Toxic criteria are normally set based on the applications or purpose and in general can be categorised as:

- Hygiene standards
- Emergency exposure limits
- Major accident hazard and land use planning limits.

There is a range of emergency exposure limits, all intended to be used to support emergency planning and response. Most of them are represented as the concentration (normally parts per million or mg/m^3 of the hazardous material in air) which results in a particular effect when someone is exposed for a specified duration. There are also indices for acute toxic exposures that are not based on a simple concentration value but take account of other parameters.

Some of the emergency exposure limits, emanating from various bodies, include the following (Nair, 2009).

- Emergency exposure guidance level (EEGL)
- Emergency exposure index (EEI)
- Emergency exposure limit (EEL)
- Emergency response planning guideline (ERPG)
- Immediately dangerous to life and health (limit) (IDLH)
- Public emergency exposure limit (PEEL)
- Short-term public emergency guidance level (SPEGL)
- Indicative occupational exposure limit valves (IOELVs).

Some of the above exposure limits have subsets covering the effect of exposure to different levels/concentrations. For example, the ERPG is the maximum airborne concentration below which, it is believed; nearly all individuals could be exposed for up to one hour without experiencing or developing certain defined effects. Three ERPGs are used, the defined effects being:

- ERPG-1: No effects other than mild transient adverse health effects or perception of a clearly defined objectionable odour.
- ERPG-2: Irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.
- ERPG-3: Life threatening health effects.

From the range of exposure limits appropriate criteria need to be selected based on the hazardous material, the site location, the mitigation measures in place and population effected by the event. Typically, three or four values (toxic concentration of the hazardous material) are selected to represent the extent of consequences. The range of consequences chosen could be to reflect no/minimal effects, minor injuries, major injuries and probable/certain fatalities following loss of containment event.

An example of selection of toxic criteria for potential release of chlorine is given in Table 2 and Table 3.

The DTL concentration differs with time of exposure. A higher concentration can be tolerated for a short duration compared to a longer duration. An example showing four calculated time steps are given in Table 3.

Table 2. Toxic criteria: chlorine

Criteria	Toxic effect	Reference
0.5 ppm	Exposure for short time without irritation and injury. May enter the hazard area for mitigation actions (with sufficient protection). e.g. for valve isolation etc.	STEL from EH40 (HSE, 2007)
108,000 ppm^2 min	Severe distress to almost every one in the area; some people seriously injured; highly susceptible people possibly being killed.	SLOT DTL (HSE, 2008)
484,000 ppm^2 min	Mortality of 50% of an exposed population	SLOD DTL (HSE, 2008)
1000 ppm	Fatal after a few breaths (within minutes); No emergency response is considered possible for the chlorine cloud at or above 1000 ppm concentration unless the operator (population) wears positive pressure breathing apparatus.	HS(G) 28 (HSE, 1999)

Table 3. Chlorine dangerous toxic load concentration at different exposures

	Exposure period (min)			
Chlorine DTL	5	10	30	60
Atmospheric concentration SLOT (ppm)	147	104	60	42
Atmospheric concentration SLOD (ppm)	311	220	127	90

INFORMATION AND DATA FOR USE IN AN EMERGENCY

The emergency planning guidelines list the set of data to be prepared for emergency which range from material data sheets to process details; from communication systems to key personnel; and from emergency control to fire fighting appliances and replenishing. This information helps in identifying the emergency and details the available resources. However, this data may be inadequate when an emergency occurs. The emergency action team will have to find answers to the many realistic questions to tackle the situation, some of them are:

- How far has the toxic cloud travelled by the time emergency services are mobilised, and how far will it travel in the next period of time?
- What is the toxic effect on people from the cloud at various downwind distances of interest, and how is this changing over time?
- How much time does the site emergency team have to isolate the leak before it reaches a vulnerable population?
- What type of mitigation is needed: e.g. is there a need to evacuate people?/Is there time to do so?
- Will people be protected in their homes with doors and windows closed?
- Is it safe to enter an area? Will a search and rescue operation be needed? What personnel protection measures will be needed?

There should be sufficient information readily available to answer the above questions, which needs to be considered in advance as there is limited time/personnel available to run consequence models during an emergency. It is therefore good practise to develop a user-friendly document which includes typical information. The document should cover data relating to a range of scenarios, which is easily reviewed to enable the appropriate option to be selected. The key to the information and the way it is presented is to enable someone to identify the correct PRA(s) to use in the emergency response with minimal training and understanding of the chemicals and processes involved.

USER GUIDANCE

The initial user requirement is to select an appropriate hazardous scenario to use as the basis for the emergency response, as it is only practicable to use representative scenarios rather than the whole range of potential scenarios. To simplify the selection the document should contain:

- Data relating to a range of predictive consequence information available to enable selection of data set to use; considering:
  - Events which result in different consequence effects, e.g.
    - Minor release – localised/on-site effects only
    - Significant release – off-site effects –ongoing until isolated
    - Catastrophic release – off-site effects –instantaneous release of inventory
  - Descriptions of event types to aid selection, e.g.
    - Minor release – e.g. seal failure, pinhole leak in pipeline or hose
    - Significant release – e.g. large hole in pipeline, hose, vessel
    - Catastrophic release – e.g. vessel rupture, external impact.

An instantaneous release will have different characteristics to an ongoing release, and whilst a key action for the latter will be to isolate the leak if possible, that is unnecessary for the former case.

Once the relevant scenario has been selected the document should guide the user to select an appropriate weather condition:

- Data relating to different weather conditions, typically
  - 5 m/s wind speed and stability D (neutral) (D5) typically represents day time in the UK
  - 2 m/s wind speed and stability F (stable) (F2) represents night time in the UK
  - Site/operational specific conditions, e.g. D10 representing a warehouse fire.

Wind direction obviously needs to be known at the time of the incident to enable the actual release contour to be selected.

At this stage the actions of the emergency response team will depend on the time lapse since the release started. It is therefore necessary to identify the current estimated consequence contours, and the potential development of the scenario, both before and after isolation, so decisions can be taken on the responses required. It is also important to be able to see the short term consequential effects, especially for a catastrophic instantaneous release, so the emergency response team can estimate the extent of casualties already sustained.

- Data relating to the development of the hazardous scenario over time (both before and after isolation of the leak)
  - At time steps – to reflect the spread of the toxic cloud when the release is detected, when it reaches significant populations on-site, when it reaches off-site populations, and the effect of isolation (if possible).

An understanding of the toxic effects needs to be simply explained, which when combined with the predicted change over time will enable the emergency response team to make decisions:

- Data relating to the severity of the event.
  - For example, exposure to 1000 ppm of chlorine results in death after a few breaths (within minutes); this indicates that the people within the 1000 ppm chlorine cloud have limited or no chance of escape or survival.
  - For example, exposure to 0.5 ppm of chlorine will be causing distress to people who are worried about the health effect to their families, however the likelihood of lasting harm is minimal so there is no need to evacuate these people. Decisions on whether they should stay indoors and close windows and doors or not will depend whether the cloud is moving towards them, or passing away.

An example of the type of information which is available from a standard predictive risk assessment is shown in Figure 1.

The range of information which could be provided to support real-time emergency response is shown in Figure 2 and Figure 3.

BENEFITS

The aim of the user-friendly documentation is to make the information easy to use a high tension situation where mistakes can easily be made. The intention is not to remove the need regular training for those likely to be involved in emergency response, both on-site and off-site, as obviously experience of the tool will improve the speed at which the information can be accessed. Sufficient exercises should be conducted to familiarise all parties with the emergency plan, information available and how to use it effectively. Periodic review and revision reflecting any changes in the process or emergency management system is also needed for ensuring the document and plan provides updated information. As the data available is by definition limited to a few representative scenarios, exercises and training will enable additional information to be communicated, which supports emergency response effectiveness, including:

- Likely location of releases
- Occupied buildings/continuously manned areas
- Isolation options (manual/automatic/local/remote)

Performing consequence modelling in advance not only provides readily available information, but also means that an appropriate consequence assessment tool has been used for the material concerned, and hence the results are more reliable.

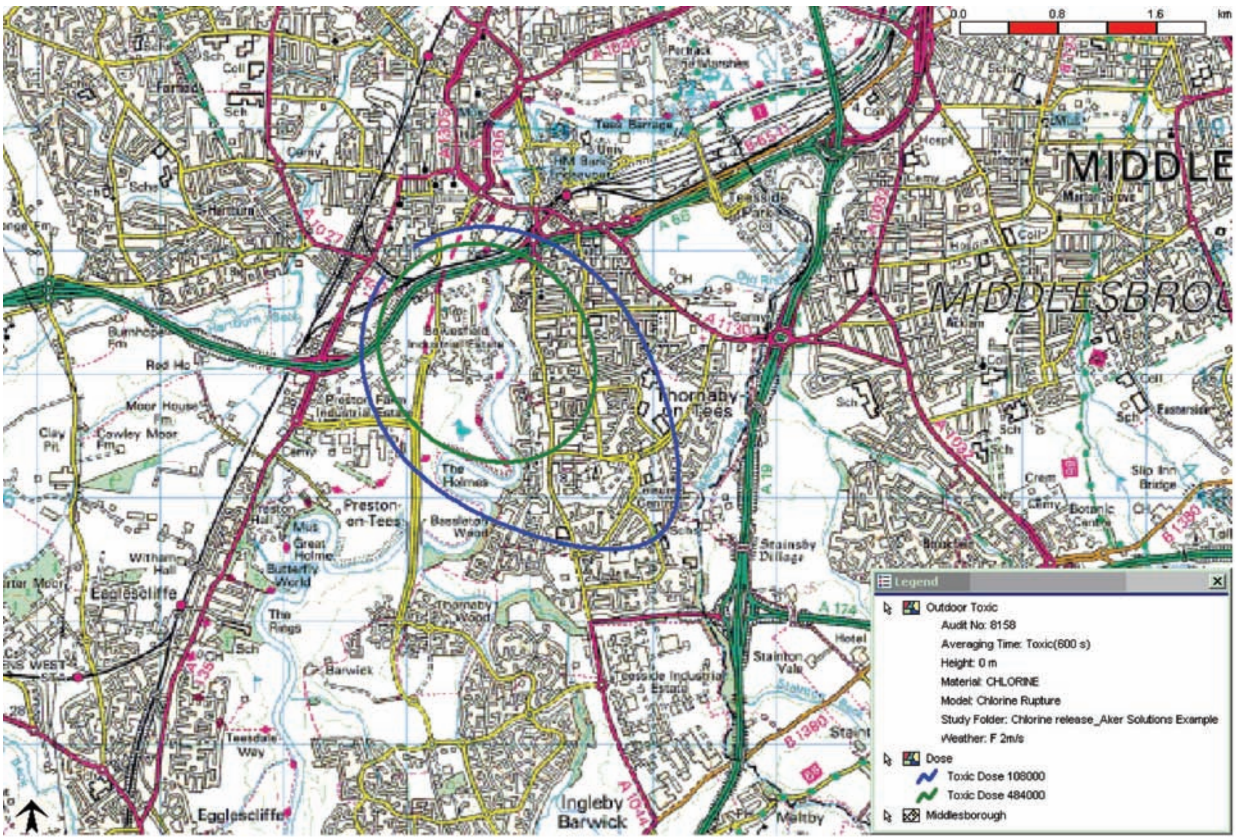

Figure 1. Typical predictive risk assessment output

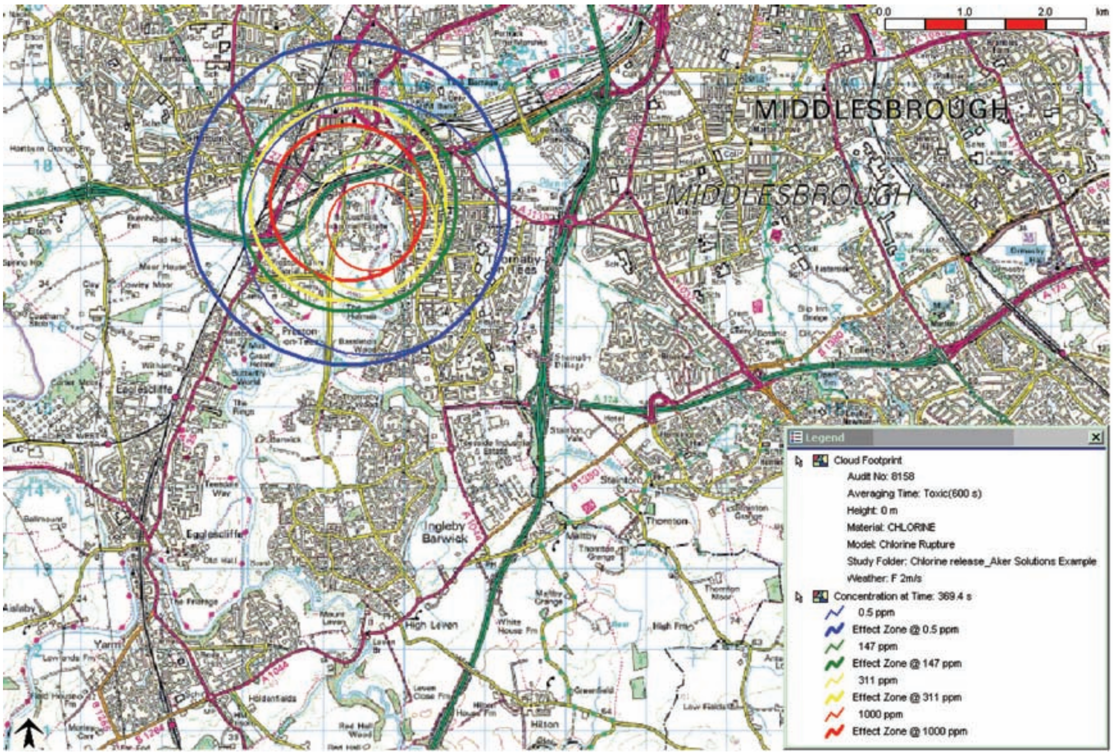

Figure 2. 5 Minute toxic cloud contours

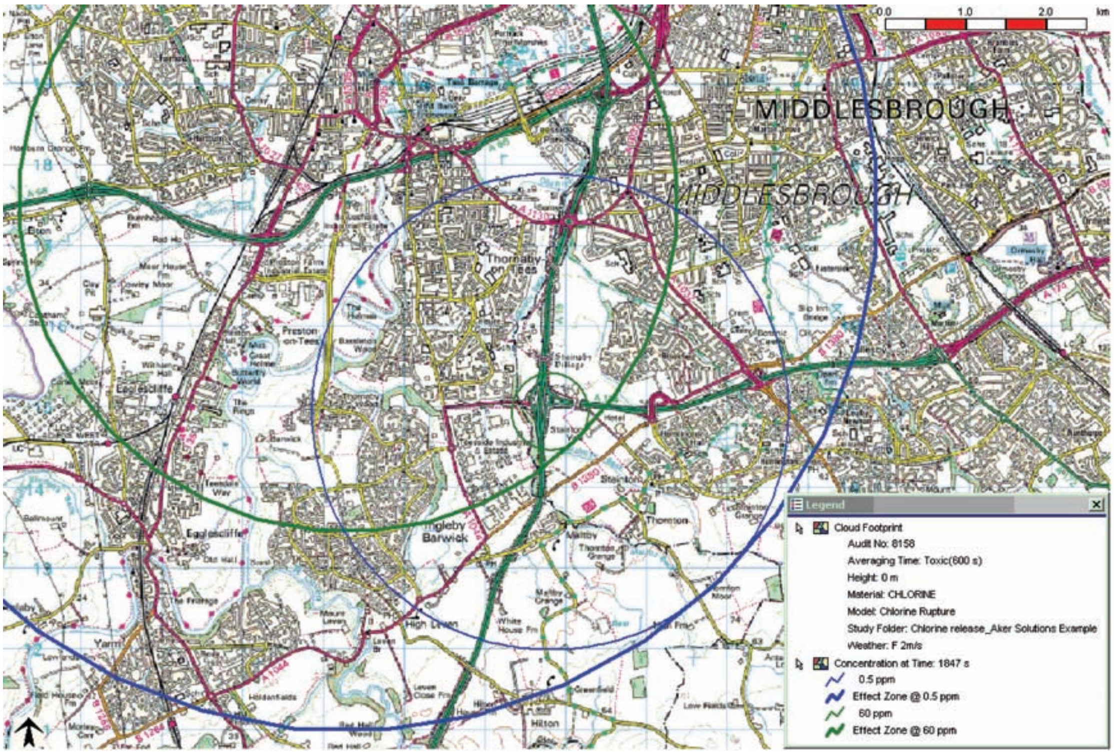

Figure 3. 30 Minute toxic cloud contours

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Where possible in-situ air monitoring will back up the information supplied, but this is not always feasible to put into action quickly, so the documentation provides a best estimate for immediate use.

This information can also be used for normal operations and for planning maintenance activities. For example, the high hazard zone surrounding a potential toxic release source can be predicted to enable access to be restricted and entry allowed only using positive pressure respiratory equipment and other suitable personal protective equipment.

CONCLUSION

Emergency planning and real-time response can be aided by a user-friendly document which enables the user to determine an appropriate set of toxic contours to be used. The selection of which data to use needs to be appropriate to the major hazard potential from a site and the relevant wind direction and weather conditions. A set of suitable toxic criteria which covers the range of harm which a substance poses is also necessary to support decisions on how to minimise casualties downwind of the release.

Pre-prepared toxic effect contours may not exactly reflect the reality of the situation which occurs, but with a range of consequential data relating to different release rates, and weather conditions, there will be some information on which to base decisions. The change of effect over time, and the different effects for smaller or larger releases can be used to influence decisions as there will also be an element of uncertainty about the modelling output.

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