Environment and Quality of Life

1987 Programme Progress Report

Industrial Hazards

Commission of the European Communities
Directorate-General for Science Research and Development
Joint Research Centre, Ispra Establishment

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Published by the
COMMISSION OF THE EUROPEAN COMMUNITIES

Directorate-General
Telecommunications, Information Industries and Innovation

Batiment Jean Monnet
LUXEMBOURG

Cataloguing data can be found at the end of this publication.

Luxembourg: Office for Official Publications of the European Communities, 1988

Printed in Italy

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INTRODUCTION

The JRC* research programme "Industrial Hazards" considers the risks associated with the operation of hazardous industries, such as processing and energy and of large technological systems such as transportation. The programme is focused, at present, on risk associated with major accidents, as problems associated with diffuse risk have been considered in the JRC Environmental Protection programme.

After Flixborough, Seveso, Amoco Cadiz, Bhopal, Mexico City, Sandoz, etc. there is growing public awareness of menaces to public health and to the environment which result from sudden catastrophic events. Public authorities, therefore, are seeking greater control over major hazardous industrial undertakings. An example of this public attention is the European Community (EC) directive on "Major Accident Hazards of Certain Industrial Activities", no. 82/501. This directive requires the Member States to take the necessary measures to protect health and safety of the public and to protect the environment: safety reports, training and drills, incident reporting, emergency planning provisions, etc.

The implementation of an adequate control of major accidents risks requires a consistent R & D effort, aiming to develop methods and to obtain data for the identification, evaluation and management of low frequency high consequences events. This R & D area is a very large indeed: it covers systems reliability, decision theory and decision support systems, behaviour of chemicals in (industrial) processes, safe pressure relief systems confined and unconfined explosions, man-systems interaction, atmospheric diffusion of toxic substances, emergency simulation and planning.

Many of these problems are analogous with those studied in the nuclear engineering field and the very considerable experience acquired in the assessment of nuclear plant safety can be ap plied to other engineering areas.

Actions crossing the border between nuclear/non-nuclear safety research are frequent and natural. We can mentioned at European level: the COST action on «Systems of Socio-Technologies and Industrial Safety», the research on cloud explosions carried out in the framework of the Reactor Safety shared-cost programme, the activity of EuReDatA sponsored by the JRC, the collaboration of JRC with chemical industry for the development of risk analysis computer codes, etc.

The tasks of the JRC in this frame are:

- to provide scientific support to the environmental policy of the EC
- to elaborate means for the enforcement of existing Community regulations
- to pursue medium and long-term studies as necessary background information for accident prevention.

This means that the JRC activities will be carried out in close collaboration with DG XI which is responsible, in association with DG V, for the Council Directive above mentioned and for the development of the Commission policy on major industrial hazards; with the DG XII/E's shared-cost programme on Major Technological Hazards which complements and augments the JRC activities to form a coherent whole and with Member State industries and research institutes in order to assure common and relevant experiments.

This is the sixth and last progress report of the four years (1984-1987) research programme «Industrial Hazards», carried out at the Ispra Establishment of the Joint Research Centre of the Commission of the European Communities.

* see for the abreviations the Glossary

SUMMARY OF MAIN RESULTS

The JRC research programme "Industrial Hazards" has been focused, over the year 1987, on the following three research activities:

- Industrial Safety and Reliability Assessment (Risk Analysis),
- Management of Industrial Risk, and
- Experiments and Theoretical Studies on Runaway Reactions.

These activities complement the shared-cost multiannual programme in th field of Major Technological Hazards and support the regulatory actions of DG XI within the frame of the EC directive on "Major Accident Hazards of Certain Industrial Activities".

Moreover, JRC is exploring the possibility to start a new activity on emergency planning for industrial hazards, on which a conference in collaboration with DG XI has been held in november 1987 at Varese.

The results obtained during the 1987 period can be summarised as fellows.

Safety and Reliability Assessment

The Benchmark Exercise on Major Hazard Analysis (BE-MHA) project, which aims to compare risk studies independently performed by different expert teams on a same reference subject, has been finalised. The BE-MHA aims at establishing a state-of-the-art review on procedures, methods, models and data bases for risk analysis of chemical facilities; at assessing corresponding uncertainties and limitations; at contributing towards common approaches for risk analysis. The reference subject is an ammonia storage facility with undersea and underground pipelines connecting it to a sea terminal and to in-plant storage facilities respectively.
The project is partially funded by the shared-cost multiannual action programme on Major Technological Hazards, by DG XI (Environment Consumer Protection & Nuclear Safety) and by JRC. The latter is ensuring the coordination of the project and will perform the evaluation of the results (expected by mid 1989).
13 European teams are involved in the project, representing about 20 organisations from 10 European countries and belonging to industry, governmental bodies, research institutes and specialised consultant groups.

The MARS (Major Accident Reporting System) accident data base is now fully operational in agreement with DG XI and within the frame of the post Seveso directive. The accident notified by the Member States have been recorded and their analysis started in order to install a correct feedback from experience events for contributing to an effective prevention policy.

Whereas industrial and research bodies such as SNAM (I), ENICHEM (I), and GRS (FRG) showed interest on the informatic tools already developed by JRC for reliability analysis (e.g. SALP-PC), significant progress has been achieved towards the development of the expert system STARS (Software Tool for Advanced Reliability and Safety analysis) in collaboration with RISØ (DK) and of tools based on the DYLAM (Dynamic Logic Analytical Methodology) approach for incident scenario evaluation.

Promotion of collaborative actions on reliability and incident data has been pursued: the support given to associations like ESR-RDA, ESRA and EuReDatA contributes to link JRC activities with general needs.

Management of Industrial Risk

The activity «Risk Management» has been mainly focused on the use and development of the IRIMS system. The main elements of the IRIMS system are a menu-driven, mouse-actuated user interface which provides easy access to the system; an information system which contains knowledge and data bases, inference machine and data base management systems; and a set of simulation models. Output is primarily in graphical form, making use of high-resolution colour graphics.

At the beginning of 1987 a demonstration prototype of the IRIMS system was operating at Ispra and had been upgraded, primarily by adding interconnections between modules.

A stand-alone transportation risk system, HELP, was developed, based on transporting the HASTM transportation risk model and the DIDASS-based optimisation module from the SUN machine to an IBM PC AT. The HELP transportation module, describes the road network in terms of a graph with arcs and nodes.

In collaboration with the Dutch Ministry responsible for environmental affairs, the integrated Ispra Risk Management Support (IRIMS) software system is being developed to produce comparative risk scenarios for the production, transport and use of cholorine in the Netherlands. The system is now including a 3-dimensional model allowing risk analysis for heavy gas diffusion and crisis management.

Protection against Runaway Reactions

This research activity is focused on two topics:

- chemical process dynamics in runaway conditions (characteristics of chemical processes and validation of existing and possible development of suitable models) and
- the behaviour of twophase/twocomponent fluid flow in ducts, vessels, vessel/duct, as well as back pressure effects and discharge characteristics of venting systems (with safety pressure relief devices).

Within the frame of the JRC research activities on the chemical and thermodynamic behaviour of runaway reactions, the construction of the experimental facility FIRES (Facility for Investigating Runaway Events Safely) has been started. The facility is mostly intended to validate specific numerical codes for control of industrial chemical processes (polymerisation, nitration, ...) and to assess the application of "early warning systems". FIRES consists mainly of a standard chemical reactor (100 l, 16 bar) housed in a bunker, of control and data acquisition systems and of auxiliary equipment. Bunker basement, chemical laboratory and control room have been realised, while reactor and auxiliary equipments are ready for installation.

Complementary research in the field of multiphase-multicomponent (MPMC) fluid flow has been performed by means of the improved small scale MPMC-facility, including phenomological properties on two-phase fluid flow regimes; depressurisation tests and parametric studies to assess the application of the SAFIRE code on predicting flow behaviour in venting systems.

Collaboration with the DIERS (Design Institute for Emergency Relief Systems) users group has been continued and the analysis the DIERS' SAFIRE code improved.

JRC activities on runaway reactions are discussed and reviewed by the European Contact Group on Runaway Reactions which includes industrial partners (Rhône Poulenc and Roussel UCLAF /F/, Hoechst /D/, ICI /UK/, DSM /NL/) and governmental and research institutions University College Dublin /IRL/, TNO /NL/, ENEA-DISP and University of Pisa /I/, HSE and Polytechnic of the South Bank, London /UK/)).

Explorative studies on Emergency Planning

JRC in collaboration with DG XI has organised a "European Conference on Emergency Planning for Industrial Hazards", which was held in Varese, on 4-5 November 1987. The conference was attended by some 200 people from 18 countries.

Papers were presented in six sessions on the following themes:

- organisations implementing emergency planning;
- in and off site emergency planning design;
- exercises and auditing of emergency plans;
- lessons learnt from emergency management for major accidents;
- information to the public prior to and during an emergency.

This conference demonstrated a world-wide interest in emergency planning and in spite of significant agreement as to the general approach, differences still exist in practice due to differing national structures. The exchange of information and experience suggested the opportunity of establishing general guidelines developed from emergency plans of organisations in technically advanced countries to be used as model for the less technically developed ones. The conference proceedings will be published by Elsevier Applied Sciences Publishers (UK) and should be available in mid-1988.

RESEARCH ACTIVITIES

1. Safety and Reliability Assessment

Public awareness of the risks associated with processing and storage of dangerous substances has been intensified by severe accidents having recently occurred everywhere in the world. As a result, regulatory bodies are requiring for those installations with the highest hazard potential, rigorous safety case submissions including to an ever increasing extent some quantification of the risks involved in normal and abnormal operation.

As far as safety analysis is concerned, in recent years many techniques have been developed for structuring the overall assessment procedures into different steps aimed at:

- hazard identification;
- systems logical modelling;
- reliability estimations;
- evaluation of frequency and consequences of significant accidents.

Limitations of these techniques do still exist both in modelling (especially low probability - large consequence events, because of intrinsic large uncertainties involved, complex interactions of technical systems with human operators, identification of dependency structures, process modelling, consequence calculations, etc.); and in practicability (detailed analyses still require heavy manual efforts that can strongly be reduced by improving computerized aids, introduction of advanced informatic technologies is still in a very preliminary phase).

Moreover, the reporting of abnormal events is being more and more recognized as an essential feedback channel for controlling and improving safety of industrial installations.

To this aim, the Council Directive on Major Accident Hazard of Certain Industrial Activities No. 82/501/EEC requires that the Member States inform the Commission about major accidents occurring in their countries. The Directive asks also the Commission to implement a register containing a summary of the major accidents which have occurred, including an analysis of the causes of such accidents, experience gained and measures taken, to enable the Member States to use this information for preventive purposes.

Objectives

Based on the described background, the main objectives of the JRC R&D activities for industrial systems safety and reliability assessment can be expressed as follows:

a. to contribute to the establishment of a common awareness in Europe about advantages, limitations und uncertainties of available models, data and procedures for safety and reliability assessment of hazardous installations; and to the elaboration of common procedures;

b. to contribute to the development and improvement of methodologies for safety and reliability assessment; and to facilitate their applications by industry, authorities and research organisations by implementing them in user-friendly computerised tools;

c. to give the Commission (DG XI) the necessary technical support in the fulfillment of the specific duty established by the Directive through design and implementation of the Major Accident Reporting System (MARS).

Results of research activities

The JRC R&D objectives are being pursued by the activities which are outlined in the following, while the principal achievements and the major projects are more detailedly described in par. 1.1 through 1.5. The R&D activities can be grouped according to the assumed objectives, and namely:

Ref. objective: a.

Harmonisation of procedures and cross fertilisation among different industrial sectors is being pursued on the one hand by the launching of the major European collaborative project "Benmark Exercise on Major Hazard Analysis" (see par. 1.1), and on the other hand by participating, promoting and supporting working groups and associations active in Europea on safety and reliability R&D efforts. Because of the relevance of the problems connected with safe operation and plant adequate maintenance, significant collaborations have been established with the Human Factor Working Party of the European Federation of Chemical Engineering, and with national laboratories such as RISØ in DK and CNR in Italy, for common research in the field of human factors. A significant support is being given to European associations like ESRA (European Safety and Reliability Association), EuReDatA (European Reliability Data Bank Association) and ESRRDA (European Safety and Reliability Research and Development Association). ESRA aims at constituting a communication networks between national associations, researchers, training and education bodies, industrial and governmental users of safety and reliability technology. The JRC support to ESRA is essentially directed towards its educational programme /1,2/ and to the publication of the Newsletter /3/. EuReDatA /4/ is aimed at accelerating the process of harmonisation of safety and reliability data collection procedures through project groups, seminars /5,6/ and courses /7/. As EuReDatA is active in the data field, ESRRDA has been recently created to harmonise R&D actions and results, and to promote the application of safety and reliability techniques in industries and decision making bodies. The duties of the General Secretary both of ESRRDA and EuReDatA are assured by the JRC which, therefore, finds well established discussion forums for linking its activities with possible multiple users.

Ref. objective: b.

Models and informatic tools are being developed and released to external users both for systems reliability analysis and for consequence analysis. In particular the user-friendly fault-tree code SALP-PC has been released (see par. 1.2), knowledge-based reliability analysis tools (see par. 1.3) are at a rather advanced state of development in collaboration with other research centres (RISØ is already involved, whereas with other institutions collaboration agreements are being discussed), and the MARA code for heavy gas dispersion has been developed and validated with experimental results (see par. 1.4).

In addition to the above achievements after exploratory studies for application of the DYLAM technique /8/ to process plant safety and reliability analysis /9/, a project has started for producing an integrated software package for analysis of accident scenarios including domino effects. Results from this project are to be expected by the end of 1988. /10/

Ref. objective: c.

The MARS data bank has been made operational, the accidents reported have been stored and the analysis work has started (see par. 1.5).

Results of topical research activities:

1.1 BENCHMARK EXERCISE ON MAJOR HAZARD ANALYSIS

Introduction

The interest in probabilistic methods for safety and reliability analysis has grown considerably in Europe over the past decade. This is due to the fact that such methods appear to offer a systematic framework for analysis of highly complex plants or systems in different decisional processes.

At system design level, probabilistic techniques are used everywhere for improving safety in a cost-effective way, and choosing among technical alternatives, often linking reliability, availability and maintainability issues in an integrated approach (RAM programmes).

At the political level, risk studies are being promoted as a support to decisions concerning strategies (e.g. comparison of risks connected with diverse technological systems), and they are entering in public debates on the acceptability of hazardous plants (Public Inquiries).

Licensing or control authorities are confronted with the problem of examining the safety cases for the major hazard installations, which might include probabilistic assessments. In some countries such as the Netherlands, acceptance of new plants is being based on risk figures; some other authorities are encouraging the use of probabilistic methods as a useful piece of information in addition to hazard identification techniques. For instance, in the U.K., the Health and Safety Executive suggests in its guidance on the contents of "Safety Cases" that: "While it may be possible for manufacturers to write a safety case in qualitative terms, H&SE may find it easier to accept conclusions which are supported by quantitative arguments."

A quantitative assessment is also a convenient way of limiting the scope of the Safety Case by demonstrating either that an adverse event has a very remote possibility of occurring, or that a particular consequence is relatively minor.

Despite its increasing use it is generally recognized that probabilistic safety analysis (PSA) is still in a developing phase, offering to the decision makers a variety of approaches and methodologies, under sometimes different technologies, and presenting the results under forms which are very difficult to compare.

Whichever the decisional process should be, consistency of methods and procedures is a prerequisite indispensable for a correct use of the approach and its results. At this aim it is necessary to understand clearly:

- the advantages and limitations of the available methodologies;
- the uncertainties linked with the use of the methodologies and the origin of these uncertainties;
- the comparability of different analyses;
- the maturity of the models used or the lack of knowledge in certain areas;
- the cost and benefit of the different approaches;
- the tuning of analysis procedures to the various scopes of the analysis.

Since the above-mentioned problems have not yet been systematically analysed, it appears, on the one hand, that different studies already published are not easily comparable, and, on the other, that all debates on ucertainties and usefulness of probabilistic methods are not yet based on factual elements.

As a contribution to clarify the problems connected with the use of PSA techniques, benchmark exercises have proved to be highly successful in the nuclear field. Indeed, the independent analysis of a reference object by different participating teams from industry, research institutes and authorities, has proven to be an effective tool to have an understanding of the available methods, their strength and their weaknesses, the uncertainties involved, their origin and their impact on the results.

Furthermore, benchmark exercises helped to arrive at a common language and a better dialogue between the various involved. It has been shown that even in the case of techniques which a priori were believed to be well established (such as the fault tree technique for reliability analysis), some very interesting lessons could be learnt /11-14/.

The increasing use of, interest in or at least movement around application of PSA in the chemical process industries, together with the positive experience with the benchmark exercise in the nuclear field, as well as some similar studies on petrochemical installations /15/, have raised a demand for organising a similar exercise for the chemical field. This demand originated from the ESRA in which delegates from industry, research institutes and authorities of the different member countries expressed their interest in the performance of similar exercises.

The feasibility of a European project on major hazard analysis has been assessed in a preliminary workshop which was held at Ispra on 28 October 1985, which resulted in the mandate to JRC

- to assess the availability of some adequate reference plants for the study;
- to provide some rather detailed proposals with indication of objectives, terms of reference and preliminary planning of the envisaged project; and
- to explore the possibility of some financial support through the cost-shared action programme.

The actions undertaken by JRC, through contacts with plant owners, industrial organisations, experts and authorities, contributed to the establishment of a proposal on which a wide consensus could be expected. Based on this proposal a project was set up as agreed and decided in the launching meeting on 17-18 June at Ispra.

The entire Benchmark Exercise should be concluded within 20 months by the issue of a final report.

Objectives

Guiding objectives are:

- to identify the state of the art in analysing major hazards;
- to obtain estimates of the overall degree of uncertainty in risk analysis.

which include:

- comparison of different methods, models and procedures;
- assessment of relative advantages and limitations according to some measures to be elaborated;
- state of available data bases;
- assessment of the variability of the results obtained by independent teams, and origin and nature of the uncertainties;
- identification of problem areas, possibly worth of separate investigations;
- possible achievement of a common awareness on the problems connected with all items mentioned above.

The study will not be limited as far as events to be included in the analysis are concerned. Significant attention will be given to the qualitative procedures for hazard identification, preliminarly to any quantitative assessment. It will then include estimation of frequencies and consequences of possible relevant incidents, and will be concluded by the determination of individual risk contours.

Reference plant

The study will be performed on an ammonia storage facility, which is located in a hypothetical site, on the base of its documentation. The facility includes the following installations:

- a sea ammonia terminal;
- an undersea pipeline to the seaside storage facility;
- a refrigerated storage tank with 15000 tons of ammonia;
- underground piping to the fertiliser plant;
- in-plant storage tanks.

Funding and participation

Most of the participating organisations are being partially funded by the Commission of the European Communities either through the JRC direct research programme, or through DG-XI, or finally through the shared-cost action programme on major technological hazards.

The participating teams represent European countries and are formed by authorities, inspection organisations, research institutes, consultants and engineering companies as well as industries. This allows the project to take into account all points of view (see /16/) and, therefore, hopefully to represent a first significant step towards a common understanding at European level of advantages and limitations of PSA in the process industry.

The participating teams are:

- Belgium: Vinçotte - Solvay
- Denmark: RISØ
- Finland: VTT-OTSO Insurance Company - Kemira Oy
- Federal Republic of Germany: Gesellschaft für Reaktorsicherheit m.b.h. (GRS) - Battelle Institute e.V.
- Greece: NRCNS "Democritos" - University of Athens - Ministry of the Environment
- Italy: ENEA - SNAMPROGETTI (ENI group) - NIER - FIAT Engineering (Civil Protection)
- The Netherlands: TNO
- The Netherlands: Ministerie van VROM
- United Kingdom: Health and Safety Executive (HSE)
- United Kingdom: Technica
- Multinational: EDRA (Engineering Design Research Analysis Sre), Italy - CEP (Contrôle et Prévention), France - IGC (Inspeccion y Garantia de Calidad S.A.), Spain - TECHNIMONT (Montedison group), Italy - Rohm and Haas, Italy.

JRC is coordinating the project by ensuring the technical secretariat, and will compare the results of the different teams, organise the comparative and conclusive meetings, and edit the final report on the project.

1.2 SALP-PC, A COMPUTER PACKAGE FOR FAULT TREE ANALYSIS ON PERSONAL COMPUTER

Main characteristics of the SALP-PC software package

The fault-tree technique is a very important tool in system reliability analysis. In the past a lot of computer codes for logical and probabilistic analysis of fault-trees have been developed on main frame computers. In the last few years the increasing performance of personal computers enabled the development of independent work stations for risk assessment, dealing not only with analysis but also with model synthesis and manipulation. In this line, the JRC-Ispra has started a project aiming at producing an integrated software for fault-tree/event-tree synthesis and analysis, STARS (Software Tool for the Analysis of Reliability and Safety) /17/. The SALP-PC, which represents one of the STARS modules, is an interactive package for fault-tree analysis. It has been developed on an IBM compatible personal computer and written in FORTRAN-77 to guarantee the maximum portability. The package contains some 14,000 executable statements. In the present version the data structure is defined in such a way to allow the analysis of fault-trees containing up to 200 primary events and 200 operators; the maximum number of minimal cut-sets (MCSs) is set equal to 4000 (order 10 max). The RAM memory requirement is less than 400 kb.

The SALP-PC is composed of six main programmes, implementing the different phases of the fault-tree analysis procedure. The allowed logical operators are AND, OR, NOT, K/N, XOR and INH. The "enabler" event of the INH operator can also be a subtree, not necessarily independent on the subtree describing the "initiating" event.

Boundary conditions can also be defined to obtain fault-trees conditioned to the state of one or more components, without having to modify the input fault-tree description.

It is possible to restart at each step of the analysis, with modified input parameters without repeating the previous steps. The possibility to perform an on-line sensitivity analysis makes the package particularly useful for design optimisation.

The problem of developing efficient procedures for determining the minimal cut-sets (MCSs) of a large fault-tree is rather complex, since the running time has always to be kept within reasonable limits; this problem becomes even more complex on personal computers due to the limited resources available.

In order to face these problems, the following solutions have been adopted:

- use of cut-off criteria for determining only a subset of the MCSs (i.e. the significant MCSs);
- a new procedure for determining the MCSs, based on the analysis of the tree at different levels of detail;
- use of efficient algorithms for cut-set minimisation;
- use of garbage collection procedures to reduce the probability that the programme may abort due to insufficient working memory space;

- pruning of the input tree (before determining the MCSs) when NOT operators or boundary conditions are present.

Each of these methodological aspects is briefly presented, while a complete description of the SALP-PC package is given in /8/.

Use of cut-off criteria

Theoretically, all MCSs should be identified, as each of them could produce the system failure. However, in practical cases, the identification of all MCSs can be not only very expensive because of the high running time, but also useless. Therefore, only significant MCSs can be determined. The significance is defined either on a structural basis (order of a MCS) or on a probabilistic basis (mission time unavailability). If the aim of the analysis is to obtain the most significant MCSs, a measure of the approximation introduced (truncation error, Pe) must necessarily be determined, without actually finding all the MCSs. With the use of the probabilistic criterion (a MCS is considered to be relevant if its mission time unavailability is not less than a pre-established threshold value P_{lim}), this measure represents an estimate of the cumulative unavailability at the mission time of not significant MCSs. If such a measure is not determined, the probabilistic cut-off is of little value. The knowledge of Pe is fundamental to judge whether or not the chosen cut-off value P_{lim} can be considered as appropriate; consequently, to be really useful, the estimate of Pe must be as close as possible to the exact value, without determining actually the disregarded MCSs.

In order to estimate Pe, a new method of analysis has been developed, based upon the concept of pseudo-module. The application of such a method also allows a significant reduction of computer time compared with other available methods.

Logical analysis methodology

In order to reduce the computer time, in fault-tree analysis it is of paramount importance to perform the modularisation phase, whose aim is to transform the input tree into a forest of independent simpler subtrees; generally, the larger the number of substrees, the less computer time is needed. This is why efforts have been spent in the past to set up ways of modularising a given tree as much as possible.

In most computer codes the modularisation is performed by determining the so-called simple modules, i.e. subtrees containing only unreplicated primary events. Some codes determine also complex modules, i.e. containing all occurrences of one or more replicated primary events. In the SALP-PC approach a strong reduction of computer time has been obtained, as well as a very good estimate of the truncation error, by defining a new analysis method based on the concept of pseudo-module. A pseudo-module (p-module) is defined as a subtree in which no occurrences of repeated subtrees appear. It has to be noticed that this definition allows replicated primary events to appear also outside the pseudo-module.

Figure 1 shows a fault-tree already modularised with independent modules. According to the definition, the p-modules - shown by dotted lines - are the subtrees G4, G10, G12, G11 and G3. When the p-modules are substituted in the main tree with single variables, the "Macro Fault-Tree (MFT)" is produced, as shown in Figure 1 by heavy lines. By following this approach the fault-tree, modularised with independent modules, is therefore transformed into the MFT and a forest of simpler but Dependent Substrees (DS). It can easily be realised that this approach always leads to a strong reduction of the fault-tree complexity, while this cannot be guaranteed by other methods.

The presence of DSs necessarily requires the definition of a two-stage analysis procedure.

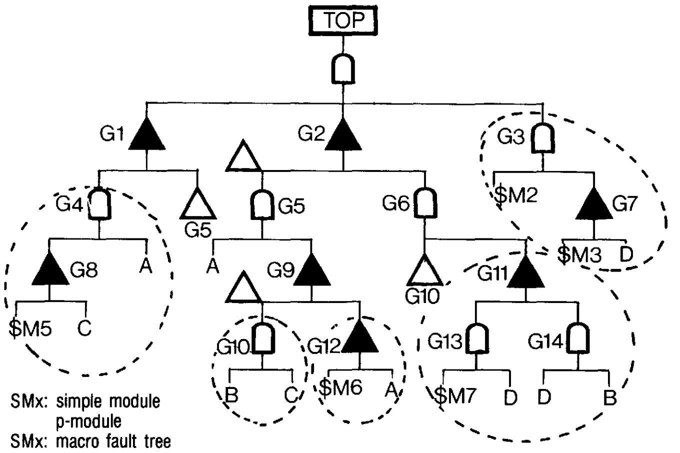


Fig. 1 - Example of pseudo module and macro fault tree generation

In the first stage the MFT and all DSs are independently analysed without making use of any cut-off technique; the set of minimal failure combinations of the MFT are here referred to as "Macro cut-sets". In the second stage, dependencies among the elements of macro cut-sets are solved. It is at this time that the cut-off technique is applied for retaining only the significant MCSs and estimating the truncation error value. A similar algorithm is applied during the simple module expansion for determining the significant MCSs of the input tree.

Out-set minimisation procedure

The minimisation procedure plays an important role in fault-tree analysis: most of the computer time is spent in minimising cut-sets. In order to reduce the computer time it is necessary, apart from using a powerful minimisation procedure, to minimise only potentially non-minimal cuts when this is strictly necessary. in SALP-PC an efficient algorithm is applied at each gate level to determine whether its descendants are dependent or not; in case of dependence, the set of combinations is partitioned and only those containing locally repeated events are minimised.

Garbage collection procedure

A problem that arises when the number of MCSs is too large is that of insufficient working memory space. In this case it is useful to apply a garbage collection algorithm to arrange data in some way so as to prevent the programme from aborting.

During the analysis of the MFT the MCSs of repeated subtrees are to be used if necessary. In case of unavailability of working memory space, the garbage collection procedure visits the part of the tree still to be analysed, identifies the reference to repeated subtrees and deletes the MCSs of those subtrees no more necessary.

During the expansion of the simple modules the probabilistic threshold value is automatically increased (or the logical value decreased when it concerns the qualitative analysis) each time the memory space is saturated. Therefore, the new not significant MCSs are deleted and their probability added to the truncation error value. This guarantees, except in some particular cases, a final result even on very complex trees.

Fault-tree pruning procedures

The SALP-PC programe allows the user to analyse fault-trees containing the NOT operator. Compared with the analysis of AND-OR trees, AND-OR-NOT fault-trees pose many additional pro-

blems and hence the algorithms for determining the minimal form of prime implicants are time-consuming. On the other hand, a fault-tree contains many variables, and negated events are defined to describe the "good" state of components, whose probability is generally either 1 or very close to 1.
Examples of such applications are found in the description of mutually exclusive events and in the event sequence analysis. In SALP-PC, simplified methods, applicable when these conditions are satisfied, have been implemented giving, as a final result, the disjunction of minimal cut-sets on which the quantitative analysis can be applied /10/. The algorithm is based on the a priori elimination of all unreplicated negated events before the modularisation phase is applied. The remaining negated events are considered until they are no more needed or logically deleting impossible combinations.

Conclusions and further development

The modular structure of the SALP-PC code has proved to be extremely interesting. This structure allows the programme to be easily implemented on various types of computers (from personal to mainframe). Moreover, the various developed processors may be applied for solving other types of problems, thus making it easy to build codes for, for example, event-tree analysis and CCF analysis.

The SALP-PC code is fast in comparison with other fault-tree analysis codes, as confirmed by the experience gained so far.

A second version of the package is planned for the end of next year. Apart from a further reduction in computer time it will be possible to analyse phased mission systems and binary systems containing multistate compounds. Furthermore, the MAPLE code for fault-tree drawing /20/ will also be implemented.

1.3 STARS: A SOFTWARE TOOL FOR ADVANCED RELIABILITY AND SAFETY ANALYSIS

Systems safety and reliability analysis consists in general of:

- a qualitative hazard analysis in which the events and scenarios relevant for the safety and/or reliability are identified and ranked on the basis of their consequences or hazard potential;
- the construction of logic system models that describe the system behaviour with respect to the above-mentionned events and scenarios either in a deductive or an inductive way; and
- the quantitative analysis of the models constructed with the aim to calculate numeric estimates and uncertainty bounds for e.g. system reliability, occurrence probability of relevant events, etc.

Various computer codes for quantitative analysis of the logic models are available. Hazard identification and the contruction of logic models are still mainly performed without or with very limited computer assistance and both require considerable effort and skill.

A need for computer assistance in modelling not only arises from the effort and cost involved, but also from the wish to reduce the analyst to analyst variability and to facilitate the scrutinising of the studies produced. These latter factors are becoming more and more important as probabilistic approaches are entering in the licensing framework /21/. Indeed, Benchmark Exercises on systems analysis /22/ and common cause failure analysis /13/ have shown that different assumptions, subjective judgement and implicit procedures used in modelling contribute significantly to the spread observed in the results and make it difficult to compare different analyses.

The STARS (Software Tool for the Analysis of Reliability and Safety) project /17, 23/ aims at developing an integrated set of CAA (Computer Aided Analysis) tools for the various tasks involved in systems safety and reliability analysis including hazard identification, qualitative analysis, logic model construction and quantification.

The project has developed from earlier experience of JRC in the field of fault-tree construction code like CAFTS /24, 25/ and analysis codes like SALP-PC /8/. In 1987, a collaboration was started with RISØ National Laboratory which also has large experience in the subject from its RIKKE code.

Overall structure of STARS

The expert system technology offers the most promising perspectives for developing a CAA tool for hazard identification and modelling. Combined with graphics and analysis capabilities, it can provide a natural engineering-oriented environment for computer-assisted reliability and safety modelling and analysis.

The overall structure of the STARS package is shown in Fig. 2 and contains the following main modules:

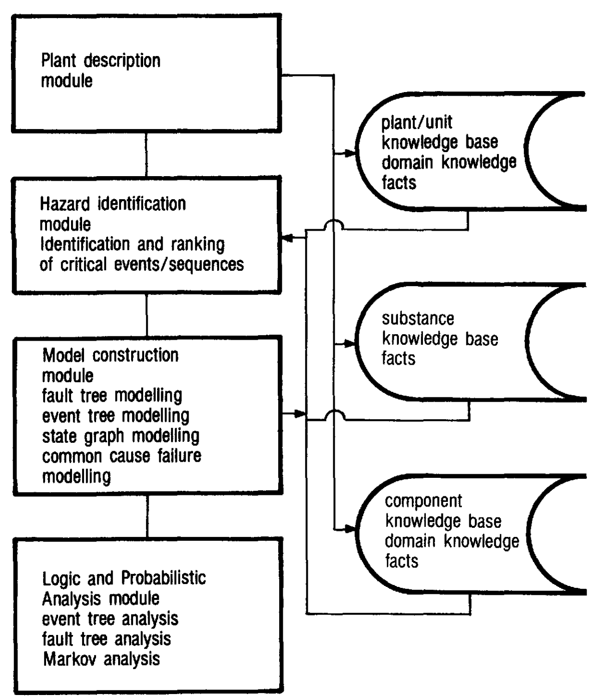


Figure 2 - STARS general structure

- ***a plant or system description module*** that will be used to build the facts data base containing the relevant information (topology, processes, functions ...) about the system or plant under study in accordance with the type of analysis (hazard identification, macro fault-tree construction, refinement of macro fault-tree ...);
- ***a hazard identification module;***
- ***a system model construction module:*** for the moment, the fault-tree modelling technique is developed but it is the intention to include event tree modelling and state graphs. Moreover, the development of common cause failure identification and modelling capabilities will be considered;
- ***a quantitative analysis module*** for performing logic and probabilistic analysis on the system models (fault/event trees, state graphs).

The hazard identification and the model construction modules make use of three knowledge bases: on units (KB1), on substances (KB2) and on compounds (KB3).

Qualitative analysis tool

The qualitative analysis tool will be used for two purposes:

- the identification of potential hazards, events and event sequences leading to hazards;
- the elicitation of process-specific knowledge to be used in subsequent modelling.

The approach will be to emulate the reasoning and expertise applied by analysis in hazard and operability studies into an expert system.
In such studies, the plant is subdivided into systems and/or units each having well defined functions. The deviations from these normal functions and the way in which these deviations propagate in the plant are then analysed.

The expert system will use three knowledge bases:

- a plant/unit knowledge base which is structured into layers: industry type, process type and unit type. The knowledge base will contain characteristics of processes and units such as:
  - potential deviations of process parameters and/or functions and rules about their possible causes and effects;
  - potential unit malfunctions or failures;
  - generic critical events or event sequences known to be relevant for certain types of processes or units (possibly in combination with certain types of substances);
  - checklists on potentially relevant facts to be prompted to the analyst.
- substance knowledge base structured into 5 layers: organic-inorganic, functional group, state of matter, flash point toxicity and toxicity of combustion products and completed with knowledge about possible reaction products (simplified reaction matrix); and
- a component knowledge base which is shared with the expert system for constructing logic models in the subproject of the STARS project concerning hazard identification. The part of this knowledge base used here contains rules whether component failures or malfunctions can cause specific process parameter deviations.

For identifying relevant events or event sequences, the expert system will perform an inductive (event driven) reasoning by the following basic points:

- a first list of potentially relevant deviations/malfunctions is identified by consulting the unit layer in the knowledge base, in which for each unit type a checklist with possible deviations is stored;
- the list of potentially relevant deviations is completed by consulting the process layer in the knowledge base, in which important (from the hazard point of view) deviations, particular to specific process types, are stored;
- the list of potentially relevant deviations is reduced by screening according to the possible occurrence of causes for the deviations at the unit or component level: i.e. a deviation in a unit is no longer considered if there are no unit/component failures or malfunctions that could cause such deviation and there is no possibility to propagate the deviation from other units;
- the reduced list of potential deviations is further reduced by screening according to the consequences of the deviation. The substance knowledge base in consulted in this screening, the retained relevant events and event sequences are more precisely identified in terms of underlying system malfunctions using the knowledge at the unit level.

The result is a list of ranked deviations to be considered for the plant under study and possibly to be modelled in detail using fault-trees or other logic models. To construct these fault-trees, the expert system of the STARS model construction module can be used.

Model construction module

The fault-tree construction tool will be largely inspired by the previous experience. A frame/rule based expert system will be used, in which the deductive (goal driven) reasoning and the heuristics, applied during manual fault-tree construction, will be modelled.

The knowledge base used for the fault-tree construction contains generic knowledge on components, knowledge specific for the system and process analysed as collected during the qualitative analysis, and knowledge needed to direct and control the reasoning process ("metarules", e.g. on incompatible situations).

The knowledge is represented in frames covering component characteristics, rules to be used for construction of macro fault-trees and rules to develop the causes of the component states.

The construction will proceed in phases (as in CAFTS):

- First a macro fault-tree will be constructed on the basis of the topological information of the functional flow diagram or P&I D obtained interactively in a plant description module, and of the process information obtained through the computer-assisted qualitative analysis. The construction of the macro fault-tree will be triggered by specifying a state or some combination of states at some node(s) in the system diagram. It will proceed by backward chaining throught rules that describe the (local) relationships between states at input, output and internal modes of components and by consulting the meta rules that control the process. Occasionally, the user may be prompted to enter information which is process-specific and which was not yet obtained by the qualitative analysis. As a typical example the user might be asked to confirm whether or not in a particular section the pressure-flow conditions are such that a reversed flow could be created under certain circumstances.

  As a result, a macro fault-tree containing component/subsystem modes leading to the top event, is obtained.
- Next, the macro fault-tree will be further developed on the basis of facts provided interactively by the user for the components and the connections of these components with support or service subsystems. These facts are fed to meta rules that control the firing of the rules which develop the fine causes of some component/subsystem mode.

The knowledge base is organised in a hierarchical way in the form of a tree. The terminal leaves of the tree correspond to different component types; intermediate nodes correspond to component classes. The knowledge is distributed over the tree: this means that some knowledge is stored at the level of classes. A terminal leave (component type) inheritates the knowledge stored in the path between itself and the root of the tree. In this way it is possible to avoid information duplication and redundancy, and to increase the maintainability of the knowledge base.

The same representation is used by the plant description module to store the information about a specific system (e.g. topology). In this way, application-specific facts and generic knowledge are stored in the same coherent way.

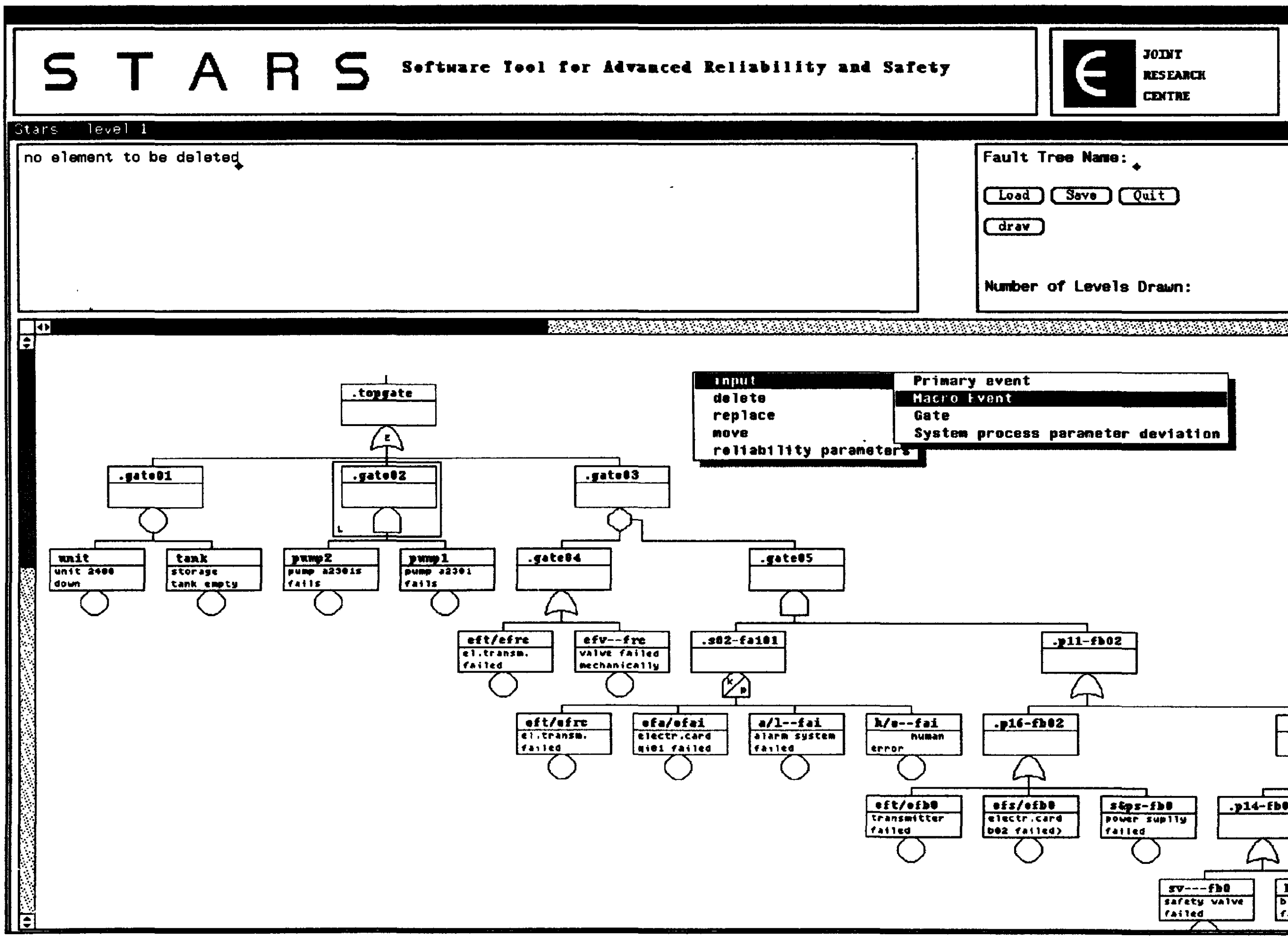


Figure 3 - STARS fault-tree editor

Conclusions

The objectives and overall structure of the STARS project were specific and the choice of the hardware and software support was performed. The structure of the knowledge bases and the knowledge representation schemata (frames) for the component knowledge base were developed.

The global concept of the hazard identification module as explained above was defined in collaboration with RISØ and VTT (Technical Research Centre of Finland). The concept will be further validated and developed as a collaboration between JRC, RISØ and VTT. For valdating the approach, typical examples of process plants (i.e. sulphuric acid production plant) will be used as test cases.

Concerning the model construction module, a start was made to implement a fault-tree construction and editing tool (see Fig. 3). The editing tool was partly based on a previous fault-tree plotting code /20/.

From the experience with CAFTS, it became apparent that functional or process related information needs to be considered during fault-tree construction alongside with topological information. The basic approach to adopt for considering this type of information was studied.

The feasibility of using the RIKKE knowledge base to feed the STARS component knowledge base was investigated by RISØ.

1.4 MARA: A HEAVY GAS DISPERSION MODEL

In many safety evaluations, the hazards due to release of liquefied substances must be determined and the concentration field of the gas blanket as a consequent their evaporation must be calculated in time and space.

Presently, a large effort is being made trying to simulate the dispersion of gaseous substances heavier than air, by means of "box-models", in which the physical variables describing the cloud are treated as constant within the cloud iteself. The box is spreading on the soil, due to the gravity force and increasing its size because of the air mixing.

The main advantage of using box-models lies in their short computing time, which makes them particularly suitable for risk analysis calculations.

In the majority of cases, box-models can take into account the following phenomena:

- cloud spreading because of gravity;
- air entrainment from the cloud top and cloud edge;
- heat transfer with the ground;
- cloud advection due to the wind;
- neutral buoyancy dispersion at great dilutions.

The treatment of the heat transfer with the ground, however, has the effect of increasing the computing time of many models, as its introduction in the cloud equations does not allow their analytical solution, without improving too much the models performances. In fact, the heat transfer due to the mixing with the entrained air is by far the most important term of the overall heat balance.

The transition to the neutral phase is in general treated in a discontinuous way, as the large dilutions are not very interesting in case of flammable gases. However, there are other cases, such as for example when releases of toxic substances occur, in which also this phase is of great importance.

Furthermore, the cloud advection is not accurately described in many existing box-models, as demonstrated by comparing the predictions of the distance travelled after a certain time with the results of the release experiments.

The MARA (Model for Analysis of Releases in the Atmosphere) computer code partly avoids these difficulties.

Code validation

The capability of the model can be shown by comparing the calculated results with some experimental data available in the literature.

The main physical assumptions can be found at Ref. /26, 27/: substantial improvements in the MARA box model have been obtained by treating the transport of heavy gas clouds in the wind direction.

The Thorney Island trials chosen to validate MARA are those identified by the numbers 008 and 018. They differ mainly by the atmospheric turbulence, and in particular by the windspeed, which varies from a low/medium value for the first (2 m/s) to strong value (6 m/s) for the second. The atmospheric stability category was D in both cases. However, this parameter is considered less important for the results comparison as it influences only the passive phase.

Figures 4a and 4b show the cloud peak concentration versus distance, both observed and calculated for the investigated releases. The agreement can be considered satisfactory, taking into account the fact that the experimental points have been determined from visual estimation of the cloud concentration upper limit, which was measured by detectors at the same radial distance from the release point.

Figure 5 shows the time dependence of the average cloud concentration, both measured and calculated for trial 008. It should again be pointed out that it is difficult to determine the average measured concentration, as the cloud is not in reality as uniform as the theoretical approach would suggest.

In Figure 6 the measured and calculated time dependence of the cloud radius is shown for trial 008. It is possible to observe that the gas radius square root (or linear increase of the gas area) with time is respeced.

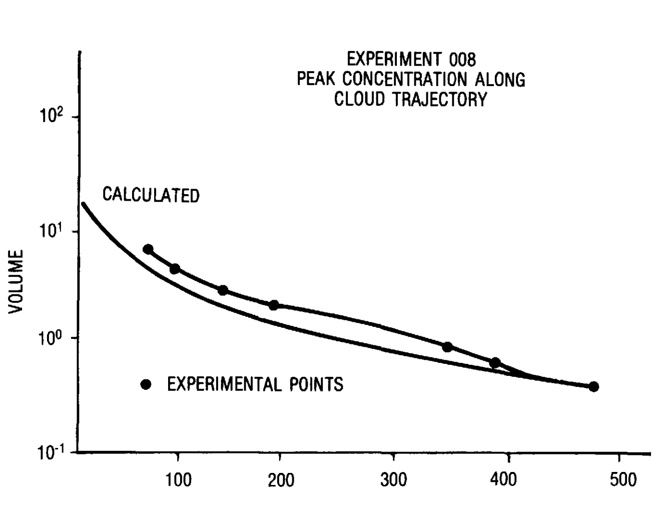


Fig. 4a - Thorney Island - wind speed 2 m/s

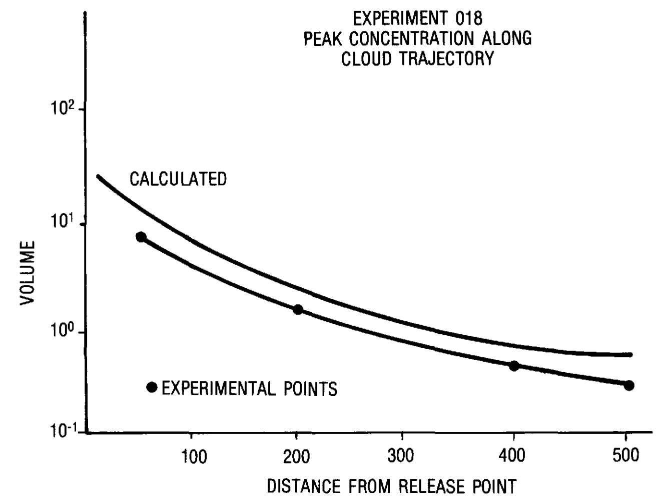


Fig. 4b - Thorney Island - wind speed 6 m/s

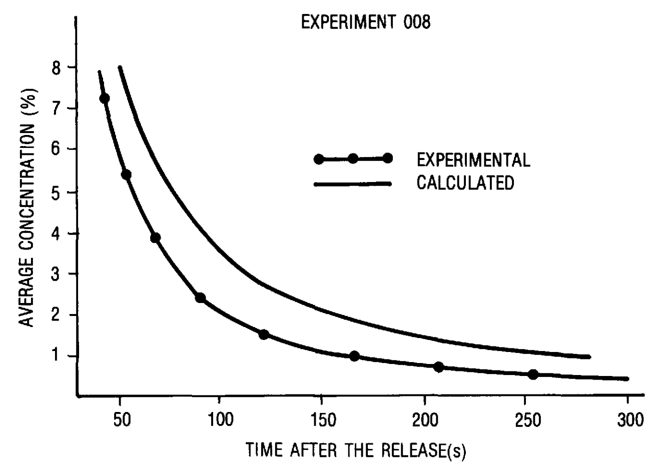


Fig. 5 - Thorney Island - wind speed 2 m/s

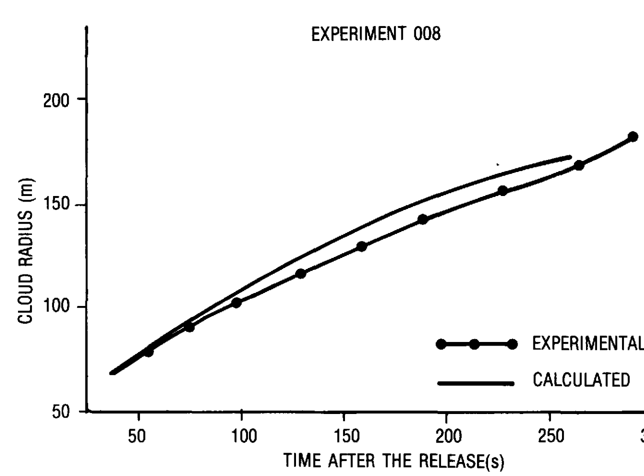


Fig. 6 - Thorney Island - wind speed 2 m/s

In Figure 7 the distance travelled by the cloud centre is reported versus time. The good agreement between the experimental data and MARA results is noticeable, particularly if we take into account the fact that the cloud advection has always been a crucial point for the simulation of this kind.

Once having observed that the general description of the cloud increases, and deformation and advection agree with experimental results, it is possible to continue in details and examine the

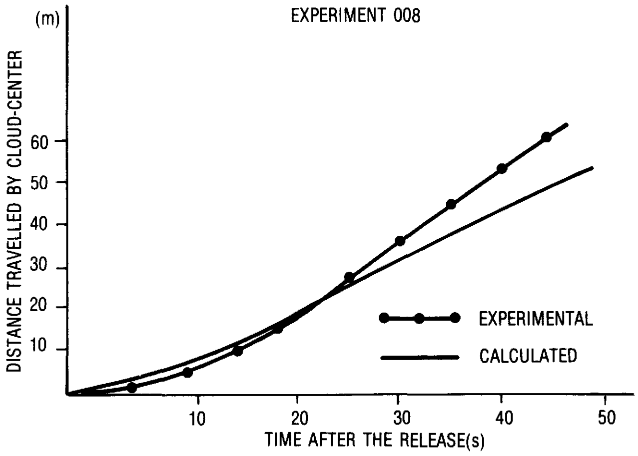


Fig. 7 - Thorney Island - wind speed 2 m/s

concentration patterns measured at the locations where the detectors were placed.

The detailed comparison between the experimental results and the calculated concentration values for some of the places is shown in Figures 8 to 11. The choice of the points for which the

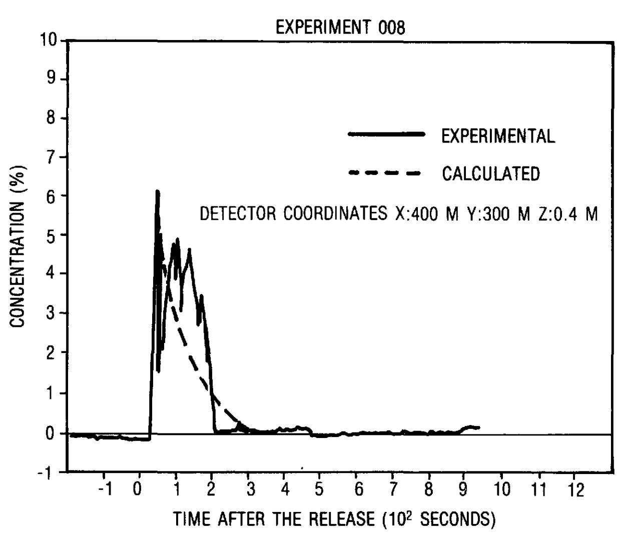


Fig. 8 - Thorney Island - wind speed 2 m/s

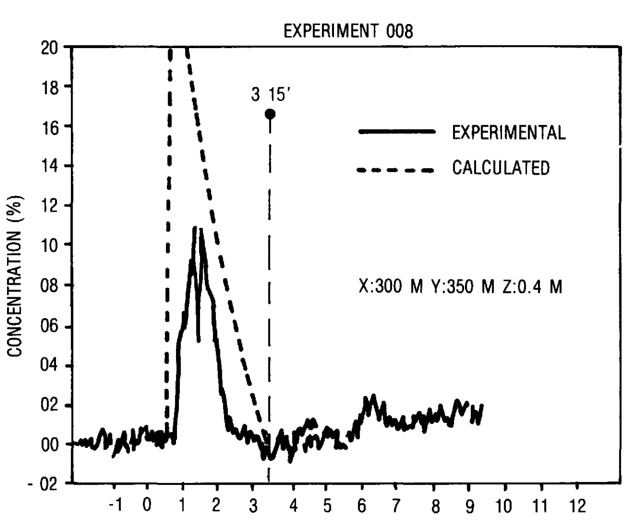


Fig. 9 - Thorney Island - wind speed 2 m/s

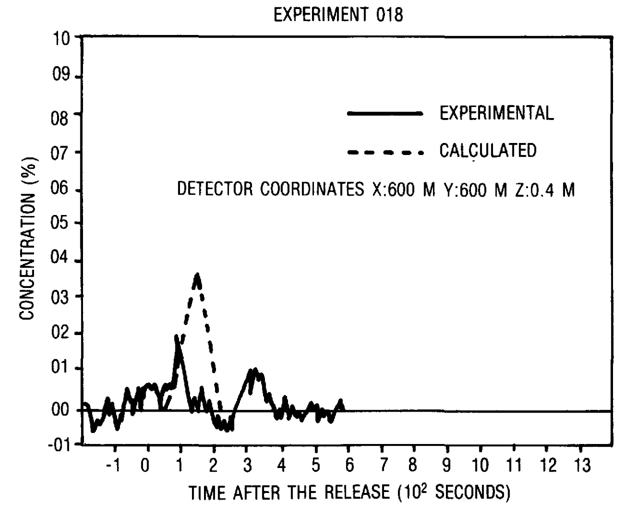


Fig. 10 - Thorney Island - wind speed 6 m/s

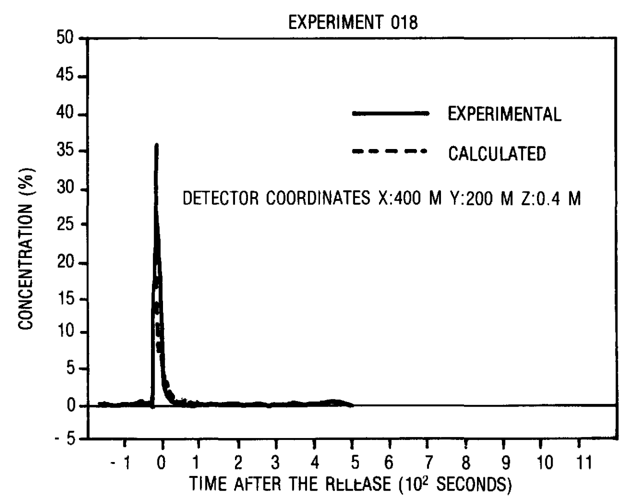


Fig. 11 - Thorney Island - wind speed 6 m/s

comparison is made, is fair, in the sense that in some of the points the agreement is pretty good and in other cases the computed values are different from the measured ones, either for the peak concentration or for its time-integral value.

In any case, examining the figures it is possible to conclude that the dispersion process is correctly simulated by the model for the purpose of safety studies.

1.5 MARS: THE MAJOR ACCIDENT REPORTING SYSTEM

Great importance is assigned by the European Council Directive to the reporting of major accidents occurring in certain industrial activities (82/501/EEC - commonly referred to as post-Seveso Directive). Accident notification is, indeed, considered to be a significant measure for an effective information policy among member states, aimed at preventing repetition of events sharing similar patterns of causes.

Member states shall inform the Commission as soon as possible of major accidents which have occurred within their territory, and shall provide it with information specified in an annex to the Directive including items such as:

- the circumstances of the accident;
- the dangerous substance involved;
- the effects on man and the environment;
- the emergency measures taken;
- the steps envisaged to alleviate the medium and long-term effects of the accident; and
- the measures taken to prevent any recurrence of such an accident.

"The Commission shall set up and keep at the disposal of the member states a register containing a summary of the major accidents which have occurred within the territory of the member states, including an analysis of causes of such accidents, experience gained and measures taken, to enable the member states to use this information for prevention purposes."

To comply with the implementation of these articles, the Directorate General XI, responsible for the environmental policy of the Commission, asked JRC to design and implement a data bank for storing the information supplied by the member states.

Development of MARS

MARS has been developed according to the following steps:

a. promotion of a state-of-the-art review on existing incident data bases;
b. drafting of a reference classification scheme for process plants;
c. finalisation of the accident reporting collection forms;
d. design and implementation of the informatic structure.

Step a

The objective of the survey was to determine the state of the art of industrial accident data bases within the European Community and the United States of America. The results of the survey summarised at ref. /28/ and more extensively in the EUR report at ref. /29/, were, on the one hand, helpful for the design of MARS, and on the other hand, enlightening the need for an accident data base designed for the main purpose of safety investigations. It resulted, indeed, that the majority of incident reporting systems were focused on injuries and fatalities, whereas information on the cause of the incident, including technical information on the various phenomena associated with the incident, is rather scarce.

Step b

A comprehensive classification scheme for process plants has been developed as a proposal for a multi-level taxonomy of industry-type, plant-generic identification, system function and process units /30/. The work was aimed, on the one hand, at the univoquous identification of plants and systems involved in accidents by assignment of appropriated codes in MARS, and, on the other hand, it was more in general aimed at the establishment of some standards for collecting performance data on significant components; data which might be useful in reliability, availability and maintainability studies as well.

Fig 12 shows the main criteria on which the classification scheme has been based. The first level of the classification (industry type) has been already introduced into the MARS collection forms; whereas the other levels might be used in labelling by keywords the relevant fields of the collection forms in view of an information retrieval based on involved systems, as well as on other relevant keywords such as causes, casualties, etc.

Conceptual design of the four levels branching structure

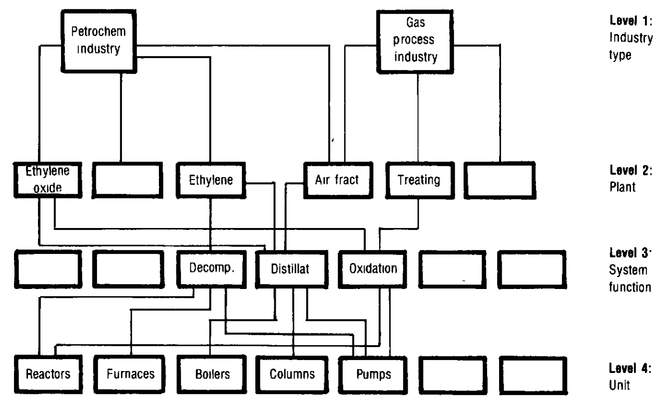


Fig. 12 - Basic criteria for plant classification

Before freezing the proposal and extending the scheme to cover all types of hazardous installations, the basic criteria are being reviewed with national competent bodies to achieve a general consensus aimed at uniformising accident reporting.

Step c

The information to be supplied in case of a major accident according to the Directive has been specified into detailed accident collection forms /31/ which should ensure a more uniform reporting from the different authorities. The proposed collection forms have been adopted by the competent authorities after some pilot exercises to check their adequacy for the purposes of the Directive. They also found a substantial consensus in the technical community and proved to be a useful tool for the accident notification. Furthermore, the reliabiltiy of the sources of information makes MARS different from other existing data bases. Indeed, because of the controlled quality of the data, MARS becomes a very useful tool for obtaining deeper insight into accident sequences, useful for implementing a prevention policy. Indeed:

- the information about substances and the related involved quantities can give an important feedback to control the list of dangerous substances (and their minimum threshold) presently covered by the post-Seveso Directive;
- the knoledge of the masses released, even if subject to a certain degree of uncertainty, can be useful for identifying source term patterns;
- the mapping of areas affected by accidents can be used for testing consequence predictive models;
- the information on the emergency measures taken and their adequacy results in a useful data base for emergency planning;
- the identification of accident causes is the fundamental step for any prevention activity. To this aim, the primary causes of the accident can be derived both from the case history description and from other specific items, thus allowing the analyst to check the consistency of the different descriptions in order to achieve reliable indications;
- the description of the measures taken to prevent the recurrence of similar accidents may represent a significant base for setting up specific and general recommendations for an effective loss prevention policy; and, finally,
- the analysis of the accident reports can help in identifying possible lack of knowledge or weaknesses on current practices of safety assessment, completeness of check lists, adequacy of existing standards, etc.

Even if the collection forms have been specifically designed for the accidents which must be officially notified to the Commission, it might be of general interest to take these formats as the basis for harmonising the way in which accident histories might be described. In this way, information on accidents might easily be exchanged between organisations wishing to learn from operational experience.

Step d

MARS has been implemented by using the ADABAS data base system available at JRC on the Amdahl 470 main frame computer.

The main procedures for data entry and inquiry have been designed in such a way as to make the use of MARS user-friendly. In practice, in the data entry mode, the description of the accident follows rigorously the collection forms (Fig. 13). Some functional keys allow the user to jump from one section to another.

```
                  M.A.R.S. -  MAJOR ACCIDENT REPORT SYSTEM


 0. ACCIDENT - REPORT - AUTHORITY      A. UPDATES HISTORY
 1. GENERAL DATA                       B. BIBLIOGRAPHY
 2. ACCIDENT TYPE                      C. KEYWORDS USED IN REPORTS
 3. CIRCUMSTANCES OF THE ACCIDENT      D. DELETE ACCIDENT
 4. EMERGENCY MEASURES TAKEN
 5. ANALYSIS OF CAUSES
 6. NATURE AND EXTENT OF DAMAGE
 7. MEDIUM AND LONGTERM MEASURES

    ACCIDENT number  ... .. ..        (member state, year, progr. numb.)
    REPORT   NUMBER  ..               (PREVIOUS REPORT     )
    FUNCTION         .                (PREVIOUS DATE    00/00/00 )


MRM1MENU---- pf5 ---- pf9 ------------------------------------------
             EXIT     HELP
```

Fig. 13 - Entry Menu to MARS

One report is kept for each accident. In the case that a report needs to be updated, each new information is associated with the date and a progressive identification number.
Some of the information describing an accident (i.e. name of the substances listed in Annex III of the Directive, corresponding CAS or EEC codes, type of accident, etc.) is already available in the data base and accessible by means of alphanumerical codes.

A set of keywords can be associated with each report. This results in a very effective and complete way of data retrieval. The codified information and the keywords are used only during the data entry and, therefore, they are not included into the collection forms that have been held as simple as possible.

The inquiry mode, which is also menu-driven, is performed by keywords selected from the set of pre-established keywords. It is possible, for a selected set of accident reports, to have either a complete or an abbreviated printout.

In addition to that it has been found very useful to have a summary of the content of the data base. This consists of updated histograms and/or tables containing:

- total number of accidents vs year;
- accidents in a certain activity field vs year;
- accidents involving given substances;
- accidents of a given type (explosion, fire, release, etc.);
- fatalities;
- etc.

Status and future developments

MARS is already fully operational and has been loaded with all the accidents notified up to now to the Commission. Analysis of the accidents has started. At the moment, access to MARS information is only allowed to the competent authorities. JRC is, however, preparing a statistical review of accident types and causes which, without violating the confidentiality requirements, might have a wider distribution.

JRC is also studying the implementation of MARS on a workstation provided with graphical facilities so that the recorded accident histories might be completed with site maps, damage contours, digitalized photos and other graphic facilities to enhance further the quality and completeness of the information.

Conclusions

The Benchmark Exercise on Major Hazard Analysis has started: its results are expected to give a significant contribution towards the establishment of a comprehensive state-of-the-art in Europe as far as procedures, models and data for risk analysis are concerned and the connected uncertainties.

Significant achievements have been realised as far as systems reliability analysis (SALP-PC) tools are concerned and a project for a more comprehensive knowledge-based software package for plant reliability and safety analysis (STARS) is in a rather advanced execution phase.

The dispersion process can be for safety studies correctly simulated by the model MARA.

The implementation of the Major Accident Reporting System and the analysis of the recorded accidents are expected to install a correct feedback from experienced events for contributing to an effective prevention policy.

Promotion of collaborative actions on reliability and incident data has been pursued: the support given to associations like ESRRDA, ESRA and EuReDatA contributes to link JRC activities with general needs.

New methodologies for process plant safety and reliability analysis (DYLAM) have been in the frame of exploratory studies succesfully demonstrated.

Acknowledgement

At the conclusion of the first pluriannual research programme (1984-87), the contributions of the people directly involved or collaborating to the described projects are here by acknowledged.

The research activity, coordinated by A. Amendola, has been performed within the Systems Engineering and Reliability (SER) Division, directed by G. Volta.

The activity could benefit of the experience gained by the parallel projects of the Programme "Reactor Safety" on Risk and Reliability Assessment, which have been coordinated by G. Mancini, who has also been involved with the promotion of the EuReDatA, ESRRDA, ESRA activities. Furthermore, development and implementation of reliability analysis tools have been obviously shared among the parallel projects to avoid duplication, and to achieve multipurpose objects, such as SALP-PC, CAFTS and STARS. Principal investigator in this field have been S. Contini and A. Poucet with the support of P. Nichele and C. Van den Muyzenberg.

Gas dispersion models (MARA) have been principally investigated by G. Graziani.

MARS has been the result of multiple studies and working phases. Finalisation of the accident reporting collection forms has been achieved through the collaboration with P. Bastianini and G. Bielli of the Division NED. L. Ferrario (Div. NED) collaborated to the

design of the Plant Classification Scheme. The MARS informatic structure has been developed at the ATI Division by R. Primavera, with the advise of S. Capobianchi and S. Carlesso. MARS is now operated by S. Contini, P. Nichele and P. Wiederstein, who provide for the maintenance of the software, the loading and the analysis of the incidents reported. The entire MARS project is being performed in strong cooperation with the DG-XI (Division Chemical Control, Industrial Risks and Biotechnology), responsible for the implementation of the post-Seveso Directive.

The support of T. Luisi to the project group's activities and to the EuReDatA secretariat must be acknowledged as well as the strong involvement of A. Pouchet, J. Flamm, A. Colombo and R. Jaarsma in ESRRDA and ESRA activities.

N. Labath gave, as visiting scientist, among other activities, a strong contribution to the application of the DYLAM technique to the safety analysis of chemical processes.

References

/1/ A.G. COLOMBO and A.Z. KELLER (Eds.), "Reliability modelling and applications", Proc. of the Ispra Course organized in collaboration with ESRA, D. Reidel Publishing Co., 1987.

/2/ ESRA Course Directory Number 1, April 1987, S.P. D.87.17.

/3/ J. FLAMM (Ed.), ESRA Newsletter, Vol. 3, No. 3, December 1986, SP/LO5.E3.86.79; Vol. 4, No. 1, April 1987, ISSN 1010-8149; Vol. 4, No. 2, August 1987, ISSN 1010-8149.

/4/ A. AMENDOLA (Ed.), EuReDatA News, No. 7, SP I.05.E3.86.92, December 1986; No. 8, SP I.87.05, December 1987.

/5/ C. FIORENTINI and L. LANCIA (Eds.), "Fire data analysis and reliability of fire fighting equipments", Proc. of the EuReDatA Seminar held in Bergamo (I), October 1986, SP I.87.34, JRC Ispra (1987).

/6/ A. AMENDOLA (Ed.), "Study cases on availability assessment", Proc. of the EuReDatA Seminar held in Girona (E), April 1987, SP I.87.64, JRC Ispra, November 1987.

/7/ A. AMENDOLA and A.Z. KELLER (Eds.), "Reliability data bases", Proc. of the Ispra Course organized in collaboration with EuReDatA.

/8/ A. AMENDOLA, "The DYLAM approach to systems safety and reliability assessment", EUR 11361 EN, December 1987.

/9/ A. AMENDOLA, N.A. LABATH, Z. NIVOLIANITOU and G. REINA, "Application of DYLAM to the safety analysis of chemical processes", Int. J. of Quality and Reliability Management, Vol. 5, No. 2, pp. 48-59 (1988).

/10/ N. LABATH, "Preliminary Studies for the Application of DYLAM Methodology to Predict Accident Scenarios." T.N. N° I.87.120 JRC Ispra October 1987.

/11/ A. AMENDOLA, "Uncertainties in systems reliability modelling: insight gained through European Benchmark exercises," Nucl. Eng. Des., 13 (1986) 215-225.

/12/ A. AMENDOLA, "Systems reliability benchmark exercise," final report, CEC-JRC, Ispra, EUR 10696, 1985.

/13/ A. POUCET, A. AMENDOLA and P.C. CACCIABUE, "Common cause failure reliability benchmark exercise," final report, CEC-JRC, Ispra, EUR 11054 EN, 1987.

/14/ A. POUCET, "Survey of methods used to assess human reliability in the human factors reliability benchmark exercise," 9th SMiRT post-conference on Accident Sequence Modelling, Human Actions, System Response, Intelligent Decision Support, München (FRG), August 24-25, 1987.

/15/ S. MESSINA, N. PICCININI, G. ZAPPELLINI, "Accident scenarios evaluation: tools and methodologies," ISS/WHO/IPCS world conference on Chemical Accidents, Rome, July 1987.

/16/ J. CLERINX and L. JOURDAN, "Quantitative assessment of risks," ISS/WHO/IPCS World conference on Chemical Accidents, Rome, July 1987.

/17/ A. POUCET, K.E. PETERSEN, "Software tool for advanced reliability and safety analysis", Proc. 8th SRE Symp., Helsingbor, October 1987.

/18/ S. CONTINI, "SALP-PC, a fault-tree analysis package on personal computer. User Manual", T.N. I.87.165, 1987. To be published as an EUR report.

/19/ A. AMENDOLA, S. CONTINI, C.A. CLAROTTI, F. SPIZZICHINO, "Analysis of complete logical structures in system reliability assessment", EUR 6888 EN, 1980.

/20/ A. POUCET, C.L. VAN DEN MUYZENBERG, "MAPLE-II, a program for plotting fault-trees", EUR 10946 EN, 1987.

/21/ A. AMENDOLA, "Systems reliability benchmark exercise," Final Report, CEC-JRC Ispra Euratom report EUR 10696 EN (1985).

/22/ A. AMENDOLA, P.C. CACCIABUE, S. CONTINI and A. POUCET, "PSA methods for technical specifications: insight gained from the reliability benchmark exercises and from the development of computerised support systems," NEA/UNIPEDE Specialist Meeting on Improving Technical Specifications, Madrid, September 7-11, 1987.

/23/ A. POUCET, S. CONTINI, N. VESTERGAARD and K. PETERSEN, "An expert system approach to systems safety and reliability analysis," 2nd Eur. Workshop on Fault Diagnostics, Reliability and Related Knowledge Based Approaches, Manchester, April 6-8, 1987.

/24/ A. POUCET, "CAFTS: computer aided fault tree analysis, ANS/ENS Int. Top. Meeting on Probabilistic Safety Methods and Applications," San Francisco, February 24-March 1, 1985.

/25/ A. POUCET, "CAFTS: User's Guide," CEC-JRC Ispra Euratom report (to be published).

/26/ G. GRAZIANI, P. MORETTI and G. VOLTA, "Dispersione atmosferica di gas pesanti: sviluppo del modello MARA e suo confronto con dati sperimentali", EUR 11132 IT (1987).

/27/ G. GRAZIANI, "Models for dispersion of dangerous gases, presented at the Meeting on The Implementation of the Post-Seveso Directive," Ministry of the Environment, Athens, October 1987.

/28/ P. BOCKHOLTS, I. HEIDEBRINK, T.R. MOSS, J.A. BUTLER, C. FIORENTINI and P. BASTIANINI, "A survey on industrial accident data bases, in: Reliability Data Collection and Use in Risk and Availability Assessment," Proc. of the 5th EuReDatA conference, Heidelberg, April 9-11, 1986 (Ed. H.J. Wingender) Springer-Verlag.

/29/ P. BOCKHOLTS et al.,
"A survey on industrial accident data bases," EUR 11072, CEC-JRC, Ispra, 1987.

/30/ G.C. BELLO et al.,
"Classification scheme for process plants," Proc. of the 5th EuReDatA conference on Reliability Data Collection and Use in Risk and Availability Assessment, Heidelberg, April 9-11, 1986 (Ed. H.J. Wingender) Springer-Verlag.

/31/ A. AMENDOLA, S. CONTINI, P. NICHELE,
"MARS: the major accident reporting system," I. Chem. E. Symposium on Preventing Major Chemical and Related Process Accidents, London, May 10-12, 1988.

RESEARCH ACTIVITIES

2. Management of Industrial Risk

The increasing size and complexity of potentially hazardous industrial operations make management and regulation of industrial risk more and more necessary for support in decision-making.

Recent advances in computer hardware and software capabilities have major implications for decision support systems. They make possible comprehensive systems which can integrate a set of simulation models with relevant data bases so that all aspects of a problem can be analysed and policy alternatives rapidly assessed. Further, interfaces can be designed to permit non-specialists easy access to methods of analysis and information management which were traditionally open only to computer experts: decision support tools now can be used closer to the actual point of decision.

The major medium term goal of this activity was to develop a computer-based, integrated risk management support system, applied to the risks of hazardous substances and suitable for use by people without specialised computer knowledge or training. This system is called IRIMS, the Ispra Risk Management Supporty System, and is based on the integration of existing simulation models and computer-assisted procedures so that risk managers can consider the relationships amongst the risks of production, environmental dispersion, product use, transport risk, and waste treatment and disposal.

The main elements of the IRIMS system are a menu-driven, mouse-actuated user interface which provides easy access to the system; an information system which contains knowledge and data bases, inference machine and data base management systems; and a set of simulation models. Output is primarily in graphical form, making use of high-resolution colour graphics. At the beginning of 1987 a demonstration prototype of the IRIMS system was operating at Ispra and had been upgraded, primarily by adding interconnections between modules.

A formal collaboration with the Dutch Ministry of Housing, Planning and Environment (VROM) had been established for adapting the IRIMS shell to the specific case of chlorine risk management in the Netherlands. IRIMS had been modified to allow zooming in on detailed maps of the Netherlands to facilitate siting risk studies.

Objectives

There were for 1987 two main and some additional objectives for this period:

- continue of the collaboration with the Dutch Government on the chlorine case study, transporting all the relevant software to Ispra and making it operational here.
- continue of the work on the consolidation of the IRIMS prototype system, specifically making improvements in the transportation risk module and in the data bases.
- in addition, it was planned to explore the feasibility of transporting some of the IRIMS (SUN-based software) to a personal computer, to continue theoretical studies of risk management and regulation and to demonstrate the IRIMS system to other potential users.

Activities for the coming years will include:

- the continuation of chlorine risk study;
- further development of the PC-based decision support system for transportation risk HELP;
- further development of the method for digitising maps and road networks;
- implementation of the new transportation risk model TRIM, which keeps accident probability and consequences separated, on the SUN; and,
- work will begin on the conceptual design of "micro-IRIMS" systems, customised for specific problems, including emergency planning and management, while a workshop of potential micro-IRIMS users will be convened to elicit user needs as a starting point for specification of design parameters.

Results of the research activities

The software and data bases developed by VROM in the framework of the chlorine study were delivered to Ispra and made operational here. This software will be continually updated, especially as digitisation of the Netherlands maps continues (about one-third completed now) and the railway network is added to the transportation data base.

A stand-alone transportation risk system, HELP, was developed, based on transporting the HASTM transportation risk model and the DIDASS-based optimisation module from the SUN machine to an IBM PC AT. DIDASS is a decision support model, based on the reference point approach, which finds a satisfactory solution through an interactive process with the user. This approach does not require that the user choose an alternative that is optimal in some "objective" sense, but allows him to select an option in accordance with his own subjective values.

The HELP transportation module, based on the HASTM transportation risk model, describes the road network in terms of a graph with arcs and nodes. The nodes represent the most important settlements and the arcs segments of the roads connecting settlements. Each arc is characterised by its length and one of four possible road types. Route generation between point of origin and destination of the shipment is based on the heuristic assumption that "shorter is better", and a branch and bounds technique used. The risks and cost of each alternative are then calculated, the costs based on a simple, linear function and the risks based on statistics on hazardous material transportation in terms of injuries, deaths and property damage for each types of route, assuming a log-normal distribution for the estimation of consequences. A data base was created for the Italian region of Lombardy and a case study of transportation risk carried out using HELP. (see for more details the topical report "Systems for Decision Support: IRIMS and HELP", par. 2.1).

In addition, a more transparent transportation risk model, TRIM, has been designed. TRIM estimates risks based on accident experience and keeps accident probability and consequence separated. The stochastic influence of wind speed, wind direction and local topography are assumed to be negligible since TRIM is intended to support strategic decision making. TRIM estimates consequences bases on two parameters which can be determined directly from accident reports if the mass of material released, the number of fatalities and the distance from the accident site to the fatalities have been recorded. A power law is assumed, with consequences proportional to the released mass, or energy, to the power n, where n depends on the consequence type.

A personal computer based vision system has been adapted for use in digitising maps to provide information for geographical data bases. The information generated can also be used to create screen images to display the results of simulations. The vision system is first used to obtain a digitised image of a map of the area of interest. The particular information required for data bases or displays can then be extracted using the program MKMAP (Make MAP) which has been developed especially for this purpose.

The program has so far been oriented towards obtaining the information required for the transport simulation models used in IRIMS and HELP. This information can be broadly divided into three types:

- areas having irregular outlines depicting the shape of a country or geographical region,
- locations and names of cities and towns,
- networks describing road or rail transportation systems.

The first type of information can be digitised automatically, while the second two types require the user to digitise them manually from the screen image, working with a mouse. Once digitised, the information can be transferred to any other machine on which it may be required. The methods have been tested and found to be quick and reliable for the amounts of information required to be digitised up to present. A map of Denmark, including major cities and road networks, has been created and transferred to the SUN 3 workstation on which the IRIMS system is held. Also a map of the Lombardy region, again with major towns and road networks, has been created and transferred to an IBM-AT personal computer and used in the HELP transportation model for Lombardy.

Programs have also been written to oblain outline maps of Europe from the AMDAHL mainframe computer and transfer them to the SUN 3 workstation. These maps include coastlines, political bounderies, rivers and lakes, and can be obtained for the whole of Europe or any individual country. The system has been tested by transferring maps of Spain and Great Britain to the SUN workstation.

In order to explore the possible uses of three dimensional models of industrial or urban sites in the context of risk studies, a three dimensional modelling program, ICON (Interactive CONstruction), has been transferred to the SUN 3 workstation and converted to function with the Suncore graphics system. This program allows the user to rapidly create a model of a site which can then be used either for display purposes or for further analysis by simulation programs. The program has been demonstrated to several potentially interested parties and has found an enthusiastic response.

The IRIMS system has been demonstrated at a number of trade fairs and professional society meetings and also to numerous visitors to the JRC. The response has been highly positive and discussions are in progress with several government agencies and industrial groups about possible collaborations in adapting IRIMS for specific studies.

Several theoretical studies which examine the context in which decision support systems are used and possible applications of them have been carried out and published in the scientific literature.

Conclusions

We have found a great deal of interest in the IRIMS approach from possible external collaborators and the existing collaboration with VROM has confirmed the feasibility of installing specific software packages preferred by the user as a module of IRIMS which is managed through the IRIMS interface. The experience of creating the HELP PC-based decision support system for transportation risks shows that it is possible to transport modules from the IRIMS system to more widely available computer hardware, and has also provided experience in resolving the software and hardware compatibility problems that need to be overcome. The work on three dimensional modelling has been well received, indicating that there are a number of potential applications of this technique to risk analysis, eg local heavy gas diffusion, and to crisis management, eg. training of emergency teams.

Results of topical research activities:

2.1 SYSTEMS FOR DECISION SUPPORT: IRIMS AND HELP

Introduction

Recent advances in computer hardware and software capabilities have major implications for decision support systems. First, they make possible comprehensive systems which can integrate a set of simulation models with a family of relevant data bases to treat all elements of a problem and the interactions between them. Second, they allow the consequences of policy alternatives to be rapidly assessed. Third, they permit non-specialists easy access to methods of analysis and information management that traditionally have been available only to computer experts, thus allowing decision support tools to be used closer to the actual point of decision.

In this report we describe the mathematical background for decision support systems and the actual software developed. Two systems have been developed at the JRC along these lines. First the Ispra Risk Management Support System (IRIMS), implemented on a dedicated "super-micro" computer, which treats the risks of hazardous substances from "cradle to grave" is described. Secondly, the HELP system, developed on a personal computer, will be presented in more details. HELP is a system dedicated to the problem of transportation of hazardous materials.

Reference point approach

The reference point approach is a well known approach in decision theory /1/. Described in words, the decision maker defines his point of "departure", and then proceeds to find the solution available, which will satisfy most of his preferences. The implementation used here is the Dynamic Interactive Decision Analysis and Support System (DIDASS), which finds a satisfactory solution through an interactive process with the user. This approach does not require that the user choose an alternative that is optimal in some "objective" sense but, rather, analogous to Simon's /2/ notion of bounded rationality, allows the user to select an option in accordance with his own subjective values.

The model proceeds in two stages. In the first, "exploratory" stage, the decision maker uses DIDASS to examine information on the range of values for the criteria and the frequency distribution of alternatives. Then the Pareto set of non-dominated alternatives is found. An alternative is called non-dominated, or Pareto alternative, when no other alternative has attribute values less than or equal to the alternative in question, provide you wish to minimise all the attributes. An alternative $\mathbf{x}_j$ is defined as a set of real numbers, one for each attribute:

$$X_j = (X_{j1}, X_{j2}, X_{j3}, \cdots, X_{jn}) \quad (1)$$

where n denotes the number of attributes in your problem.

For each attribute a preference or goal G_n is defined:

$$G_n = \begin{cases} -1 & \text{if the jth attribute is maximized} \\ 1 & \text{if the jth attribute is minimized} \\ 0 & \text{if the jth attribute is ignored} \end{cases} \quad (2)$$

An alternative $\mathbf{x}_j$ is then dominating the alternative $\mathbf{x}_i$, if and only if

$$G_n \cdot X_{jn} \leq G_n \cdot X_{in} \quad (3)$$

for all attributes.

In words, the Pareto set contains the alternatives where the values of all attributes are not worse than in any other alternative. From this we can see that an alternative containing the optimun for a given attribute always is a member of the Pareto set. Due to the relative small number of alternatives, the method chosen for identifying the Pareto set is purely combinatorial.

In the second, "search" stage, a particular solution is selected on the basis of the users' specification of a theoretical point in the criteria space, the "reference point", **f**. The point is defined for each criterion by the users' choices of the preferred value within the possible range, normally a hypothetical point. A typical choice could be the point defined by the minimum of all the attributes. Based on this point, we then search for a function, which expresses the deviation from this point, of all the alternatives. This function can of course be chosen in different ways, but one of the more logical is the Euclidian distance. The distance between two alternatives is expressed by introducing the following function:

$$d(\bar{f}, \bar{x}) = \| \bar{f} - \bar{x} \| \quad (4)$$

$$d = \sqrt{\Sigma (f_i - X_i)^2} \quad (5)$$

Various scaling factors may be applied if the user feels uncomfortable with a value for one or several attributes which is larger than the reference point in the case where a minimisation is wanted.

Using the above equation, the model identifies a real point in the set of alternatives, the "efficient point", which represents the solution amongst the possible alternatives which is closest to the reference point, i.e., the "distance" *d*, is minimised.

In the reference point approach, the various alternatives generated by the transportation risk model are compared against a reference point chosen by the user. Mathematically, this involves calculating the distance between the reference point and each alternative as shown in equation (5).

If the numerical values of the attributes of the decision problem under consideration are of the same order of magnitude, the distance (Euclidean norm) from the reference point to the alternatives seems, in the absence of user preferences to the contrary, to be a good basis for comparison. However, if they are orders of magnitude different, as is the case with risk and cost, this method will always act to preferentially minimise the difference of the numerically larger attribute (i.e. cost) because the difference in the other attribute (risk) is numerically negligible in comparison.

When the values of the attributes have the same order of magnitude, and no scaling factor is used, it is roughly equivalent to using the attribute mean as a scaling factor when the attributes are of quite different magnitude. The user should be aware that whatever scaling factors are chosen, they implicitly determines how the attributes are weighted. Other possible scaling factors are the maximum, the minimum or the reference point values for each attribute. The use of the maximum or the minimum penalises alternatives with a large standard deviation, while the use of the reference point leaves the user open to possible charges of manipulating the outcome, since it is he who selects the reference point to begin with. This is especially true if the system is to be used to justify decisions in a policy context. However, it should be noted that it is only when trying to determine the efficient point that scaling factors are important, the Pareto set being independent of scaling.

Another possibility is the application of penalisation factors to penalise alternative with all attribute values inside the positive cone in the criteria space with its vertex at the reference point. Using the penalisation factor ρ the equation (5) is changed to:

$$lp = lp = \sqrt{\sum_{i=1}^{i=n} (\rho_i \cdot (f_i - q_i)^2)} \quad (6)$$

For example $\rho_i = 100$ may be if $f_i < x_i$. This means that attributes outside the preferred area penalised by approximately a factor 10. In all other cases, $\rho_i = 1$ has been used. Of course ρ should be considered as an input variable, and the calculations can therefore be repeated with different values.

The method described above is used both in IRIMS and in HELP, and it should be stressed that this is only one of a number of possible decision support models.

The IRIMS System

The Ispra Risk Management Support (IRIMS) System /3/ was developed by the Joint Research Centre with support from contracts given to the International Institute for Applied Systems Analysis. Its primary goal was to demonstrate the feasibility of a system which integrates data bases with a set of simulation models diverse enough to analyse the complete life cycle of hazardous substance, e.g., the risk arising in manufacture, transportation, product use, and waste treatment and disposal. The data bases and simulation models are linked to a multi-attribute decision support tool which allows the evaluation of alternative risk management strategies. In fig. 1 the general structure of IRIMS and the interactions with the user is shown. The user may get information directly from the databases, from the simulation model (and give input to them) and interact with the decision support system.

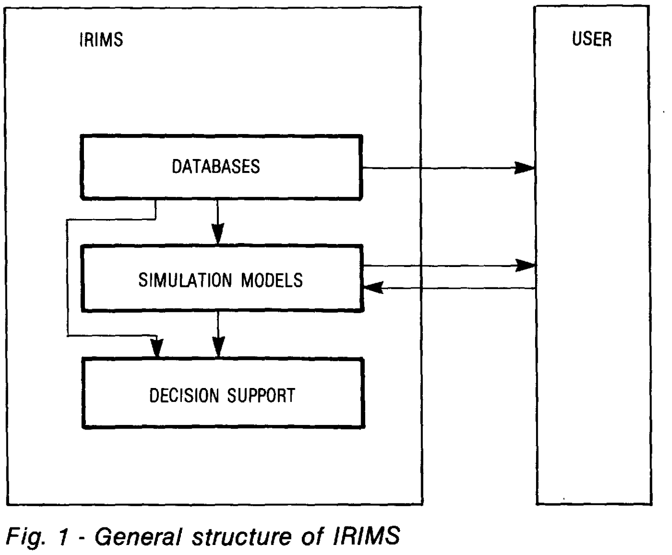


Fig. 1 - General structure of IRIMS

A further goal of IRIMS was to design an attractive and easy to use interface that would make the system accessible to people without experience of computer technology (but with an adequate technical understanding of the problems under study).

The design process, described elsewhere /4/, included a workshop of policy makers to elicit their views as to which features the system should have.

The IRIMS data bases, containing information relevant to risk management, are valuable sources of information in their own right and also provide inputs to the simulation models. The data bases include information about properties of chemical substances, the chemical industry, past industrial accidents, relevant laws and regulations, and geographical features.

The simulation models were mostly pre-existing pieces of software which were adapted for use in IRIMS. They are the transportation risk model (which will be described in more detail later), the waste treatment and disposal model, a group of models which form the environmental impact analysis module, and models for the analysis of the chemical industry and specific chemical processes. To aid in decision support, a multi-criteria optimisation routine, based on the reference point approach (described above), is included.

The IRIMS system has an open, modular structure so that new models can be introduced as needed for particular applications. The models and data bases are integrated through an interface (of slightly above average intelligence) which interacts with the user through high-resolution colour graphics and easy-to-use, mouse-actuated menus which require almost no key board input. All results are displayed in graphical form. The present version of the system is a demonstration prototype, implemented on a dedicated SUN-3 workstation. On fig. 2 and 3 two examples of the graphical interface is shown:

The IRIMS system is now being customised for a case study of the risks associated with the production, transportation and use of chlorine in the Netherlands. This is being done in the framework of a formal collaboration with the Dutch Ministry of Housing, Physical Planning and the Environment (VROM).

IRIMS has now been demonstrated to a number of potential user organisations. These demonstrations found a great deal of interest in the IRIMS approach, but have also revealed an interest amongst smaller regional authorities and specilised agencies in decision support systems that could be hosted on less sophisticated workstations.

Thus it was decided to explore the idea of a "micro-IRIMS" system, hosted on a personal computer. To test feasibility, IRIMS software relevant to decisions about the transportation of hazardous substances was transported to a PC, and a geographic data base was developed for the Italian region of Lombardy. This system, known as HELP, is described in greater detail in the next section.

The HELP System

The hardware system selected for the development of HELP is one that could be available to many potential users: the IBM PC AT with the MS DOS operating system which allows mixed language programming, eg, Fortran, C and Pascal, and is the operating system for a wide range of IBM-compatible computers. Modelled on IRIMS, HELP contains a data base, a transportation risk model and a multi-attribute decision model which are integrated through a graphic interface /5/, as shown in fig. 5.

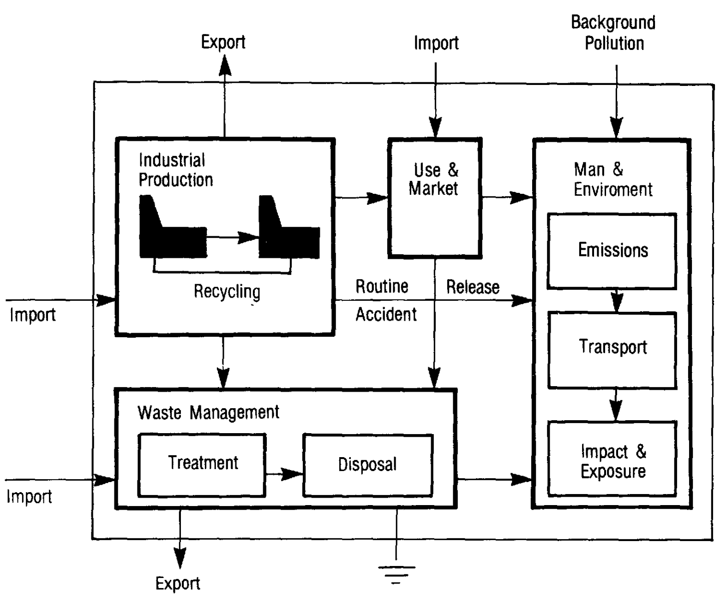
Prototype Demonstration Version 12/86. All rights Reserved.

This software system is developed under contract to the Commission of the European Communities, CEC, Joint Research Centre, Ispra Establishment, Italy, by the International Institute for Applied Systems Analysis IIASA, A-2361 Laxenburg, Austria.

IRIMS TOP LEVEL MASTER MENU:
Hazardous Substances Database
Industrial Accidents Reports
EC Directives and Regulations
Geographical and Regional Databases
Chemical Industry Databases
Industrial Structure Optimization
Chemical Production Technologies
Process Plant Risk Analysis: SAFETI
Industrial Waste Streams Database
Transportation Risk/Cost Analysis
Environmental Impact Assessment
Multi-Criteria Data Evaluation
EXPLAIN CURRENT MENU OPTIONS
SELECT TO STOP AND QUIT IRIMS

to select a menu item, position the mouse pointer, and press the left mouse button...

Fig. 2 - The main menu of the IRIMS system



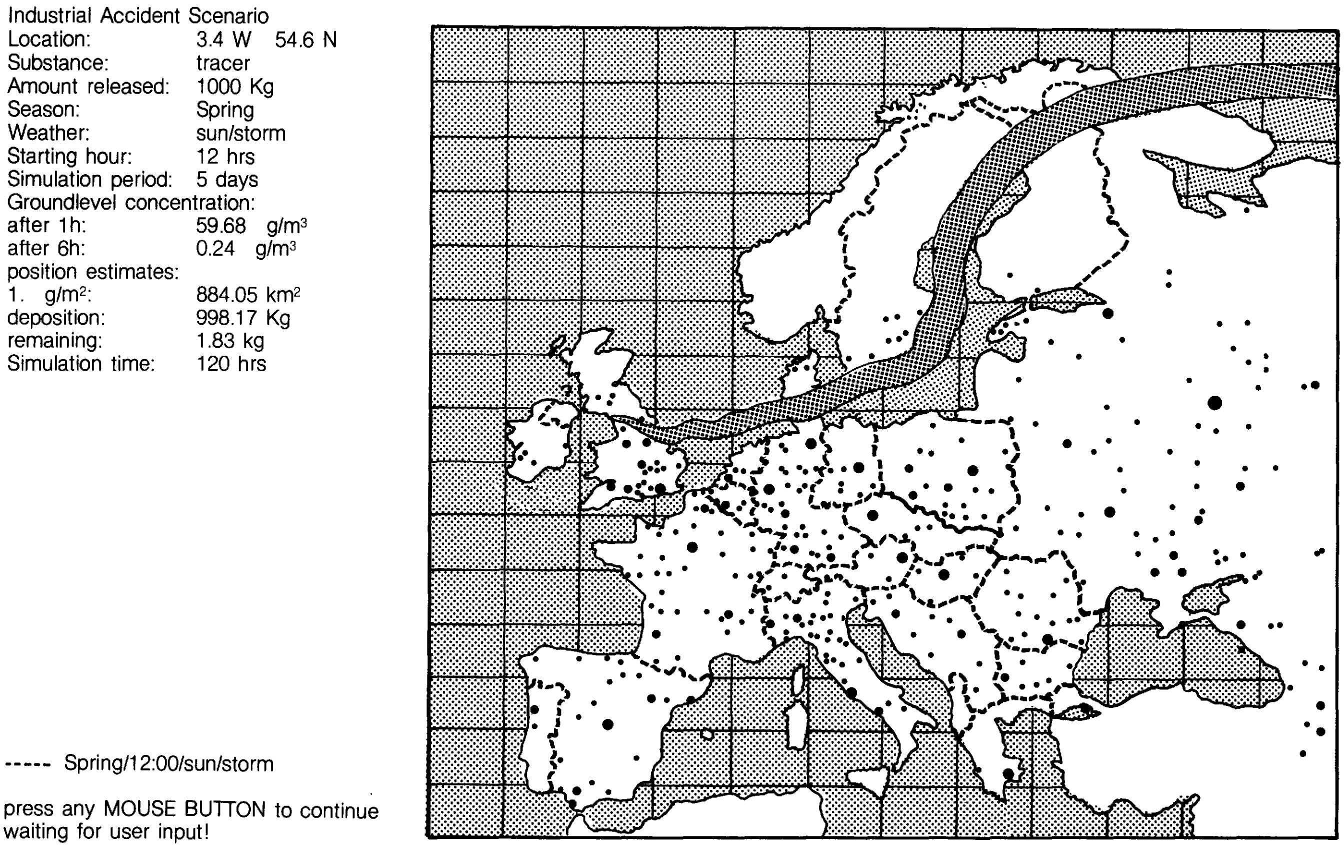


Fig. 3 - Example of Graphical display of results in IRIMS

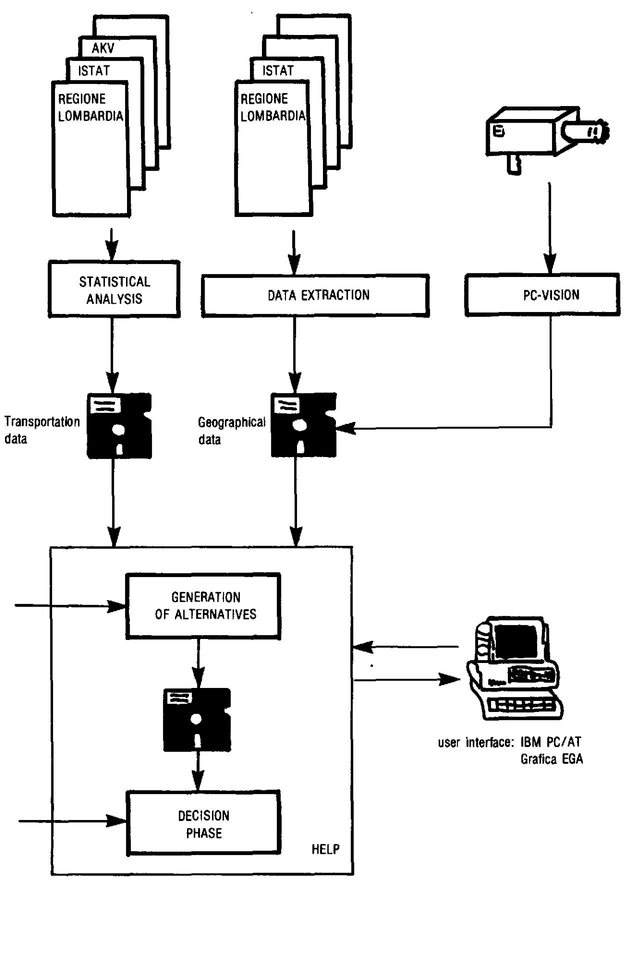


Fig. 7 - Scheme of the overall HELP system

The Transportation Module

This module is based on HASTM (the Hazardous Substances Transportation Model), a model for risk and cost analysis of transportation /6/.

The HELP transportation module describes the road network in terms of a graph with arcs and nodes. The nodes represent the most important settlements and the arcs segments of the roads connecting settlements. Each arc is characterised by its length and one of four possible road types. Route generation between point of origin and destination of the shipment is based on the heuristic assumption that "shorter is better", thus a branch and bounds technique is used. The risks and costs of each alternative are then calculated. The cost function is a simple, linear function:

$$C = C_f + C_{km} \cdot L \qquad (7)$$

where C_f represents fixed costs and C_{km} is the variable costs. The variable costs depend on the size of the shipment and the route length, as follows:

$$C_{km} = C_0 + C_1 \cdot \min(x, \bar{x}) + C_2 \cdot \max(0, x - \bar{x}) \qquad (8)$$

where $\bar{x}$ represents a step change in tariff. The risk calculation is based on accident statistics on hazardous material transportation in terms of injuries, deaths and property damage for each type of route, assuming a log-normal distribution for the estimation of consequences. The probability of an accident occurring in an arc, r, of length L kilometre, with the probability of occurrence/km, $p(r_t^c)$, is:

$$p_a(r) = 1 - (1 - p(r_t^c))^L \qquad (9)$$

If the entire route is formed by N arcs, the total probability of an accident is:

$$p = \sum_{i=1}^{N} \prod_{k<i} (1 - p_a(r_k)) \cdot p_a(r_i) \qquad (10)$$

q_t is defined as the probability that, if an accident occurs, it occurs in a particular land-use category, t, and using the log-normal distribution, the expected value of the consequences **C** are given by:

$$C = \sum_{t=1}^{T} q_t \cdot e^{\mu_t + \frac{1}{2}\sigma_t^2} \qquad (11)$$

where μ and σ^2 represent the expected value and variance of the distribution. Multiplying probability of occurrence and distribution of consequences we have the expected value of the risk, **R**:

$$R = \sum_{i=1}^{N} \prod_{k<i} (1 - p_a(r_k)) \cdot p_a(r_i) \cdot \sum_{t=1}^{T} q_t \cdot e^{\mu_t + \frac{1}{2}\sigma_t^2} \qquad (12)$$

As the decision maker must consider more than the expected value of risk, i.e. the maximum consequences, the variances are also relevant. Following Aitchison-Brown (7) the variance can be expressed as:

$$V = \sum_{t=1}^{T} q_t \cdot e^{2(\mu_t + \sigma_t^2)} - \left[\sum_{t=1}^{T} q_t \cdot e^{(\mu_t + \frac{1}{2}\sigma_t^2)} \right]^2 \qquad (13)$$

This defines the problem in terms of seven criteria, six related to risk (mean and variance of deaths, injuries and damage) and one for the total cost.

The Data Base

Data on geographic characteristics and on traffic and accident densities have been acquired for the Italian region of Lombardy. Cost data from the Federal Republic of Germany have been used (8) and informal checks confirm that they are consistent with Italian shipping costs.

Information on the individual nodes and arcs of the road network was generated using a semi-automatic system of image digitalisation developed at our centre by Peckham /9/ in which a road map image is stored directly in computer memory using a PC-Vision system /10/. The resulting data base contains coordinates of each settlement and the distances between them, labelled with the appropriate land use categori, i.e. urban, suburban and rural.

Risk calculations are based on historical data from Lombardy /11, 12/ on accident frequency per year for each category of road. It should be noted that there is considerable uncertainty on the derived data. Consequences are estimated using a probability distribution /13/ which uses historical data on accident severity in various land use categories. The digitised network is shown in fig. 5, and in fig. 6 a detailed scheme of HELP is shown.

Discussion

The implementation of the IRIMS prototype has indeed shown that the integrated approach towards risk management is feasible, and that it is possible to design software systems to support these decisions. The hardware chosen for IRIMS turned out to be very good for this application, though not readily available to all potential users. Finally these discussions about portability lead to the design of the HELP system.

The HELP system is a example of the "micro-IRIMS" system mentioned earlier, scaled-down in scope and hosted on less sophisticated hardware. The hardware chosen for HELP was a IBM PC (AT 2 with graphics). Even for this relatively large personal computer, unforeseen problems emerged in adapting software from the SUN-3 (with UNIX operating system) which hosts IRIMS.

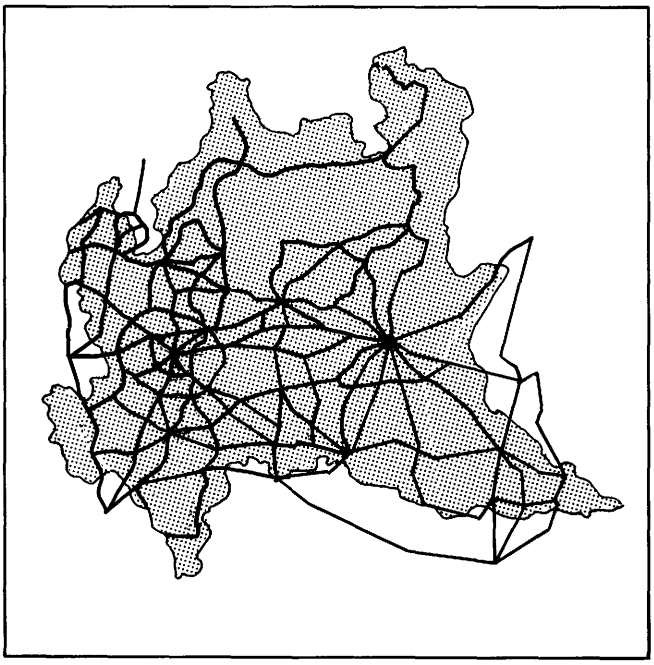


Fig. 5 - Road Network of the Italian Region Lombardy

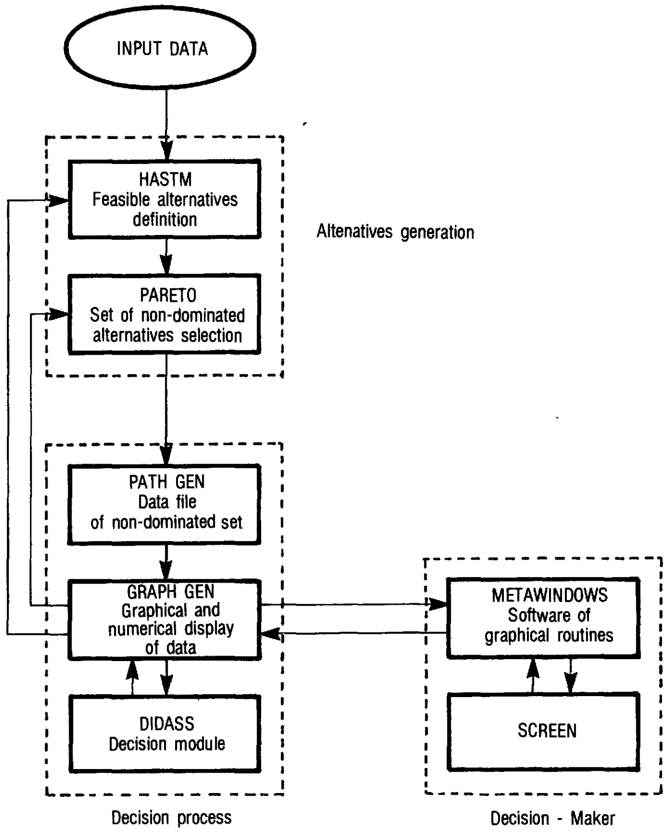


Fig. 6 - Detailed HELP scheme

Our conclusion from this first micro-IRIMS pilot experience is that smaller decision support systems are indeed feasible, and the size and capabilities of the hardware will depend upon the needs of the client and the particular application. It seems clear, that the IBM-AT would be the smallest system compatible with the demands of a system intended for real operational use. In addition to system size, higher resolution colour graphics would be an advantage as would a UNIX operating environment to facilitate the use of mixed programming languages.

An IBM System 2 computer is on order and will be evaluated to assess its suitability. In any case, it seems clear that if a decision support tool is to gain widespread use, it must be available on some "mainstream" computer system. We are also collaborating in the organisation of a workshop of policy makers from regional regulatory authorities which will ascertain the demand for smaller decision support tools and, if so, what user needs are.

With respect to the reference-point based, multi-attribute decision support tool, used in both IRIMS and HELP, we intend to explore the implications of introducing a scaling factor into the procedure for evaluating decision alternatives. This is not a trival problem, since slightly different scaling methods can give a quite different ordering of alternatives and, in fact, even have philosophical implications for the decision process. It is therefore important that users are aware of the effects of scaling methods (and even of not scaling at all), so that the choice of scaling method can be done in a transparent way.

References

/1/ WIERZBICKI, A.P.,
"A mathematical basis for satisfying decision making, Mathematical Modelling" vol. 3 - 1982.

/2/ SIMON, H.A.,
"Administrative behaviour," Macmillan, New York - 1957.

/3/ IRIMS,
"The Ispra Risk Management System. A computer based prototype," EUR report 10862 EN - 1986.

/4/ OTWAY, H., HAASTRUP, P.,
"Designing Risk Management Systems," Annals of Operational Research. (1988) In press.

/5/ DAL BON, G., HAASTRUP, P., PARUCCINI, M.
"HELP, A Decision Support System for the Transportation of Hazardous Chemical Substance." Eur report (in preparation).

/6/ KLEINDORFER, P., VETSCHERA, R.,
"Risk-Cost analysis model for the transportation of hazardous substances," Ludwig Boltzmann Institute, Vienna - 1985.

/7/ AITCHISON, J., BROWN, J.,
"The lognormal distribution," Cambridge University Press, Cambridge - 1957.

/8/ Arbeitskreis fuer Verkehrssicherheit (AKV),
Seminar 1980, Muenster - 1980; cit. in Kleindorfer, P., Vetschera, R.: "Risk-Cost analysis model for the transportation of hazardous substances," Ludwig Boltzmann Institute, Vienna - 1985.

/9/ PECKHAM, R.,
"Digitising maps with PC-Vision," JRC Tech. Note in preparation, Ispra - 1987.

/10/ "Imaging Technology Incorporated: ITEX/PC Programmer's manual," Woburn, MA - 1985.

/11/ ISTAT: "Statistica degli incidenti stradali," vol. 3, Roma - 1986.

/12/ ISTAT: "Le Regioni in cifre," Roma - 1987.

/13/ NAYAK, R., et al.,
"Event probabilities and impact zones for hazardous materials accidents on railroads," A. Little Inc., Cambridge, MA - 1983, cit. in.: Kleindorfer, P., Vetschera, R.: Risk-Cost analysis model for the transportation of hazardous substances, Ludwig Boltzmann Institute, Vienna - 1985.

3. Protection Against Runaway Reactions

In chemical processes, runaway reactions, i.e. exothermic reactions getting out of control, represent a potential hazard source. These processes may happen not only during chemical processing but also at storage.
The consequences of such incidents result in loss of containment ranging from controlled venting via an emergency relief system through mild ejection of a part of the reactor inventory into the working area, to explosive rupture of the reactor which, in some cases, is followed by a fire and/or a secondary explosion.

Depending on the nature of the released materials (flammable, explosive, toxic) risks do exist for the personnel, the plant and, in some cases, even for surrounding areas both on- and off-site.

Quite often runaway reactions play an important part in the chain of a developing incident, therefore, the aim of the present activity is (a) to investigate their characteristic features in order to develop early detection and process control systems anticipating uncontrolled runaway excursions and (b) to study venting characteristics of reactive mixtures in order to prevent overpressurisation or overheating due to uncontrolled reactions in process plants.

A further aim is the development of physical models and mathematical tools for the scaling up of laboratory tests to real scale facility for safe plant venting lay out. This implies also the study of the limitation of scaling up laws.

The research activity can be distinguished into two complementary activities:

- behaviour of chemical process dynamics under runaway conditions, to be performed in the FIRES;
- the relief and venting of containment systems, i.e. multiphase multicomponent flow regimes in vessels, venting ducts and safety (pressure) relief devices, performed in the MPMC test facility.

The experimental activities are supported by theoretical studies based on JRC multiphase-multicomponent (MPMC) computational fluid dynamics expertise developed during the last few years in connection with the nuclear safety research programme. The main objective of these theoretical studies is to develop computer models capable of giving reliable predictions concerning runaway reactions in batch reactors and associated emergency relief systems. The activity is closely associated with the FIRES experimental programme and the test analysis of MPMC flow of non-reactive fluids.

JRC has contributed as member scientifically to the DIERS Users Group (DUG).

Objectives

The overall objectives for the both activities are:

Process dynamics under runaway conditions:

- identification of dangerous states of some selected chemical reactions:
  - nitration
  - polymerisation
  - diazotisation
  - oxidation
  - decomposition
- development of a safety approach based on "dangerous states control" (complementary to the approach on venting relief).
- validation of codes.

Venting and relief systems, limited to the thermohydraulics of MPMC fluids with and without exothermal heat sources:

- understanding of prototypical phenomena;
- availability of quantitative data for the development of basic models, describing the state of the:
  - fluid within the reaction vessel
  - flow in tubes, opening and quenching systems.
- scaling questions with respect to geometry and physical properties of components involved.

Objectives for 1987 were:

- further design and construction of FIRES;
- validation studies of models (SAFIRE);
- phenomenological study of the influence of the influence of the geometry and physical properties on two-phase fluid flow regimes;
- reference depressurisation tests with water for multiphase-multicomponent investigations;
- parametric studies with SAFIRE.

The following activities are foreseen:

- after commissioning, calibration and bench test performance of FIRES and FISIM, experiments will be performed with chemical reactions (of very high kinetics type (instant), such as neutralisation), followed by (endothermic) reactions with, kinetics, than can be quantified;
- experiments with chemical reactions (well-known kinetics) with possible runaway properties, especially
  - toluene mononitration by mixed acid;
  - suspension polymerisation of methyl methacrylate;
  - the diazotisation as subject of experiment is yet in phase of investigation.
- "in-vessel" fluid state will be investigated on phase and component distribution for given pressure, temperature, physical distribution for given components, and constraint in case of no chemical reaction, as well as in case of superimposed reactions present.
- fluid flow in venting tubes and release to "ambient" (quenching systems):
  - flow characteristic modelling;
  - phenomenological and quantitative understanding of fluid dynamic processes;

- quantification of the influence of the geometry (length and diameter) and properties (surface tension and viscosity) on the flow characteristics in order to make correlations or codes for the prediction of venting characteristics available;

- "release" into a storage tank, limiting to the quenching of the vapour phase, separation of the gaseous phase and cooling in order to use this design component for modelling a process plant with respect to the back pressure effects and back coupling effects on the flow in the discharge tubes and flow regime in the reaction vessel in case of emergency venting;
- development of "system codes" (of systems consisting of chemical reactors, venting lines and storage-quenching devices) based on measurements of the reaction characteristics of prototypical chemical reaction classes and or real reaction processes, which includes the problem of scaling;
- the influence of the up-scaling (from lab. scale to real size) on the reaction process and the thermodynamic state conditions of the system, particularly concerning geometry pressure and temperature. A feasibility study is going on for a large scale test facility consisting of a chemical reactor, venting lines and storage - quenching device with following properties: volume 20 m^3, scaling ratio steps from 1:100 to 1:1, max. pressure 250 bar, max. temp. 450°C.

Results

The main results of this research activity can be summurised as follows: progress of the realisation of FIRES, the perforamce of six studies and experiments on MPMC fluid flow, code validation and a plenar meeting of the ECG-RR on 19 - 20 March 1987.

3.1 FIRES

The activities were mainly devoted to the design, construction, installation and equipment of the FIRES, as like as the set up of the annexed chemical lab.

The FIRES (Facility for Investigating Runaway Events Safely), consisting basically of a bach type chemical reactor, completely equipped and instrumented to carry out batch and semi-batch type chemical processes, enables to pursue the following objectives:

- experimental verification of models for conditions close to runaway;
- test and development of detection, identification and control techniques to prevent runaway (early warning systems);
- assessment of procedures for fast shutdown.

The FIRES consists of a chemical reactor completely equipped with a fast-shut-down system (relief system, stopping-by-fast-injection device, fast-emptying-and-cooling system), measurement instrumentation, condenser, of an early warning system, a simulator and a data acquisition system as well as of auxiliary equipment like reagents insertion system, cover atmosphere, cooling/heating system. The reactor and a part of its equipment are housed in a bunker consisting of a 6 m diam. steel safety containment, anchered to a reinforced concrete basement, while auxiliary plant, control room, chemical laboratory, reagent store, equipment room, etc. are ontside the experimental bunker.

Chemical reactor

The inside glass-lined reactor is of a conventional type, characterised by a volume of 100 l, a max. pressure of 16 bar and a max. temperature of 525°K and equipped with an integral standard cooling jacket system (completed by a glass-lined condenser of equivalent capacity as the heat exchanger) and a stirrer.

Fast-shut-down system

This fast-shut-down system is based on three mutually independent emergency devices: (a) a safety relief device (realised by a bursting disc working at 5 bar) with venting system, (b) a stopping device by fast injection of an inhabitor by an automatically working mechanism and (c) a fast emptying and cooling system based on slowing down of the kinetics of the reactions by lowering the temperature of the reacting mass, which is obtained by a fast discharge into a tank partially filled with an inert liquid fluid at lowest temperature.

Reactor instrumentation

The instruments are very sensitive and shall measure at high precision (temp. at + 0.04°K, pressure at + 0.08 bar, pH at + 0.02, Redox potential 0.1 %, electr. conductivity 0.1 %) in order to assure an accurate and consequently reliable supervision of the main parameter affecting the reaction, realised by an online detection with distributed control system.

Early warning system

The "early warning" system is based on the instrumentation, filtering and analysis of the temperature of the reacting mass and of the heat transfer fluid, computing and analysing the respective derivates and starting than an alarm signal.

Simulator

The FISIM (FIres SIMulator) as mathematical simulator is an essential supporting tool for the safe and optimal operation of FIRES, which can represent the influence of the main operating conditions (stirring, heat transfer, insertion of reactants, etc), can charaterise the vapour phase, can consider the reactor accessories, can follow the evolution of the chemical system and its main deviations from the ideal situation as fas as the thermodynamical and fluid-dynamical aspects are concerned.

Control and Data Acquisition System (DAS)

The distributed control system is based on a micro-computer, heading the hierarchy, with a processor. The system manages the data acquisition and plant control sub-systems using a PC control peripheral, which is controlled by programmable logic.

Moreover the DAS has a "historical" data base which automatically supplies the behaviour of the various magnitudes being controlled, as a function of various time bases.

Experimental reactions

The following chemical reactions are planned to be subject of experiment.

- Toluene mononitration by mixed acid
  The reaction is highly exothermic and the problem is accentuated because of the heat of dilution of the nitrating acid (mixed acid) and the low heat capacity of the medium.
  As the organic species are only sparingly soluble in the acid, industrial nitration is a heterogeneous process involving two liquid phases: an acid (or aqueous) phase and an organic phase. This means that in order to decribe the nitration in these conditions, two phenomena, taking place simultaneously, should be considered:
  - chemical reaction
  - interphase mass transfer

- Suspension polymerisation of methyl methacrylate

  This is an exothermic reaction with many industrial applications. It is characterised by having free-radial kinetics with an autoacceleration phenomenon known as the "gel effect", that is a reduction in the termination rate of polymer chain radicals due to the increase in viscosity of the particles at high conversion. This produces a rise in the net rate of polymerisation. The inmiscible monomer is placed in an acqueous phase and dispersed by agitation. The water serves as both the dispersion medium and as a heart transfer agent with the advantage that moderate viscosities throughout the reaction are obtained.

3.2 MPMC fluid flow in relief venting systems

The following studies and experiments (on the MPMC-TF) have been performed:

- influence of the geometry and physical properties on the flow regime;
- MPMC basic studies
- parameters Studies of SAFIRE Code

Flow regime studies

The experiments were performed in 120 cm long cylinders of 16, 20 and 40 mm diameter filled with fluid. Air was fed into the cylinder from the bottom through a frit. Two pressure pick-ups, 40 cm apart along the flow path allowed the mean density measurement of the mixture. High speed photographs were taken in order to correlate the flow pattern with void fraction and gas flow rate.

The studies were performed with stagnant liquid and cover the following range of parameter variations:

Diameter:	16, 20, 40 mm
Surface tension:	72,3 m N/m, 34,4 m N/m
Viscosity:	58, 23; 275; 280 times the viscosity of water (η = 1,0 cP)
Air flow rate:	from 1,6 . 10^{-3} m^3/h to 0,8 m^3/h

Influence of the geometry on the flow pattern

It is common knowledge in two-phase flow that the change of the diameter at unchanged gas loading entails a change of the flow pattern. This is enhanced with altering the surface tension and viscosity of the fluid. Tests with demineralised water are performed for reference. Fig. 1 shows the flow pattern map as a function of void fraction gas flow rate and diameter. The characteristic flow patterns at 0,1 m^3/h gas flow rate for three different tube diameters are shown in Fig. 2. By only changing the diameter of about a factor of two, the flow pattern changes from bubble flow to long slug flow independent of the tube length. Fig. 2 gives an example of the flow pattern at a gas flow rate of 0,1 m^3/h which is also reproduced in Fig. 1. The influence of the geometry on the flow pattern is more pronounced for fluids with higher surface tension.

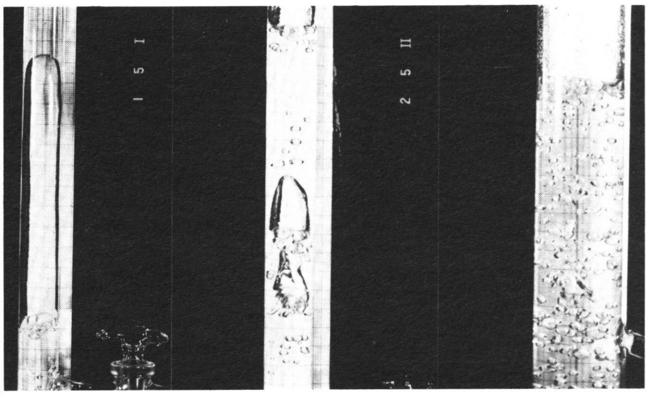


Fig. 2 - Influence of the geometry on the flow pattern (demineralized water, = 66,39 mN/m, gas flow rate: 0,1 m^3/h)

Table I - Pattern

B I bubble I	bubbles of ϕ <1/4 tube ϕ "d"
B II bubble II	bubbles of 1/4 d<ϕ<3/5 d
S I slug I	slug length L < 1,5 d
S II slug II	slug length 1,5 d < L < 4 d
S III slug III	slug length L > 4 d

SC semi-churn
SD slug-dome
SO slug oval
G grapes
C cigar
A annular
F foam
FS foam-slug

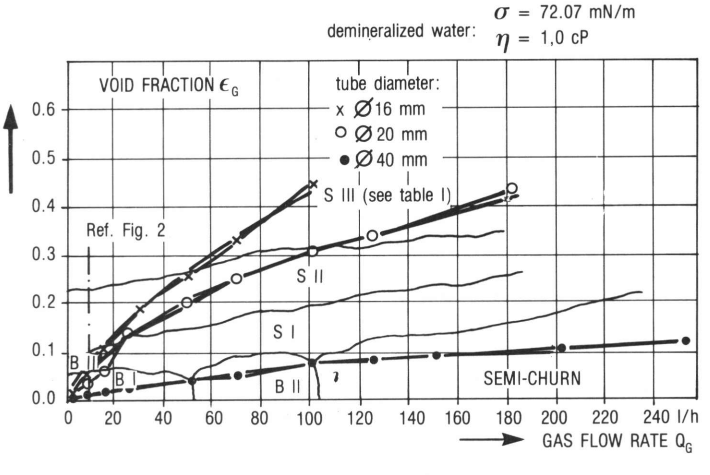


Fig. 1 - Void Fraction Versus Gas Flow Rate

Influence of the surface tension (adding traces of Falterol)

The change of the fluid surface tension has a strong influence on the flow pattern. In the present tests, the surface tension was changed to half of that of demineralised water. The resulting flow pattern, due to changing only the surface tension, is shown in Fig. 3. As shown, slug flow or transient flow patterns do not appear. Independent of the diameter of the test cylinder, only bubble flow at low gas flow rate, which changes immediately into foam flow, has been observed. The effect of the surface tension on the flow pattern for different tube diameters but constant gas flow can be shown. One notes the tendency of the gas bubbles to agglomerate. Bubble coolescence is only observed at high gas loading rate which seems to be due to hydrodynamic mechanisms.

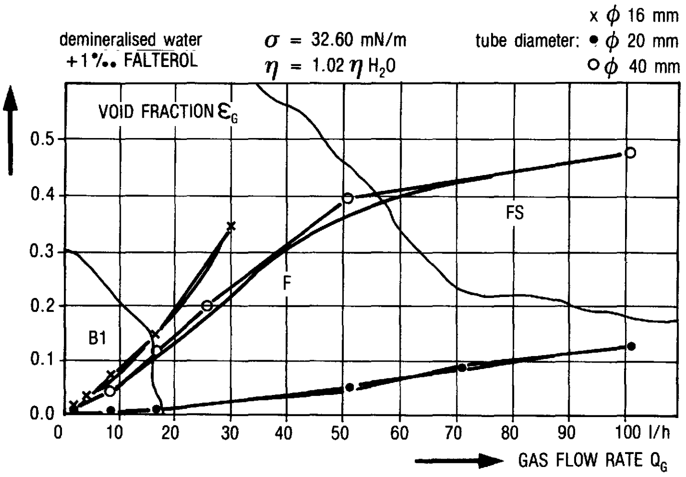


Fig. 3 - Void Fraction Versus Gas Flow Rate

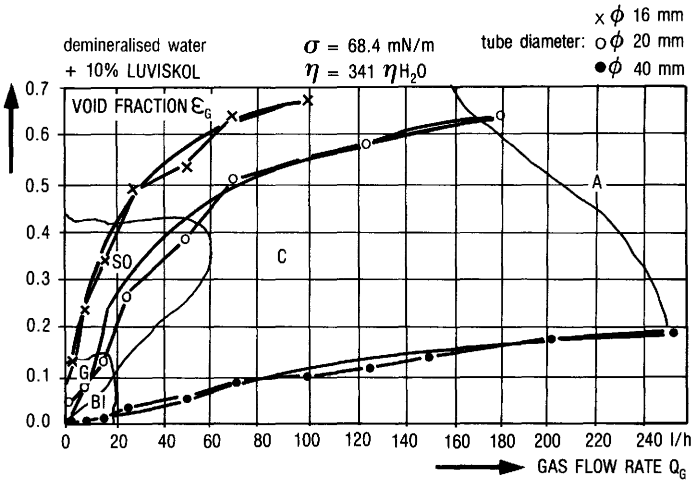


Fig. 5 - Void Fraction Versus Gas Flow Rate

Influence of the viscosity (adding Luviskol)

The effect of the viscosity on the flow pattern is very differentiated, especially as far as the flow pattern configurations are concerned. Flow patterns not yet reported in the literature have been observed: for example, at low gas flow rate and fluid viscosity $\eta > 200\ \eta\ H_2O$ grape-like clusters dominate the flow regime.

Another stable configuration observed for a viscosity range of 100 to 340 times that of demineralised water is the mushroomlike slug-chain configuration which appears at the transient from bubble regime to fully developed slug regime.

So the alteration of the flow pattern at identical test conditions but varying viscosity could be identified. A general survey of the effect of viscosity on the flow regime is shown in Fig. 4 and Fig. 8. The diagrams show that with increasing viscosity the "cigar type slug' and annular flow regime become dominant.

The significance of these studies is to draw the attention to the importance of the physical properties on two-phase regimes. The studies will be continued and extended also to forced convection flow of the liquid component.

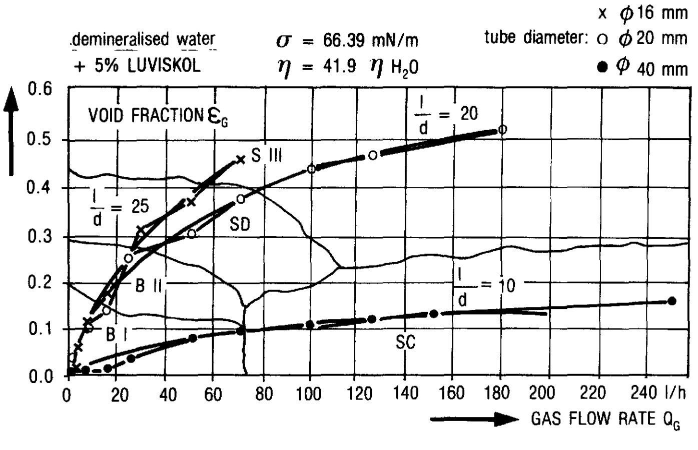


Fig. 4 - Void Fraction Versus Gas Flow Rate

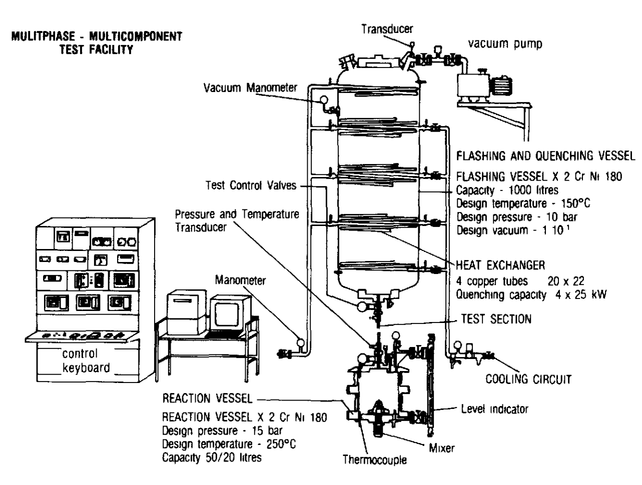


Fig. 6 - Multiphase - Multicomponent Test Facility

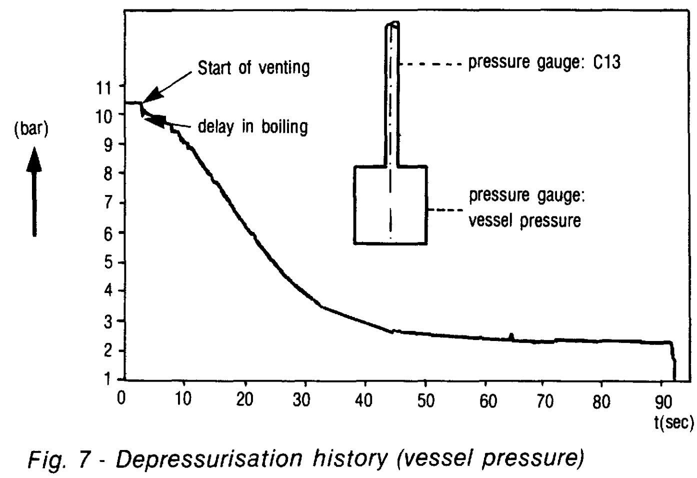


Fig. 7 - Depressurisation history (vessel pressure)

Basic studies on multiphase-multicomponent fluid flow

The basic studies on MPMC fluid flow have been performed on the small scale MPMC-TF. This adopted (for ex. equipped with additional measure instruments) existing test facility consists mainly of a lower pressurisation (50 l) vessel, a (1,5 m) test section and a flashing vessel with a quenching capacity of 100 kW. (see schema, fig. 6) This test facility enables to study the flow

of MPMC mixtures in ducts and its flashing into a vessel under controlled conditions, where void fraction and component velocity can be measured with special methods and sensors. Two test sections of 20 and 40 mm diameter with pressure and temperature junctions and windows for visualisation have been constructed and the necessary equipment for surface tension and viscosity measurement has been installed. Since one of the measuring methods of the phase and component distribution in the venting duct has been based on simultaneous closing of valves up- and downstream of the test section, extensive calibration tests have been performed.
The facility is being prepared at present for tests with decomposing fluids (H_2O_2) in order to simulate runaway processes under known conditions.

During the 1987 reporting period emphasis was given on depressurisation tests with demineralised water being used as reference data for the investigation of venting characteristics of fluids with variable properties. Tests were performed at the following initial conditions:

Vessel pressure: 5, 10 and 15 bar
Back pressure: 1 and 5 bar
Filling: 90, 75 and 50%

Typical results of some tests (performed at initial conditions: vessel pressure 10 bar, back pressure: 1 bar, filling 90%, fluid: demineralised water) are shown in figures 7, 8 and 9.

Fig. 7 shows the pressure history in the vessel following the opening of the relief valve venting into the quenching vessel at 1 bar. Venting started at 90% filling and terminated at saturation corresponding to the quenching vessel pressure (filling at the end of venting: v: $\eta = \sim$ 55%).
As shown, 80% of the pressurisation was released in a time span of 25 seconds. Fig. 8 shows measurements along the venting section in C13. In contrast to the pressure in the vessel strong instabilities occur.

Information of the "in vessel" situation can be obtained from "on line" level and the pressure measurements. The recording of fig. 9 shows a fast "level decrease" during the first venting phase followed by volume "swelling" which can be attributed to bulk boil off. Another characteristic feature of the depressurisation of demineralised water is the delay in boiling which exhibits also fig. 7.

The analysis of the experimental results is underway.
Conclusions at this state of progress would be premature.

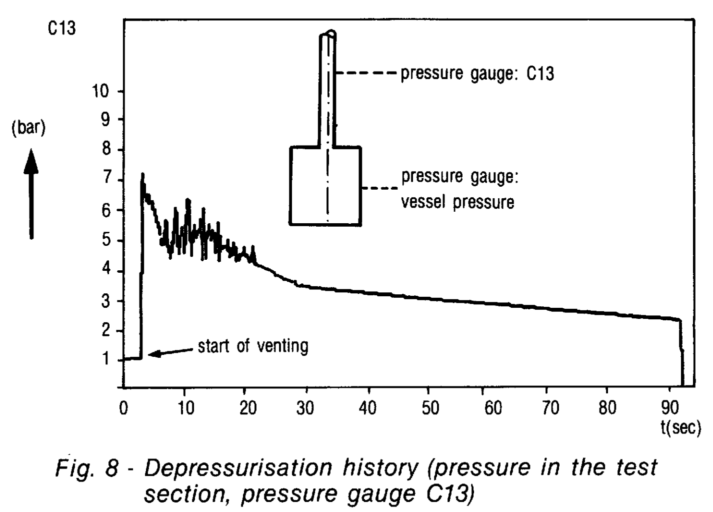


Fig. 8 - Depressurisation history (pressure in the test section, pressure gauge C13)

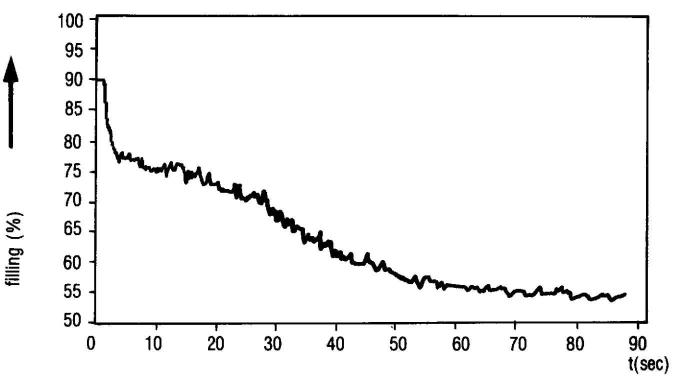


Fig. 9 - Depressurisation history (filling)

3.3 Modelling of runaway reactions

The DIERS' computer code SAFIRE is a generally designed code capable of analysing several types of chemical reactors. As part of the "Industrial Hazards" Programme, the work started with a general parametric overview study of the SAFIRE code for non-reactive water depressurisation tests under different physical, operational and vent size parameters. The dimensions corresponding to the available MPMC test rig have been chosen as standard geometric and operation conditions. These studies, which have been initiated in August 1987, are still in progress and will be compared with experimental results for verification of the used physical models and to check whether operational conditions and the variation of the size and length of the venting line are reproduced.

The assessment of the SAFIRE code /1/ has been undertaken with the analysis of the following problems:

a. water blowdown of a partially filled vessel through a long pipe and comparison with experimental data from the Multicomponent Multiphase Test Facility MPMC-TF JRC-Ispra and with calculations performed with the computer code RELAP5/EUR;
b. fluoridric acid discharge from a storage vessel and comparison with separate calculations made by the firm SNAM with a TNO computer code, and
c. cumene hydroperoxidation reaction and comparison with experimental data found in open literature.

SAFIRE's capabilities have been improved by adding as time-dependent variables the inflow of reactants into the reactor vessel (see point d). The code has also been modified in order to overcome convergence problems encountered in some cases and an ancillary graphical package has been implemented. Input data sets are now easily prepared with the help of a JRC-developed interface called SAFIN, which consists of a series of menus to be chosen by the user.

a. Water blowdown tests.

This section deals with a series of three water depressurisation experiments performed with the MPMC-TF (see fig. 6).

Various initial pressures and void fractions have been investigated in the three experiments and the corresponding data are summarised in Table II. All the tests considered have been performed under saturation conditions. According to the observed flow regime in the pipe, the SAFIRE calculations have been made using the partial vapour-liquid disengagement option with churn turbulent flow in the vessel coupled with the homogeneous equilibrium model for the long pipe description /2/. The formulation used in SAFIRE for the vessel flow is based on the 1D drift flux model proposed by Wallis /3/ and Zuber /4/. In the modelling of the transient vapour-liquid disengagement, the vapour mass fraction entering the vessel vent line is determined from the following relation (representing mass conservation /2/):

$$\frac{x \cdot v \cdot \Omega}{\lambda U} = \frac{1}{1 - C_0 \epsilon \cdot a} \qquad (1)$$

where:

x = vapour mass fraction entering the vent line during two phase vent flow
v = vapour phase specific volume
Ω = vent to vessel area ratio
G = mass flow
C_0 = radial distribution or shape parameter used in the drift flux model
U = rise velocity of individual bubbles
a = (1-x) / (Rx)
R = vapour to liquid specific volume ratio
λ = α / (1-C_0)
α = average void fraction in the vessel
ϵ = $(1-\alpha)^n / (1-\alpha^m)$
n,m = correlation parameters to be chosen according to the vessel flow regime adopted

Table II: Main SAFIRE input data used for the calculations of MPMC tests "1", "2" and "3" concerning water blowdown

	TEST "1"	TEST "2"	TEST "3"
VESSEL DATA:			
Initial pressure	0.62 MPa	1.03 MPa	0.66 MPa
Initial temperature	433. K	454. K	435. K
Initial void fraction	0.36	0.10	0.001
Vessel volume	0.05 m^3	0.05^3	0.05 m^3
Vessel diameter	0.4 m	0.4 m	0.4 m
"Radial distribution factor"	1.,1.4	1.,1.4	1.4
VENTING PIPE DATA:			
Pipe length	1.5 m	1.5 m	1.5 m
Pipe diameter	0.02 m	0.02 m	0.02 m
QUENCH VESSEL DATA:			
Initial pressure	0.15 MPa	0.25 MPa	0.101 MPa

As described in /2/ the parameter C_0 is defined by the relation:

$$C_0 = \frac{<\alpha j>}{<\alpha> \cdot <j>}$$

where j indicated the superficial velocity and the symbol < > represents an area average property. The value $C_0 = 1$ defines an ideal 1D system with uniform radial void fraction distibution. As a result of DIERS investigations /5/ a value $C_0 = 1.5$ has been recommended for the interpretation of water depressurisation data.

With regard to the MPMC-TF water blowdown tests summarised in column 1 and 2 of Table II, the value $C_0 = 1.4$ for the SAFIRE calculations has been found to be the most appropriate for reproducing the experiment data. Figs. 10 and 11 show the pressure (A), the void fraction (B) and the inventory (C) time histories in the vessel for tests 1 and 2, respectively. In all the figures, the experimental data and the SAFIRE calculations made with $C_0 = 1$ and $C_0 = 1.4$ are represented. It is possible to see that with the latter value of C_0, SAFIRE can successfully reproduce the variables measured.

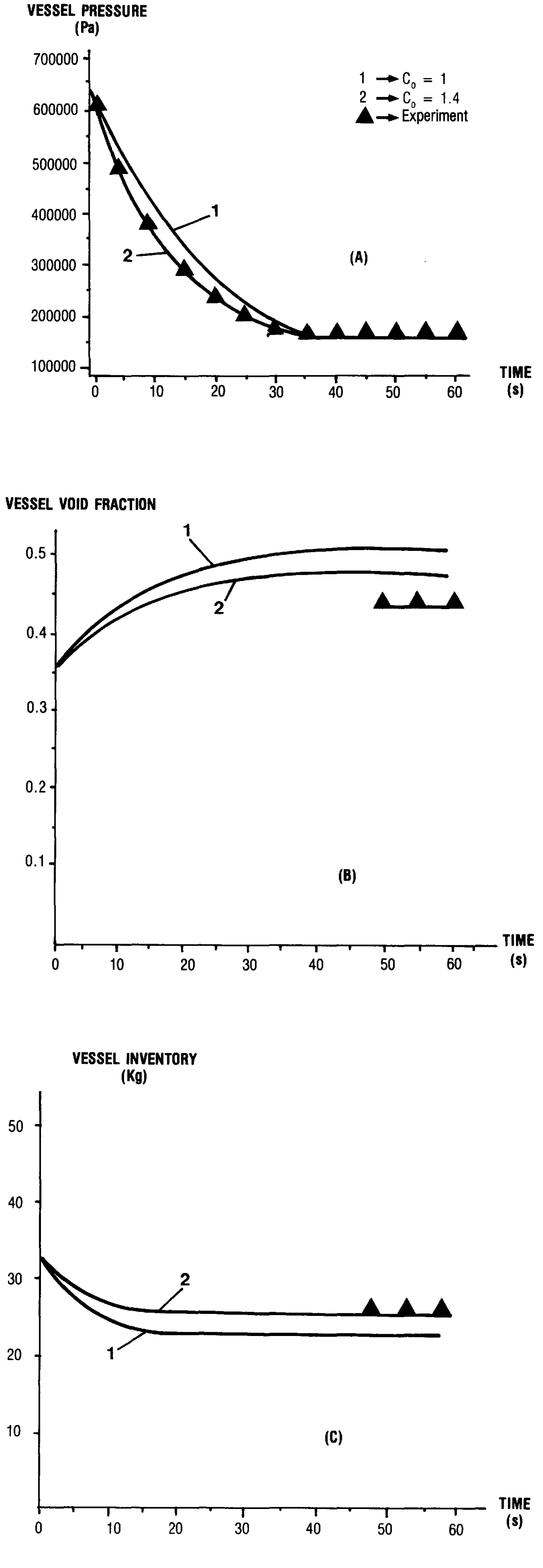
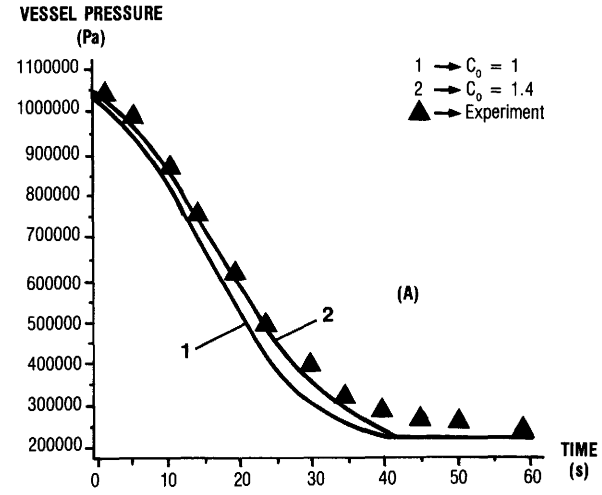
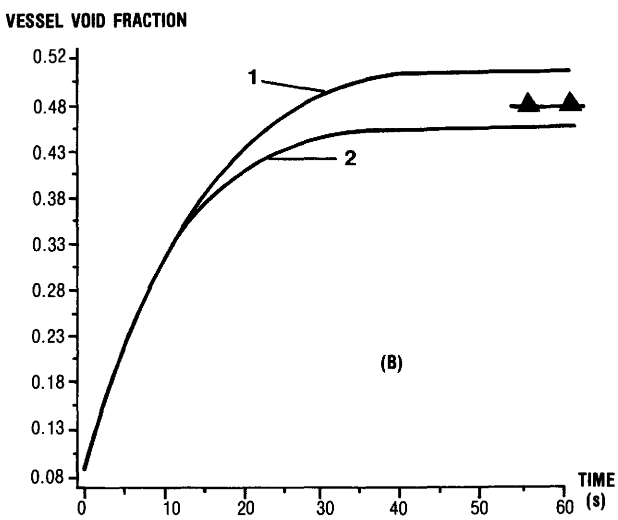


Fig. 10 - Comparison between SAFIRE calculations and measured data concerning the water blowdown test "1" performed with the MPMC-TF





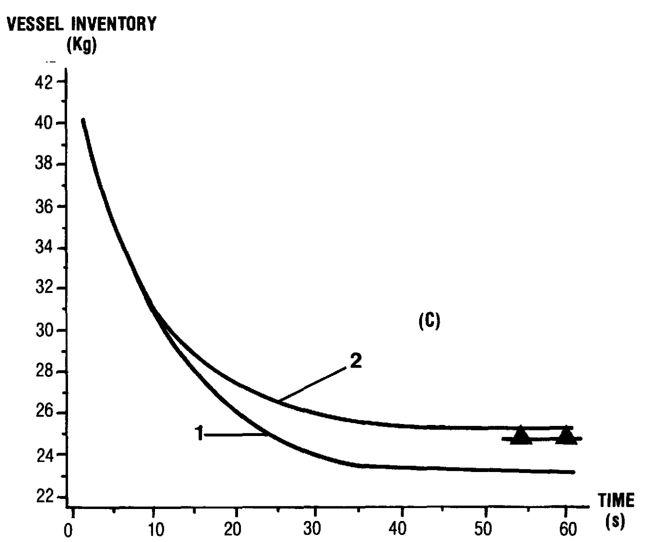
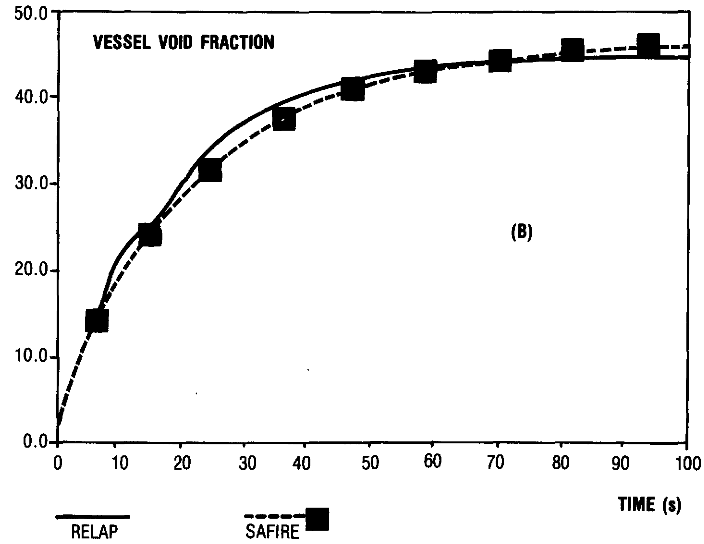


Fig. 11 - Comparison between SAFIRE calculations and measured data concerning the water blowdown test "2" performed with the MPMC-TF

Test 3 (see Table II - third column) has been calculated with SAFIRE and with the JRC version of the USNRC code RELAP5 named RELAP5/EUR /6/, /7/. RELAP5/EUR is a 1D code based on a "five equations" model which has been extensively validated against more than 50 water blowdown experiments in the JRC-LOBI facility which is used for the simulation of thermo-hydraulic transients in a LWR cooling circuit. Fig. 12 (A) shows the comparison between pressure time histories calculated with the two codes and the experimental data. Fig. 12 (B) represents the comparison between the void fraction time histories computed by SAFIRE abd RELAP5/EUR. In fig. 13 similar comparisons for the mass flow rate (B) and for the vessel inventory (A) time histories are shown. The agreement between computed results and experimentala data is satisfactory.



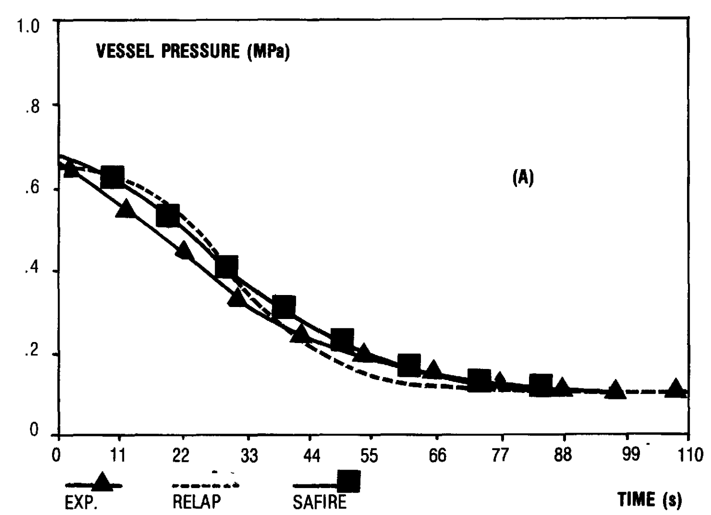


Fig. 12 - Comparison between SAFIRE, RELAP5 and experimental data concerning the water blowdown test "3" performed with the MPMC-TF

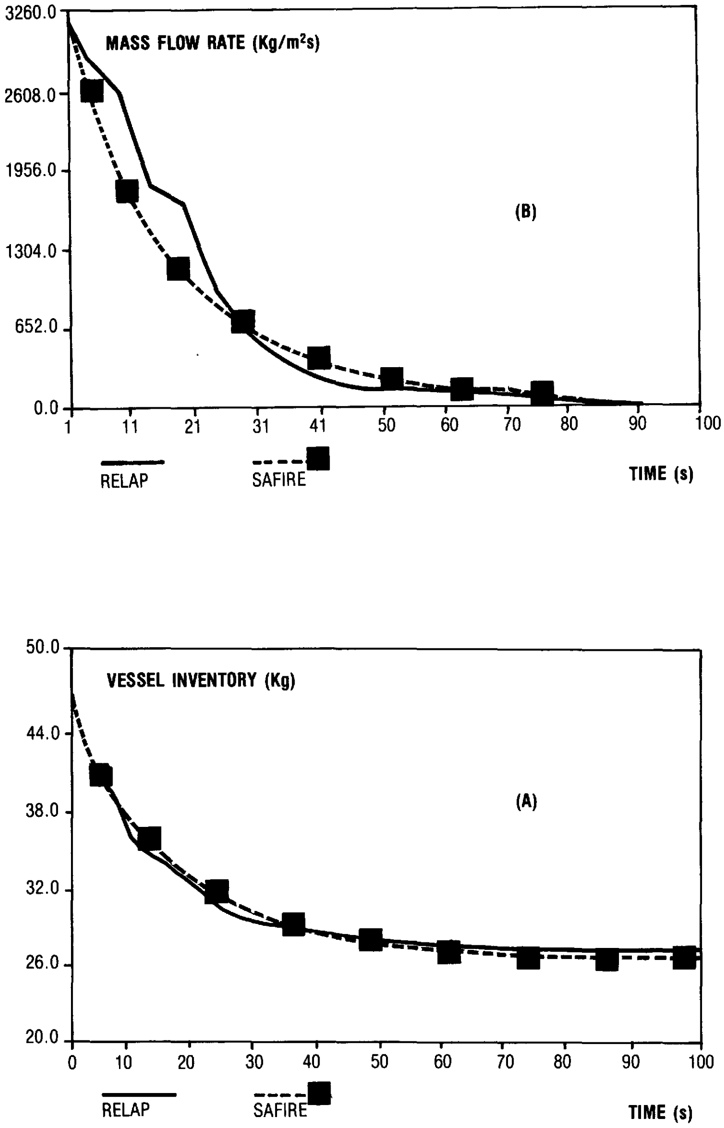


Fig. 13 - Comparison between SAFIRE and RELAP5 concerning the water blowdown test "3"

b. Fluoridric acid (HF) discharge from a storage vessel

For safety analysis the firm SNAM has performed the assessment of the discharge of a fluoridric acid storage vessel in the case of rupture of the bottom discharge pipe. The initial conditions assumed are: pressure = 0.189 MPa, temperature = 311 K, void fraction = 0.001 and mass of the liquid acid (in saturation conditions) = 61000 kg. The model adopted for the vent system is a bottom nozzle of diameter = 0.02 m. The SNAM calculations have been made with a computer code developed by the dutch Bureau for Industrial Safety TNO /8/. The calculations performed by the JRC differ from those made by SNAM only in the temperature dependence of the HF physical properties which are taken into account by SAFIRE but are considered constant in the TNO computer code.

In fig. 14 the mass evacuated versus time predicted by the two codes are represented. The comparison between the mass velocity and the vessel temperature time histories have been also computed with the two codes. Negligible discrepancies between the calculated results demonstrate that temperature dependence of the HF properties can be disregarded in the range of temperature considered. In addition it can be concluded that SAFIRE results are consistent with the TNO code predictions.

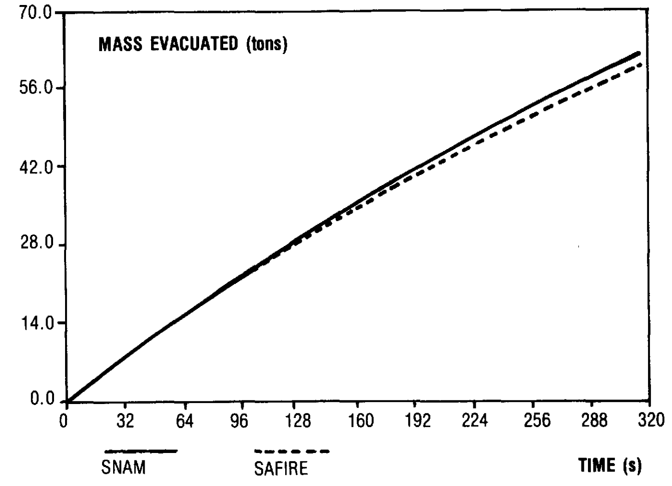


Fig. 14 - Acid storage VESSEL voiding - mass evacuated versus time

c. Cumene hydroperoxidation reaction

In order to assess how SAFIRE can represent chemical reactions, the isothermal hydroperoxidation of the cumene investigated in calorimetric scale by Fortuin and Waterman /9/ was submitted for code calculation. The reaction considered is the following one:

C6H5CH (CH3) 2 + 02 ⟶ C6H5C (CH3) 200H

The semi-batch reactor used has a volume of 0.4 l, an agitation system working at 880 revolutions per minute and operates at a constant temperature of 393 K. Initially, 0.225 l of cumene was loaded and oxidation was performed by introducting molecular oxygen at a flow rate of 25 l per hour for a time period of three hours.

In these conditions the partial pressure of the oxygen has no influence on the reaction rate. The activation energy is estimated in 16 Kcal/mole and the reaction heat in 27.7 Kcal/mole.

Temperature dependent physical properties have been considered in the SAFIRE calculations for the three components participating in the reaction. For the simulation of the semi-batch operation it has been necessary to perform a code modification which will be briefly described in the next section. Fig. 15 shows

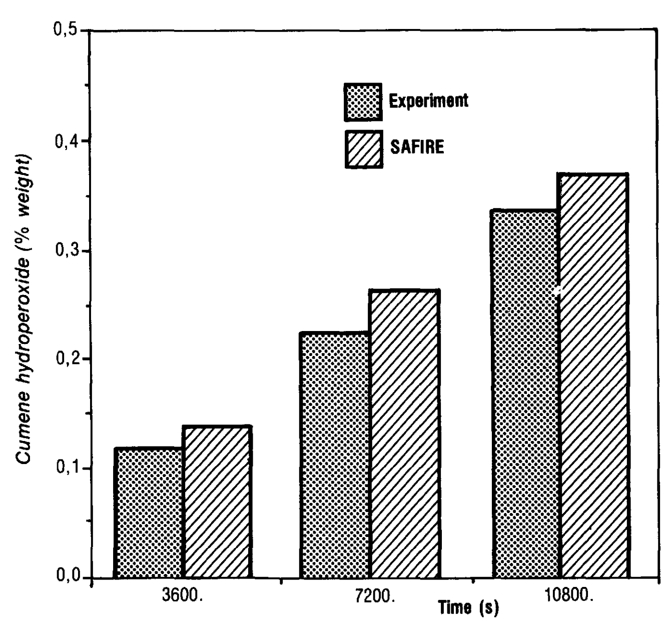


Fig. 15 - Comparison between SAFIRE calculations and experimental data concerning a chemical reaction (cumene hydroperoxidation)

the comparison between the experimental data /9/ and the results calculated by SAFIRE. The small overprediction could be due to the formation of secondary products (acetophenon, dimetilphenilcarbinol, ...) which have not been modeled in the computer calculation.

d. SAFIRE extension to semi-batch reactors

The original version of SAFIRE accomodated only batch reactors. In order to extend the modelling capabilities of the code to include semi-batch reactors the JRC developed a modified version /6/. The energy and mass balance equations were changed by introducing the terms concerning the input flow of up to three components during the operation. The input section modified requires the following data:

NOF = number of input flows (maximum value = 3)

for each flow:

MEX (I) = total mass of the flow I to be introduced
START (I) = initial time for the introduction of the flow I
STOP (I) = final time for the introduction of the flow I
TEMP (I) = temperature of the input flow I
IGAS (I) = flow phase indicator (=1 gas; =2 liquid)
MEX (I,J) = mass fraction of each component in the input flow (J=1, NC; NC=total number of components)

The subroutines modified are KINPAC, DIFFUN and HEATUP. The validity of this development has been verified so far only for the cumene hydroperoxidation reaction.

DIERS Users Group (DUG)

The JRC as member of the DUG, has presented two papers ("JRC programme in RR-studies" and "JRC experience with the computer code SAFIRE") in the DUG-meeting of 3/5.03.87 at San Diego, where also the FAI bench scale apparatus VSP was propagated, which is an essential tool for collecting data, needed by SAFIRE in order to perform emergency relief and venting analysis.

European Contact Group on Runaway Reactions

The «European Contact Group on Runaway Reactions» (ECG-RR) of interesting institutes and industry partners aims to serve for fruitful input and exchange of knowledge in this field to make the experiments more significant.

The first meeting of the ECG-RR has been held in 19/20.03.87, during which was decided to split up group for the time being for practical reasons into two ad hoc working groups dealing with MPMC resp. FIRES.

Conclusions

The realisation of the FIRES is in state of progress: ready are bunker basement, chemical lab., auxiliary rooms, mechanical structure, reactor with auxiliary equipment, early warning systems and parts of the control and data acquisition system, of the instrumentation and of the simulator.

The MPMC studies has been based in the following three aspects:

- Phenomenological study of the influence of the geometry and physical properties on two-phase fluid flow regimes
- Depressurisation tests with water as reference tests for multiphase-multicomponent investigations
- Parametric studies with SAFIRE

The phenomenological studies showed for a wide range of change of viscosity (up to 300 times of the viscosity of water) and moderate change of surface tension (half of that of water) a very strong effect on the pattern configuration. These investigations will be continued with forced convection of the fluid component.

Since the depressurisation tests with demineralised water have been performed in order to produce reference maps for multiphase-multicomponent flow investigations, emphasis was given on the accurate measurement of the flow and state characteristics in the venting line and reaction vessel varying vessel and back pressure, filling rates of the reaction vessel and venting tube geometry.

The feasibility study of a large scale facility for simulation and real reaction, venting and quenching of reaction products in case of uncontrolled runaway has been continued.

The modelling work performed was concentrated on the parametric studies with the SAFIRE code. Comparison tests with the depressurisation measurements with demineralised water are initiated. On the basis of the JRC experience gained so far with the computer code SAFIRE through comparisons with experimental data and other code calculations, the following preliminary conclusions can be reached:

- SAFIRE can successfully reproduce experimental data concerning water depressurisation tests
- SAFIRE calculations compare satisfactorily with other code calculations

However, the code does have inherent limitations and these must be considered:

- SAFIRE presents a menu of models which have to be selected by the user. This means that the code has marked user-dependent predictive capabilities.
- SAFIRE requires a temperature-dependent characterisation of the material properties and an accurate identification of the chemical kinetics.
  These data are available for well-known products only and are lacking for others.
- SAFIRE is a zero-dimension code and cannot take into account all the geometry-dependent effects.
- SAFIRE cannot model non-equilibrium phenomena

Nevertheless SAFIRE is an original and to some extent unique calculation tool which can be satisfactorily employed if appropriate engineering judgement is used.

References

/1/ M.A. GROLMES, J.C. LEUNG,
"Code Method for evaluating Integral Relief Phenomena"; Chem. Eng. Progress, August 1985.

/2/ DIERS-FAI/83-27,
"Emergency Relief Systems for Runaway Chemical Reactions and Storage Vessels: A Summary of Multiphase Flow Methods"; October 1983.

/3/ G.B. WALLIS,
"One Dimensional Two-Phase Flow"; McGraw Hill Book Company, Inc., 1969.

/4/ N. ZUBER, J. HENCH,
"Steady-State and Transient Void Fraction of Bubbling Systems and Their Operating Limits: Part I: Steady-State Operation"; General Electric Report 62GL100, July 1962.

/5/ DIERS-FAI/83-1,
"Phase III Large Integral Tests DIERS III-4: Experimental Results for Series II Tests"; January 1983.

/6/ F. PRAOLINI,
Masters Degree Thesis; unpublished report; 1987.

/7/ H. STAEDTKE, B. WORTH, W. KOHLAR,
"RELAP5 Assessment with LOBI Small Break Test Results"; presented at The Special Meeting on Small Break LOCA Analysis in LWRs; Pisa, 1985.

/8/ "Methods for the Calculation of the Physical Effects of the Escape of Dangerous Material (Liquid and Gases)"; Bureau for Industrial Safety TNO; NL, March 1980.

/9/ J.P. FORTUIN, H.I. WATERMAN,
"Preparation of Cumene Hydroperoxide"; Special Supplement to Chemical Engineering Science, vol. 3, p. 60-66, 1954.

EXPLORATIVE STUDIES

Emergency Planning

STATUS AND TRENDS IN EMERGENCY PLANNING

Since the beginning of the first pluriannual research programme on industrial hazards, JRC started investigating R&D needs for improvement of design and actuation of emergency plans.
In particular the problems connected with the development and use of advanced informatic tools for emergency management, and, with the needs for measures for risk communication in emergencies were selected, among other topics, as subjects for more in depth investigations.
These problems appeared, indeed, to present on the one hand, a general interest for different kinds of emergencies and, on the other, to have direct links with parallel activities being carried out under other headings of the programme: such as risk analysis, accident data bases, decision support systems for risk management, and, general support to risk regulation underway in the Community.
In addition to these particular investigations, it was deemed useful to complete identification of possible future research needs for the other aspects involved in effective emergency planning.
This reason motivated the JRC first to organize a rather restricted Brainstorming on the Research Needs (Ispra, 13-14 January 1987), /1/ then to collaborate with DG XI in the organisation of the European Conference on Emergency Planning for Industrial Hazards, which was held in Varese (I), on 4-5 November 1987. This latter event was launched by the Commission to assess the state of the art in implementing the articles of the post-Seveso Directive, concerning the establishment plans and to identify needs for harmonisations of the approaches going on in the EC. This paper is aimed at outlining the major outcomes of the activities carriet out. It first summarised the results of the two events mentioned above, then discusses the insights obtained by the main studies performed; finally, it points out the principal investigation lines which might further be explored by forthcoming activities.

Survey of Emergency Planning Status and Needs for Improvements

The status of emergency planning in Europe has been derived from the Varese Conference /2/ which also confirmed the results of the experts' brainstorming. Both events covered topics such as national regulations and practices; design and implementation of on-site and off-site emergency plans; auditing and exercising; lessons learnt from real emergency management; modelling, monitoring, informatic and rescue tools; communication to the public both before and after an incident and decision making.

Despite different legal background and organisational structures, it appeared that much effort has been devoted to comply with the obligations resulting from the Seveso Directive, which are certainly producing positive effects. Of course, full implementation of the Directive requirements was easier, where there was already a suitable framework in existence. The discussions however showed that some common problems do exist, which call for further work on the improvement of emergency planning systems.

Reference standards for safety distances, allowable toxicity levels, and similar things need to be harmonised in the Community.

The question of prepardness with respects to contents of safety reports (worst case vs probable accident scenarios) has not received a satisfactory answer during the conference.

Another interesting aspect is the integration of emergency planning for industrial areas involving plants whist not being covered by the Directive, but having the potential to provoke or to aggrevate emergencies.

Very often monitoring or identifying the substances released during an accident has caused problems.

The connections between on-site emergency (i.e. control room) and the decision of external alerting or interventions should be better analysed.

Modelling and simulating emergencies conditions for assessing adequateness of envisaged measures. Auditing of emergency planning is not yet a well established subject. On-line predictive capability models and their integration in emergency management tools are being studies and significant improvements may be expected in the future. Experience from remote handling gained in other fields should be exploited for robotising particular intervention tools.

Decision making in emergency still appeared to be a difficult and therefore critical issue, for instance when and how to evacuate, how to ensure a consistent and non contradictory collection of data from all available sources, responsibility structures etc.

Decision support tools and easy accessibility to data bases, which at the moment are at a study level, can be expected in the future to play an important role during emergencies.

Finally, the problems connected with risk communication prior to and during a real emergency, in all their implications (failure of communication channels, media and type of communication, the need to inform the public without provoking rejection versus technological systems etc.) appeared of major concern both for the authorities and the industrialists.

On these two last topics further indications have been derived by the studies summarised in the following.

Advanced Information Technology for Emergency Management

Evaluation of the use of expert systems for data base system development and emergency management was the subject of a study sponsored by JRC and performed at RISØ by J. Rasmussen et al. /3/.

The study is very instructive since, before proposing purely technological approaches, it analyses in depth the problem domain in emergency management and the desired features for a decision support system: the problem is to design systems which are also effective during situations which have not been foreseen design, and which are not familiar to the user. In addition, such systems will be operated by a wide variety of users whose background and formalisation of needs are poorly known.

In such cases a model or conceptual framework must be used which describes the interaction in terms of related categories defining the boundaries of a design envelope within which users can generate effective ad hoc tactics suited to their subjective preferences.

Therefore an in depth analysis of decision process, goals and constraints, strategies and information retrieval organisation for effective use of relevant data bases in emergencies has been performed.

The resulting theoretical framework has been confronted with a real legislative and practical approach, i.e. the organisations of emergency management in Denmark, with lessons learnt by analysis of selected accidents, and, finally, with interviews of experts actually involved in emergencies (fire and civil defence officers).

The conclusion from the study indicate that

- the recent development of advanced information technology, together with the trend towards more cognitively oriented approaches to studies of decision making, offer promising lines of development of improved tools for emergency management;
- the structure of the decision making process involves multiple responsabilities, at different locations (front-line, operational centre etc.): the literature reviews and experts' interview have revealed no model of real life distributed decision making, which will be adequate for the design of support of the decision process.
  This is clearly a topic for future research;
- data bases and different sources of information useful in emergencies are being established including accident description, results of risk studies, material characteristics etc. Benefit might be gained from improved and more integrated data base design, from expert system features. Such aspects can be further investigated;
- on the other hand tools for design of data bases for distributed decision making are now becoming available from the artificial intelligence research.

As a result it can be recommended to direct efforts towards models, integrated data base designs and informatic system architectures for the organisation of the distributed data bases and the coordinated information emergency retrieval necessary for effective management.

Risk Communication

Recent legislative trends in the European Community and in the United States are to require that industry and government provide those exposed to the risks of industrial activities and products information about the nature of those risks. These requirements have emerged as one of the central features of industrial risk management. The activity of providing risk information is commonly known as risk communication and it has become a new research area as people realise the difficulties of communicating complex technical information, with a strong emotive dimension, to lay people.

To evaluate these developments the JRC sponsored research /4/ to provide an overview and analysis of the industrial risk management function, its goal, and the intrinsic and extrinsic factors which influence decision making in the firm. The emergence of risk communication policies in the EC and in the USA are viewed in terms of theories, legal developments and implementation. The main differences are in the public's right to information in the US, which must be supplied by industry, as compared to the EC situation where industry supplies information to the competent authorities who, in turn, inform the public on a more restricted basis. In contrast to Europe, risk communication in the US appears to be increasingly viewed as an alternative to more traditional forms of regulation. In both contexts there is tension between industry's concern about the confidentially of trade secrets and the requirement to provide public information about specific substances and quantities of materials used in manufacture.

In another study sponsored by the JRC /5/ the technical problems of formulating and communicating risk information were analysed. Literature relating to risk communication in the fields of decision research, educational psychology, warning systems and health education, among others, was reviewed and some suggestions made to improve hazard communications.

The Seveso Directive specifies that people likely to be exposed to hazard in an accident be informed of the behaviour to take in an emergency. This brings up the unexpectedly complicated question of how to package information so that people will accept it as being credible. Beyond this, it must be phrased in a comprehensible way that it can be understood easily and retained for possible later use. Even more important, assuming that communications have been understood and remembered, people must still be willing to comply with the advice given should an emergency arise.

The provision of hazard information can be divided into three categories: information provided to inform people about measures taken to prevent hazards (pre-pre information); information provided on how to act should an accident happen (pre-post information); and information during management of the emergency after an accident has occurred (post-post information). A further distinction is that information can be provided to people in an active way, or passively in the sense that the information is made available if people take the initiative to seek it out.

There is still considerable work to be done in this area, for example, in linking communication acceptance to institutional credibility and in understanding the relationship between the acceptance and retention of information and the expectations of the audience. A study /6/ was carried out to assess the effectiveness of media communications for improved emergency communications.

References

/1/ H.B.F. GOW,
"Summary of the Brainstorming on Research for offsite Emergency Planning for Hazard, in Industrial Facilities," 13-14 Jan. 1987, JRC Internal Document, (PER 1306/87).

/2/ H.B.F. GOW and R.W. WAY (Eds),
"Proceedings of the European Conference on emergency planning for industrial hazard", Varese, Italy, 4-6 Nov. 1987. (to be published by Elsevier Applied Science Publishers Ltd in July 1988).

/3/ J. RASMUSSEN, O.M. PEDERSEN and C.D. GROENBEY,
"Evaluation of the use of advanced information technology (expert systems) for data base system development and emergency management in non-nuclear industries", EUR 11228 EN, April 1987.

/4/ M. BARAM,
"Corporate Risk Management: Industrial Responsibility for Risk Communication in the European Community and the United States," JRC Internal Document, T.N. 1.87.129 PER 1395/87, Oct. 1987.

/5/ D. VON WINTERFELD,
"User-Model Interaction in Decision Support Systems and Risk Communication Principles," JRC Internal Document, T.N. 1.87.131 PER 1397/87, Oct. 1987.

/6/ H. OTWAY, et al.,
"An Analysis of the Print Media in Europe following the Chernobyl Accident," EUR 11043, 1987.

J.R.C. PUBLICATIONS

Publications and Presentations

Industrial Safety and Reliability Assessment

A. AMENDOLA,
"The European approach to risk management", IIASA task force meeting on Technological Risk in Modern Society, Laxemburg (A), March 18-20, 1987.

A. AMENDOLA and P. HAASTRUP,
"Risk identification and management: an integrated approach", ISS/WHO/IPCS, World conference on Chemical Accidents, Rome, July 7-10, 1987.

A. AMENDOLA, N.A. LABATH, Z. NIVOLIANITOU and G. REINA,
"Application of DYLAM to the safety analysis of chemical processes", Int. J. of Quality and Reliability Management, Vol. 5, No. 2, pp. 48-59 (1988).

A. AMENDOLA and A. SAIZ DE BUSTAMANTE (eds.),
"Reliability engineering", Proc. of an Ispra Course held at the Polytechnic University of Madrid, D. Reidel Publishers, Dordrecht (NL) (1988).

A. AMENDOLA (ed.),
"Study cases on availability assessement", Proc. of the EuReDatA seminar held in Girona (E), April 1987, SP-I.87.64, JRC-Ispra (1987).

A. AMENDOLA and A.Z. KELLER (eds.),
"Reliability data bases", Proc. of the Ispra Course organised in collaboration with EuReDatA, D. Reidel Publishers, Dordrecht (NL) (1987).

A. AMENDOLA,
"The DYLAM approach to systems safety and reliability assessment", EUR 11361 EN, December 1987.

A. AMENDOLA, S. CONTINI and P. NICHELE,
"MARS: the major accident reporting system", I. Chem. E. Symposium on Preventing Major Chemical and Related Process Accidents, London, May 10-12 (1988).

P. BOCKHOLTZ, I. HEIDEBRINK, T.R. MOSS, J.A. BUTLER and C. FIORENTINI,
"A survey on industrial accidents data bases", EUR 11072, CEC-JRC Ispra (1987).

A.G. COLOMBO and A.Z. KELLER (eds.),
"Reliability modelling and applications", Proc. of the Ispra Course organised in collaboration with ESRA, D. Reidel Publishing Co. (1987).

S. CONTINI,
"SALP-PC, a fault tree analysis package on personal computer, user manual", Technical Note No. I.87.165, 1987 (to be published also as an EUR report).

G. GRAZIANI,
"Models for dispersion of dangerous gases, presented at the Meeting on The Implementation of the Post-Seveso Directive," Ministry of the Environment, Athens, October 1987.

G. GRAZIANI, P. MORETTI and G. VOLTA,
"Dispersione atmosferica di gas pesanti: sviluppo del modello MARA e suo confronto con dati sperimentali", EUR 11132 IT (1987).

N. LABATH,
"Preliminary Studies for the Application of DYLAM Methodology to Predict Accident Scenarios." T.N. N° I.87.120 JRC Ispra October 1987.

Z. NIVOLIANITOU,
"Risk and safety analysis of chemical plants, a case study of the naptha catalytic reforming unit of a refinery", PER 1357, JRC-Ispra (1987).

A. POUCET,
"Survey of methods used to assess human reliability in the human factors reliability benchmark exercise," 9th SMiRT post-conference on Accident Sequence Modelling, Human Actions, System Response, Intelligent Decision Support, München (FRG), August 24-25, 1987.

A. POUCET, C.L. VAN DEN MUYZENBERG,
"MAPLE-II, a program for plotting fault trees", EUR 10696 EN (1987).

A. POUCET, S. CONTINI, N. VESTERGAARD and K. PETERSEN,
"An expert system approach to systems safety and reliability analysis", 2nd Eur. workshop on Fault Diagnostics, Reliability and Related Knowledge Based Approaches, Manchester, April 6-8, 1987.

A. POUCET and K. PETERSEN,
"Software tool for advanced reliability and safety analysis", Proc. 8th SRE symposium, Helsingor, October 5-7, 1987.

A. POUCET,
"CAFTS: user's guide", Technical Note No. I.88.16, JRC-Ispra (1988).

J. RASMUSSEN, O.M. PEDERSEN, C.D. GROENBERG,
"Evaluation of the use of advanced information technology (expert systems) for data base system development and emergency management in non-nuclear industries", EUR 11228 EN (1987).

G. REINA and A. AMENDOLA,
"DYLAM 2 (Release 1) - description and how-to-use", Technical Note No. I.87.128, JRC-Ispra (1987).

Management of Industrial Risk

B. ALE, P. HAASTRUP,
"Integrated Risk management Support Systems in Holland. Presented" at the "Society for Reliability Engineers Symposium", Helsingor, Denmark, October 5-7, 1987. Publication no. ORA 33.421.

M.S. BARAM,
"Corporate Risk Management: Industrial Responsibility for Risk Communication in the European Community and the Untied States," October 1987. Technical Note I.87.129.

CANNELL, H. OTWAY,
"Audience perspectives in the Communication of Technological Risk," Futures, in press.

G. DAL BON, M. PARUCCINI,
"Rassegna di modelli per la decisione a molti obiettivi," TN I.87.107, Agosto 1987.

P. HAASTRUP,
"Risikoanalyse af en by eller kommune," EUR report. In press.

P. HAASTRUP,
"Assessment of the risk of transportation hazardous materials. A relative approach based on simplified physical knowledge." Presented at the "International Symposium on Risk Analysis in Environmental Impact Assessment", Milano, November 26-27, 1987.

P. HAASTRUP,
"Ispra Risk Management Support System. To be published in: Dansk" Kemi.

H. OTWAY,
"Experts, Risk Communication and Democracy," Risk Analysis, 7, 2, 125-129, 1987. ART 27.317.

H. OTWAY, D.L. SIMMS,
"Criteria for Technological Choice." Public Administration, 65, 2, 131-143, 1987. ART 27.331.

H. OTWAY,
"Risk Analysis and Pharmaceuticals: A Guide for Decision Makers. In: A. Hartzema, M. Porta and H. Tilson (eds.). Introduction to Pharma-epidemiology," Harvey Whitney Books, Cincinnati (in press).

H. OTWAY,
"Safe Technological Systems: Reflections on the Conditions for their Social Acceptability." Presented at the seminar: "Safe Technological Systems," Laxenburg, Austria, May 11-12, 1987. To be published in proceedings of the workshop (in press).

H. OTWAY, P. HAASTRUP,
"Designing Risk Management Support Systems." Presented at the 12th Symposium on Operations Research, Passau, FRG, September 9-11, 1987. To be published in Annals of Operations Research (in press).

H. OTWAY, P. HAASTRUP, W. CANNELL,
G. GIANITSOPOULOS, M. PARUCCINI,
"Risk Communication in Europe After Chernobyl: A Media Analysis of Seven Countries." Industrial Crisis Quarterly (in press).

H. OTWAY and P. HAASTRUP,
"On the Social Acceptability of Inherently Safe Systems". To be published in IEEE Transactions on Engineering Management.

M. PARUCCINI,
"Applicazione di un sistema di supporto alla decisione nella gestione del rischio industriale." To be published in "Rassegna della Protezione Civile."

M. PARUCCINI, G. DAL BON.
"HELP. Sistema di supporto alla decisione riguardante il trasporto di sostanze chimiche pericolose in Lombardia." To be published in "Rassegna della Protezione Civile."

R.J. PECKHAM, P. HAASTRUP and H. OTWAY,
"A computer-based system for Risk Management Support Decision Support systems" (in press).

J. SCHNEIDER,
"Qualität und Sicherheit in risikobehafteten Unternehmen und Vorhaben." Presented at the VDI-Kreis Industrielle Systemtechnik, Duesseldorf, Oct. 1987. ORA xxxxx.

D. VON WINTERFELDT,
"Experts Systems and Behavioural Decision Research." Technical Note No. 1.87.130. October 1987.

Protection against Runaway Reactions

A. BENUZZI, F. PRAOLINI,
"Extension of SAFIRE to Semi-Batch Reactors", Paper to be presented at the: DIERS Users Group Meeting, Washington D.C., April 19-22, 1988, Technical Note No. I.88.42, JRC Ispra (April 1988).

H. HERNANDEZ, J.F. GUYONNET, J.M. ZALDIVAR,
"Simulation de réacteurs chimique discontinus", Développement du code SIRAS, Université de Technologie de Compiègne (UTC), Compiègne, France/JRC-Ispra (Mars 1988).

PIERRE SCHROER,
"Influence de la tension superficielle et de la viscosité sur la configuration d'écoulements diphasiques" (thèse de fin d'études), Université Valencienne/JRC-Ispra, August 1987.

J.M. ZALDIVAR,
"Toluene Nitration", A review on selected topics applied to batch processes, Technical Note N° I.87.125 / PER 1387/87, JRC-Ispra, October 1987.

J.M. ZALDIVAR,
"Methyl Methacrylate Polymerization, A review on Selected Topics Applied to Batch Process", Technical Note No. I.88.47 / P.E.R. 1499/88, JRC-Ispra (April 1988).

Explorative studies on emergency planning

M. BARAM,
"Corporate Risk Management: Industrial Responsibility for Risk Communication in the European and the United States, Technical Note N° 1.87.129 PER 1395/87, JRC-Ispra, Oct. 1987.

H.B.F. GOW,
"Summary of the Brainstorming on Research for offsite Emergency Planning for Hazard in Industrial Facilities", 13-14 Jan. 1987, Technical Note N° PER 1306/87, JRC-Ispra, 1987.

H.B.F. GOW and R.W. KAY (Eds.),
"Proceedings of the European Conference on emergency planning for industrial hazards" Varese, Italy, 4-6 Nov. 1987 (to be published by Elsevier Applied Publishers Ltd in July 1988).

H. OTWAY, P. HAASTRUP, W. CANNELL,
G. GIANITSOPOULOS, M. PARUCCINI,
"An Analysis of the Print Media in Europe following the Chernobyl Accident," EUR 11043, 1987.

J. RASMUSSEN, O.M. PEDERSEN and C.D. GROENBEY,
"Evaluation of the use of advanced information technology (expert systems) for data base system development and emergency management in non-nuclear industries". EUR 11228 EN, April 1987.

D. VON WINTERFELD,
"User-Model Interaction in Decision Support Systems and Risk Communication Priciples," Technical Note N° 1.87.131/PER 1397/87, JRC-Ispra, Oct. 1987.

GLOSSARY

CAFTS	Code for Computer Aided Fault Tree Syntesis
CCF	Common Cause Failures
CEC	Commission of the European Communities
CNR	Centro Nazionale di Ricerca
DEERS	Design and Evaluation of Emergency Relief Systems
DG	Directorate General
DG XI	DG for Environment Consumer Protection and Nuclear Safety
DG XII	DG for Science, Research and Development and JRC
DIDASS	Dynamic Interactive Decision Analysis and Support System
DIERS	Design Institute for Emergency Relief Systems
DS	Dependent Subtrees
DUG	DIERS Users Group
DYLAM	Dynamic Logic Analytical Methodology
EC	European Communities
ECG-RR	European Contact Group on Runaway Reactions
ERCCI	European Reliability Computer Code Index
ESRA	European Safety and Reliability Association
ESRRDA	European Safety and Reliability Research and Development Association
EuReDatA	European Reliability Data bank Association
FIRES	Facility for Investigating Runaway Events Safely
FIREXP	FIRe EXPeriment
HASTM	Hazardous Substances Transport Model
HELP	Decision support system dedicated to the problem of transport of hazardous materials using a PC
HSE	Health and Safety Executive
ICON	Interactive CONstruction
IRIMS	Ispra Risk Management Support system
JRC	Joint Research Centre
MARA	Model for Analysis of Releases in the Atmosphere
MARS	Major Accident Reporting System
MCS	Minimal cut-set
MFT	Macro Fault-Tree
MKMAP	Make MAP
MPMC	Multiphase-Multicomponent
PC	Personal Computer
PSA	Probalistic Safety Analysis
RAM	Reliability Availability and Maintainability
RR	Runaway Reactions
SAFETI	Software for the Assessment of Flammable, Explosive and Toxic Impact (Computer-based system for risk analysis of process plants)
SAFIRE	System Analysis for Integrated Relief Evaluation
SALP-PC	Sensitivity Analysis by List Processing-Personal Computer
SIRAS	SImulation de Réacteurs chimique Appliquée en Sécurité
TF	Test Facility
TRIM	Transport RIsk Model
VROM	Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieu beheer (Dutch Ministry of Physical Planning, Housing and Environment)
VSP	Vent Sizing Package

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European Communities - Commission

EUR 11879 — Industrial Hazards

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Luxembourg: Office for Official Publications of the European Communities

1988 - IV, 48 pp. — 21.0 x 29.7 cm

Series: Environment and quality of life

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This is the sixth and last progress report of the four year (1984-1987) research programme «Industrial Hazards», carried out at the Ispra Establishment of the Joint Research Centre of the Commission of the European Communities.
In this fairly new area for JRC research are considered the risks associated with the operation of hazardous industries, such as processing and energy, and a large technological system (such as transportation).
The programme is focused on risk associated with major accident, as problems associated with diffuse risk have been considered in the JRC Environmental Protection Programme. Moreover, this R & D area overlaps in many points the analogous area extensively investigated at JRC on safety of nuclear energy. Therefore, the first criterion in setting up this programme has been the best use of the experience and competence gained by JRC nuclear safety and environmental research groups. The second criterion has been to support, where needed and possible, the Commission policy on major industrial hazards. Some of the proposed activities will be carried out in close collaboration with DG XI (which is responsible for the development of this policy) and with experts from research institutes and industry and with the shared-cost multiannual programme on Major Technologies Hazards managed by the DG XII/E which complements and augments the current activities of the JRC to form a coherent whole.
The JRC research programme Industrial Hazards consists of three research activities: 1. Industrial Safety and Reliability Assessment, 2. Management of Industrial Risk, and 3. Experimental and Theoretical Studies on Runaway Reactions. The activities 1 and 2 aim at the development of methods for the assessment of major risks in industrial plants and regional industrial systems, while activity 3 has in view to understand how an accident can develop, when initiated, and how its consequences can be limited by suitable provisions.
This report summarises the results obtained so far on the above mentioned activities.