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OSIRIS: software for the consequence evaluation of transportation of dangerous goods accidents

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Abstract

Outil de Simulation des RISques (OSIRIS) is a hazard simulation tool for the training of firemen or manufacturers during interventions with dangerous raw material transportation. This software allows one to obtain a quick answer regarding areas touched by the accident and to provide assistance for judicious decision taking as well as to define the means to implement and the time of reaction to realise an efficient intervention. OSIRIS simulates different types of accident like calculation of leak flow, calculation of evaporation flow, simulation of toxic gas dispersion, confining, simulation of explosions, simulation of fires. Three types of result are obtained: numerical values, graphs of evolution according to distance, effect distances drawn on a map of the accident site.

In the second part of the publication, a simulation of a toxic gas dispersion accident is realised. OSIRIS is a decision-taking help tool which allows a simple use and a reduced calculation time, and that is able to simulate many cases of technological accidents.

Keywords: Fire; Explosion; Toxic gas release; Computer software; Hazard assessment; Risk assessment; Consequence analysis

Software availability

Name of product: OSIRIS

Developed by: G. Dusserre, C. Bourelly

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Email: gilles.dusserre@ema.fr

Available since: 1998

Coding language: Delphi 5

Programme size: 5 Mo

Hardware requirement, minimum: Pentium+16
Mo+Windows 95

Hardware requirement, advised: Pentium II+32
Mo+Windows 95

1. Introduction

The analysis of previous accidents teaches us that one third of technological accidents are linked to dangerous

raw materials transportation (Vilchez et al., 1995). The typical example is Houston where five people were killed and 178 injured by the release of 17.2 tonnes of pressurised anhydrous ammonia following the crash of an articulated lorry in a highway accident (Pederson and Selig, 1989). At the opposite of permanent installations, a risk assessment for dangerous goods transport along a road is difficult to realise if one wants to take several types of environments encountered along the trip into account. In this framework, regulations appear to allow one of the best risk managements in case of accident.

However, to implement a fast and efficient intervention with appropriate organisational and technical means, one has to be able to estimate the effects generated by such an accident and to train intervention teams in order to bring assistance with a decision tool for crisis management.

Several software has been developed to provide decision help to fire rescue and/or industrialists. Some of them are presented in the Table 1. Their main features are identified like the type of simulation effects of major accident and the type of results. All software, in the Table 1, has integrated a model of gas dispersion and

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Table 1
Software involved in crisis management and their main features

Name of the software	BREEZE	CAMEO	OSIRIS	MIDAS	RISK WIT	GASTAR	ALOHA	FLACS 98	FNAP	SEVEX
Name of the establishment	Trinity consultants	WYDE991	LGEI	Midas	VTT automation	CERC	NSC	GEXCON	INERIS	ATM PRO
Available since	1983	1985	1995						1994	
Type of danger										
Atmospheric dispersion	X	X	X	X	X	X	X	X	X	X
Aquatic dispersion										
Soil dispersion										
Explosion	X		X	X	X			X		X
Fire			X		X					X
Language	English	French-English	French-English	English	English	English	English	English	French-English	French-English
Database										
Number of products	13	5000-8000	120	12	45	21	+900	11	+50	100
Results										
Numerical	X	X	X	X	X	X			X	X
Graphic	X	X	X	X	X	X	X	X	X	X
Cartographic	X	X	X	X					X	X
GIS	X	X	X	X			X		X	X
Decision help tool		X	X		X					X
Formation	2 Days	Recommended	Educational software	Recommended		Recommended	Recommended	Recommended	0.5 Day	2 Days
	www.breeze-software.com	www.epa.gov/ceppo/cameo	www.midas-at.com	http://www.vtt.fi/aut/rm/riskana/indexe.htm	www.cerc.co.uk/software/gastar.htm	www.epa.gov/ceppo/cameo	www.ineris.fr	http://www.gexcon.com/index.php?src=flacs/flacs.html	http://users.skynet.be/www.ATM-PRO.com/NEW	

some them have an explosion and fire model too (OSIRIS, Riskwit and SEVEX for example). Many of them have a link with a geographical information system in order to take into account the features of the accident environment. A further development of OSIRIS software will be a link with a geographical information system.

In order to better apprehend accidents linked to dangerous raw materials transportation and to take appropriate decisions with regard to the considered accident, a training software called Outil de SIMulation des RISques (OSIRIS, risk simulation tool) has been developed. The aim of this software is to train people that manage crisis situations in case of technological accidents through the simulation of the several accidental phenomena such as explosion, fire, and toxic gas dispersion. These simulations take into account such factors as the implied product characteristics (physic-chemical and toxicological) or the meteorological conditions for instance. This will allow one to implement appropriate means to protect potential targets (human beings, environment...).

This software gives a quick answer regarding areas hit by the accident and provides an assistance to take the judicious decisions with regards to the means to implement and the time of reaction to perform an efficient intervention. Simulations of accidents are realised thanks to well-known models taken from the literature. This software is currently distributed by several companies, by the TEES company in France and by the Verdini company in the USA.

Three types of results are obtained:

- numerical values;
- evolution graphs according to the distance;
- effect distances that are reported on the accident site map.

2. OSIRIS presentations

OSIRIS is software running under Windows. The main objective of OSIRIS is to provide information that permits the management of people and environment in case of accident during harmful raw materials transportation. It is able to simulate many technological accident types and to provide features of implied products thanks to the use of the different modules:

- calculation of discharge rate;
- calculation of evaporation flow;
- simulation of toxic gas dispersion;
- confining;
- simulation of explosions;
- simulation of fires;
- converter unit;
- database of products.

Each of these autonomously running units is integrated in a main window of OSIRIS.

3. Accident simulation

3.1. Discharge rate

This module calculates the flow from a gaseous breach, liquid or two-phase flows in case of a tanker's leak.

By choosing a product in the scrolled list, the value of the release rate of a tanker can be determined. This calculation will be used to simulate other phenomena such as atmospheric dispersion of toxic gas. Calculated release rate can be of three different types.

3.1.1. Gas phase release (Mills and Paine, 1990)

This can result from a breach in the vapourised phase of a pressurised gas tank. The model used (Eq. (1)) is based on the equation of Bernoulli. The rate of flow is critical and the leak occurs on a capacity or a conduct in gaseous phase with a constant pressure upstream

$$Q_{\text{gas}} = KS \sqrt{PM_v \gamma \left[\frac{2}{g + 1} \right]^{\frac{\gamma+1}{\gamma-1}}} \quad (1)$$

where Q_{gas} , is the gas mass flow rate (kg s^{-1}); K , the discharge coefficient (dimensionless); S , the cross-sectional area hole (m^2); P , the absolute gas pressure (Pa); M_v , the gas density (kg m^{-3}); and γ , the Poisson ratio (dimensionless).

3.1.2. Liquid release (Ziomas et al., 1989)

A leak on a tank will release liquid until the height of the liquid above hole becomes null, with the ability to calculate the tanker emptying time for products stored at atmospheric pressure. The model used (Eq. (2)) to simulate a flow in liquid phase is the equation of Bernoulli, disregarding the hydrostatic pressure in the tank and assuming a breach in the inner-wall, that is to say with no charge loss

$$Q_{\text{liquid}} = M_v KS \sqrt{2gh + 2 \frac{P - P_a}{M_v}} \quad (2)$$

where Q_{liquid} , is the liquid mass flow rate (kg s^{-1}); P_a , the atmospheric pressure (Pa); g , the gravitational acceleration (m s^{-2}); h , the liquid height above hole (m).

3.1.3. Two phase release (UIC, 1987a,b)

Most of accidents linked to release from liquefied gas under pressure tanks are a mixing of gas and liquid. During a two phase release, the formation of vapour and the charge loss of the diphasic mix slow the flow down. The proposed model (Eq. (3)) is based on works of the Chemical Industry Union (UIC) that proposes an empirical formula that divides the value of the liquid flow by a

$$Q_{\text{diphasic}} = \frac{Q_{\text{liquid}}}{a} \quad (3)$$

where Q_{diphasic} , is the two-phases mass flow rate (kg s^{-1}); Q_{liquid} , the liquid mass flow rate (kg s^{-1}); and a , the constant (2.5) (dimensionless).

3.2. Evaporation

In the case of a leak on a tank of liquefied gas under pressure, three phenomena contribute to the transformation of liquid in gas.

3.2.1. The flash fraction (Mills and Paine, 1990)

The flash fraction (Eq. (4)) corresponds to the transformation from the liquid to the vapour phase for a fraction of liquid under pressure when it is suddenly lowered to the atmospheric pressure.

$$T = C_{\text{pl}} \frac{T_{\text{eb}} - T}{H_{\text{vap}}} \quad (4)$$

where T , is the flash fraction (%); H_{vap} , the enthalpy of vaporisation (J kg^{-1}); C_{pl} , the specific heat liquid phase at constant pressure (J (kg K)^{-1}); T_{eb} , the boiling temperature (K); T , the liquid temperature (K).

3.2.2. The formation of aerosol

The assumption that the rate of aerosol formation is equivalent to the flash fraction rate is supposes.

3.2.3. Vapour emissions from liquid spills (UIC, 1987a,b)

By introducing easily measurable data as temperature, ground type, surface of the layer and duration of evaporation, one will be able to quantify the emission rate due to the evaporation from a pool. It is necessary to take into account three types of thermal contributions.

3.2.3.1. Heat transfer from ground (Lannoy, 1990)

This constitutes the essential source of heat provided to the liquid. The model (Eq. (5)) takes into account parameters of conductivity and thermal diffusion ability of the ground (Lannoy empirical parameter), ground temperature, boiling temperature of the product and the evaporation duration of the layer

$$P_{\text{sol}} = C \frac{T_{\text{sol}} - T_{\text{eb}}}{\sqrt{\pi a t}} \quad (5)$$

where P_{sol} , is the heat flux by conduction (W m^{-2}); C , the thermal conductivity (W (m K)^{-1}); a , the thermal diffusivity ($\text{m}^2 \text{s}^{-1}$); T_{sol} , the subsoil temperature (K); t , the time after the start of spill (s).

3.2.3.2. Heat transfer from atmosphere (Lannoy, 1990)

The model (Eq. (6)) takes into account, parameters of

convection coefficient, boiling temperature of the product and the ambient temperature

$$P_{\text{air}} = h(T_{\text{air}} - T_{\text{eb}}) \quad (6)$$

where P_{air} , is the convected heat flux from air (W m^{-2}); h , the heat transfer coefficient to the atmosphere ($\text{W m}^{-2} \text{K}$); T_{air} , the ambient temperature (K).

3.2.3.3. Solar radiation contribution (Lannoy, 1990)

This is assumed equal to an average value of 540 kW m^{-2} .

Knowing the liquid spill surface, the time of evaporation and having estimated the total thermal contribution, the evaporative emission is calculated. The determination of the total gaseous flow is made by combining the terms of evaporation flow, two-phase release as well as the flash fraction rate.

3.2.4. Dispersion

Emission of a toxic gas is one of the major risks met in chemical industry. The toxic gas release can be continuous or instantaneous. The evolution of the dispersion phenomenon generated by toxic gas release is complex because it implies specific parameters such as meteorological conditions and obstacles effects. Three main numerical models (Mohan et al., 1995) are available in the literature; these models are sorted by growing complexity:

- gaussian models;
- integral models;
- three dimensional models.

OSIRIS uses gaussian models that are both simple to use and properly adapted to crisis management cases. Gaussian models are based on a mathematical formula expressing the concentration at any point according to experimental parameters. Concentrations thus calculated strongly depend on the estimation of standard deviations used in these models. Two sets of standard deviations resulting from experimental measures are proposed:

- Standard deviation of Pasquill-Gifford (Eq. (7)) (semi-empirical method) (Hanna and Drivas, 1987)

$$S_x = S_y$$

$$S_y \text{ or } S_z = ax^b + c \quad (7)$$

where S_x , S_y , S_z are the down-wind, cross-wind and vertical dispersion parameters of cloud (m); x , the distance from the source (m); a , b , c , the Pasquill-Guiford coefficients (Table 2).

- Standard deviation of Doury (Eq. (8)) (semi-empirical method) (Doury, 1984)

$$S_y \text{ or } S_z = (At)^K \quad (8)$$

Table 2
Pasquill–Guiford coefficients

Stability class	$x < 1\text{ km}$			$x > 1\text{ km}$		
	A	b	c	A	b	c
A	S_y	0.215	0.858	0	Same factors as $x < 1\text{ km}$	
	S_z	0.467	1.89	0.01		
B	S_y	0.155	0.889	0		
	S_z	0.103	1.11	0		
C	S_y	0.105	0.903	0		
	S_z	0.066	0.915	0		
D	S_y	0.068	0.908	0		
	S_z	0.0315	0.822	0		
E	S_y	0.050	0.914	0	0.050	0.914
	S_z	0.0232	0.745	0	0.148	0.15
F	S_y	0.034	0.908	0	0.034	0.908
	S_z	0.0144	0.727	0	0.0312	0.306

Table 3
Doury coefficients for normal diffusion

Transfer time (s)	A_x or A_y (m/s)	A_z (m/s)	K_x or K_y (dimensionless)	K_z (dimensionless)
0–240	0.405	0.42	0.859	0.814
240–3 T280	0.135	1	1.130	0.685
3 T280–97 000	0.135	20	1.130	0.500
97 000–508 000	0.463	20	1.000	0.500
508 000–1 300 000	6.50	20	0.824	0.500
> 1 300 000	200 000	20	0.500	0.500

where t , is the time after the start of the release (s);
 A , K are the Doury coefficients (Tables 3 and 4).

These two standard deviation sets are based on the notion of stability category. The stability category is determined with experimental solar radiation and wind speed measures.

Table 4
Doury coefficients for low diffusion

Transfer time (s)	A_x or A_y (m/s)	A_z (m/s)	K_x or K_y (dimensionless)	K_z (dimensionless)
0–240	0.405	0.20	0.859	0.500
240–97 000	0.135	0.20	1.130	0.500
97 000–508 000	0.463	20	1.000	0.500
508 000–1 300 000	6.50	20	0.824	0.500
> 1 300 000	200 000	20	0.500	0.500

The two main limitations of gaussian models are the following:

- The meteorological conditions are assumed to be stable and the ground is assumed to be flat.
- The whole plume is assumed to preserve itself, so there is

No product deposition (components eaching the ground are reflected inside the plume).

No product absorption of component by the liquid entities or by the vegetation.

No chemical transformation, except in the case of hydrogen fluoride (HF). In fact, a part of HF undergoes an oligo-polymerisation reaction with ambient air.

This dispersion unit is useful for the simulation of the dispersion of a gas in the atmosphere during a continuous confining loss (leak). It allows, when conditions of the release are known, the estimation of the pollutant concentration in the atmosphere at a given point and a given time. A graph of the concentration according to the distance can be plotted as well as a map of the areas exposed to the pollutant.

Three types of releases (Riou, 1989; TNO, 1997a,b; Lees, 1986) can be simulated:

- Instantaneous release (Eq. (9))

$$C(x,y,z) = \frac{M}{2\pi^{3/2}S_xS_yS_z} \exp\left(\frac{-(x-ut)^2}{2S_x^2}\right) - \frac{y^2}{2S_y^2} \left[\exp\left(\frac{-(z-h)^2}{2S_z^2}\right) + a \exp\left(\frac{-(z+h)^2}{2S_z^2}\right) \right] \quad (9)$$

where C is the concentration (kg m^{-3}); M , the mass of product (kg); h , the source height (m); u , the wind velocity (m s^{-1}); t , the time after the start of release (s); x , y , z , are the down-wind horizontal, cross-wind horizontal and vertical coordinates (m); a , the soil reflexion parameter (dimensionless).

- Puff model (Eqs. (10)–(12))

$$M_i = Q(t) \frac{t(i-1) + t(i)}{2} [t(i) - t(i-1)] \quad (10)$$

where M_i , is the mass of the n th puff (kg); $Q(t)$, the mass flow rate for the finite-duration t (kg s^{-1}); $t(i)$, the end time release of the n th puff. Total mass M (kg) of release product

$$M = \sum_{i=1}^N M_i \quad (11)$$

where N , is the number of puff

$C(x,y,z,t)$

$$= \sum_{i=1}^N \left\{ \frac{M_i}{8(2\pi)^{3/2} S_{xi} S_{yi} S_{zi}} \exp\left(\frac{-(x-u(t-t_i))^2}{2S_{xi}^2}\right) \right. \\ \left. - \frac{y^2}{2S_{yi}^2} \right\} \left[\exp\left(\frac{-(z-h)^2}{2S_{zi}^2}\right) + a \exp\left(\frac{-(z+h)^2}{2S_{zi}^2}\right) \right] \quad (12)$$

- Gaussian plume model (Eq. (13))

$$C(x,y,z) = \frac{Q}{2\pi u S_y S_z} \exp\left(\frac{-(x-ut)^2}{2S_x^2}\right) \\ - \frac{y^2}{2S_y^2} \left[\exp\left(\frac{-(z-h)^2}{2S_z^2}\right) + a \exp\left(\frac{-(z+h)^2}{2S_z^2}\right) \right] \quad (13)$$

If one considers a plume-shaped continuous release of toxic gas, one determines concentrations at the coordinates point (X,Y) with meteorological data (wind speed and wind direction, categories of stability or diffusion type). The value of the immediately dangerous for life and health (IDLH) distance of the toxic gas considered is calculated.

Graphs representing the evolution of content by pollutant according to release point distance can be plotted as well as exposure zones on a map of the site. The graphic representation is circle-shaped but not plume-shaped. In fact, the result representation like a circle shaped permits to take into account the worst case when it occurs several modifications in wind-direction during the gas dispersion.

3.3. Confining (Fulleringer, 1995)

In case of toxic gas release in the atmosphere, the confining to closed buildings is a possible solution. This module is used to evaluate the necessary time for the pollutant to penetrate into a closed building. It can also give the concentration (Eq. (14)) in the building after a given period of time depending on the type of draught proofing (the internal and external concentration fraction follows an exponential law that depends on the time of exposure and the rate of air renewal in a room).

$$\frac{C_{int}}{C_{ext}} = 1 - \exp\left(-W \frac{t}{60}\right) \quad (14)$$

where C_{ext} is the concentration in the outer air (ppm); C_{int} , the concentration indoors (ppm); t , the time (min); W , the ventilation rate (h^{-1}).

This unit allows the assessment of the risk for the neighbouring population during the accidental dispersion of a toxic gas and the appropriate decision taking by rescue services, either to evacuate or to confine people potentially affected by this accident.

3.4. Explosion

This module is devoted to a boiling liquid expanding vapour explosion (BLEVE) type explosion and to unconfined vapour cloud explosion (UVCE) type explosion.

Effects of these explosions are:

- the blast also called overpressure;
- the potential emission of projectiles;
- the thermal flux.

This unit is used to calculate thermal effects of a BLEVE (diameter (Eq. (15)), duration (Eq. (16)) and thermal effects of the sphere of fire (Eq. (17)), and the overpressure effects of the UVCE. The model (SEI, 1990; UIC, 1987a,b; Fulleringer, 1991; TNO, 1997a,b) used for the phenomenon of a BLEVE is empirical and has been established by the TNO, based on experiments and on the feed-back of experiments during the main accidents. A hemispheric expansion of the fire sphere is considered

$$D_{max} = 6.48M^{0.325} \quad (15)$$

where D_{max} , is the fire ball diameter (m); M , the mass of product (kg)

$$t = 0.852M^{0.26} \quad (16)$$

where t , is the duration of exposure (s)

$$\frac{F_{emitted}}{F} = \left(\frac{R_{bf}}{R}\right)^2 \quad (17)$$

where $F_{emitted}$, is the heat flux emitted ($=200 \text{ kW m}^{-2}$); F , the heat flux at a distance R (kW m^{-2}); R_{bf} , the radius of fire ball (m); R , the distance from the source (m).

The equivalent TNT model (SEI, 1990; Lannoy, 1990; TNO, 1997a,b) used to determine the TNT equivalent of an explosion of UVCE type is based on a correlation between the consequences of the explosion of a mass of product X with the mass of TNT having generated the same effects at the same distance. This correlation (Eq. (18)) is defined as being the link between the energy of combustion of the TNT equivalent mass and the combustion energy potentially available in the mass of product released during the explosion.

$$a = \frac{M_{TNTequi} \times Q_{TNT}}{M_{product} \times Q_{product}} \quad (18)$$

where a , is the TNT equivalency based on energy (dimensionless); M_{TNT} , the equivalent mass of TNT (kg); $M_{product}$, the equivalent mass of product (kg); Q_{TNT} , the combustion energy of TNT per unit mass (kJ kg^{-1}); $Q_{product}$, the combustion energy of product per unit mass (kJ kg^{-1}).

The results can be represented on a graph or a map. Assistance concerning effects on people and on environ-

ment as a function of the incident thermal flow and of the incident overpressure are also available.

3.5. Fire

The first module allows the determination of the radiant heat flux for a layer fire of hydrocarbon according to the distance at which the intervention team is located. The calculation formula (Eq. (20)) (Michaelis, 1998) takes into account the combustion speed, the in-air lightening factor, the emitted flux (Eq. (19)) determined by the Stefan–Boltzmann law (Drysedale, 1985), and the distance from the source.

$$\Phi_o = \varepsilon \sigma T^4 \text{ Stephan–Boltzmann law} \quad (19)$$

where Φ_o , is the total energy emitted (W m^{-2}); ε , the emissivity (measure of the efficiency of the surface as a radiator); σ , Stephan–Boltzmann constant ($5.67 \times 10^{-8} \text{W m}^{-2} \text{K}^{-4}$); T , the temperature (K)

$$\Phi = 0.05 \times \Phi_o K \left(\frac{D_{eq}}{x} \right)^2 \quad (20)$$

where Φ , is the radiant heat flux (W m^{-2}); Φ_o , the total energy emitted (W m^{-2}); K , the rate of combustion; D_{eq} , the equivalent diameter; x , the distance from the source (K).

The second unit allows the determination of quantities of water, of emulsifier and means (pumps, canons...) to implement an intervention against a fire (SEI, 1989; DSC, 1989). Flow rate of foaming solution

$$Q_{sm} = S T_{am} \quad (21)$$

Quantity of foaming solution

$$V_{emul} = Q_{sm} t \frac{C_e}{100} \quad (22)$$

Quantity of water

$$V_{eau} = Q_{sm} t - V_{emul} \quad (23)$$

Number of water canon and pump

$$N_c = \frac{Q_{sm}}{Q_c} \quad (24)$$

$$N_p = \frac{Q_{sm}}{Q_p} \quad (25)$$

Volume of foaming solution

$$V_m = F Q_{sm} t \quad (26)$$

where Q_{sm} , is the flow rate of foaming solution (l min^{-1}); S , the surface of the pool (m^2); T_{am} , the rate of froth application ($\text{l min}^{-1} \text{m}^{-2}$); V_{emul} , the quantity of necessary foaming solution (l), V_{eau} , the quantity of necessary water (l); t , the duration of the intervention (min); C_e , the concentration of foaming solution (%); N_c , the number of

necessary water canon; Q_c , the flow rate of a canon (l min^{-1}); N_p , the number of necessary pump; Q_p , the flow rate of a pump.

Foam is one of the most efficient means in the struggle against liquid fires. It works in three ways:

- it prevents oxygen input into the liquid on fire;
- it stops the emission of flammable fumes;
- it cools the surface thanks to its water component.

The fire module is used to calculate water and emulsifier quantities and necessary equipment for an efficient intervention.

3.6. Converter

This module contains a tool that allows users to quickly convert the main units. It is made of five main categories. Each one corresponds to a type of unit: concentration, density, pressure, temperature, discharge rate and speed.

3.7. Database of products

The OSIRIS database of products can be consulted and updated. This database informs on products properties (chemical and toxicological characteristics) (Air Liquide, 1976; CANUTEC, 1996; Drysdale, 1985; INRS, 1995; Sapeurs Pompiers de Genève, 1996; Weast, 1986).

OSIRIS automatically recuperates products characteristics during calculations.

A navigation menu above this list allows one to move rapidly and to reach update functions (product research, data modification, addition of a product, deletion of a product from the database). The research for a product can be made by its name or by its ONU number.

4. Example of an application

Let us consider an imaginary accident, in which a tanker of chlorine falls over on a national road with near potential targets as a school, a retirement house or a residential district. The OSIRIS software is going to allow us to evaluate damages induced by this accident, first of all:

- by estimating the leak flow of the tank (discharge rate module);
- then by simulating the dispersion of the chlorine cloud (dispersion module);
- and finally to propose an assistance to decision by calculating the concentration inside rooms with the help of the confining unit to know whether it is better

to evacuate or to confine the population potentially affected.

4.1. Step 1: calculation of the discharge rate

The following data are necessary:

- the name of the product: chlorine;
- the ambient temperature (15 °C);
- the temperature of the product (15 °C);
- the pressure of storage (if it is unknown, the software is able to estimate it with the interpolation of vapour saturating pressure curves that are integrated) (5.84 bars);
- the type of orifice (breach);
- the size of the orifice (25 mm);
- the height of liquid above the orifice (2 m).

In the case of a two phase release, the evaluated discharge rate is 4.72 kg s^{-1} (Fig. 1).

4.2. Step 2: simulation of the dispersion of the cloud of chlorine with the help of a gaussian model of plume-shaped continuous release

The following data are necessary:

- the wind speed (2.5 m s^{-1});
- the average direction of the wind (South West);
- the stability class (according to the cloud cover and to the wind speed) (normal for Doury and C for Pasquill-Gifford);
- the discharge rate calculated at the previous step (4.72 kg s^{-1}).

The following results are obtained:

- The concentration value (kg m^{-3} and ppm) at the chosen distance (750 m) is 64 ppm for Doury's model and 50 ppm for Pasquill-Gifford's model (Fig. 2).
- The immediately dangerous for life and health (IDLH) value is reached at 1136 m for Doury's model and 1008 m for Pasquill-Gifford's model (Fig. 2).
- An evolution graph of the concentration according to the distance from the release point, (Fig. 3).
- The ability to visualise distances at which the value of the concentration equal to the IDLH concentration and to the value limits exposure (VLE), which can be considered as the threshold limit value (TLV) are reached. The results are presented under the shape of a circle because it is assume that the wind direction can change very quickly (Fig. 4).

This last result visualises on the map potential targets that are the most exposed to this accident. In the studied case, a holiday camp located to 750 m downwind.

Safety teams must be able to estimate the toxic risk towards the population in order to know if it would be better to evacuate or confine it. In this goal, it is necessary to calculate the concentration to which people are exposed with the atmospheric dispersion unit and, then, with the confining unit, to estimate the concentration inside the place and to compare it to threshold values that are available.

4.3. Step 3: calculation of the concentration inside a place

The concentration outside the place and the type of

Fig. 1. Two-phases release of chlorine tanker.

OSIRIS

Exit Print ... ? Help

Product : CHLORINE

Wind speed (m/s) : 2,5 External temp. (°C) : 15

Wind direction : SW Product temp. (°C) : 15

Welcome Leak flows Evaporation Dispersion Confinement Explosion Fire Conversion Database

Coord. X (m) : 750 Leak flows (kg/s) : 5,84

Coord. Y (m) : 0 Height of release (m) : 0

Coord. Z (m) : 0

Leak flows : ☒ Calculated value ☐ Other value

Coef. of ground reflexion : ☐ Total absorption ☒ Total reflection

Instantaneous heaves Continuous trail of smokes Help

Doury

Diffusion : Normale

Concentration (g/m3) : 0,184 IDLH distance (m) : 1136

Rate (ppm) : 64

Pasquill - Gifford

Classes of stability : C

Concentration (g/m3) : 0,146 IDLH distance (m) : 1008

Rate (ppm) : 50

Map Chart

Fig. 2. Determination of chlorine concentration at 750 m and IDLH distance.

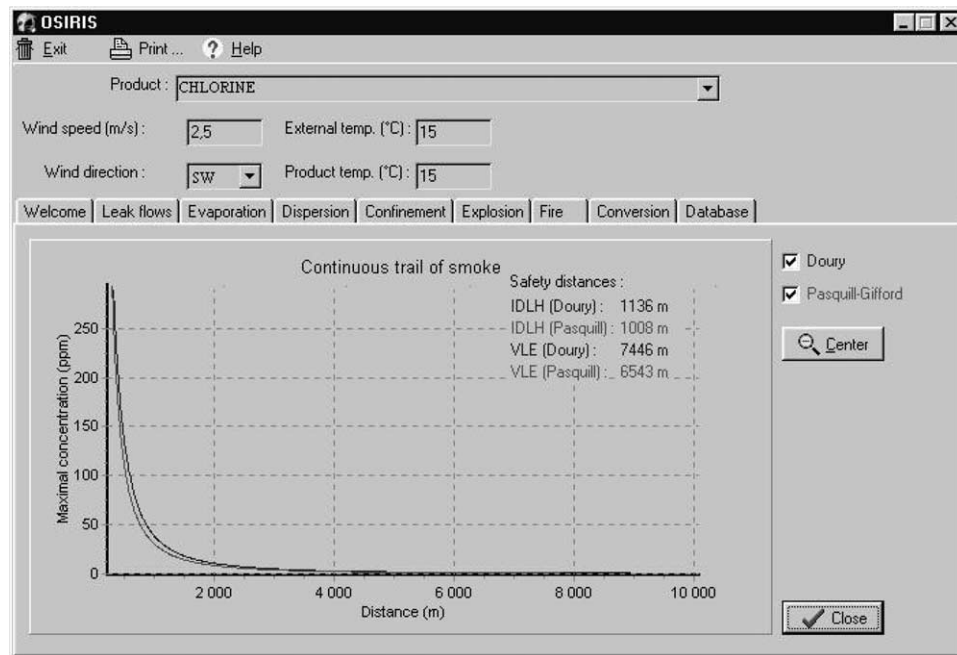


Fig. 3. Graph of chlorine concentration evolution according to the distance.

stopping-up (which is linked to the air renewal rate in the place) being known, the internal concentration for a given exposure time or the necessary time to reach the defined concentration threshold from which people

health is in danger can be evaluated. With these results, the decision either to evacuate or to confine the population can be taken. In the present study,

- an external concentration of 64 ppm is calculated;

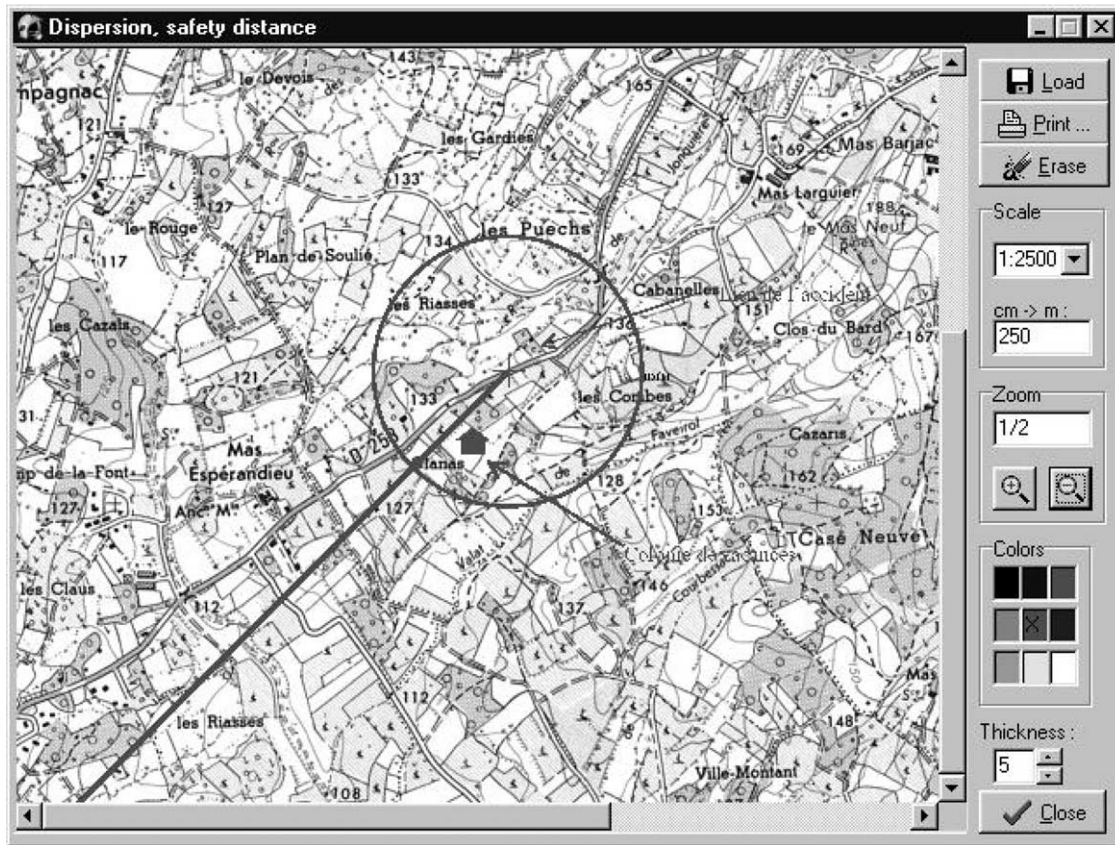


Fig. 4. Zones allocated by chlorine dispersion.

- a type of stopping-up (draught proofed ventilation).

So, the IDLH concentration of chlorine (30 ppm) is obtained after 190 min. Then, confining seems to be a good solution (Fig. 5).

This tool is interesting because it allows us to describe and simulate a technological type accident in its totality and to provide help to take decisions.

Fig. 5. Determination of confining efficiency.

5. Conclusion

This software is a training tool for firemen or manufacturers during intervention with accidents linked to dangerous raw materials transportation. The mathematical models used allow the simulation of phenomena such as explosions, fires and toxic gas dispersion. Moreover this software has both advantages, simple use and reduced calculation time.

OSIRIS is therefore an user-friendly tool for decision-taking help, it is able to simulate many cases of technological accidents.

At present, the users of OSIRIS software are the French emergency and fire district department (SDIS) and many industrials. OSIRIS is available both in French (with the SI units) and English (with the imperial units) versions.

OSIRIS allows users to know the limits of the modelling used so as to maintain a realistic view of results obtained through the software.

The interest of using OSIRIS is to provide simulations of real situations of accidents linked to dangerous raw materials transportation, to try to manage them in the best way.

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