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Rapid analysis of risk assessment using developed simulation of chemical industrial accidents software package

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ABSTRACT: The environmental consequences are defined as consequences of accidental release of hazardous substances to the natural environment. This release can lead to many hazards depending on the material stored. The consequences of these hazards to the environment are widespread and have significant importance to human communities living in the surroundings. The mathematical models are extremely useful tools to predict the impacts of chemical process accidents. The objective of this paper is to develop a software package for accident simulation and damage potential estimation. The software is coded in visual basic and is compatible with windows working environments. The software is called Simulation of chemical industrial accident. This application is a comprehensive software package which can be integrated with geographical information system to predict and display the consequence of chemical hazards. The software is a user-friendly and effective tool for evaluating the consequences of major chemical accidents, process decision making for land-use planning, namely locating suitable hazardous installations, hazardous waste disposal areas and emergency response plan.

Key words: *Chemical process accident, mathematical models, visual basic, geographical information system*

INTRODUCTION

In recent years there has been a significant increase in public awareness of the potential dangers posed by the usage of chemicals and their effects to both human beings and the environment. Operational mistakes (such as elevated pressure and temperature beyond critical limits) in chemical industries can cause catastrophic consequences to life and the environment leading to financial loss. Major industrial hazards are generally associated with the potential for fire, explosion or dispersion of toxic chemicals. These usually involve the release of material from containment, that is, in case of volatile materials, followed by its evaporization and dispersion (Lees, 1996).

Consequences or impacts of the chemical accidents depend on the properties of the substances involved and their physical states (gas, liquid, solid, temperature, pressure, etc.), the equipment used (vessels, piping, valves, etc.) and the operations involved (storage, transport, chemical reaction, etc.). The most gruesome toxic gas release accident occurred at Bhopal which claimed over 20,000 lives (Khan and Abbasi, 1999). Whereas the most serious accident by flammable gases stored took place at Mexico city in 1984. Approximately, 500 people were killed and over 7,000 were seriously injured. The surrounding area was truly dramatic (Pietersen, 1984). There are several ways to evaluate the risk assessment for chemical hazards accidents. The traditional way works via using mathematical models. The Mathematical models are extremely useful tools to simulate the consequences of possible industrial accidents. It is essential to know that it is difficult to implement manually the risk assessment through mathematical techniques. Therefore, the complex development of the accidents scenarios can be achieved by using the consequential modeling combined with various computer software. The computer programs or codes must be able to evaluate the consequences of the hazards. This is to assist those

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who are not specialists in the physical and chemical phenomena associated with such release. Since the evolution of geographic information systems (GIS) which supports various fields of study including risk assessment, GIS has become a useful tool to explore the consequences of chemical hazards. GIS provides powerful tools for spatial analysis whereby their capabilities for complex and dynamic analysis are limited. Although traditional simulation models are powerful tools for complex and dynamic situations, they often lack the intuitive visualization and spatial analysis functions that GIS offers. Obviously, the integration of GIS and simulation models, together with the necessary databases and expert systems, within a common and interactive graphical user interface (GUI), should make more powerful and easy to use and understand risk information systems. Based on a dedicated GIS as the central tool and user interface, the databases of hazardous installations and hazardous chemicals are linked in a hypertext structure. These include tools for spatial risk assessment based on externally generated risk contours and link to the models describing accidental and continuous atmospheric releases, fire and explosion risk analyses. All the models utilized are fully integrated with the underlying GIS layer and include an embedded rule-based expert system to help with the model input specifications and the interpretation of the model results. Model results take the form of interactive graphics and animated topical maps for an intuitive understanding and a more efficient interactive analysis. Widespread computer software were used in the past to evaluate the consequences of the major accident hazards. These software are coded in different computer languages, such as C++, visual basic, fortran, delphi and pascal (or any other code which may run under the microsoft windows operating system) and can be connected to other computer tools to provide an attractive user-friendly “front-end platform”. There are several available commercial software in the market for safety and risk assessment. Areal locations of hazardous atmospheres (ALOHA) is a computer program designed specially for use by people responding to chemical accidents. Process hazard analysis software tool (PHAST) by det norske veritas (DNV) is designed for fire, explosion and dispersion accidents. The fire, release, explosion and dispersion (FRED) software, created by Shell Company, is used to calculate some effects such as blast waves from high pressure vessel failure, blowdown of two-phase pipelines and subsea gas releases. The safety abroad first educational travel information (SAFETI) package was developed by Technica for the risk assessment of chemical process industry facilities. The world bank hazard analysis (WHAZAN) consequential analysis package calculates the consequences and hazard zones resulting from incidents involving toxic and flammable chemicals (Pietersen, 1984). It was developed by Technica to implement methods described in manual of industrial hazard assessment techniques commissioned by the World Bank (Technica, 1985). hazardous dispersion of gases (HAZDIG) software was developed by Khan and Abbasi for generating scenarios for the emission and gaseous dispersion of hazardous chemicals (Khan and Abbasi, 1999). yonsei automatic generator of accidental scenarios (YAGAS) was developed by Kim, *et al*., (2001). This system automatically formulates a list of accidental events and generic hazardous substances which yields a qualitative description of accident events related to the process hazards. However, users such as engineers, physicists etc. engaged in hazard assessment are no longer satisfied with programs that only accept input from a file or that only produce line printer output. Instead, they expect the code writer to exploit the full capabilities of modern programming languages and operating environments to provide user-friendliness and enable the output to be presented in a variety of formats (screen, printer, plotter and disc) Kinsman, *et al*., (1994). Inspirational ideas and proposals to create, design and develop software can be used in accident stimulation to determine potential damages. The software allows the users to overcome their weaknesses in using computer programming and instead enables them to analyze their study through the probable way through probability method. The software can run under the microsoft windows operating system and can be connected to other computer tools to provide an attractive user-friendly “front-end platform”. The main objective of the development of this software was initially to train people who are involved with the emergency response plan by helping them through the provision of a simulator that is capable of simulating different accidental scenarios such as scenarios of toxic gaseous dispersion, fire and explosion of hazardous chemicals and then by customizing the results for risk analysis and emergency response management.

MATERIALS AND METHODS

SCIA is a software package for evaluating and analyzing any likely hazards from industrial accidents. The performance of developing this software was performed through simulation of several mathematical models for different types of hazards. It includes various hazard models such as fire, explosion and toxic release models. These models can be used to examine radiation, overpressure and toxic dispersion hazards from various scenarios. The simulation system helps to estimate the consequences of possible accidents in a fast and reliable way. SCIA is a software running on Windows operating system (95, 98, NT and XP) and the codes are built using visual basic language (VB). The simulation system helps to estimate the consequences of possible accidents in a fast and reliable way. All the programs have been written and designed within an object-orientated framework using VB. SCIA is designed to work as a stand-alone user-friendly software. Furthermore, the software enables users to use GIS technology for screening/scenario assessment. The advantages of using the GIS software for chemical risk assessment applications are immense and these applications are gradually being utilized by a wide variety of users. With the availability of GIS technology, it becomes increasingly possible to develop such software in an efficient and timely manner. The mapping functionality has been developed to allow users to use SCIA as an effective graphical tool. Users will be able to define the cases by locating them on maps and editing them by selecting from the map view. The results can be saved using different formats, exported to Microsoft Excel and later plotted using Microsoft Excel or VB itself. The application is supported by the useful options to make the software increasingly user-friendly, such as MSDS for each material to help the users understand and acquire some knowledge about the materials and conversion units to convert the units without using any external references, internal help to guide the users on how to use the software and various lists of symbols to give a clearer explanation for the short names. This software allows the users to view the results as GUI and then saves them in either text or word format and lastly prints them. Furthermore, the software is designed in such a way that whenever the users make a mistake while utilizing the application, the error message will prompt them on the fault. Therefore, the SCIA software makes it easy for the environmental and safety professionals to identify the hazards associated with accidental releases, fires, explosions and then describes the potential impacts of those risks.

The SCIA consists of four main modules, namely outflow, explosion, fire and toxic release. Each module consists of a few sub-modules which enable the users to perform hazard analysis calculations and obtain result based on case studies. The recent works reported in this paper will discuss the outflow release, vapour cloud explosion (VCE), boiling liquid expanding vapour explosion (BLEVE), fire and fragmentation hazards.

Outflow models are the first stage in developing the majority of consequence estimates used in the SCIA software. Identification of property of the outflow is important because it affects the flow rate estimated for a given hole in vessels, pipes, or other containment devices. Outflow phenomena can exist in three scenarios, i.e. liquid outflow, gas outflow and two phase outflow. Various models have been developed to estimate the outflow scenarios, e.g. model of Bernoulli and Torricelli to estimate the discharge of pure liquids and vapour through a sharp-edged orifice and the model of Chemical Industry Union developed to estimate the outflow for a two-phase discharge (Perry and Green, 1984; UIC, 1987).

An explosion arises due to extremely rapid combustion and expansion of gases which generate a sudden violent release of energy, this violence depends on the rate at which the energy is released. The explosion is usually classified as VCE, BLEVE and missiles.

VCE is defined as explosion within tanks, process equipment, pipes in culverts, sewage systems, closed rooms and underground installations. A vapour cloud explosion is one of the most serious hazards in the process industries because a vapour cloud may drift some distance from the point where the leak has occurred before exploding; it may thus threaten areas lying far away from the source of the vapour cloud. Researchers have developed numerous models such as the TNT and TNO models to calculate the peak overpressure from the explosion hazard. The TNT equivalent model is the simplest model and is used to estimate the consequences of vapour cloud explosion hazards (Brasie and Simpson, 1968). This method is based on the assumption of equivalence between the flammable material and TNT, factored by an explosion yield term (Baker, *et al*., 1983). The principal parameters of the blast wave from the TNT explosion are the peak overpressure and the impulse of the positive phase duration. The descriptions for these parameters have been given by a number of authors (Baker, *et al*., 1983; TNO, 1990; Lees, 1996). According to the TNO model, the explosions are classified as either deflagrations or detonations, and different models are used for each case. This model allows the peak overpressure and the duration time of the explosion to be estimated. Various mathematical models to estimate these parameters are discussed by Wiekema, (1980) and TNO, (1990).

BLEVEs occur when a sudden release of a large mass of pressurized superheated liquid in the atmosphere takes place. The resulting fireball actually derives from the atmospheric burning of a fuel-air cloud in which energy is mostly emitted in the form of radiant heat. Various models have been developed to calculate the BLEVE behaviour. All the models use a power law correlation to relate the BLEVE diameter and duration to mass (CPQRA, 2000). Useful formulas for BLEVE are used to calculate peak fireball diameter, fireball duration and the center height of fireball (Hardee, *et al.*, 1978; Roberts, 1982; TNO, 1990; CCPS, 1994; Lees, 1996; DiNenno, *et al.*, 2002). In order to characterize the radiation from fireballs, it is necessary to define the size and dynamics of fireball, and then, to assess the radiation based on these results. One of the simplest practical models for evaluating the thermal radiation from fireball hazards is the point source model. This model has been used to estimate the intensity of thermal radiation from the resulting fireball (Roberts, 1982; Hymes, 1983; Papazoglou and Aneziris, 1999).

When a vessel containing a pressurized gas ruptures, the resulting stored energy is released. This energy can produce a shock wave and accelerate vessel energy fragments (CCPS, 1994). An important consideration in the analysis of the hazard associated with an accidental explosion is the effect of the fragments generated by the explosion. When the explosion occurs in a closed system, the fragments of the containment may form missiles. The problem is considered under the following aspects: size, number, velocity, energy and range. The total number of fragments is approximately a function of the vessel size (Holden and Reeves, 1985). The technique for predicting initial fragment velocities from pressure vessel ruptured was introduced by (Moore, 1967). The velocities have been estimated from empirical data on the assumption that any size charge will propel the fragments the same distance. The empirical calculation to estimate the fragments velocity range is given by Clancey (1972). A crude approximation to estimate the projectile ranges can be related to the fireball radius (Birk, 1995).

Fire is the release of energy during the oxidation of a fuel with most of the energy being in the form of heat. When a flammable gas is released into the atmosphere, different kinds of fires may occur depending on the release mode and the degree of delayed ignition. Three components must be present if a fire is to occur: fuel, oxygen and heat. If one of the components is missing, fire does not occur and if one of them is removed, fire is extinguished (Lees, 1996). It is convenient to divide gas fires into the following types: flash fire, jet fire, pool fire and fireball. The thermal radiation hazard from a fire depends on a number of parameters, including the composition of the fuel, the size and the shape of the fire, its duration, proximity to the object at risk, and thermal characteristics of the object exposed to the fire.

A flash fire occurs when a vapour cloud, formed from a leak, is ignited without any significant overpressure. The major hazard of flash fires is the heat effect from thermal radiation affecting objects in the nearby vicinity of the flash fire or in the path of the flash fire whether on land or water (Ashe and Rew, 2003). The important parameters in a flash fire are flame shape, heat transfer assessment and duration. The models to estimate these parameters are given by the authors: Eisenberg, *et al.*, (1975); TNO, (1990); Andereassen, *et al.*, (1992) and Lees, (1996).

A jet fire occurs when the flammable gas emitting from a pipe or equipment is ignited and burns on the orifice (Lees, 1996). Jet fire modelling incorporates many mechanisms, similar to those considered for flash fires. The important calculations in a jet fire are flame shape, flame tilt, flame dimensions and heat transfer assessment. The models for estimating these parameters are described and discussed in details by the authors: Kent, (1968); Howerton, (1969); Eisenberg, *et al.*, (1975); TNO, (1990); Andereassen, *et al.*, (1992) and Lees, (1996).

Pool fires can occur when a significant quantity of liquid is released and immediately ignited. A pool fire may also occur on the surface of a flammable liquid spilled onto water (Petrolekasa and Andreoub, 1999). Pool fire models are composed of several sub-model components. The important parameters which can be considered when the pool fire is estimated are: burning rate, pool size and flame height, flame tilt, flame drag and flame sag, flame surface emitted power, geometric view factor, atmospheric transmissivity and heat transfer. These parameters are described in detail by the following authors: Burgess and Hertzberg, (1974); Moorhouse, (1982); Babrauskas, (1983); TNO, (1990); Andereassen, *et al.*, (1992); Lees, (1996); Rew and Hulbert, (1996); Cuchi and Casal, (1998) and Kashef, *et al*., (2002).

A fireball occurs when there is a release of some considerable violence and when vigorous mixing and rapid ignition take place. The fire is burning with sufficient rapidity as to cause the burning mass to rise into the air as a cloud or ball (ERM, 1996). Fireball incidents are generally associated with the BLEVE incidents.

The assessment of accidental release and dispersion of hazardous chemicals have necessitated the development of a number of techniques and methodologies. There are more than several mathematical models of varying degrees of sophistication that attempt to address most of the physical processes that can potentially be involved in postulated accident scenarios (Howerton, 1969; Simmons, *et al.*, 1973; Eisenberg, *et al.*, 1975; Solomon, *et al*., 1976; Kletz, 1988; Lees, 1996). Gaussian models are widely used for regulatory purposes. The basis for the Pasquill-Gifford model is Gaussian dispersion in both the horizontal and vertical axes (Hanna, 1982; Pasquill and Smith, 1983)

RESULTS AND DICCUSSION

In order to estimate the consequences of an accident involving people and constructions, usually the method used is probit analysis. Usually, the estimation of the number of people affected by a given accident is achieved through the conversion from the probit variable to the percentage of people affected by means of tables and figures. There is a significant problem when the calculations are done by means of a computer program or by manual calculating, which requires access to a numerical library and significant errors, can be introduced; computer tools operate much better with analytical expressions than with tabulated data.

Human beings are capable of withstanding relatively high dynamic pressures: if the pressure is static, the human body is capable of withstanding even considerably higher pressures (Andersson, 1997). The direct effects of overpressure on humans are eardrum rupture, lung haemorrhage, whole body displacement injury and injury from shatter glasses. People who are killed due to blast waves are usually subject to objects falling on them. In order to estimate the consequences of an accident on people, a function relating the overpressure to the magnitude of the impact is required. Probit analysis has been widely used in hazard assessment. The probit equation for eardrum rupture, particularly lung haemorrhage, lethality, body translation to impulse, glasses breakage and structures damage have been suggested by a number of people introduced as Fugelso, *et al.*, 1972; Eisenberg, *et al.*, 1975. Structural damage caused by blast waves from explosions has traditionally been correlated in terms of the peak overpressure of the explosion. The effects of the blast damage on the construction are based on the determination of the peak overpressure resulting from the pressure waves. Good estimates of blast damage can however be obtained using just the peak overpressure. It is important to know that the small structures suffer less from diffraction loading because the time interval in which the shock wave that envelopes the object may be less than the plastic response of the object to differential loading. For very large buildings and structures, differential loading may cause damage ranging up to complete destruction. Damage to a building in case of an accidental gas explosion is not a serious problem as long as the building is not collapsing or dangerous fragments are not thrown out within or from the building. The method for estimating the impact of overpressure and blast wave on humans and constructions are discussed briefly by several studies (Fugelso, *et al.*, 1972; Eisenberg, *et al.*, 1975; Baker, *et al.*, 1983; TNO, 1990; Lees, 1996).

The damage potential of a fire in terms of heat load generated by the fire is a function of the type of release, flammability and the quantity of the chemicals involved, strength of the ignition source and finally the type of fire. The assessment of the hazards of a major fire event requires a relationship between the thermal load (a function of the radiation intensity and exposure time) and the effects on people. The estimation of the effects of thermal radiation on humans and construction is a key step in the assessment of hazard for installation where flammable liquids or gases are stored. Heat from thermal radiation can cause various harms to human body. People may become casualties as a result of receiving large thermal radiation doses. If excessive heat is conducted rapidly to the lungs, a serious decline in blood pressure may be resulted alongside capillary blood vessel collapse, leading to circulatory failure. Skin tissue burns are commonly classified as the first, second and third-degree burns. The first-degree burns involve just the outer layer of skin. The second-degree burns penetrate more deeply into skin. The third-degree burns usually are dry, charred, or pearly white. The probit equations are used to estimate the probability of an impact (e.g. fatality and/or injury) for a specified harm dose from thermal radiation. Various probit equations to estimate the probability of injuries or death due to high thermal radiation have been suggested by the following authors: Baker, *et al.*, (1983) and TNO, (1990). The effects of thermal radiation on structures depends on whether they are combustible or not and the nature and duration of the exposure. All structural materials classified as combustible or non-combustible. Wooden materials will fail due to combustion, whereas steel will fail due to thermal lowering of the yield stress. The degree of damage may vary with the basic material and building configuration. The building materials and the design of the details of construction have always played an important role in building fire-safety. High radiation from fires, such as the BLEVE fireballs, may rise a considerable distance above the ground and this makes them relatively difficult to be avoided (Tsao and Perry, 1979; Roberts, 1982; Baker, *et al.*, 1983; TNO, 1990; Lees, 1996).

The fragmentation zone safety distance should be calculated to reduce the risk of harm from fragmentation thrown out from the explosion to those working on the worksite and to the local population. Theoretical methods can be used to estimate the impact of fragmentation hazards (Tsao and Perry, 1979; Baker, *et al.*, 1983; Holden and Reeves, 1985; Brown, 1986; TNO, 1990; Lees, 1996; Baum, 1998; TNMA, 2001; Zhang, *et al.*, 2003).

The toxic substance can cause immediate fatality to human life at very high concentration. Toxic materials in contact with any part of the body will result in a freeze burn of varying severity depending on the length of exposure. Different probit functions have been proposed by Ten Berge and van Heemst, (1983); Withers and Lees, (1985) and Lees, (1996) to obtain the fatality from toxic release. SCIA is a software package for evaluating and analyzing any probable hazards from industrial accidents. The performance of developing this software was done through simulation of several mathematical models for different types of hazards. The simulation system helps to estimate the consequences of possible accidents in a fast and reliable way. SCIA is a software running under Windows operating system (95, 98, NT and XP) and the codes are built using visual basic (VB) language. VB is an event-driven language which helps programmers easily create programs that must constantly check for and respond to a set of events, such as key presses or mouse actions. VB language can perform various functions such as scroll bars, dialogue boxes, buttons, icons etc. included in a user interface and events such as scrolling and clicking and has double-clicking in the form of the objects. Although other languages can be used to develop such software, VB was chosen because it is easy to use and has the ability to interface with other applications in the windows operating systems such as microsoft access for database storage, VB itself or microsoft excel for plotting, hyper text marking language (HTML) to build the hint and explanation forms, Help tools to build the internal help and the GIS mapping tool to provide geographical locations of the affected areas. The SCIA software is designed to help and train people who do not have a strong background in evaluating the hazards using computer language. The users will not have to spend weeks or months to study chemical hazards. The user will only have to click a few buttons that will do the job. Furthermore, there is no possibility to make mistakes in the computation, which usually happens due to manual calculation. It was developed using VB language whose state of art consists of a GUI as front end (the visual interface which allows the user to interface with the system) and mathematical models as back end (the programming code). The results of calculations using the codes can be presented in tabulated or graphical forms, then saved and transferred (exported) to the GIS software for risk presentation. The computation of the mathematical models for outflow, explosion, fire and toxic releases has been written in the VB program, following the flowchart illustrated in Fig. 1.

The development of this software was divided into seven distinct stages to enhance effective coordination of the various relevant activities:

- Planning the application
- Designing the database
- Building GUI
- Writing the computer program

- Embedding the ArcGIS controls with the SCIA application
- Testing and debugging the application through using case studies
- Deploying the project into a distribution package

Fig. 2. illustrates the main front page of the SCIA package (i.e. general interface). The general interface is used to obtain selections from the user for evaluating the hazard. It consists of eight menus: file, edit, view, scenario, security, help, run and tools. These menus consist more submenus which can be used to make the SCIA work as a user-friendly software. Other menus can be easily added in the future based on the system requirement. The SCIA software is designed to be flexible for any further additions or modifications. If the product is not listed in the database, SCIA will enable the users to register new chemical product and run the system under similar conditions. Fig. 3 illustrates how the users can key in material names, types and properties and start running SCIA in the normal way. All the properties necessary to register a material in the database must be through this interface. The compound field requires the chemical name of a material or product type, density of material, molecular weight and combustion heat. Once the users key in the input data (i.e. inputs available in the interface presented in Fig. 3), the new material will be automatically stored in the database.

GIS provides the accessibility for software users to view all of the necessary deployment data in place concerning hazards of chemical materials. Data can be added, subtracted, or modified by using computer mouse operations. Alternative plans can be created, analysed and modelled by using GIS. The Arc-GIS engine is a comprehensive library of embeddable GIS components for developers to build custom applications. Using the Arc-GIS engine, developers can integrate GIS functionality into an application with the data being available for calculations in non-GIS components. Developers need much less than the full-featured the GIS products, yet they may require access to sophisticated GIS logic in their application (ESRI, 2004). VB developers can build a focused the GIS mapping application by adding a map control, a table of contents control and selected toolbars to the application. The finished application can then be installed on any Arc-GIS engine runtime seat for deployment. The Arc-GIS controls can be used to build applications in two ways. First, the Arc-GIS controls can be embedded into an existing application to add additional mapping capability. Second, the Arc-GIS controls can be used to create a new stand-alone application. The Arc-GIS controls can be loaded from the VB environment by displaying the VB components dialog box, where you can add the Arc-GIS controls by selecting the control name. In SCIA, the GIS form has been designed by adding the Arc-GIS controls: Map-control, Page-layout-control, ArcReader-control, TOC-control and Toolbar-control. The Map-control and Page-layout-control provided with Arc-GIS engine can work with the map documents. Users can load map documents and other files with different formats. Toolbar control and TOC-control are designed to work with all other controls. The Toolbar-control along with the other Arc-GIS controls offers a rich development environment such as feature selection, graphics, map navigation, etc. The Toolbar-control works in

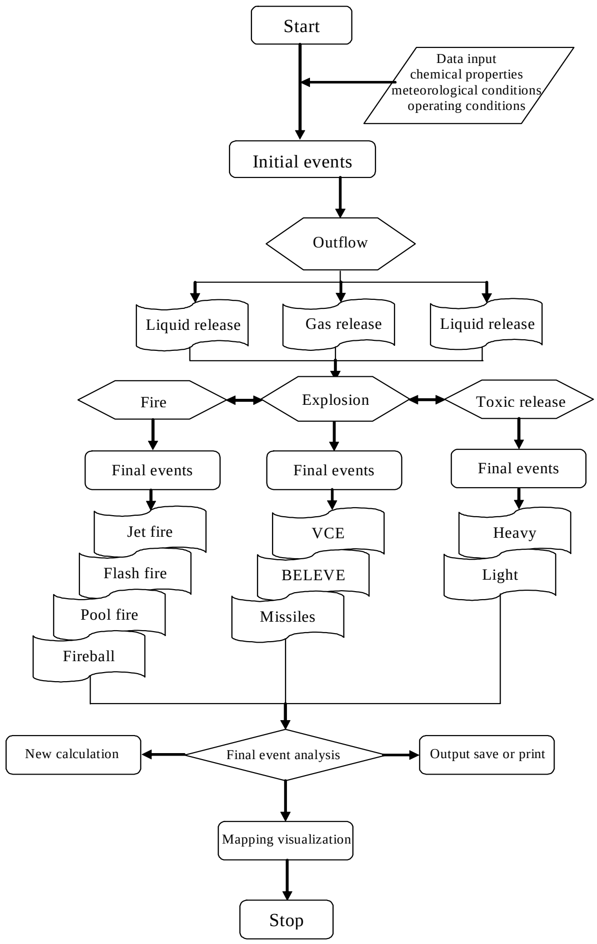

Fig. 1: Main structure of SCIA software

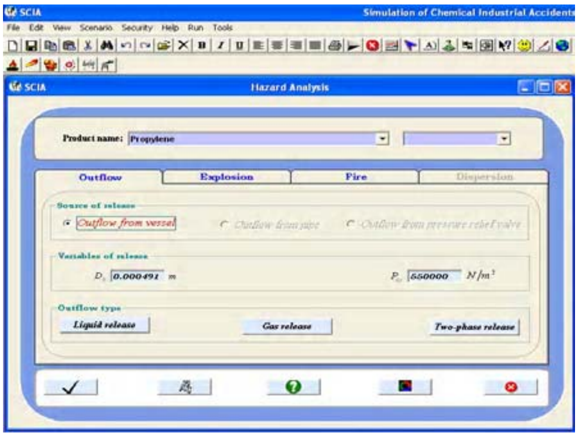

Fig. 2: Main Front page of SCIA Package

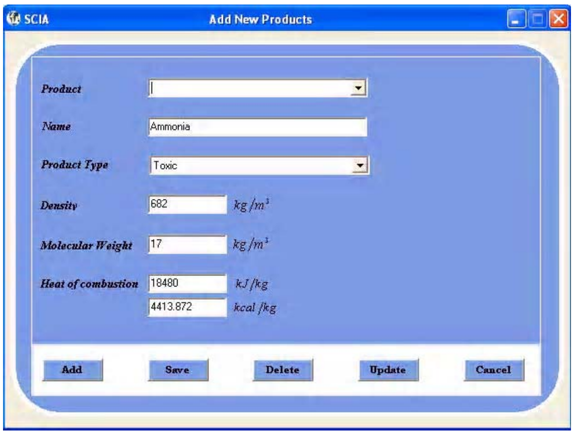

Fig. 3: SCIA option for add new material

conjunction with a 'buddy control'. The 'buddy control' can be a Map-control, Page-layout-control, Reader-control, Scene-control or Globe-control. The Toolbar-control hosts a panel of commands, tools and menus that work with the display of the 'buddy control'. The Arc-GIS system is built and extended using Arc-objects software components and has multiple developer application programming interfaces (APIs). Arc-objects is at the core of all the Arc-GIS products (e.g., Arc-GIS engine) providing a common developer experience across all the Arc-GIS products. There are some subroutines that are common to the Arc-GIS interface. The "Map-control-On Map- replaced" event procedure to set some of the information display map units. The "Open-itm-Click" is an event to enable the users to open maps with certain formats (.mxd, .mxt, .pmf, .dxf). The "Map-control-itm-Click" is an event to activate the Map-control tool and hides the currently activated tool. In order to provide spatial solutions to non-GIS users, the developers need the ability to build domain-specific, easy-to-use applications that can incorporate the power of a comprehensive GIS system into a user-friendly experience. These applications, if built from scratch, can be an overwhelming development effort and may not be time- or cost-effective. The developers can use the Arc-GIS engine developer kit to build standalone applications successfully. GIS allows spatial relationships between the population and hazards to be examined and it can be useful for the hazard identification and exposure assessment phases of risk assessment. The SCIA software provides tools for mapping and identifies potential risks of chemical hazards occurrences around the community. The users utilizing the SCIA software can start the screening/scenario assessment by clicking on the GIS icon in the main toolbar and then can link the results to the GIS form. In the GIS form, the users have various options such as load maps, create buffer zones, zoom in and out, write text, save map, etc. In addition, several hazard zones are overlaid onto the facility map in order to demonstrate the possible public exposure to the defined hazard levels. The method presents the hazard zone as a circle around the point of release from the source. This presentation, referred to as a vulnerability zone, is misleading, since everyone within the circle would be exposed to the impact of the accident. Hazard zones can easily be displayed graphically on local maps that show vulnerable populations, such as nearby homes, schools, nursing homes, businesses, parks and recreational areas. A more realistic illustration of the potential hazard zone around the accident point is given by the darkened cloud in Fig. 4. The cloud area illustrates the hazard footprint that would be expected when a rupture of the 9119 kg propane tank occurs.

SCIA is a comprehensive suite for modelling flammable and toxic chemical accidental releases. It includes various hazard models such as fire, explosion and toxic release models. These models can be used to examine radiation, overpressure and toxic dispersion hazards from various scenarios. The software consists of various formulas for evaluating chemical hazard consequences from explosion, fire and toxic release. All models share one windows interface that includes a comprehensive chemical database containing about 100 industrial chemicals. These materials are stored in the database using a smart and flexible method. Therefore, users can add, delete and update them when needed. The evaluation of a scenario can be characterised as a dialogue between the user and the computer whereby the system asks some questions and then runs the calculation program after the answers have been provided. Depending on the result, new questions can be asked and so on. Several calculation programs are included in the accidental release part of the system. The software evaluates the consequences of released flammable and/or toxic gases outdoors. The calculations of the consequence for both humans and components in the vicinity of the fire and release have been provided by this software. The models included in the package are well established whereby many of them are based on empirical equations. Evaluating the consequences of a discharged hazardous substance is a rather complicated process. The software provides solutions for different scenarios, for example, methods to evaluate explosion hazards such as the TNT and TNO methods. Also, the software consists of methods to estimate the hazards from fire, such as the consequences of flash fire, jet fire, pool fire and fireball. There are many different mathematical models that were used with all these types of chemical hazards. The software also includes methods to evaluate the fragmentation hazards and toxic dispersion. These mathematical models have been successfully simulated and implemented in an interactive VB environment. Using this comprehensive software, the results obtained from simulating the mathematical models for chemical risk assessment can be used in different ways, for example, for comparative (or relative) risk analysis, scenario analysis, probabilistic analysis and screening/ scenario assessment. The results can then be shown as GUI forms (Fig. 5), saved with different formats, exported to Microsoft Excel, plotted using Microsoft Excel or VB application (Fig. 6) and then can be linked to GIS for hazard screening. Furthermore, the software is designed in such a way that whenever the users make a mistake while using the application, the error message will prompt them on the fault. Therefore, the SCIA software makes it easy for environmental and safety professionals to identify hazards associated with accidental releases, fires and explosions and, after that, describe the potential impacts of those risks. Thus, the SCIA software is a good computation tool for the consequences of major chemical accidents.

To confirm the validity of the fire, explosion and gas dispersion procedures, the SCIA software has been extensively validated. The results from these methods are extensively validated with other commercial softwares such as FRED, (2004), BIS, (2003), EFFECT, (1987) and MAXCRED (Khan and Abbasi, 1998) or with the established data. In order to compare the results from the SCIA software with other commercial software, the research took an example to study a release of 9119 kg of propane gas.

The discussion here is done to study the impact of the VCE hazards to humans from the current software.

Then, the results were compared with the other results that were predicted by Lees, (1996) and

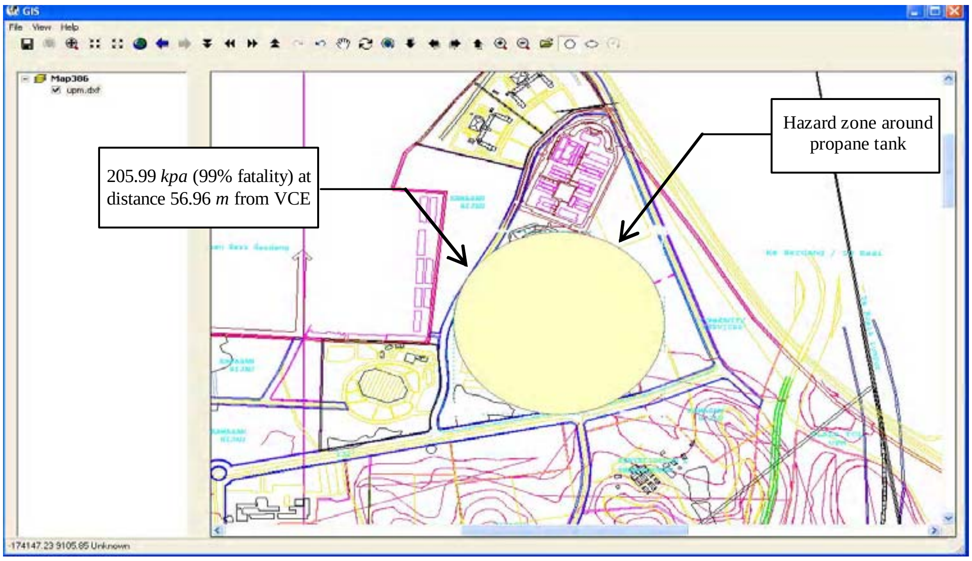

Fig. 4: Potential hazard zone from VCE around the accident center

Eisenberg, *et al*., (1975). The direct effects of overpressure on humans are eardrum rupture, lung haemorrhage, whole body displacement injury and harm from shatter classes. The SCIA software has produced a graphical plot of the percentage of lung haemorrhage vs. distance from the explosion center (Fig. 6). Fig. 6 reveals that for 10% and 99% human lung haemorrhage cases, the distance would be 56.96 m, 44.88 m and the overpressure would be 122.13 kPa, 205.98 kPa, respectively. The personnel at a distance of 44.88 m or closer will be killed by lung haemorrhage. The results from Lees, (1996) and Eisenberg, *et al*., (1975) for the same material type and amount of release are presented in the same figure (Fig. 6). It is useful to know that the results are thoroughly tested and compared between both softwares whereby no significant deviation can arise. The results from the SCIA software are found to be consistent with no significant deviation arising for all trials. These results confirm two facts: First, the coding of the mathematical models for computing the consequences of chemical accidents has been successfully completed. Second, the software is considered as a stand-alone application; therefore, the users can run the software on Windows environments without having to preinstall VB or Arc-GIS engine on that machine.

Assessment of the hazards posed by the storage of flammable or toxic liquids in large tanks can be assisted by the use of mathematical models to calculate the consequences of leakages. These consequences may include fires or explosions from dispersion of flammable vapours, or harm to persons from inhalation of toxic vapours. The mathematical models are difficult to implement manually for a number of reasons, such as the fact that the calculations involved are difficult and time-consuming to perform; a large number of these calculations are required; there are many event outcomes to follow and it is hard to keep track of these. For these reasons, the best estimation can be done by using chemical risk assessment software. The framework for developing chemical risk assessment software applications for chemical hazards has been described in this paper. The software is called SCIA and was developed using the VB programming language. All the programs have been written and designed within an object-orientated framework using VB. The software is developed to run under Windows platform installed on a PC and designed to work as a stand-alone user-friendly software. Furthermore, the software enables the users to use the GIS technology. The mapping functionality has been developed to allow the users to utilize SCIA as an effective graphical tool. The users will be able to define cases by locating them on maps and then to edit them by selecting from the map perspective. As a conclusion, the product is ideal for real-world applications, such as the decision making process for land-use planning, namely to locate suitable hazardous installations, hazardous waste disposal areas and emergency response plan (ERP). It can also be used for teaching “process safety” and “environmental risk assessment”.

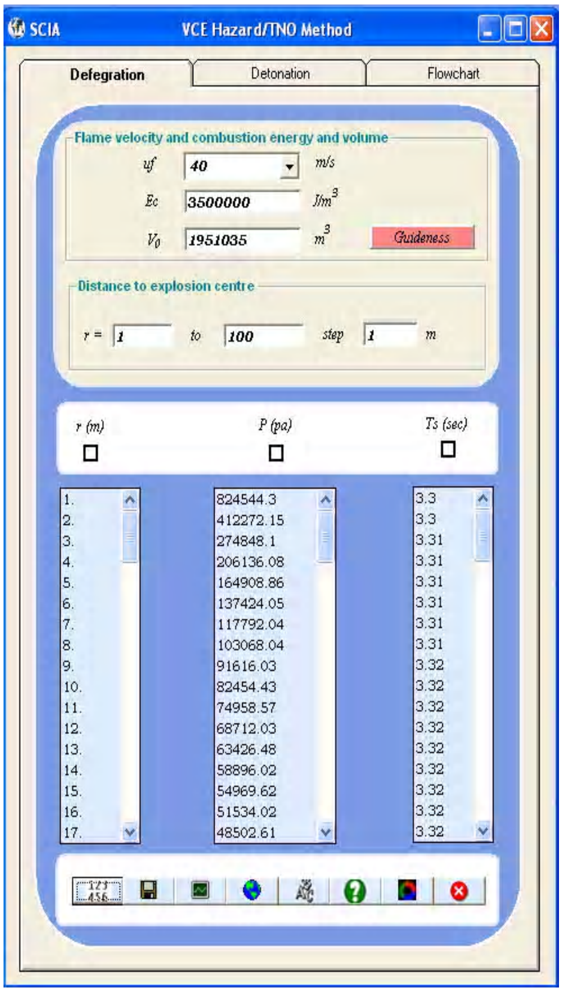

Fig. 5: Input values as a textbox and display results as a listbox

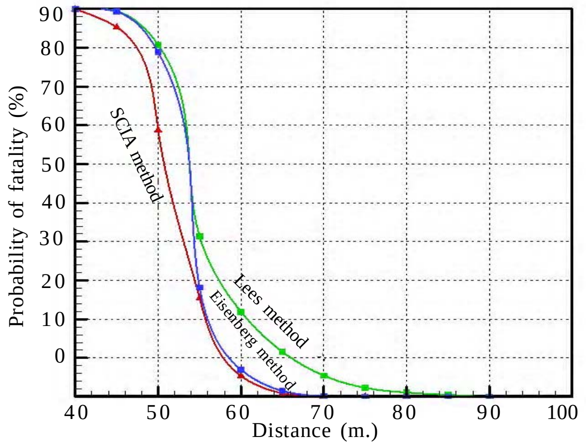

Fig. 6: Comparison of the probabilities of lung haemorrhage by VCE hazard (release of 9119 kg propane tank)

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