EC Safety Management Research *

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1. Scope

The purpose of this paper is to present and discuss EC research¹ on Safety management. Most of this research is carried out within its Major Industrial Hazards Programme. To put the EC research in context the discourse is extended to cover related EC legislation (since one of the purposes of the research is to serve EC policy making) and also European research that is outside EC programmes.

2. Introduction

Industrial progress has a profound impact on the environment and our lives. Although we have, on the whole, benefitted from technological advance, the risks posed by large-scale industrial plant can be worrying. The tendency to concentrate processes and inventories for efficiency can lead to the possibility of very large accidents, threatening lives and the environment over large distances. The hazards from industrial plants are illustrated by a number of major accidents such as those at Flixborough, Seveso and Basel.

Because of the strength of the European chemical industry (it is one of the few sectors where Europe is clearly the world leader) and our high population densities, (Table 1) these issues are more important in western Europe than elsewhere. The possibilities of siting chemical plant in Europe remote from habitation are limited.

Table 1: Comparison of chemical industry production in the US and the EC

	Population (million)	Area (million km ²)	Chemical Industry Production (BECU)	Density of Population per km ²	Density of Production ECU/km ²
EC	345	2.63	337	146	130000
US	249	9.37	237	27	25000

Data from the European Chemical Industry Council

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¹ Cole S. and Wicks P., A review of European Community research in Major Industrial Hazards, 1987 to 1993 (includes a short description of all EC Major Industrial Hazards research projects).

It is natural therefore that the EC has paid particular attention to Major Industrial Hazards both in terms of legislation and research. In contrast in the US, measures to control MIH and public support for research have only just been initiated by the present administration.

Originally this programme concentrated on the chemical and physical aspects of released materials but recently the emphasis has shifted towards management issues, especially safety management of chemical plant.

3. The European activities: legislation and research

The scope of EC legislative and research activities in Major Industrial Hazards are shown in Table 2. The initial emphasis of both the legislation and the research was on the physical aspects of hazards. However since 1990 risk management has been introduced to the research and it is expected to form part of future regulatory requirements.

Table 2: CEC Major industrial hazard activities

RESEARCH ACTIONS*		REGULATORY ACTIONS**
Direct actions carried out by the JRC Industrial Hazards Working Environment	Shared-Cost projects carried out by European laboratories under contract Major Technical Hazards 1986-1990 Major Industrial Hazards 1990-	Policy Environment Action Programmes Action programme IV 1987-1992 Action programme V 1993-2000 Legislation Seveso Directive

Legislation

The major EC legislation in the area of MIH is the EC Directive "on major accident hazards of certain industrial activities" (the Seveso Directive 82/501/EEC). This was adopted in 1982. In it are listed processes and substances with appropriate threshold quantities – an equivalent hazard concept. The directive deals only with stationary installations. Its formal requirements are:

- notification to appropriate authorities;
- preparedness, the implementation of internal and external emergency planning.

Specifically excluded are nuclear installations, military installations, explosives and mining operations.

Current EC legislation and policies on Environmental issues are developed within a series of "Environmental Action Programmes". The 4th (1987-1992) and the 5th (1992-2000)² pay particular attention to industrial accidents. The 5th Programme "Towards Sustai-

* Related activities are also carried out within Cost and Eureka.

** Also actions arising from Single Market policies (DG III) and from Occupational safety (DGV).

² Council Resolution 93/C 138/01 on a Community programme of policy and action in relation to the environment and sustainable development, February 1993.

nability" sets targets in this area and specifies the period (1993-2000) for their achievement. These targets are:

- improved safety standards;
- development of safety management standards;
- improvement and harmonisation of implementation measures;
- increasing coverage of policy to all dangerous establishments.

In order to achieve these aims, the Seveso Directive and its implementation are being reviewed and after effort by the CEC and competent authorities, a fundamental revision of the Directive has been prepared, but at the time of writing is not published.

Further EC legislation having an impact on industrial hazards has arisen from other EC policies. In particular the EC has introduced legislation relating to safety at work which, in practice, has an impact on major hazards. The framework for subsequent specific legislation was established by Council Directive 89/39/EEC on the introduction to encourage improvements of the safety and health of workers at work. This invites the CEC to propose further Directives on specific aspects of occupational safety and indeed specific Directives have now been passed (somewhat amusingly termed the "six pack" sometimes in the UK) relating, for example, to exposure to carcinogens and risk management.

Another source of relevant legislation is that relating to the Single Market. The concern is to ensure that safety legislation in each Member State does not act as a barrier to trade. A timely example is the Council Directives³ relating to market supervision of explosives for civil uses. This specifies essential safety requirements for civil explosives and establishes harmonised standards. Part of this Directive will come into force this year. Further legislation is expected on civil use of other dangerous materials.

Research

The EC supports two types of research. There is "shared-cost" research. This is research that is administered from Brussels where participants from the EC, and under certain circumstances European Free Trade Association countries (and recently East Europe), carry out research under contract. The EC normally covers 100% of project costs for universities and 50% for companies. The second type of research is direct research that is carried out by the EC's own Joint Research Centre. The JRC is divided into a number of institutes, two of which are relevant to MIH: the Information Systems and Engineering Institute and the Safety Technology Institute. Both are based at Ispra in northern Italy. The JRC carries out research for other parts of the CEC, to support EC policies and in some cases under external contracts.

4. The content of EC research

The EC funded research in Major Industrial Hazards should be regarded as a co-ordinated programme with the merits of both types of research (shared-cost and direct) being applied according to the problem to be tackled. A sketch of the areas of current work is shown in Table 3.

³ Council Directive 93/15/EEC on the harmonisation of the provisions relating to the placing of the market and supervision of explosives for civil uses.

Table 3: On-going research

Shared-Cost Projects	JRC Direct Actions
<p>Major Industrial Hazards</p> <p>1. Release phenomena</p> <ul style="list-style-type: none"> – source term and two phase flow – vapour cloud explosion – vapour dispersion – catastrophic fires – dust explosions <p>2. Risk Assessment and Management</p> <ul style="list-style-type: none"> – risk management – risk assessment – hazard identification – human behaviour and risk perception <p>3. Mitigation Technologies</p> <ul style="list-style-type: none"> – water curtains – water sprays 	<p>Industrial Hazards</p> <ul style="list-style-type: none"> – chemical batch processes (runaway reactions) – emergency pressure relief – modelling of VCE's – modelling of dispersion – emergency management – safety critical systems – safety and reliability assessment <p>Working Environment</p> <ul style="list-style-type: none"> – hazard identification – man-machine interface – human behaviour

Funding of research at a European level to quantify major chemical hazards began in the early 1980's with the gas dispersion tests on Thorney Island. In 1987, the EC launched its first series of projects specifically aimed at the understanding of chemical hazards. This was called the Major Technological Hazards programme and covered 6 projects, 4 of which concentrated on physical aspects of releases. These aspects were: two phase releases, vapour cloud dispersion, flame propagation and torch fires.

These projects involved large scale experimentation, wind tunnel simulation and extensive modelling. The two remaining projects concerned human perception of risks and a benchmark exercise to compose methods used in Probabilistic Risk Analysis. These projects have now finished and the final reports are listed hereunder^{4,9}.

In the second Framework Programme of EC R&D, MIH research was considerably expanded both in terms of finances and scope. With 15 MECU of Community Funds being allocated. In addition to the work in improving understanding of chemical and physical accident phenomena, two new areas were added:

- technologies to prevent or ameliorate accidents,
- risk assessment and management.

This division of activities was maintained in the new Environment Programme of EC research activities which is part of the 3rd Framework Programme, under which new projects are being started in the years 92 to 95.

As far as Safety Management is concerned, the relevant work is covered by the heading Risk Management and Assessment within this area the aim is to provide a basis for more rigorous and scientifically based management of industrial risk. The following topics are subject of work:

- transfer of research developments into methodologies and tools of assessment and validation procedures for software and existing failure-rate data bases;
- analysis of and trend identification in accident causes and examination of how accident and near miss data can be more effectively recorded;
- development of auditing systems to assess the ability of industries to operate safely and with concern for the environment;
- determination of industrial best practices and formation of organisational codes of practice and examination how industry conforms with safety standards;
- modelling and validation of communication processes. Examination of decision making processes and development of emergency planning procedures;
- examination of organisational behaviour and change during a crisis, i.e. cognitive task and analysis, task responsibility, training tools;
- development of models of human and group behaviour and effect on company culture;

⁴ Two Phase Releases of Toxic and Flammable Substances – Thermal Ignition, Source Term and Fire Effects, Final Report of Major Industrial Hazards project MTH-AA, Barton J.A. and Moodle K. Edited by S. Contini.

⁵ Research on Continuous and Heavy Gas Clouds, Final Report on Major Industrial Hazards, project MTH-BA, CEC DG XII, Brussels.

⁶ Experimental parameter study into flame propagation in diverging and non-diverging abstracted flows, Final Report on Major Industrial Hazards project DB, Visser J.G. and Bruijn P.C.J., CEC, DG XII, Brussels.

⁷ Physical Modelling of Torch Fires, Final Report of Major Industrial Hazards project MTH-FG, Duijm N.J.

⁸ Summary of Final Report of the European Benchmark Study Major Industrial Hazards.

⁹ Final Report of Major Industrial Hazards project MTH-LD, Disinformation in Major Chemical Accidents, CEC, Brussels.

- examination of regional/national variations in safety culture and managing risk;
- examination of the human tolerance of risk and analysis of the social benefit/detriment of industrial operations.

In addition to the research administered by the EC, two structures have been set up for European cooperation in research on a wider basis. These are COST (Coopération européenne dans le domaine scientifique et technologique) and EUREKA.¹⁰ COST now involves 25 European states cooperating on basic research. One particular project relevant to safety management was “COSTA1” which investigated the human contribution to safety in industrial situations. The final report¹¹ became the foundation of European cooperation in the area of Risk Management. It resulted in the establishment by the CEC of SHARE (Safety and Hazard Research cooperation in Europe) which aims to reinforce European interactions in this area. EUREKA involves 21 countries and aims at improving industrial competitiveness. Two projects relevant to safety management have been started, both aiming at developing software tools. Formentor, which is now finished, developed a set of tools to help operators safely control a complex plant. Membrain is developing tools for emergency management.

These projects and those other Eureka projects relate to industrial hazards are listed in Table 4.

Table 4: Eureka Projects Relevant to Major Industrial Hazards

Project	Start	Aim
COSTA1	1986	survey on risk management
FORMENTOR	1987	decision support
GASYS	1985	gas sensors
FOAM	1989	environmentally friendly fire fighting foam
MEMBRAIN	1990	tools for emergency management
FIDESY	1990	fire detection using optical and infrared imaging
ATMOSPHERE	1990	monitoring of air quality and emergency response
MEXOS	1990	modelling of gas and mist explosions

¹⁰ EUREKA 5 Year Report 1986-1991, and Annual Progress Report 1992, available from EUREKA Secretariat, 19H Avenue des Arts, Boite 3, B-1040 Brussels, Belgium.

¹¹ Systems of Sociotechnologies and industrial safety. Wahlström B., and Leplat J., Olson G., Sten T. and Versteeg G., COSTA1 project Final Report.

Dissemination of results

Although project partners and outside sponsors of the research make a substantial contribution to the efforts and funds, nearly all the results are publicly available. A complete list¹² of the refereed scientific publications from the shared-cost projects is available. Additionally, the CEC has set up the VALUE programme and through CORDIS can provide an information service based on electronically accessed data bases, aiming to support all the shared-cost research actions.

The CEC also has strong links with pan-European organisations which assist in dissemination of information. These include the European Safety Reliability and Data Association, the European Chemical Industry Council and the European Federation of Chemical Engineers (see Table 5). In the field of Risk Management the CEC has set up SHARE¹³ (Safety Management and Hazard Assessment Coordination in Europe) to help bring researchers together, to focus European research on real problems and to provide means for disseminating the outcome of this research to industry and regulators.

Table 5: European organisations involved in dissemination of MIH technology

Organisation	Objectives	Contact
European Process Safety Centre (EPSC)	to provide access and safety information including research	Secretary B. Hancock EPSC, Rugby, UK
Safety Management and Hazard Assessment Research Coordination	to increase interaction between researchers	Secretary: S. Cole CEC, Brussels
European Safety Reliability and Data Association (ESReDA)	to promote research, development and dissemination of reliability JRC supplies secretariat	Secretary: J. Flamm JRC Ispra
European Safety and Reliability Association (ESRA)	to advance and promote safety and reliability technologies	Chairman: Dr. P. Kafka GRS, Germany
European Chemicals Industry Council (CEFIC)	industry representation	Research Director: D. Bricknell, Brussels
European Federation of Chemical Engineering (Working Party on Loss Prevention)	professional body	Secretary: Prof. A. Duxbury, Loughborough University

¹² A list of Refereed Publications made within the EC's Major Industrial Research Projects, Cole S., Wicks P., CEC DG XII, August 1993.

¹³ SHARE: Safety Management and Hazard Assessment Research Cooperation in Europe, a brochure published by CEC DG XII.

5. Some results

Large-scale experimentation and modelling of release phenomena

Some of the most important results to date of the programme lie in the understanding of chemical and physical phenomena. This is not surprising given that work in the other areas has only started on a significant scale in the last two years. One form of results is the series of data-sets from large scale tests characterising the physical phenomena of releases. For example data-sets have been established from large scale experimentation on the:

- dispersion of heavy gases including the effects of obstacles ;
- properties of jets (ignited and unignited) of natural gas and pressurised liquids;
- heat transfer to objects impinged by jet fires;
- two phase flow of some industrially important fluids through constrictions;
- Boiling Liquid Evaporating Vapour Explosions (BLEVE's);
- fires and explosions of obstructed flammable vapours;
- low pressure gas torch fires including heat transfer to impinged objects;
- liquid (pool) fires.

In addition large scale simulations of fires of stored materials are being carried out to characterise the toxic plumes from possible industrial fires.

These data are valuable, such types of tests being difficult and expensive to carry out. In each case the large scale tests are supported by wind-tunnel simulations and sometimes reduced scale tests. These data can be made available to interested outside bodies.

The testing has been accompanied by very substantial efforts in model development and validation of existing models. For each of these hazardous phenomena there is a need for models of different types according to the problem being tackled. For quantitative risk analysis, very many potential accidents must often be modelled, and there is a need to use computationally efficient models. On the other hand Computerised Fluid Dynamics is suitable for problems where just one or a few very well defined scenarios are to be treated. A possible alternative for some phenomena is physical modelling (use of wind-tunnels). An idea of the scope of the modelling work can be gained from the list of codes being developed, validated or listed in Annex 1. The reader is also referred to the presentation by Giot, Duijm, Buchlin, Webber and Hall at a recent conference¹⁴ which cover the major elements of release scenarios.

Safety management

The accent in the early 1980's and before both national and EC research programmes devoted to industrial hazards, was on the physical aspects. It has become appreciated that organisational and human aspects of organisations are at least as important in improving protection. These have now become central aspects of the research. Most of this work is still ongoing but some results are described here.

In both the US and Europe there has been a fierce debate on the use of quantitative methods for evaluating risks from chemical plant. Critics claim that Quantitative Risk Analysis is not sufficiently developed to give reliable results. The EC supported a "Benchmark"

¹⁴ Jet flame attack on vessels. Presented by Duijm N.J. at IDC conference, Problem Clouds II, 15-16 April 1993, Amsterdam. Proceedings to be published in J. Loss Prevention in the Process Industries.

exercise in which different teams carried out Quantitative Risk Analyses in parallel on one plant. The project demonstrated⁸ wide differences in modelling between the teams. These results suggest strongly that care must be taken in the use of Quantitative Risk Analysis and interpreting its results. It is suggested also that further work needs to be carried out to identify more tightly the sources of variation.

Traditionally "QRA" has tackled the physical aspects of process plant. A range of management auditing techniques have been or are being developed aimed specifically within the EC's work a comparison of auditing techniques used in a range of companies in different EC countries is being carried out. Also more sophisticated auditing tools are being developed in the "SMART".¹⁵ Specifically the techniques aim to be more soundly based than those presently existing such as ISRS, IRIS or C-CHASE. The results are being tested in a range of UK and Dutch companies.

Several projects have tackled various areas of uncertainty with PRA particularly looking at interpretation or results in social terms. The "Socrates"¹⁶ software suite is one of the products of this work, providing a PC tool that can introduce sophisticated cost/benefit concept into QRA.

The "STARS" (Software Toolkit for Advanced Reliability and Safety Analysis)¹⁷ project offers a computer based tool for the systematic analysis of the safety and reliability of a plant. It helps analysts:

- collect the information needed for the analysis and structure of this information in an *object oriented model* of the plant;
- *identify potential hazardous events and event scenarios* making use of pre-compiled knowledge about typical process plant units, chemical substances and chemical reactions;
- *model and analyse causes* of undesired events making use of pre-compiled knowledge about typical components and their behaviour;
- *model and analyse consequences* of undesired events and the impact of those on man and environment.

A unique project studies through questionnaires and interviews the flow of information following 2 major accidents (those at Le Havre, France, October 1986 and Basel, Switzerland, November 1986). In itself the data on how messages become corrupted is very interesting. It can, and has, helped design models of behaviour in crisis situations. Most interestingly the study compares reactions and responses in different countries: Switzerland, France and Holland. The main conclusion of the study was the need to ensure that the key people in local administrations and emergency services have specific training for response to the possible Major Industrial Hazard in their region. This work is now being taken further with models for information flow having been developed; they are being tested in other large accidents.¹⁸

¹⁵ Presented at EC/ESReDA International Seminar on Operational Safety, Lyon, France, 14/15 October 1993. Proceeding edited by Cole S.T. and Wicks P.J., available from CEC, Brussels.

¹⁶ SOCRATES: Progress Report No. 1, April 1992. Available from CEC.

¹⁷ STARS, Software Toolkit for Advanced Reliability and Safety Analysis: enquiries to Dr. A. Paricet, JRC, Ispra, Italy.

¹⁸ See presentation by Consolini M. in ref. 35.

There are principally two different approaches to analyse the impact of the operator's performance. One tries to look at the details of human cognition in order to understand how the occurrence of erroneous actions can be minimised or prevented. The other approach investigates how the performance of the operator influences the development of an event. An example of the second kind of solution is found in the System Response Generator¹⁹ (SRG). The SRG analyses systems performance by the simulation of both the physical process and operator actions. The main concern with the SRG is to specify how an event might progress and what the possible consequences might be, rather than when or how often a specific event will occur. The SRG is thus an instrument for qualitative rather than quantitative analyses. The fundamental innovation of the SRG is the consistent method for dynamically generating responses by combining simulations of both the physical process and the human operator.

FORMENTOR²⁰ is a Eureka project involving the JRC which has developed a technological approach, generic to many industries, whose operators could benefit from decision support systems to help them cope with unusual situations. These include various process industries, aerospace, power generation, and oil exploration and production. Project work has involved developing application systems for specific plant, while carrying out parallel theoretical and methodological work to ensure that the results are of general applicability, and also that the different techniques used are integrated into a coherent approach.

6. Some problems

Within the last ten years the EC has changed from being a minor player in supporting research in industrial hazards to being the major public actor in Europe.

A strong public role by the EC in this field is beneficial in helping to reduce duplication of efforts. The CEC is probably the only practical choice as the administrator of public research on a European scale in industrial hazards, but it is not ideal for this role. There are of course the general criticisms of the CEC research (too bureaucratic, slow decision making,...) but whatever the truth of these, they are outside the scope of this paper. The main criticism of EC Major Industrial Hazards research has been a perceived lack of impact.

The origin of this is two-fold. Firstly, researchers have not been active enough in promoting their own research. Secondly, there is a certain remoteness of some of the projects from potential users: these being industry, regulators and legislators. It is a simple observation that some of the major chemical and petrochemical companies do not participate. Of course there are some good reasons for them to hesitate. For even medium sized companies the EC's financial contribution to R&D projects is small. EC project timetables may be inconvenient and the decision making process uncertain. However, there are great benefits to academic participants in a real world input, and to industrial companies in associating with, and being seen to associate with, leading-edge research in environmental safety. The hurdles must be overcome.

¹⁹ Reliability Assessment of Interactive Systems with the System Response Generator. European Safety and Reliability Conference, Copenhagen, June 10-12, 1992.

²⁰ The Role of the Goal Tree – Success Tree Model in the real time supervision of hazardous plant. Nordrik J.P., Mitchison N., Wilkens M. Submitted to Reliability Engineering and Safety Systems, 1993.

7. Future work

At the time of writing a second and final Call proposals have recently been closed for the EC's (shared-cost) Environment Research Programme. MIH is a feature of this Call and the three areas are retained as outlined in Table 3. Given the experience of the recent Call, the CEC would expect a high number of high quality proposals (in the most recent Call the funding requested/that available was about 10/1).

After this last Call in the Third Framework Programme further EC research will be funded under the 4th Framework Programme 1994-1998. The content of the 4th Framework Programme is not certain, so far only the CEC proposal has been published. This has to be considered by Council and Parliament. It appears possible that work on industrial hazards may be reduced in priority perhaps resulting in a stopping or a reduction of either or both the shared-cost and the JRC's direct research.

8. Conclusions

1. The EC has become the major public supporter of European research in Major Industrial Hazards.
2. There are many results from this work. Those relating to the understanding of chemical and physical phenomena of hazardous releases are particularly valuable as there is little other data of equivalent quality. Most of the codes used to estimate consequences of accidents, a vital competent for safety causes, have been developed or influenced through this research. Results are freely available to outside bodies.
3. Most results are freely available. The CEC is taking a deliberate initiative to promote the dissemination of these results.
4. The programme has also improved communications between European researchers working in the field with a consequent improvement in the quality of research.
5. The last set of projects in the present programme will be started in 1994. This *may* be the last set of projects launched by the EC in this area.
6. In ongoing and new work there is a need to ensure that the substantial volume of results reaches potential users.

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ACRONYMS OF INSTITUTIONS

CEA	=	Commissariat de l'Energie Atomique (France)
CMR	=	Christian Michelsen Research (Norway)
CISE	=	Centro Informazione Studi Esperienze SpA
DNV	=	Det Norske Veritas (Norway)
EDF	=	Electricité de France
ENEA	=	Ente per le Nuove Tecnologie l'Energia e l'Ambiente (Italy)
FMI	=	Finnish Meteorological Institute
FRS	=	Fire Research Station (UK)
HSE	=	Health and Safety Executive (UK)
IC	=	Imperial College London
INERIS	=	Institut National de l'Environnement Industriel et des Risques (France)
IST	=	Institut Superior Technico, Lisbon
JRC	=	Joint Research Centre
KfK	=	Kernforschungszentrum Karlsruhe (Germany)
SRD	=	Safety and Reliability Directorate (now called AEA Consultancy Services)
TEL-TEK	=	Telemark Innovation Centre (Norway)
TNO	=	Netherlands Organisation for Applied Scientific Research
TÜV	=	Technische Überwachungsvereine (Germany)
UCL (B)	=	Université Catholique de Louvain (Belgium)
UCL (UK)	=	University College London
UPM	=	Universidad Politécnica de Madrid
VKI	=	Von Karman Institute (Belgium)

ANNEX 1

Examples of modelling development carried out within the EC's Major Industrial Hazards Research Programme

	Code acronym	Project Participant	MIH Project	Ref.
– Complex flow and flashing				
Prediction of critical flow rates in multicomponent, vapour/liquid mixtures	FLIERS	UCL (B)	MTH-AA STEP 91 EV5VX	7, 20
Thermohydraulic modelling of a flashing liquid in 2/3 dimensions	TRIO-MC	CEA	MTH-AA STEP 91 EV5VX	7, 20
Langrangian modelling of two phase flows in 2/3 dimensions		IST	STEP 91	20
– Release and subsequent dispersion of heavy gas				
Evaporation and dispersion of a volatile droplet cloud	AEROCLOUD	DNV FMI	STEP 91 STEP 125	21
Ammonia drop behaviour	DROP	UCL (UK)	STEP 116	22, 23
Multi-phase releases and dispersion	CLOUD	CISE	STEP 116	23
Interaction of heavy gas with obstacles	MERCURE ADREA	EdF	STEP 125	24
Heavy gas dispersion in a sloping terrain	"shallow water"	SRD	MTH-BA STEP 125	24, 25
Heavy gas dispersion in a sloping terrain	DRIFT	SRD	MTH-BA STEP 125	24, 25 26, 27
Heavy gas dispersion in a sloping terrain	"shallow water" SPILL	Univ. of Cambridge	STEP 125	24
– Two phase releases including fire effects				
One dimensional modelling of torch/jet fires	TORCIA	Ars	MTH-FG STEP 98	10, 28, 29
One dimensional modelling of torch/jet fires	UPMIRE	UPM	MTH-FG	28, 29
Effects of jet fire on a vessel	ENGULF	Ars	MTH-FG STEP 98	10, 28
Applications of PHOENICS to jet fires and jet fire interactions with vessels	PHOENICS	UPM	MTH-FG STEP 98	10, 28
– Gas cloud explosions				
Gas cloud explosions in obstacle arrays with turbulence	REAGAS	TNO	STEP 111	30, 31
Gas cloud explosions in obstacle arrays with turbulence	COBRA CFD	British Gas	STEP 111	30, 31
Combustion in a gas cloud explosion		IC	STEP 111	30, 31
Flow-obstacle interactions		IC	STEP 111	30, 31
Gas cloud explosions in obstacle arrays with turbulence	FLACS	CMI	STEP 111	30, 31
Gas cloud explosions in obstacle arrays with turbulence	EXSIM	TEL-TEK	STEP 111	30, 31
– Water Sprays				
Hydrodynamics and mass transfer modelling of water sprays	REAL	VKI	EV5V72	32