ANNUAL·REPORT·90

Institute for Safety Technology

JOINT RESEARCH CENTRE

COMMISSION OF THE EUROPEAN COMMUNITIES

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EXECUTIVE SUMMARY

NUCLEAR ACTIVITIES

In the area of nuclear reactor safety studies, the Institute for Safety Technology (STI) concentrated its efforts in analysing experimentally and numerically phenomena which characterize highly-improbable but very severe accidents either for light water or for sodium cooled reactors.

Pluriannual efforts culminated in spring 1990 to the release and distribution of the European Accident Code EAC which is expected to become the European reference code for predicting the consequences of an energy release during a power excursion in a breeder reactor.

Equally significant was the progress made in the "Source Term" evaluation (definition of radioactive material accumulating in a light-water reactor containment following a hypothetical accident). A new informatics structure was developed together with European Organizations for a comprehensive Source Term calculation code which will be verified, amongst others, against experimental data to be obtained with the Phebus in-pile tests jointly sponsored by CEA and the JRC.

In the FARO facility (a 100kg UO_2 melting device connected to various test sections), additional results were obtained for the evaluation of possible blockage formation when molten material penetrates cold structures located beneath the reactor core. Modifications to the FARO facility are being made which will allow the simulation of in-vessel phenomena during damage of a LWR core. This new activity is jointly sponsored by the JRC, US NRC and EPRI.

As concerns the LOBI facility (a 1:700 volume scaled model of a four loop 1300 MWe PWR), 5 experiments from the test matrix agreed with the European partners were executed with the related analysis and documentation work. The CATHARE-2 code was implemented on the Ispra computer and a new improvement/validation programme was started in cooperation with CEA.

In the STI nuclear isle, three new laboratories for waste, fusion and safeguards activities are approaching completion and have made substantial progress in their licensing procedure :

- Concerning waste, functional testing and commissioning have continued in the PETRA facility. The critical areas for increased performance and plant flexibility were indentified, taking into account customer requirements, in particular the specifications proposed by ENEA in the frame of the existing collaboration contract. The analytical hot-box has been commissioned together with the pneumatic link-up with the radiochemistry building. The computerized process-control system has been updated, tested and made operational.

- The civil structures in which the safeguards performance laboratories PERLA will be located have been completed and the installation of services has commenced.

  Concerning the measurement of low and very low Pu contents in waste drums, the neutron signal frequency distribution of cosmic radiation and its time variation has been investigated experimentally and theoretical studies were performed to reduced the sporadic contribution of cosmic radiation to the measure of the Pu in the mg range even in concrete matrices.

  The development of user-friendly instrument software on neutron, and gamma spectrometry continues. A gamma Headquarters data base has been completed and used in a performance exercise.

An international workshop on Pu isotopic composition determination through the MGA code has been carried out with the participation of EURATOM/IAEA, EC and US laboratories in October 1990.

A first assessment and intercomparison of calorimeter performance has been carried out.

Studies have been performed on neutron measurements interpretation models in particular the theory for Time Correlation Analyser (TCA) dead time corrections.

Two PHONID instruments for the assay of large U samples and a gamma spectrometric system for the assay of MTR fuel assemblies have been delivered to the Safeguards Directorate including a new data evaluation system.

Eight training courses for the use of non-destructive analysis instruments and application of radioprotection rules were provided. A new physical inventory verification exercise on Pu material was given.

- With regard to the construction of the European tritium laboratory (ETHEL) the civil infrastructure systems such as the building, electrical supplies, heating & ventilation and fire detection, their fabrication/installation has been completed and system testing initiated. All experimental and process glove-boxes have been manufactured and installed in the laboratory and significant on-site testing fulfilled. Similarly, fabrication of the small and large caissons has been concluded with only testing to be undertaken. The gaseous detritiation units serving all of these containments have been installed in the building and await final connection. Fabrication of principal tritium services such as the tritium magazine and waste conditioning plant has ended and these units, together with the radiological protection and general data acquisition and control systems, are ready for installation. Finally, the commissioning organisation with the architect-engineer has been established and the document of proposed tests, together with initial procedures, has been agreed.

NON-NUCLEAR ACTIVITIES

The Institute started activities in the non-nuclear safety research area only a few years ago and has been able this year to present its first significant experimental and theoretical results.

Industrial Hazards

FIRES (Facility for Investigating Runaway Events Safely) was put into operation in August 1990 with a series of neutralization and esterification reaction experiments . The objectives of these experiments was the validation of scaling criteria for heat transfer and runaway reaction prediction, the investigation of the reliability of data obtained from different sources, the validation of kinetic schemes from small-scale experiments and the adjustment of FISIM (the numerical simulator of FIRES)

First promising results were also obtained in the numerical simulation of reactive transonic flows as they occur during deflagration/detonation processes. A pilot version of a computer code was developed for the numerical simulation of two-dimensional multicomponent reactive transonic flow. The numerical solution method applied belongs to the class of "High Resolution Techniques" which allow the accurate tracking of flow discontinuities (e.g. shock waves, contact discontinuities). Due to the use of unstructured grids, a large flexibility exists to represent (even complex) geometrical boundaries. Confined (internal) as well as external flows with obstacles can be easily described.

On request of the Institute for Remote Sensing Applications, a small effort in the area of modelling marine transport processes has been persued. This includes testing of models for barotropic simulation of circulation in the northern Adriatic during BORA-wind episodes and the development, in collaboration with the University of Hamburg, of a model describing the Adriatic sea phytoplankton dynamics.

Reference Methods for the Evaluation of Structure Reliability

The objective of this activity is to gain a better understanding of the nonlinear cyclic and dynamic behaviour of materials and structures by performing experiments and developing constitutive and structural-member models leading to the computer simulation of complete structures.

To permit testing of large- and full-scale models of structures, a new laboratory based upon a reaction-wall/strong floor system is being constructed. Completion of this facility, which will be unique in the Community, is planned for the end of 1991. The facility will be used for pre-normative research in support of the development of structural design codes and will be available to industry for testing innovative design concepts and prototypes.

The Institute is working in close collaboration with a number of research organisations in the Member States grouped into an Association in order to set up an integrated research programme on the earthquake behaviour of civil engineering structures.

Experimental activities in the Institute laboratories consisted of testing reinforced concrete members under multiaxial cyclic loading. To evaluate the potential of the pseudodynamic test method for simulating earthquake loading of structures, tests were made at various cycling frequencies and incorporating hold times to allow stress relaxation in reinforced concrete. As a support to the research in structural dynamics, tests at various strain rates were performed on structural materials (concrete, steel) using specimens and test equipment for biaxial dynamic loading developed in-house.

New forms of the pseudo dynamic test method are being studied, including the use of implicit time-integration algorithms and control systems based on digital concepts are being developed.

In the area of computational mechanics, activities have concentrated on the development of models for predicting the nonlinear cyclic behaviour of reinforced concrete members, as well as on the numerical definition of seismic action input. The resulting software tools are being incorporated in the CASTEM-2000 finite element code system developed by CEA-Saclay and now used as the basic computer program system for our project. Further refinements have also been made in the PLEXIS-3C code for fast dynamic structural problems. These include sliding models along fluid-structure interfaces and the application of the arbitrary Lagrangian-Eulerian formulation to structures undergoing very large deformations.

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1.1.1. REACTOR SAFETY

THE LOBI PROJECT

Introduction

The LOBI Project represents a significant contribution to light water reactor (LWR) safety research and development. The primary objective of the research programme is the generation of experimental data pertinent to the thermal-hydraulics of pressurized water reactors (PWRs). Within this context experiments are conducted in an integral system test facility for a range of postulated PWR accident conditions with specific emphasis on :

- Identification and/or verification of basic phenomenologies relevant to loss-of-coolant accidents (LOCA) and special transients (ST) in PWRs of current design
- Provision of an experimental data base for the development and/or improvement of analytical models and the independent assessment of large system codes used in LWR safety analysis.

The LOBI test facility is a full-power, full-pressure experimental installation representing an approximately 1 : 700 scale model of a 4-loop, 1300 MWe PWR. It comprises two primary loops, the intact and the broken loop, each containing a main coolant circulation pump and a steam generator. The simulated core consists of an electrically heated 64 rod bundle arranged in an 8 x 8 square matrix inside the pressure vessel model; nominal heating power is 5.3 MWe. The primary and secondary cooling systems operate at typical PWR conditions : 158 bar and 294 - 326 °C on the primary side and 64.5 bar and 210 - 280 °C on the secondary side.

The test facility was commissioned in December 1979 and was operated until June 1982 in the MOD1 configuration for the investigation of large break LOCAs; it was then extensively modified into the present MOD2 configuration which incorporates design and instrumentation features best suited for the characterization of phenomenologies relevant to small break LOCAs, anticipated and abnormal transients, recovery procedures and accident management strategies.

The overall research programme comprises two test matrices defined A and B which include test cases of general interest to PWR safety analysis.

- The test matrix A is performed in the framework of a R&D contract between the Commission of the European Communities and the Bundesminister für Forschung und Technologie (BMFT) of the Federal Republic of Germany
- The test matrix B is performed in the framework of the Commission' reactor safety research programme with indipendent contribution from several industrial and institutional organization of EC member countries.

Test results from both the A and B programmes are freely accessible and available to all EC member countries. Through a special arrangement with the Organization for Economic Cooperation and Development some LOBI tests have been included in the international code assessment programme of the OECD Committee on the Safety of Nuclear Installations and are thus available also outside the EC context.

The experimental programme is supported by comprehensive code application and assessment activities. RELAP5/MOD1-EUR and RELAP5/MOD2 in their IBM versions as well as CATHARE, ATHLET/DRUFAN, TRAC and RETRAN are being used either within the JRC or by outside organisations for test design and test prediciton calculations. Development and implementation of new measurement techniques are also integral part of the overall research strategy.

Achievements

Following the completion of the contractual A-programme on 31.12.1989, the LOBI experimental programme in 1990 was entirely dedicated to the execution of tests from the Community B-programme. During the report period the following tests were executed :

BT-04 : Simulation of a post-accident recovery procedure relevant to the steam generator tube rupture (SGTR) scenario. This test was performed on request of the French Commissariat a l'Energie Atomique (CEA) in collaboration with Framatome .

BL-34 : Simulation of a 1 % cold leg break LOCA (low power) with unavailability of ECC injection from the high pressure injection system. This test was defined in the LOBI LOCA programme Task Force to serve as counterpart test to the BETHSY 6.2 TC test.

BL-44 : Simulation of a 1 % cold leg break LOCA (full power) with unavailability of ECC injection from the high pressure injection system. This test was defined as complementary to test BL-34 to assess scaling concepts in thermal-hydraulic experiments.

BT-56 : Simulation of an accident caused by a sequence of multiple failures. This test was sponsored by the UK Nuclear Electric.

BT-15/16 : Simulation of a loss of feedwater with SG boil-off and refill. This test addressed specific phenomenologies relevant to secondary system heat transfer degradation. The test was performed on request of the UK Nuclear Electric in collaboration with the AEA Technology Centre.

Plans

The LOBI test facility will be operational until mid 1991. Within this time frame four tests are envisaged for execution on the basis of test facility full availability. These tests are defined within the Community programme and include BT-17 (Germany), BT-06 (France), BL-40 (Spain) and BL-06 (France). Thereafter, the LOBI activities will be mainly devoted to test analysis and documentation.

ASSESSMENT AND IMPROVEMENT OF LWR SAFETY CODE CATHARE2

This work is proceeding by way of a bilateral agreement between the JRC and CEA, Grenoble, the purpose being to provide independent assessment of the code through comparison of calculated results with various experiments performed in the LOBI test facility. During 1990, the work has concentrated on assessing the ability of CATHARE2 to predict the key thermohydraulic phenomena observed in several small break loss-of-coolant experiments. This is reported back to the CATHARE team in Grenoble by way of twice yearly CATHARE Users Club meetings.

The agreed programme of code assessment studies includes fast and slow LOCA simulations and also secondary-side blowdown transients. In the first phase of this work, three prototypical LOBI experiments have been analyzed. These include LOBI tests A2-81 and BL-12, two complementary small-break LOCA experiments, respectively with and without high pressure injection system and secondary-side cooldown in each case. The third experiment, test BL-34, represents a more challenging 6% break LOCA with three dryout/rewet events and is a counterpart with BETHSY test 6.2TC and the ROSA4-LSTF test SB-CL-21. It therefore provides a means of addressing scaling problems in three different facilities which have important consequences in the safety of full-size pressurised water reactors. Other tests selected for code assessment include the two LOBI Steam-Line-Break experiments.

Technical support for the main code assessment activities started with the implementation of CATHARE2 on the JRC central computer system (Amdahl). Version 1.2 of the code was installed in April 1990, with an updated version added in late 1990. Modifications were also made to post-processing routines to interface CATHARE2 with existing and new post-processing software packages, eg. interactive colour graphics display package (IsoVu) to facilitate interpretation of code results. Various code input datasets have been set up to model the details of the LOBI test facility.

Although the code assessment work is far from complete, initial results suggests that several problems exist in the code relating to the correct modelling of direct contact condensation of steam onto a subcooled liquid jet, simulating the injection of cold ECCS water. A problem of modelling the continuity of liquid levels in vertical regions of the system is also an unresolved issue.

FARO

Introduction

FARO is an experimental facility in which a number of phenomena related to severe accidents can be investigated using real reactor materials. The main feature is the possibility of melting quantities of 100-150 Kg of UO_2 or oxide mixtures at a temperature of 3000°C. The melt can then be released into test sections to study:

- fuel jet impingement on structures;

- fuel freezing and plugging in channels;

- coolant jet penetration, fragmentation and general fuel-coolant interaction problems.

The experimental programme was first devoted to the studies of LMFBR severe accident problems in the three test sections BLOKKER I, BLOKKER II, TERMOS.

Since 1988, studies have been under way to assess the possibility of using the facility for LWR severe accident studies. A programme is now being defined for the study of in-vessel melt quenching phenomena, while the LMFBR test programme is being discontinued.

A series of models and computational codes have been developed for test precalculation and interpretation, in particular the CONDIF and SMURF codes, for predictions of the molten pool behaviour, the codes JET 3D, BOUNDY and MELT for the description of plate perforation tests. For plugging and freezing tests, the French CEA code BUCOGEL was used, while for jet penetration the JENA code has been developed.

Achievements

During 1990 two experiments of the BLOKKER II test series have been performed. In these tests, the melt penetration and freezing in rectangular cavities (simulating LMFBR inter-subassembly gaps) were investigated at 400° and 900°C initial structure temperatures.

In the first test the test insert contained, besides one circular reference channel of 4 mm diameter, four rectangular channels of various surface areas with widths ranging from 4 to 6 mm and a length of 2 m (see Fig. 1.1). The UO2 injection pressure was 0.6 MPa, the melt temperature 3000°C and the initial channel temperature 390 to 560 °C. Table 1 summarizes the experimental results. The penetration distance (400 mm) in the reference channel agrees well with formerly measured values; a UO2 mass of about 4 kg was found to be drained through the 6 mm wide channel before plugging. Fig.1. 2 shows a summary of melt front penetration versus time in the various channels, as derived from corresponding thermocouple data, which varies from about 1 m to more than 2 m. The contribution of the BLOKKER programme to the understanding of these freezing phenomena is most relevant with respect to tests performed elsewhere. An increased draining capability of UO2 in rectangular channels has been found with respect to circular channels of similar radial dimensions.

The limited number of tests in 1990 was due to the preparation of the facility for its new utilization in the field of LWR safety, which was recommended by the Member States and discussed also with non EC organizations (USNRC, EPRI, PSI-CH). Necessary modifications of the plant have been studied and designed and new main components ordered. This includes also the order of a new MF (medium frequency) furnace for the melting of about 200 kg of a stainless steel, zirconium and oxide mixture to produce LWR corium for future interaction experiments.

Various back-up tests on electrical heating of UO_2/ZrO_2 mixtures and on fuel jet break-up have been performed. Using a slightly changed melting procedure, 50 kg of a UO_2 (80 w%)/ZrO_2 (20 w%) mixture has been melted and released in a catch vessel and the corresponding melt temperatures have been measured by means of UTS-techniques.

The preparation of a first scoping test (to be performed in spring 1991) has been started, using the existing TERMOS facility and a fuel mass of 50 kg mixed oxides for the interaction with 200 kg of water at 50 bar initial pressure

The implementation of a new version of the computer code TEXAS, developed by Prof. Corradini (University of Wisconsin) for the description of the molten/fuel coolant interaction in the FARO-LWR configurations has been achieved. Several test scenarios have been pre-calculated. Preliminary thermohydraulic calculations using the computer codes RELAP5-EUR and SAFIRE for FARO-LWR vent sizing have been performed. In addition, the FARO-BLOKKER II tests have been interpreted with the new version of the CEA code BUCOGEL.
In September 1990 a Technical Exchange Arrangement between US-NRC and STI-JRC has been signed: this arrangement foresees cooperation in the field of severe accident analysis and in particular the execution of at least five FARO tests in the next three years.
The test programme for LWR severe accidents in FARO is is the subject of detailed discussions with experts of EC Member States.

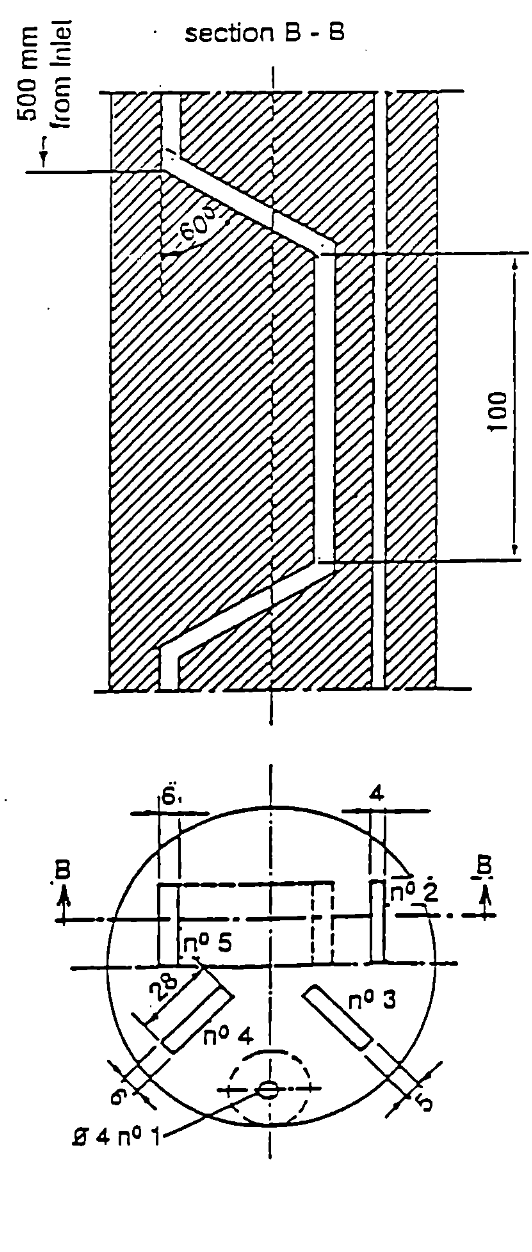


Fig. 1.1 Rectangular Channels Insert for Freezing

Table 1 Melt Penetration in Rectangular Channels

TUBE N°	TUBE WIDTH (mm)	MAXI. DIST. (mm)	PENET. TIME[1] (ms)	PENETRATION VELOCITY (m/s)	DRAINED UO_2 (kg)
1	Ø 4	400	100	3.6	0
2	4	1200	-	-	0.1
3	5	2000	380	5.3	0.5
4	6	2000	270	7.4	4.0
5	6*	1500	250	3.3	0

1 50 mm down from the channel inlet

* with semi-hexagonal twist

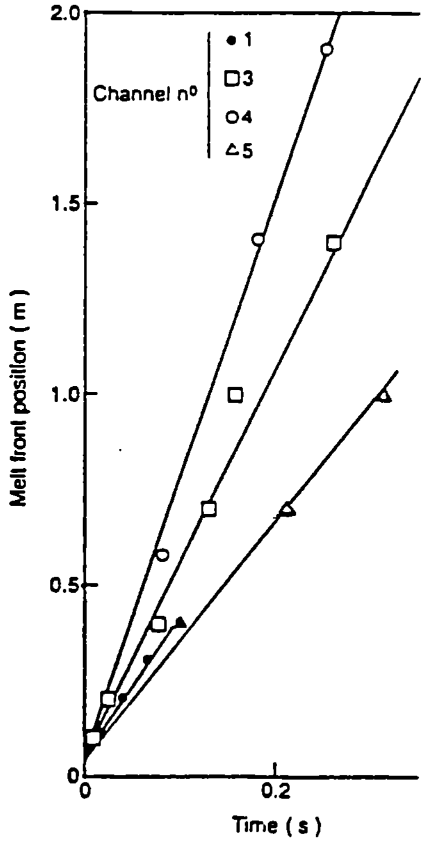


Fig. 1.2 Melt Front Penetration in Channels

SOURCE TERM

Introduction

This research area became one of the most important in the Commission Reactor Safety Programme for 1988-1991. The objective was to set up a series of well coordinated actions contributing in a significant way to the estimation of source term, that is the quantity and quality of radioactive products accumulating in the containment building in case of hypothetical LWR severe accidents.

The most important of these initiatives was to join the French Phebus FP programme with a substantial funding as well as participation in the project and analysis work. A contractCEA-Commission was signed on July 12, 1988: the Phebus Fission Product Project was at that time in its pre-design phase.

In addition, other actions have been started: precalculations of Phebus FP tests, code development and validation, development of advanced instrumentation for in-pile tests, study of physical and chemical properties of aerosols and FP released during severe accidents. All these works are performed by the JRC and by national laboratories through Shared Cost Actions (SCA).

The JRC team detached at Cadarache assures the participation in the design and development of the facility.

Achievements

<u>Phebus FP programme</u>

In the Phebus FP facility, located at the CEA Cadarache Centre, the core, the primary circuit and the containment building of a pressurized water reactor (PWR) are represented by a test fuel bundle, the in-pile section, FP line, experimental system and containment tank. The present Phebus reactor will be modified, receiving a new core cooling system and a new (FP) building.

The components of the Phebus FP facility are designed for the following scenario:

- the test fuel is irradiated inside the in-pile section, using the existing LOCA pressurized water loop, for approximately 2 weeks, in order to regenerate a significant inventory of fission products with half-lives between 10 h and 10 d;

- the loop is then drained, under simultaneous reduction of the reactor power, and the in-pile section isolated from the LOCA LOOP (which is only used to cool the outer structures during the experimental phase);

- for the experimental phase the inner volume of the in-pile section is swept by a steam-hydrogen flow while reactor power and test fuel temperatures are increased. The resulting test scenario includes all stages of a severe core degradation in a pressurized water reactor accident during which fission products are released and transported through the FP line and experimental system into the containment tank before being released into the atmosphere tank.

Milestones of the project in 1990 have been :

- completion of about 50% of the gross civil engineering work on site,
- specification and ordering of all large components and other long delivery items,
- final design and definition of all experimental circuit components, following a detailed specification of scope and objectives of the first test FPT 0,
- several safety-related studies were completed,
- a new experimental instrumentation plan has been compiled.

Instruments and measurements have been examined both against experimental/analytical requirements and for feasibility. Several R & D activities have been pursued with the scope to qualify instruments for the anticipated Phebus FP environment (high temperatures, high radiation levels, transient conditions).

New power supply, data acquisition and control systems have been specified and entered the industrial design phase.

For 1991 the completion of all construction activities is planned, together with on-site assembly of large components.
Fig.1.3 ,shows the overall program planning 1991-1998, using FPT 0, FPT 1, ... or 0, 1, 2, ... to designate subsequent tests.

The JRC team seconded to Cadarache was involved in all phases of the Project. Among others it took particular responsibilities in the fields of experimental instrumentation, post-test analytical techniques, circuit component layout, decontamination techniques, and remote handling.

The chief forum for presenting the results of collaboration with the CEA analytical team concerned with Phebus-FP and for dialogue with the Phebus-FP Project is the Scientific Analysis Working Group, which meets quarterly, and contains representatives of CEA, CEC, Member States and external partners in Phebus, including the U.S. and Japan. In between the plenary meetings so-called Preparatory SAWG meetings between CEA and JRC take place monthly, and ad-hoc meetings are also held to tackle urgent questions, Project requests etc.
The JRC team has been responsible for the organisation of a benchmark calculation of the first test, FPT-0, and for the analysis of the results. The exercise which attracted participants from the U.S., CEC, CEA, Spain and Germany, demonstrated the overall feasibility and representativeness of the first Phebus-FP test, but also revealed that some aspects of the specification of the test are unlikely to achieve the test objectives and so require revision. The benchmark, by comparing the predictions of several different teams and codes for the same problem, also revealed areas where predictions are in good agreement and hence, it is hoped, reliable, and other areas, e.g. the later phases of core degradation, where considerable differences were found between the predictions, suggesting that modelling is incomplete or uncertain. For these aspects the specification of the Phebus tests cannot rely only on calculations, but must also consider information from similar test series such as CORA, Phebus-SFD and PBF-SFD tests.

The Containment Task Force whose aim was the definition of the dimensions (see Fig.1.5), material and internal components (see Fig.1.6) of the vessel installed to represent the reactor containment,and subject to severe technological and safety constraints has finished its work.

Based on the Benchmark results and discussions within the SAWG, CEC and CEA have prepared a programme of work for FPT-0 which combines contributions from both in-house teams and from SAWG members. The work programme splits up the test geometry into bundle, circuit and containment, and for each component requires the definition of a base case and the performance of sensitivity studies. If general criteria of feasibility and representation are satisfied, it is expected that the set of base cases will constitute the test specification for FPT-0. Regarding the bundle, JRC-Ispra has assumed responsibility for the determination of the power and mass flow rate histories, the assessment of the location and timing of blockages and FP chemistry in the bundle (needed to determine the redox conditions specified in the test matrix). JRC-TUI will evaluate the expected fuel cracking and its consequences for FP release. Concerning the circuit JRC will evaluate aerosol formation and FP chemistry in the critical region above the bundle and FP chemistry at selected times and locations in the remainder of the circuit. Concerning the containment, the basic thermohydraulics will be determined by the JRC, aerosol physics calculations will be shared with CEA.

An active collaboration with JRC-TUI is helping to define the fuel state before the test and the FP release (particularly difficult to calculate for nearly fresh fuel). Bundle calculations (see design on Fig. 1.7) are proceeding with the ICARE-2 code, and thermal calculations are underway to evaluate the temperature field above the bundle. When this is known it will be used as input to VICTORIA to determine the aerosol formation and FP chemistry. Familiarisation with VICTORIA and comparison with SOLGASMIX for selected test problems is serving as preparation for the planned VICTORIA calculations both for the bundle and for the circuit. Containment thermohydraulics analysis requires the adaptation of available codes to take account of special features of the Phebus-FP containment vessel, particularly the active condenser structure. The JRC has introduced this feature into the CONTAIN 1.10 code, and is doing the exploratory calculations needed to define the test thermohydraulic conditions.

A second related work programme is that for the precalculation of the remaining Phebus-FP tests,in order to dimension the components, define experimental protocols, degree of representation, possible revision of the test matrix etc. Although the last test will not be performed before 1997, some items of the work programme are already urgent, particularly those affecting caisson design, heating and cooling systems and other civil engineering matters.

Code Implementation and Development

In 1990 the JRC has acquired and implemented many of the basic calculational tools necessary for the task of Phebus-FP analysis. The bundle thermohydraulics and core degradation code ICARE-2 was received from CEA and now operates both on the Amdahl mainframe and on a workstation. A study of the hydrogen balance revealed a defect in the modelling which will be corrected by CEA in their next release of the code. Following the establishment of an agreement with the USNRC, the VICTORIA FP chemistry and aerosol transport code was received and has been installed on a workstation. The RAFT aerosol transport code from EPRI has been tested and compared with TRAPMELT in a series of test calculations; the containment thermohydraulics, aerosols and iodine chemistry codes JERICHO, AEROSOLS-B2 and IODE from CEA have been installed and adapted to the JRC's graphics software, and the iodine chemistry code IMPAIR-2 has been received from the Paul Scherrer Institute (CH) and installed. The CONTAIN code from USNRC has been updated to version 1.10, and very recently the containment aerosol codes NAUAMOD5 and NAUAMOD5-MC have been received from KfK. Test calculations with these codes and adaptations to

Phebus requirements as described above have accounted for considerable analytical effort.

The major JRC-sponsored effort in the area of code development concerns ESTER (European Source Term Evaluation Reference), which is intended to become a best-estimate code incorporating the best available models for the various aspects which determine the source term. The individual models are expected to be developed or obtained from various laboratories in Europe and outside, and hence the basic structure of ESTER has to be designed in such a way as to accommodate, to the maximum extent possible, modules developed using different philosophies, data structures etc., and cause them to share information through a common database, use common input/output facilities etc. A SCA contract started in 1990 awarded the work of developing the framework of ESTER to a consortium of CISI Ingenierie and IKE Stuttgart. The design phase for ESTER involves many decisions crucial for the success of the ESTER concept, and the JRC has interacted strongly with the contractors while attempting to involve the Member States in the develoment work. The JRC organised a meeting of experts on software integration for Source Term, which gave its blessing to the overall architecture of ESTER, and another meeting of Quality Assurance experts, who have agreed to act in a consulting role concerning the proposals advanced by the contractors for quality control, both during development of the structure and during the subsequent phases of adding modules, issuing versions, collecting proposals for improvements etc.. More recently, as the problem of specifying the ESTER structure in such a way as to minimise the effort needed for interface development when accommodating new codes and modules has become apparent, the JRC has organised two meetings of European experts to analyse the possibilities for both a common data structure and a common input format for circuit thermohydraulics codes and for bundle/core degradation codes. With all this information in hand, decisions have been taken in consultation with the contractors, after which the final design document is being prepared and issued. The development of a prototype version of ESTER incorporating the ICARE2 and FIPREM (FP release) codes can then proceed rapidly.

A second code development taking place under SCA is that of VICTORIA, the contractor being AEA Winfrith. The work will improve the efficiency and modelling of the code, and will also prepare it for integration in ESTER.

The Shared-Cost Action coordination concerns also other works with an analytical slant such as the development of improved fuel degradation and FP release models (IKE Stuttgart), of chemical kinetics models (UPM Madrid), and of state of the art reviews concerning tellurium chemistry (UPM plus CEN, Mol). New contracts for 1990 SCA concerning the integration of existing modules into ESTER and the development of new models for FP release and transport have been selected.

A paper based on the containment verification studies at the NEA/CEC/CEA Workshop on Aerosol Behaviour and Thermalhydraulics in the Containment was presented, and the complete Phase B Scoping Calculations Summary Report should appear as an EUR report in due course.

New possibilities of cooperation have been opened by the invitation to the CEC to participate in the USNRC Severe Accident Research Programme (SARP). Thus the CEC-sponsored VICTORIA developments of AEA Winfrith can now be complemented by those at AECL Canada, Argonne, Oak Ridge and Sandia. Access to U.S. experimental programme and code development data is much improved by the SARP collaboration.

Reactor Physics Calculations

The Monte Carlo perturbation code KENEUR, extensively used in the reactor physics analysis of PHEBUS-FP experiments had to be upgraded to meet all the requirements specified by the project management. Originally in KENEUR, an upgraded version of KENO-IV developed at JRC-Ispra, only keff had been subject to perturbation estimates.
New algorithms which were introduced, make it possible to calculate perturbation effects of all target quantities, such as space energy dependent fluxes, absorption and fission rates and detector responses.

To achieve this goal, the target quantities are now calculated separately for each volume element representing an element of the fission matrix. Then, after normalizing the results, the different contributions are weighted with the value of the corresponding element of the source vector and summed.

To validate the new methods, they were applied to several three-dimensional benchmark problems promoted by the Nea Committee of Reactor Physics. After this validation exercise had proved to be successful, KENEUR has been used extensively in the analysis of power distributions and neutron fluxes in planning and design studies of PHEBUS-FP experiments. In particular coupling factors for different coolant densities and flux changes due to different fuel melt-down scenarios were calculated.

To minimize computing costs KENEUR was moved to a PC-based Transputer board. After a number of software changes the functioning of the code in serial mode has been confirmed. The development of a parallel version is underway.

Aerosol and FP properties

Two important research projects (SCAs) were concluded in 1990.

The first one, at AEA Technology Winfrith, was extensive research on FP chemistry related to LWR severe accident conditions, for instance on the effect of high temperatures on the chemical compounds which might be generated in the presence of control rod material vapours and boric acid. The results of these tests were analysed and their application for model development and validation were discussed in the final report.

The second one, performed in the REST facility at KfK-Karlsruhe, was an experimental investigation on the potential contribution to the overall Source Term due to resuspension in the containment atmosphere of aerosols deposited and dissolved in the sump water, in case of extensive sump water boiling during the late stages of an accident. The results showed that the amount of radioactive material which became airborne might not be negligible.

Two SCAs on FP/aerosol instrumentation in support of Phebus-FP were terminated at the beginning of 1990. One of these was a feasibility study of the on-line application of the inertial spectrometer (INSPEC) developed by Lavoro & Ambiente, Bologna to measure particle size distribution. The instrument was adapted to the high temperature conditions of Phebus-FP and subsequent tests validated the feasibility of the design.

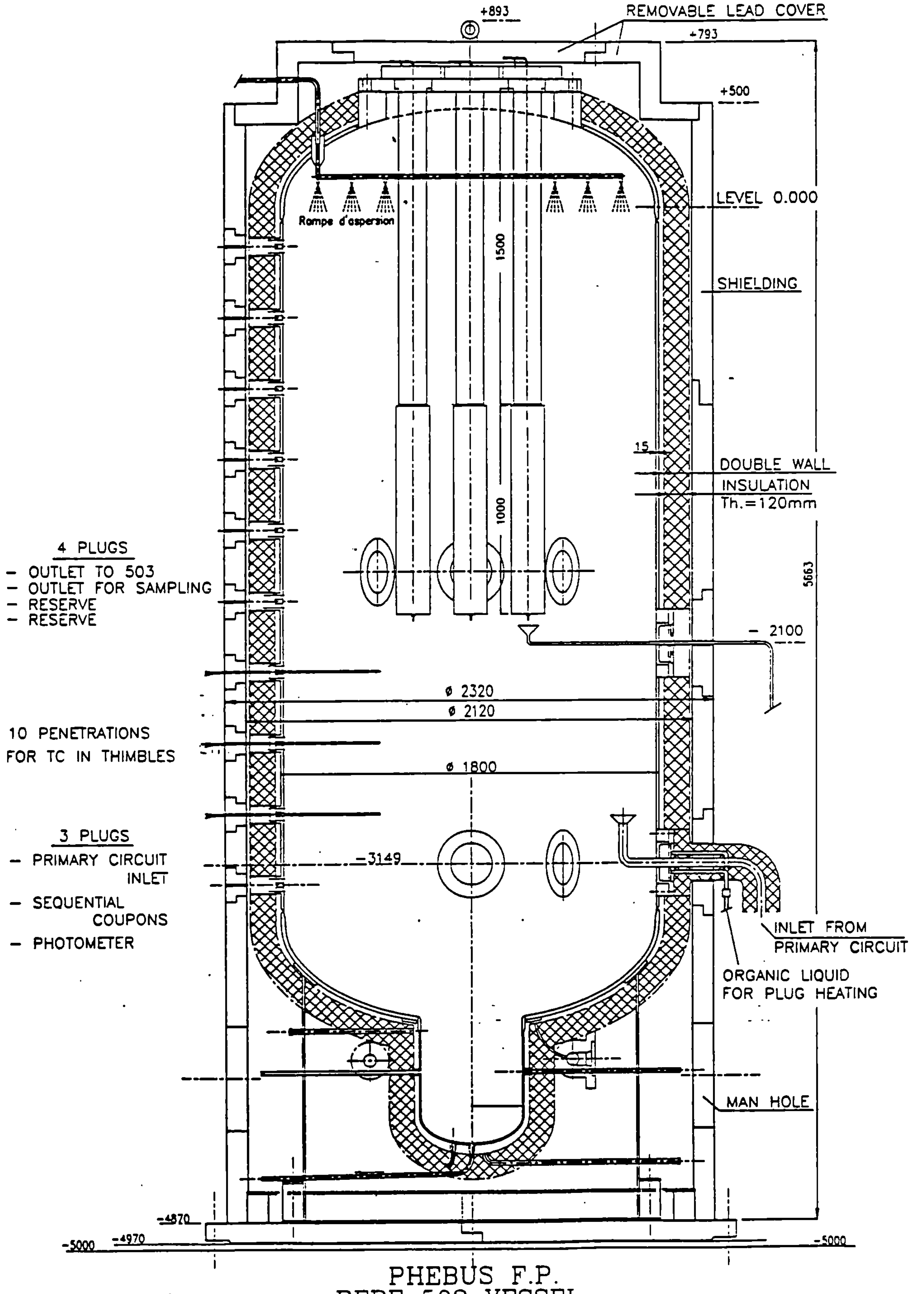
The second action, performed by AEA Technology Harwell investigated other measurement devices in view of their applicability for Phebus-FP. In particular it was proved that a differential gamma spectrometer, able to distinguish between FPs deposited on a wall and those suspended in the gas flow, can be used in the specific conditions of Phebus-FP.

Two new actions were taken up during 1990 concerning thermochemical data acquisition of FP compounds. To specify the priority of the compounds to be investigated, an FP-chemistry specialist meeting was held in January 1990 in Ispra. According to the derived priority list, approximately 24 compounds were characterized by the two laboratories Winfrith and ECN Petten. This research, which is very important for source term evaluation, will be continued also in 1991.

Fig. 1.3

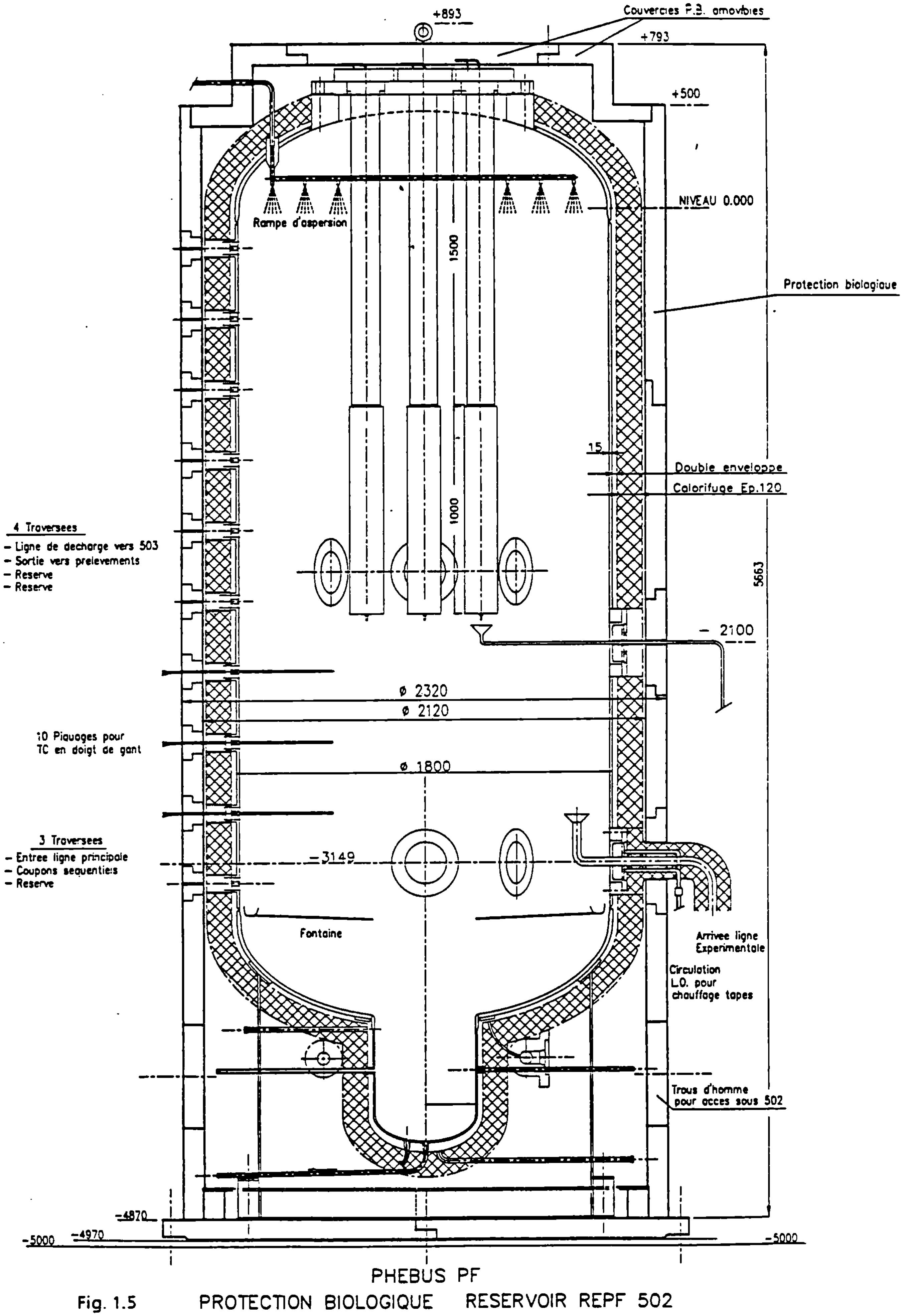
PHEBUS FP PROGRAM
OVERALL PLANNING CHART

	1991	1992	1993	1994	1995	1996	1997	1998	1999
• Dimensioning calculations	FPT1	FPT2	FPT3	FPT4	FPT5				
• Instrument calculations	FPT1	FPT2	FPT3	FPT4	FPT5				
• Operational procedures	FPT0	FPT1	FPT2	FPT3	FPT4	FPT5			
• Detail design	1	2	3	4	5				
• Manufacture, ass'y testing	0	1	2	3	4	5			
• Final check - out		0	1	2	3	4	5		
• In - pile irradiation		0	1	2	3	4	5		
• Sample recovery and dispatching		0	1	2	3	4	5		
• Decontamination, disassembly, waste disposal		0	1	2	3	4	5		
• Experimental circuit ass'y	0		1	2	3	4	5		
• FP sample analysis		0	1	2	3	4	5		
• Test fuel bundles PIE			0	1	2	3	4	5	
• Post - test calculations & reporting									
• Test report			0	1	2	3	4	5	
• Final report				0	1	2	3	4	5
• PHEBUS FP information seminars	+	+	+	+	+	+			



PHEBUS F.P.
REPF 502 VESSEL

Fig. 1.4



PHEBUS PF

Fig. 1.5 PROTECTION BIOLOGIQUE RESERVOIR REPF 502

PROJET

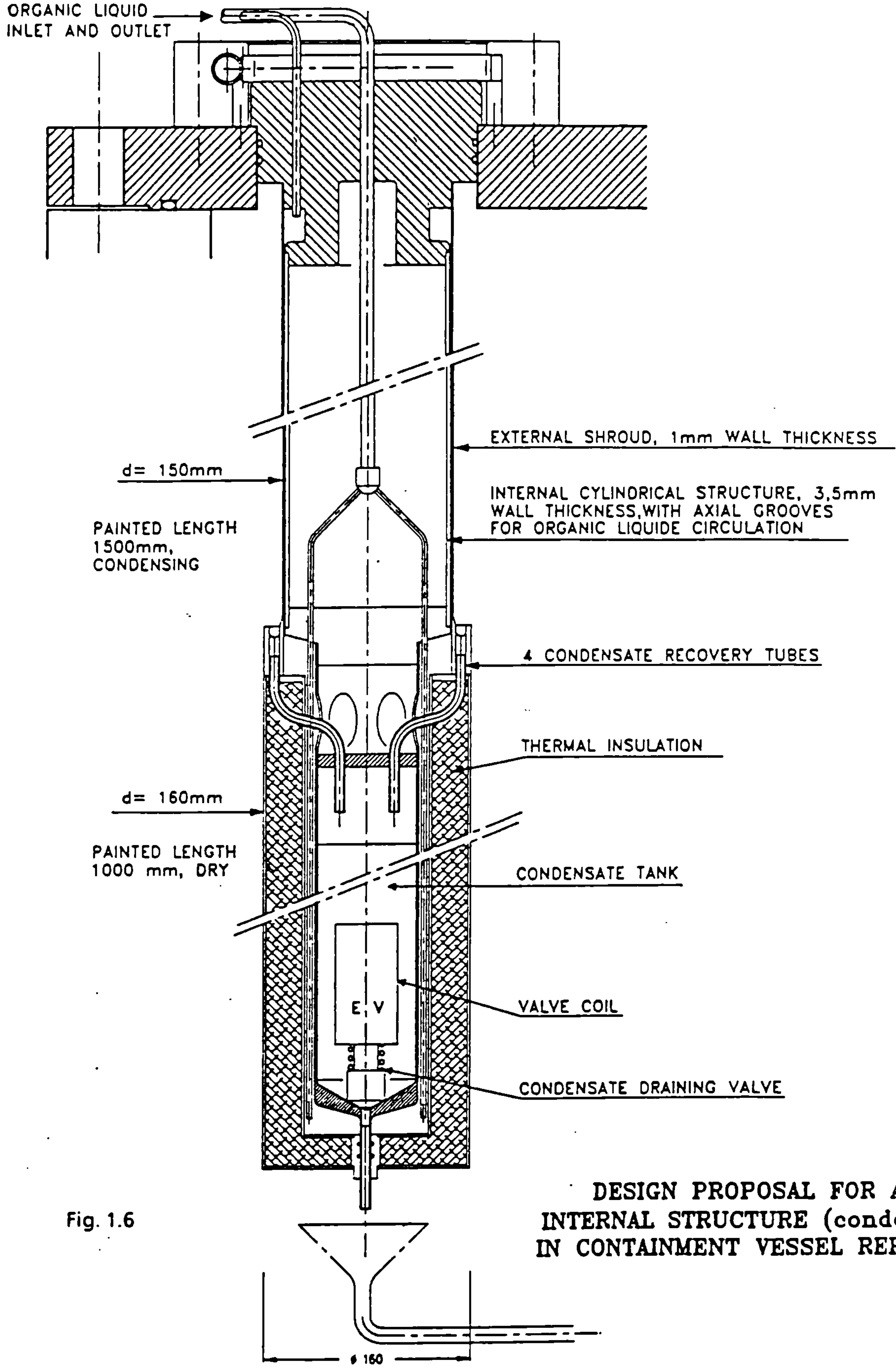


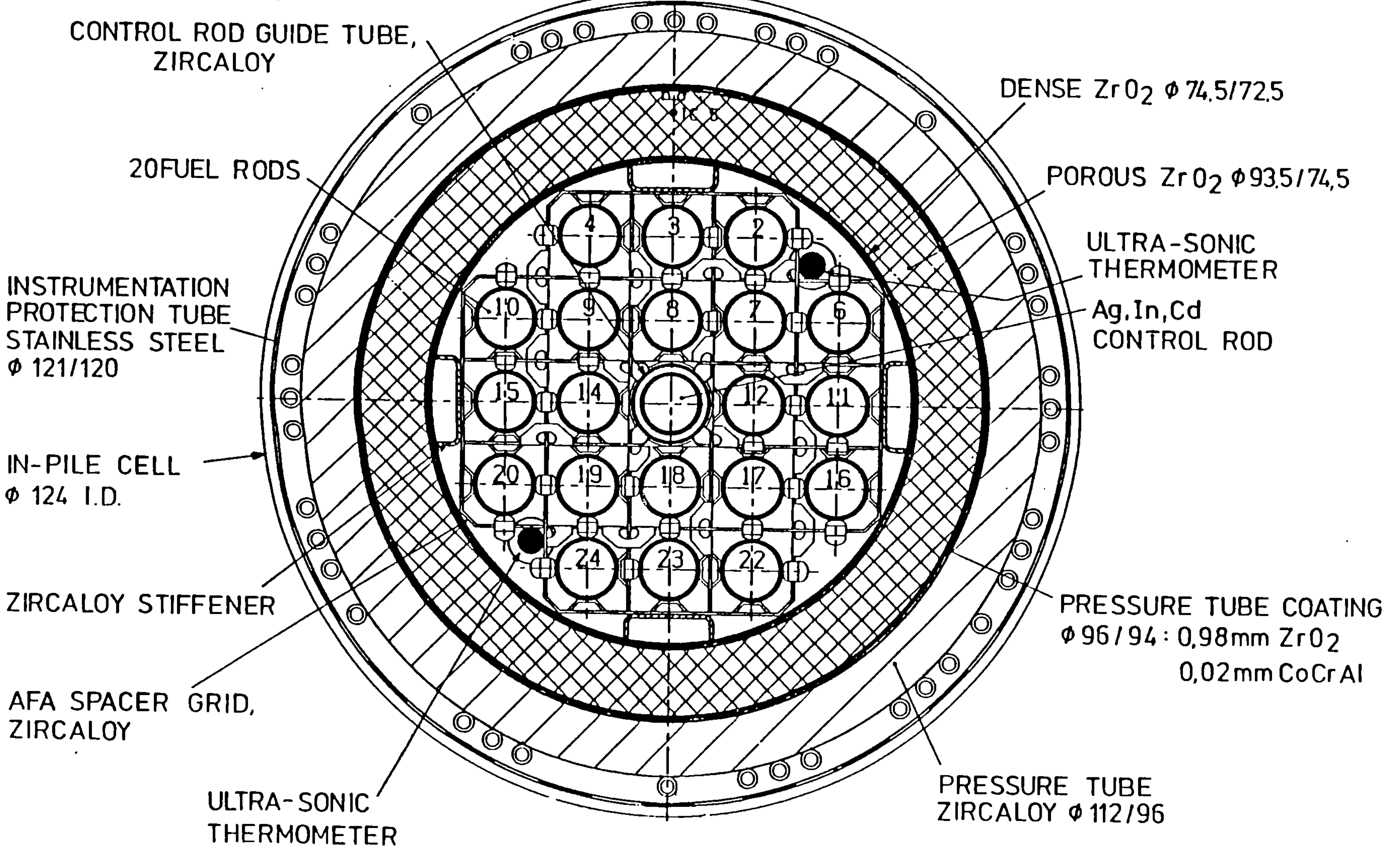
Fig. 1.6

DESIGN PROPOSAL FOR AN INTERNAL STRUCTURE (condenser) IN CONTAINMENT VESSEL REPF 502

Fig. 1.7

Phebus FP In-Pile Section FPT 0.

CROSS SECTION ON DRIVER CORE MID PLANE



EUROPEAN ACCIDENT CODE (EAC)

Introduction

This work is presently aimed at the further development, validation and distribution of the EAC-2 code for the improved calculation of unprotected Loss-of-Flow, Transient Overpower and Loss-of-Heat Sink accidents in Liquid Metal Fast Breeder Reactors (LMFBRs). EAC-2 contains significantly improved modelling in comparison to the earlier EAC code version. This is particularly true in the areas of fuel pin behaviour and molten fuel motion both inside the fuel pins and in the coolant channels following cladding failure. Moreover, the code simulates properly the hexagonal geometry of an LMFBR and contains presently a simplified time-dependent 3D neutron diffusion calculation.

The development and validation efforts are regularly discussed by a User/Expert Group that meets every half year. During the next year the European Fast Reactor (EFR) Associates will decide whether EAC-2 or the American SAS4A code will form the basis of the long term European Reference Code.

Achievements

In early 1990 a first version of the EAC-2 code was released to CEN-Cadarache, KfK Karlsruhe, AEA Risley and Belgonucléaire. In the middle of the year a second version with several corrections but no new modelling was released.

- Comparisons of EAC-2 with whole-core loss-of-flow and overpower benchmark calculations were performed. An example of the comparison with the earlier WAC/LOF calculations is shown in the Fig 1.8. During the first 12 seconds, which are not shown, the power drops due to structural expansion of the core. The early power history and the power rise to about 100 times nominal agree well with some other calculations. However, no high power peak was calculated. This is related to the use of the pin failure criteria of the TRANSURANUS fuel pin behaviour code. Two of the stress and one strain type criteria predicted cladding failure at fuel melt fractions of only 35% areal melting at the midplane of the lead channel. The other codes had assumed cladding failure at 70% fuel melt fraction in this irradiated channel. With the low melt fraction at pin failure only short molten fuel pin cavities exist inside the pins in the EAC-2 calculation. Therefore no significant compactive in-pin fuel motion but a sizeable fuel dispersal in the channels occurs leading to shutdown of the reactor.

- The MDYN material dynamics model was upgraded by including the treatment of a separate frozen fuel crust on the hexcan structure (important for the analysis of CABRI experiments), improving the treatment of sodium boiling for short (millisecond scale) time steps and starting the development of a model for the ablation of molten steel by molten fuel flows.

- Validation efforts were started for the integrated EAC-2 models for fuel pin behaviour, sodium thermohydraulics and fuel motion by analysing CABRI experiments. The first comparisons look encouraging.

- Work on the new mechanistic cladding failure model was continued at AEA-Harwell. The new model showed good agreement with the initial failure in a few CABRI experiments. At the Transuranium Institute at Karlsruhe the new pin failure model was coupled to the stand-alone version of the TRANSURANUS pin behaviour code. The latter is also integrated into EAC-2.

- An efficient new neutron cross section generator called KWIKXS was developed and coupled to the 3D HEXNOD neutronics code

The calculation of diffusion reactivity worth curves from perturbation theory was completed and partially validated. A new theory was developed for calculating transport reactivity worth curves based on the nodal HEXNOD code.

The HEXNOD code, the KWIKXS cross section generation and the reactivity worth calculation were coupled to EAC-2 in a way that this package can be called at any time in the transient. This represents a simplified adiabatic solution to the 3-D time-dependent problem. The more accurate quasistatic HEXNODYN model has been extensively tested but was found not to be efficient and flexible enough yet for practical applications.

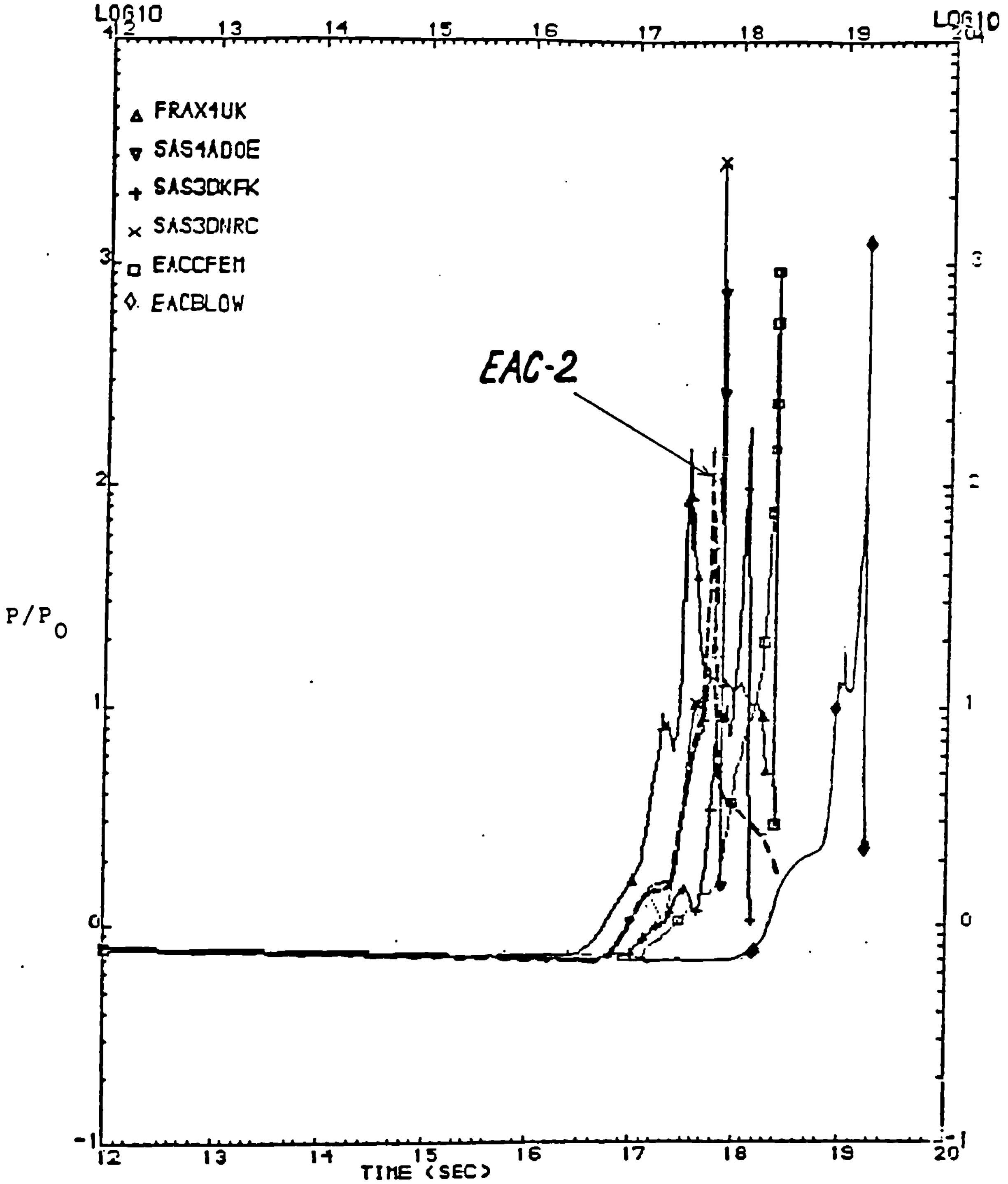


Fig. 1.8 Normalized Power VS. Accident Time

1.1.2. WASTE

PETRA

PETRA is a hot cell facility capable to produce various types of fully active conditioned waste. The programme is specifically oriented to analyse and verify processes suitable to minimize waste and to improve waste quality.

The activity associated with the PETRA facility during the period in question can be summarised as follows:

-decontamination and refurbishment of the cells 4411/4304
-modifications
-licensing
-planning and work programme.

Decontamination

Indirectly associated with PETRA was the need to clean and decontaminate the two cells 4411/4304 adjacent to the PETRA installation which have already been utilised in hot operation for more than 2 decades. In a second phase some necessary refurbishment work such as for the electricity supply, remote handling equipment and the fire fighting system has been performed. The fuel chopping machine which has been designed and built in-house and patented after successful testing, will be placed in one of these cells.

Modifications

In order to proceed in parallel with the decontamination of cells and modifications of PETRA, a special protective screen cover was installed maintaining access to the rear of the three PETRA cells.

Modifications were made to optimise remote handling and easy access, for operational reasons and for requests of ENEA related to our contractual agreements and to licensing questions.

With the decision to use stainless steel mixer-settlers instead of plexiglass ones, the opportunity was taken to prepare a new flowsheet utilising two cycles, eliminating two mixer-settler batteries, re-positioning of pumps and piping layout, generating more free space to manoeuvre with the telemanipolators. Prior to installation in cell 4307, these mixer settlers were successfully tested utilising cerium as a solute transfer under the typical process flow conditions.

The TDR liquid level probes have been replaced by probes built and tested in-house, based on the measure of capacitance for level determination. Some TDR probes are to be maintained for research purposes. Conductivity probes were designed and tested in-house before installation in the three hold-up vessels of the solvent extraction circuit.

The systematic testing revealed the need to improve the functioning, particularly of the heating system adapted for the dissolver, denitrator and evaporators. New improved ceramic insulated heaters have been purchased and tested to replace the original band heaters.

Licensing

The Italian Safety Authority (ENEA-DISP) convened its Technical Committee in May and expressed a positive opinion of the PETRA construction. A few safety-related modifications were identified and the procedures were announced which will to be adopted for the step-wise commissioning of single and combined tests by the plant in the presence of ENEA-DISP inspectors. The provisions of Article 45 of the Italian Nuclear Law (DPR 185) will apply.

Planning and Work Programme

The planning foresees the completion of the modifications and cell refurbishment by the end of February 1991. Testing on the safety related systems is planned until the end of April 1991. The preparation of documentation according to art. 45 will be complete by February 1991. The period March to June 1991 will involve the necessary preparation for the DISP - Technical Committee for hot-test authorisation.

SAFETY OF FINAL STORAGE IN GEOLOGICAL FORMATION: MATERIALS RESEARCH ASPECTS.

Investigations on behalf of the Institute for Advanced Materials were performed on the form in which Technetium (Tc) is retained in a borosilicate glass containing simulated high level nuclear waste.
The effect of corrosion in clay and sea sediments on the release of Tc was also investigated.

In order to define the form in which the Tc was present in the glass, electron microprobe analysis was used, combined with optical microscopy and scanning electron microscopy / x-ray energy dispersion spectroscopy.

Most of the Tc was concentrated in one of two types of dispersed metallic inclusions.

After three months leaching in clay, Tc had disappeared in this phase. The sample leached in sea sediments for three months shows that the amount of Tc lost from the "rich" phase is smaller than in clay.
The final report has been sent for publication (1).

1.1.3. SAFEGUARDS

Development of non destructive assay methods for Safeguards.

In the frame of the Safeguards and Fissile Material Management programme the following principal tasks are executed by STI :

1. Development and performance assessment of measurement systems for nuclear materials;
2. Operation of PRE-PERLA and construction of PERLA Facilities.

Development and Performance Assessment

The accurate measurement of the isotopic composition of Pu fuel samples by high resolution gamma spectroscopy is of importance for the mass determination of Pu by neutron correlation techniques and by calorimetry. During the past year several gamma-spectrum unfolding codes were applied to measurement data obtained with PERLA standards.

Studies related to the Pu-mass determination from the spontaneous fission rate via neutron correlation counting using the PERLA standards were performed for the improvement of the shift register algorithms. An algorithm for the dead time correction necessary for the triple correlation techniques has been completed and is being tested using small PuO_2 samples.

Studies are continuing to determine the statistical error of gamma-spectroscopy, active and passive neutron assay.

A comparison between a water cooled and an air-cooled calorimeter demonstrates nearly the same precision for both. The air cooled calorimeter is much easier to use.

Use of PRE-PERLA and Construction of PERLA

The PRE-PERLA laboratory is fully operational. The existing U and Pu standards represent a significant fraction of the material handled in fuel cycle facilities. They are used for calibration and performance tests of instruments and software. PRE-PERLA is extensively used for:

- Pu isotopic determination of fuel samples
- Pu mass determination by calorimetry and neutron correlation measurements
- U enrichment measurements
- activities carried out for D.G. XVII.

The construction of the PERLA laboratory is continuing.The civil engineering part has been completed.

1.1.4. FUSION

HYDROGEN ISOTOPES EXTRACTION, PURIFICATION AND SEPARATION

The objective is to investigate the capability of synthetic modified zeolites to treat gaseous streams bearing tritium arising from fusion devices, such as NET. Particular emphasis has been addressed to the use of zeolites of the mordenite and Y family which appear to be very appropriate materials for the treatment of gaseous streams in the presence of tritium. The items studied are in particular:

- the separation of hydrogen isotopes,
- the argon purification from gaseous impurities with low atomic number (Z),
- deuterium and hydrogen extraction from large He streams,
- purification of the hydrogen isotopes from impurities of the plasma exhaust.

Hydrogen isotopes separation

As previously reported [1] the Ni-Ca-Na mordenite small pore and the Ni-Na mordenite small pore have given the best results on the separation of the hydrogen isotopes with respect to many other materials used for the same purpose. In order to improve the separation factor at temperatures far above those of liquid nitrogen attempts were made by the CHROMPACK INTERNATIONAL company on the preparation of capillary columns with NaM and Ca-NaM with Al_2O_3 binder and binder free Ni-NaM.
The preparation has been successful and the first results have demonstrated that:

a) the prepared coat suspension is stable enough during the coating process;
b) the Al_2O_3 binder has a negative influence on the chromatographic properties of the zeolite;

c) the Ni-Na mordenite large pore seems to be an appropriate sorbent for the analysis of low Z gaseous components.

First encouraging tests were also obtained with substrates containing Pd and Pt at 77K [2].

Argon purification from low Z gaseous components

The purpose of this research is the preparation of a modified zeolite in such a manner that argon is purified from N_2, O_2, CO, CO_2 impurities at temperatures not lower than 215K.

A set of experimental runs has been carried out with Na mordenite modified by using different percentages of M_3BO_3. Although good results have been obtained, these substrates were found to be unstable under repeated thermal treatment. Thus another procedure has been chosen for the modification of Ca-Na mordenite using Na_2SiO_3 $9H_2O$ by which stable sorbents have been obtained. Representative results are reported in Fig. 4.1. The research is progressing for the optimisation of the pore size. Moreover, the adsorption isotherms for single and multi components are being determined.

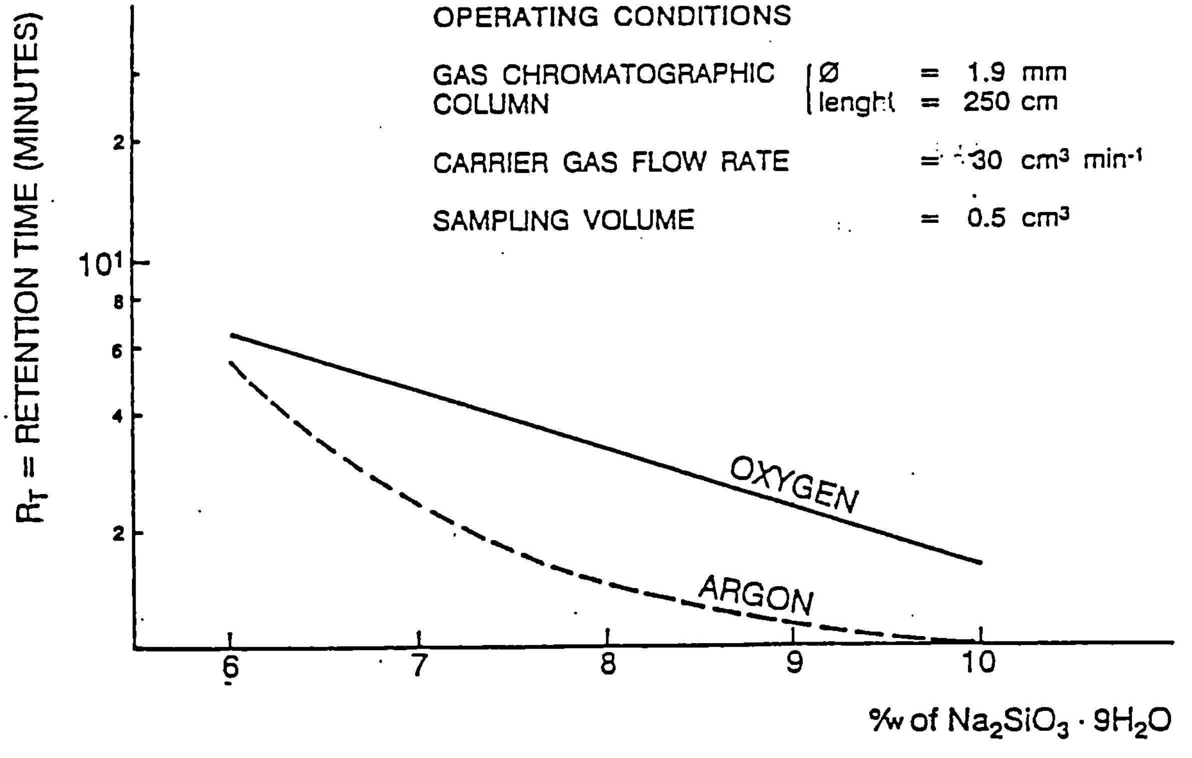


Fig. 4.1 RETENTION TIMES OF ARGON AND OXYGEN AT 273K AS A FUNCTION OF THE AMOUNT OF SODIUM METASILICATE USED IN THE PROCEDURE OF PORE REDUCTION OF Ca 62 °/w - Na MORDENITE.

HYDROGEN ISOTOPES- MATERIAL INTERACTION

1. Transport of hydrogen isotopes in liquid breeder blankets.

a. Calculation of tritium inventory and permeation.

A numerical code has been used to calculate the time dependence of tritium inventory and of tritium permeation into the coolant and into the first wall boxes of the water-cooled liquid-breeder blanket concept of DEMO. Two structural materials have been studied, the AISI 316L austenitic steel and the DIN 1.4914 martensitic steel MANET-1.

As tritium permeation into the coolant is unacceptably high in these blankets, tritium permeation barriers have to be used by application of coatings of low surface recombination coefficient and/or low diffusivity materials on the structural materials. Two types of coatings, Al_2O_3 and TiC, at various surfaces of the two structural materials have been investigated.

The tritium inventory in blankets with TiC coating is always higher than in a blanket without coating (~. 20g) and can reach several hundreds of grams, which can be accepted by fusion reactor designers. Tritium permeation into the coolant in a MANET 1-DEMO blanket without coating is more than 10^{-3} g.s^{-1} or 100 g day^{-1}. This unacceptably high value can be reduced up to 6 orders of magnitude by a 10µm thick TiC coating on the coolant side surface of the blanket due to the very low surface recombination and diffusion rate of tritium in TiC.

Further calculations for stagnant Pb-17Li in the blanket and TiC coatings on both sides of the cooling tubes showed a slightly increased tritium inventory but a drastically reduced tritium permeation into the coolant. The predominant part of tritium produced in the blanket permeates into the first wall boxes from where it can be recovered by direct pumping. This method needs no external tritium recovery system and can give a simple and effective alternative for tritium recovery.

b. LIBRETTO 3

The in-pile irradiation programme LIBRETTO is being carried out within the European Fusion Technology Program on Blanket Technology as a joint project between JRC Petten, Advanded Materials Institute and JRC Ispra., Safety Technology Institute. The irradiations are performed in the High Flux Reactor (HFR) at Petten.

Up to now, two series of experiments have been performed: LIBRETTO 1 and LIBRETTO 2. A third set of experiments, LIBRETTO 3, is at the design stage.

The objective of LIBRETTO 3 is mainly to test the efficiency of proposed tritium permeation barriers. The experiment will consist of four capsules where three ones will be coated with a permeation barrier, and the fourth will act as a non-coated reference capsule. One capsule will be coated with Al_2O_3 by C.E.A. (France). The other two capsules will be coated with Al_2O_3 and TiC by JRC Ispra. A He-stream will be bubbled through the molten Li-Pb alloy during irradiation.

Several trial runs had to be performed to check the quality of the layers obtained by C.V.D. (Chemical Vapor Deposition) The company in charge had to redesign its procedure in order to guarantee a homogeneous deposit. The irradiation is scheduled for the first and second quarters of 1991.

2. Solubility, diffusivity and surface rates of hydrogen isotopes in fusion reactor materials.

a. TZM

The Mo-based alloy TZM (wt% composition Mo $\geq$ 99.2, Ti $\approx$ 0.5, Zr $\approx$ 0.08 and C $\approx$0.04) has been proposed as a structural material for the divertor and/or the first wall structure to support the graphite tiles in one of the conceptual designs of NET.

The experimental results have been employed to predict the Tritium-TZM system behaviour by extrapolation using Ebisuzaki's and Katz's models / 1, 2 /.

Temperatures between 673 and 873 K and loading pressure in the range 10^3-10^5 Pa have been used. An improvement in the analysis of data consists of simple modelling of the surface processes which gives values for the surface recombination rate and for the adsorption rate , which are directly proportional to the sticking coefficients.

The diffusion model predicts a characteristic time $\tau_D = r^2/D$(r = sample radius, D = diffusivity) independent of the loading pressure P_0, so that normalized release curves at different P_0 but at the same temperature should coincide. High pressure values of D have been used to find the experimental temperature dependence of the diffusivity of hydrogen and deuterium (Fig.4.2).

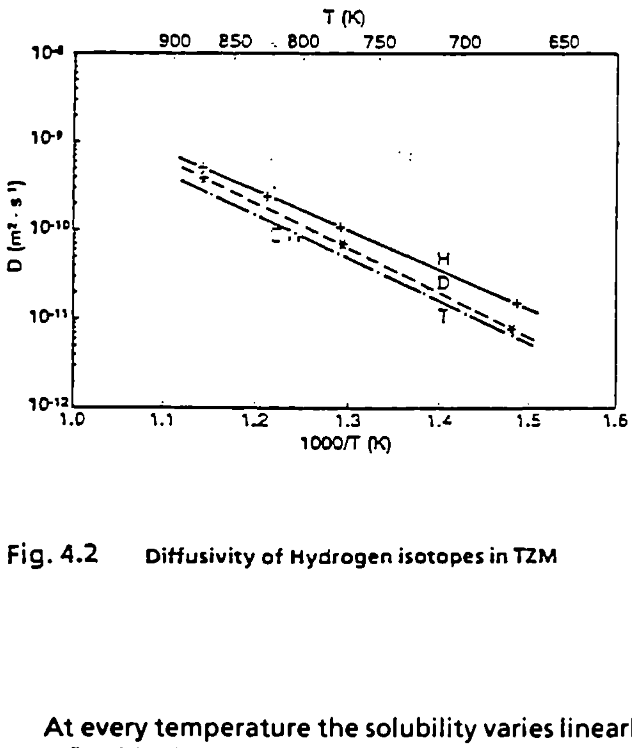


Fig. 4.2 Diffusivity of Hydrogen isotopes in TZM

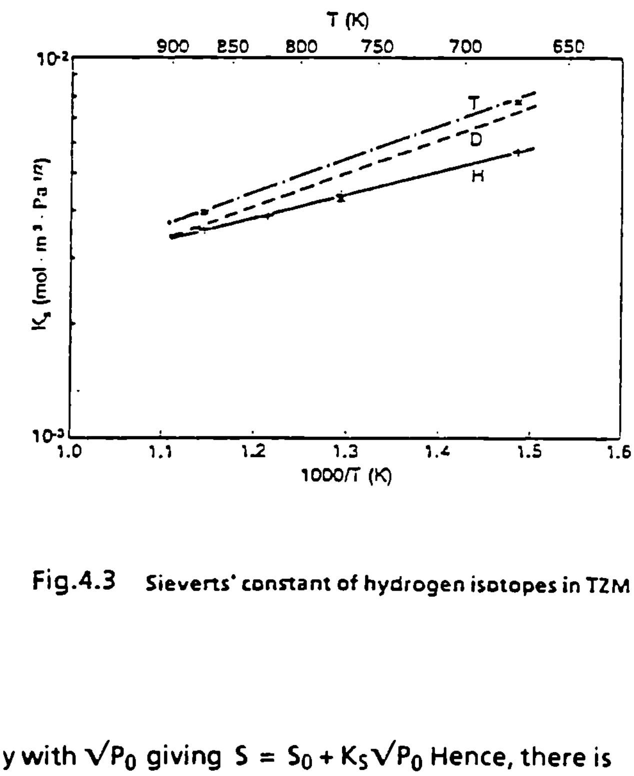


Fig.4.3 Sieverts' constant of hydrogen isotopes in TZM

At every temperature the solubility varies linearly with $\sqrt{P_0}$ giving $S = S_0 + K_S\sqrt{P_0}$ Hence, there is a "residual solubility" i.e. the intercept at $P_{*} = 0$, that disturbs the expected behaviour. It can be interpreted as a contribution from surface contaminants that release hydrogen on reacting with the metal. This contribution is generally very small and can be neglected, but in this case the solubility is also very small, in the 0.1 to 1 mol.m^{-3} range. The value of S_{*} at 873 K is equivalent to 0.2 H monolayers, if a roughness factor of 10 is used.

The measured temperature dependence of Sieverts' constant $K_S = (S\text{-}S_{*})/\sqrt{P_0}$ is shown in fig. 4.2, in an Arrhenius' plot. The solution reaction on TZM is exothermic, in opposition to pure Mo. The surface recombination and adsorption rates are determined from the gas release curves at low loading pressures P_0.

The curves were calculated according to [3, 4]

b. DIN 1.4914

The ferritic steel DIN 1.4914 is one of the two first wall and structural materials, which are proposed for NET and DEMO.
First measurements of solubility and diffusivity of hydrogen indicate that :

- the hydrogen solubility is considerably smaller,
- the activation energy of solution is higher,
- the diffusivity is considerably higher, and
- the activation energy of diffusion is smaller

in the DIN 1.4914 martensitic steel MANET than in the austenitic steel AISI 316L.

3. Recycling of hydrogen isotopes from first wall materials of fusion reactors.

An installation to study the recycling of hydrogen and deuterium was used during 1989 in preliminary measurements of the recycling characteristics of the steel AISI 316L (paper presented at ICFRM-4, Kyoto, Japan). During 1990 this installation was considerably improved by adding a very sensitive quadrupole mass spectrometer (QMF) system with additional three-lens optics. This was a lengthy process due to the intrinsic characteristic of the new QMF, which involved many man-hours for the modification of the installation, its mounting and calibration. This system permits the measurement of the gas composition in the core of the installation, i.e. the ion source volume. This is accomplished by switching on the cross-beam ion source of the QMF. Furthermore the plasma and the chemical composition of the target surface (qualitative SIMS) can be measured, due to the special ion optics mounted on the QMF. The knowledge of the plasma composition is needed for the determination of the particle flux on the target and that of the target surface composition is necessary because the recycling flux strongly depends on the conditions of the target surface.

A further improvement of the recycling installation is a new target which can be cooled (temperature controlled target). Tests will be carried out using as coolants .compressed air (or other gas, for example He), water and silicon oil.

Parallel to the above project the executive design of an installation to study tritium recycling from different materials is in progress.

A constant pressure is needed in order to keep the plasma discharge in the ion source. This is achieved by keeping a continuous flow of the gas under study through the ion source volume. In the test bed installation this corresponds to a flow of 0.1 mbar.l.s.$^{-1}$. However, this will be too large a flow when tritium is used, therefore a new ion source has been designed where improvements on the cooling system of the walls should allow reduction of the flow. The detailed design of the new ion source is complete and construction will start in 1991.

4. Tritium permeation through engineering components.

A new activity which started during this year on behalf of JET is the study of the permeation of tritium through bellows. This is the first of a more generic series of experimental studies on tritium interaction with engineering components and therefore the title of the project.

The object of this experiment is to obtain data on tritium permeation through engineering components typical of those used on large fusion experiments that will operate with tritium. This experiment will deal with steel (SS AISI 316L) and Inconel 625 bellows used at JET to accomodate thermal movements, allow fine adjustments for alignment of components, allow operation of some components, give some degree of damping of mechanical shocks and in many cases permit very large movements of connected systems.

Of the two types of bellows used in JET (thin and thick-wall bellows), the present experiment will be performed on the thin-wall type, because their ratio A/x (area to thickness of the wall) dominates the overall permeation behaviour of the systems.

It is known that oxide layers are permeation barriers, provided the layers be intact. This condition might not be met in the case of bellows where a continuous flexing might produce cracks in the surface layer. The proposal is to do these experiments including mechanical flexion.

A further aspect to be considered is the chemical form in which the tritium will reach the atmosphere. Limited work in the area HT/HTO discrimination at low temperatures will be carried out. If significant HTO is found at low temperatures, no further discrimination work will be undertaken.

In order to approach the conditions of a fusion machine, the bellows under study will be heated and placed in an air atmosphere of 15% relative humidity. After evacuation of the bellows a suitable partial pressure of tritium will be introduced.

The conceptual design of the experiment has been finished and ordering of the required components has been started.

Fuel Cleanup System (F.C.S)

A selection of the type of modified zeolites has been made for each trap of the F.C.S. in such a manner so to have a sharp selective separation of the $(M,D,T)_2$ from the low Z impurities. The parameters that govern the behaviour of adsorption of each component in a mixture are the equilibrium and the transport coefficients [5]. So far, the equilibrium constants for single pure components have been determined by the adsorption isotherms obtained by breakthrough curves at different partial pressures for O_2, N_2, H_2, D_2 in the range of temperatures between 239 and 77 K on Na and Ca-NaM, while only few transport coefficients have been determined for H_2 and D_2 by the theory of moments [6] on Na-, Ca-Na, Ni-NaM. Theoretical evaluations will determine the campaign of experimental work on binary and ternary mixtures and the values of the coefficients obtained will be introduced in the mathematical model of adsorption processes already developed [7], for scaling of processes like the pressure swing parametric pumping , for which an apparatus has been set up and tested successfully for the enrichment of O_2 in air.

KINETICS OF DEUTERIUM DESORPTION FROM Pb-17Li EUTECTIC

The values of the deuterium mass transfer coefficient in the liquid film as well as the specific deuterium adsorption and desorption rates have been determined for the design of the tritium extraction unit for the blanket of a fusion reactor containing Pb-17Li as a liquid breeder material.

In addition to the design of tritium extraction units, the permeation of tritium into coolant is very important for its potential environmental impact and for the cost of the coolant detritiation plant.

Some years ago, experimental work was started at the Ispra laboratories to investigate the kinetics of hydrogen isotope desorption from Pb-17Li and its permeation from the liquid alloy to the coolant. In the previous "Institute for Safety Technology" report, the results related to the kinetics of D_2 desorption from the liquid Pb-17Li eutectic by helium gas were reported.

The mechanism determining the overall deuterium mass transfer rate, involving the molten Pb-17Li in contact with a gaseous atmosphere could be described by the following sequence:

- transport of the deuterium by diffusion and convection in the bulk eutectic;
- transport of the deuterium by diffusion through a layer of eutectic adjacent to the gas-eutectic interface;
- heterogeneous reaction at the interface leading to the deuterium atoms recombination;
- diffusion of the deuterium through the gas-phase boundary layer;
- transport of the gaseous deuterium molecules by diffusion and convection from the gas phase boundary layer in the bulk gas.

Over the whole temperature range explored, the experimental data lie very close to those obtained from a mathematical model over a wide range of helium flow rates. In the case of very high He flow rates the theoretical values are underestimated. This can be explained by the increased gas-liquid contact surface due to both the ripple effect on the alloy surface layer and/or to the helium gas impinging effect on the alloy.

ETHEL - The tritium handling experimental laboratory

While previous years have involved a significant amount of design work, 1990 can be considered the year during which ETHEL's fabrication and equipment installation activities. made substantial progress.
Difficulties during fabrication resulted in a delay of about four months since the previous annual report as shown in the attached figure.

Completion of the building's seismically qualified shell structure was reached in the spring. In parallel with basic civil work, general infrastructure activities such as the installation of the building's Heating and Ventilation system and Electrical systems proceeded. With regard to the former, component tests have commenced. Connection between the ESSOR distribution boards and ETHEL's Technical Gallery has been concluded.

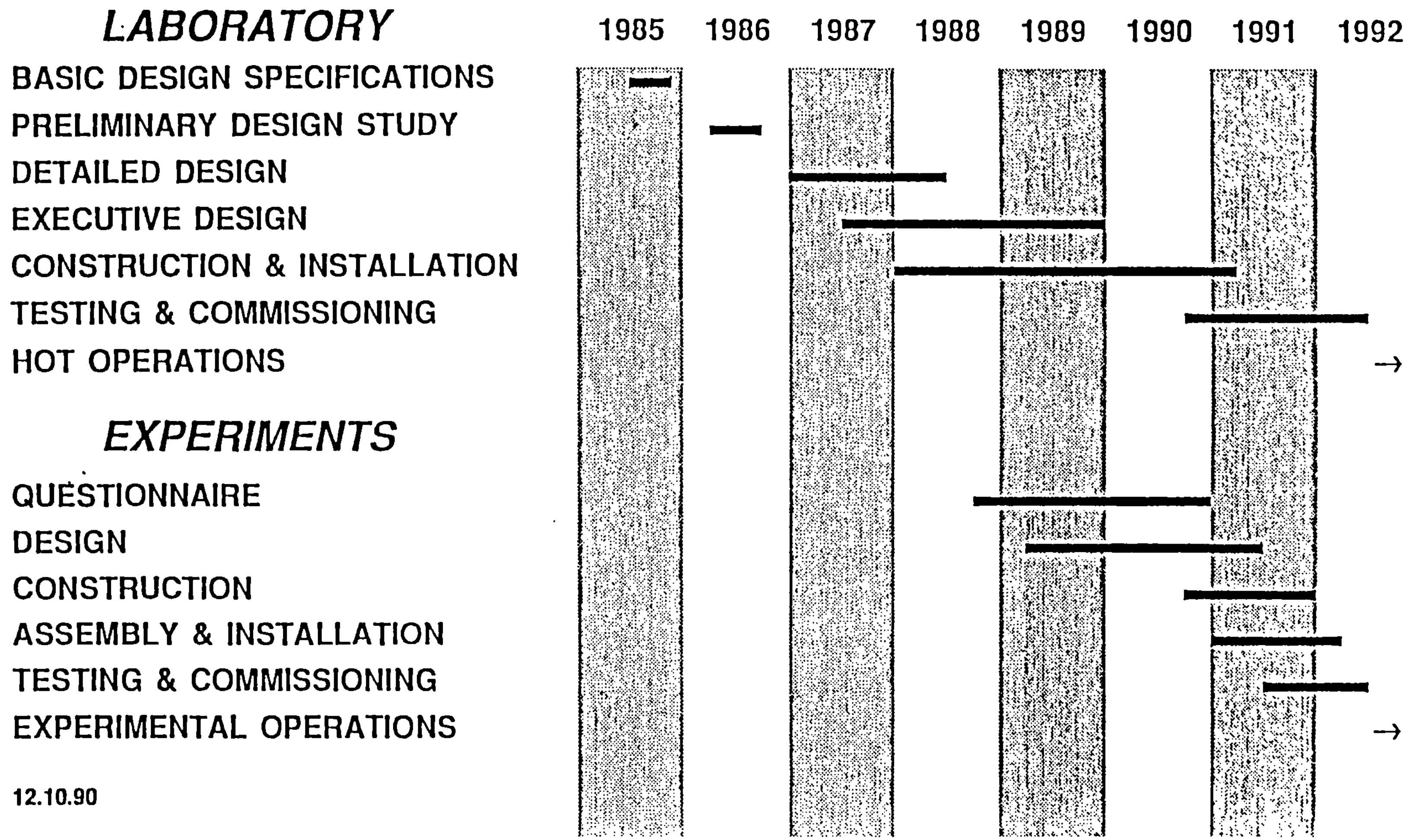
The Large Caisson is installed with on-site testing to be finished early 1991, the small caisson is nearing completion of off-site tests. Other containments envisaged for research purposes, basically the Experimental Glove-boxes, are all installed in the laboratory and undergoing final testing. Throughout the year, construction of all the principle tritium components, namely the Gaseous Detritiation System, has proceeded. All the detritiation units are now installed in the building and await connection to the containments they serve, i.e. glove-boxes, caissons,buffer tanks, an activity which will be completed early 1991. At the same time, the piping of the building's active drainage system and civil pipework. will be completed

The Waste Conditioning Plant and associated glove-box have undergone off-site testing with the secondary containment partially assembled within ETHEL, while the nearby SW Store crane is awaiting on-site tests.

Problems have arisen in both the Tritium Magazine and Radiological Protection systems because of delays in the delivery of key components. Concerning the former, installation of the system in the associated glove-box is proceeding although the U-getters are only expected to be available early 1991.

In parallel to the above activities, a commissioning organisation has been established with the architect-engineer. A general commissioning proposals document has been formulated from which the different procedures for commissioning the systems or groups of systems are being developed. The activity of contractual commissioning may commence before concluding the installation of the later systems (e.g. Tritium Magazine and RP) and is expected to last approximately 5 months after which a further 12 months will be devoted to JRC-Ispra commissioning, still without tritium, under the auspices of the Licensing Authority, ENEA-DISP.

Table 2 Scheduling of ETHEL and initial experiments



FUSION SAFETY
Thermal behaviour of divertor plate

In the framework of the studies for ITER (Fig. 4.4), JRC performed a parametric analysis [8] to understand the thermal behaviour of the monoblock divertor plate (Fig. 4.5), using data and wall loads (10-MW/m2 and 15-MW/m2) agreed with the Net-Team.

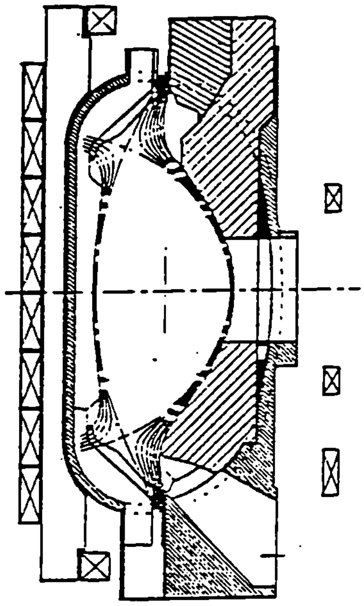


Fig. 4.4 - ITER elevation view

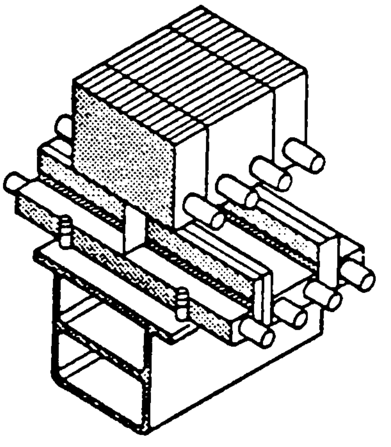


Fig. 4.5 - Monoblock divertor

The component consists of an armour of graphite tiles, each one crossed by two tubes of the water cooling system (Fig.4.6); the study takes into account many different thicknesses, three materials for the graphite (Pirolytic, Carbon Fiber Composite and SEP-carb.) and two for the tubes (Copper and Mo-Re alloy).

A preliminary investigation was made to define the thickness necessary to limit the surface temperature at 1273 K.

The accident analysis was related to LOCA's assuming plasma burning continuation or plasma shut down; the undercooling transients involved one single tube or both tubes, in order to evaluate the efficiency for safety of a design with two independent cooling circuits.

The results showed that for cases with plasma burning continuation, a double cooling system could be relevant for safety only if Pyrolitic Graphite (PG) armour and Mo-Re tubes are considered; for cases with plasma shut down also the SEP-Carb with Mo-Re tubes solution could be effective, but the results are strongly dependent on the plasma shut down transient.

For technological reasons, PG graphite can not yet be taken as the reference; assuming a plasma shut down time of 10 sec. and a wall loading of 15 Mw/m2, the best solution seems to be a 5 mm thick SEP-Carb. armour and 1mm thick Mo-Re tubes. The maximum temperature reached during the transient is of about 2000 K (Case s152 of Fig. 4.7).

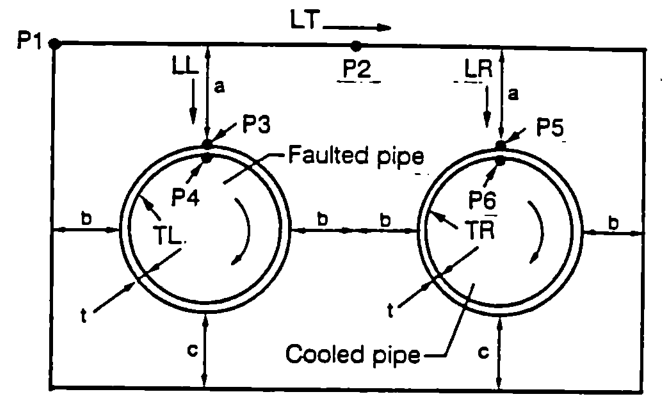


Fig. - 4.6 Divertor model

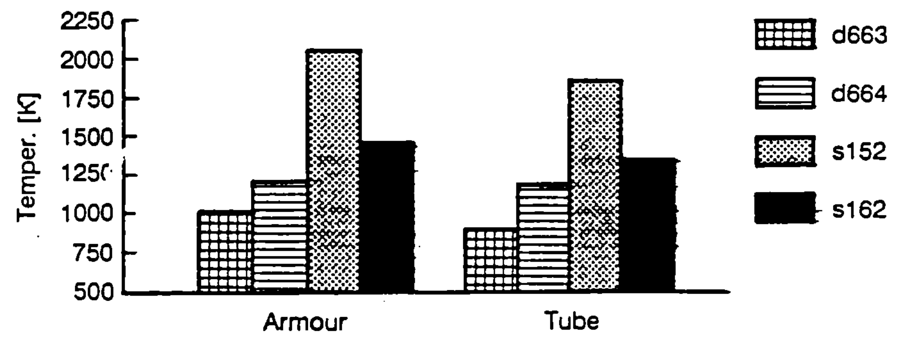


Fig. 4.7 - Max. temperatures for plasma shut-down

To improve the divertor design and in particular the SEP-Carb. thickness, the effects of the sweeping of the separatrix moving around its center was studied also [9]; this condition generates a thermal load varying in time on the divertor plates.

The component behaviour was evaluated for a nominal sweeping of 0.3 Hz and also in accidental cases such as a Loss Of Sweeping Accident (LOSA), change in sweeping frequency (from 0.3 Hz to 0.1 Hz) and change in sweeping peak (from 15 Mw/m2 to 30 Mw/m2).

The results lead to the preliminary conclusions that a plasma sweeping of 30 mm radius around the null point with 0.3 Hz of frequency can reduce the average divertor surface temperature allowing a 16 mm thick armour.

The loss of sweeping accident has no immediate major consequences, but the plasma must be shut down to avoid important erosion due to the high temperatures reached during the steady state.

The change in frequency from 0.3 Hz to 0.1 Hz does not produce very important peak temperature changes (fig. 4.8) but the amplitude of the thermal cycle becomes much higher; the consequences in terms of structural stability of the graphite must be assessed.

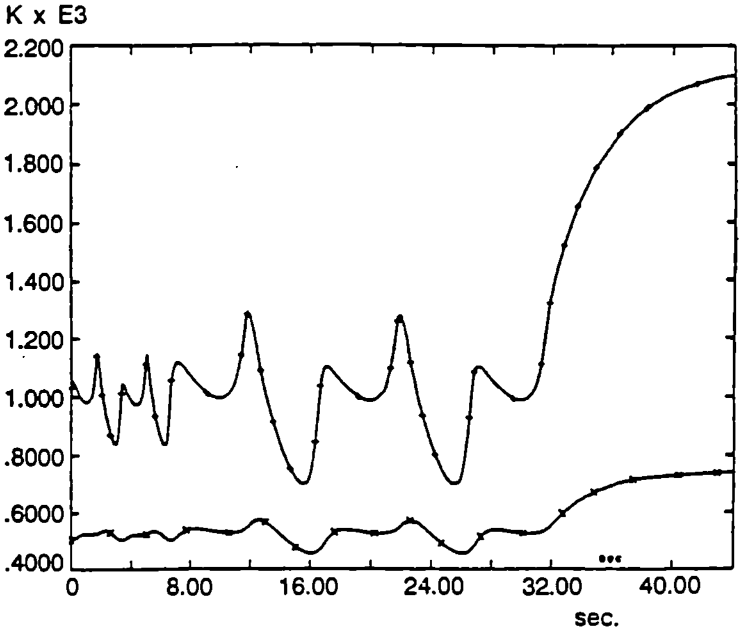


Fig. 4.8 - Temperature history resulting from change in sweeping frequency

The change in peak flux from 15 MW/m2 to 30 MW/m2 raises the mean temperature of about 1000 K (Fig 4.9), leading to a peak of about 2400 K; high erosion rate of the armour must be expected, so that the plasma must be shut down to avoid major hazards.

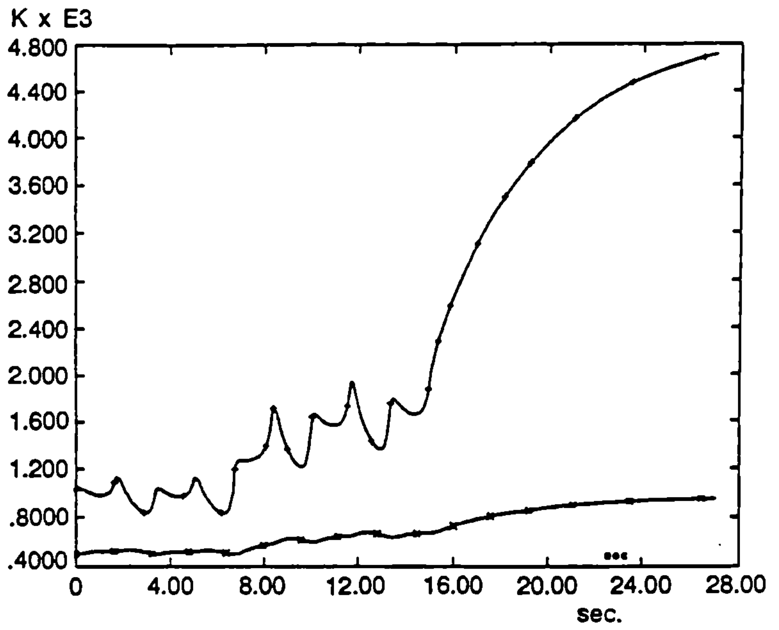


Fig. 4.9 - Temperature history resulting from change in peack flux

THERM - Status of the development of the programme

THERM is a bidimensional F.E. computer programme developed at JRC/STI/AMD for the analysis of the severe thermal transients of the plasma-facing components of fusion reactors.

The development of the code has been completed; it is strictly interfaced to CASTEM-2000 being based on the same structure of objects assumed as the standard communication system between the programmes.

All the analyses related to ITER and furnished to the NET-Team were performed with THERM and included as "home-work" in the ITER report.

Pb-17Li/water interaction tests

Pb-17Li/water interaction experiments simulating a large break in a liquid metal blanket module (water cooled) have been performed in the BLAnket Safety Test facility (BLAST) installed in the JRC Ispra Laboratory.

During the reporting period, three large scale tests (470 kg Pb-17 Li) have been performed in the BLAST facility under the conditions listed in the following table:

Table 3

BLAST	7**	8*	9***
Melt temperature (°C)	350	500	350
Coolant Temperature (°C)	225	225	260
Injection pressure (bar)	60	60	100
Subcooling (°C)	50	50	50
Injection time (s)	4	4	4
Injector penetration in the melt (mm)	50	50	50
Expansion tube (mm)	8	50	8

* with tube bank
** with tube bank and vent passage of 8 mm Ø for a length of 200 mm
*** with tube bank and vent passage of 8 mm Ø for the total expansion tube length (2.1m)

The results can be summarised as follows :

- the melt temperature increase from 350°C to 500°C (BLAST 8) does not appear to have much influence on the pressurisation history of the reaction vessel (the pressure never exceeded the actual water injection pressure), but measurements show that the maximum temperature increase near the inection tube is about 200°C;

- a different picture, as far as the pressurisation of the reaction vessel is concerned, is obtained in the BLAST experiments performed with strong throttling between the reaction vessel and the expansion system (BLAST 7 and 9).

In comparison to other BLAST tests, these experiments prove that the pressurisation phase is more rapid than the observed previously and the pressure in the reaction vessel is higher than the injection pressure (the maximum values are : 100 bar at 60 bar injection pressure, and 130 bar 100 bar injection pressure) for a period of time of approx. 200 ms. During this time, the pressure decreases until the actual water injection pressure is reached. The quantity of injected water in these tests was very small, 0.27 kg in BLAST 7 and 0.35 kg in BLAST 9, whereas in the other BLAST experiments the average was 1.4 kg;

all the BLAST experiments indicate that the chemical reaction is self-limiting and, due to the hydrogen generation and production of solid LiOH and Li_2O, the melt is partially insulated from the water so that energetic vapour explosions appear unlikely.

BEHAVIOUR OF MECHANICAL PROPERTIES UNDER IRRADIATION : FATIGUE CRACK GROWTH UNDER LIGHT ION IRRADIATION IN THE CYCLOTRON

Scanning electron microscopy (SEM) examination of the fatigue fractures surface of AISI type 316 stainless steel specimens, irradiated and unirradiated, were carried out. The results of the fractography can be summarised as follows :

- the fracture surfaces of AISI 316 stainless steel type fatigued at 100. 200 and 300°C exhibit a transgranular mode fracture which is characterised by a ductile failure process. The appearance of crystalline fractures, typical striations and tearing dimples characterises the three stages of fatigue crack propagation;

- the striation spacings correlate well with the crack growth rates calculated from macroscopic measurement of the crack length and number of cycles in a certain stress intensity range;

- the coexistence of striations and dimples indicates that there exists a transition from the pure fatigue striation mechanism to a void coalescence mechanism of crack propagation along with rapidly increasing crack growth rates. The tearing dimples and tearing ridges are an indication of a better ductile failure process in this temperature range;

- fracture surfaces of the specimens irradiated by in-beam20 MeV protons are quite different from those of unirradiated specimens. This is attributed to the irradiation hardening which causes the slightly low rate of fatigue crack growth at low fluence and low temperature [10].

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1.1.5. INDUSTRIAL HAZARDS

Introduction

The objective of the work is to investigate process and equipment failures in the chemical and process industries. Emphasis is on elucidating transport phenomena associated with the following sequence of events:

- anomalies in operation of chemical reactors (section 2),
- emergency fluid discharge and dumping (sections 3 and 4),
- release of hazardous fluids with subsequent dispersion and possible explosion (sections 5 and 6).

The development of relevant flow measurement techniques is described in section 7.

Work is expected to contribute to safe plant design and operation, validation of simple models for use in risk analysis, and to formulation of acceptable guidelines for safety methodologies in industry.

Process Dynamics Close to Runaway in Batch Chemical Reactors

The FIRES Project

Research on process dynamics in conditions close to runaway is carried out in the FIRES Project (Facility for Investigating Runaway Events Safely).

The main objective of FIRES is the study of off-normal behaviour of batch and semi-batch chemical processes, specifically:

- To develop criteria for the inherent safety of processes by studying the characteristics of reactive mixtures and determining the critical operating conditions.
- To study and develop measures for the prevention of uncontrolled thermal excursions and the associated overpressurisation phenomena, including control and early detection systems, and interlocks.
- To apply the knowledge gained to develop an expert system to assist (on-line) and to train (off-line) plant operators.

The experimental facility installed within a bunker comprises a fully automated chemical batch reactor equipped with sensitive measuring devices, and provided with an early warning detection system, shutdown systems, and emergency pressure relief, so that hazardous chemical reactions can be investigated safely [1].

In parallel with the experimental facility, a mathematical simulator of FIRES (FISIM, FIres SIMulator) has been developed in order to ensure good performance and optimal exploitation [2]. For a given case study, the simulator serves as an aid and a complement to experiment design, and subsequent data analysis. Furthermore, it is capable of performing parametric sensitivity analysis, to assess optimal and safe operating conditions and to follow the behaviour of the system when failures arise. At a later stage of the development, this tool will be used for estimating kinetic data, assessing emergency shut-down procedures, on-line monitoring and control [3].

In addition to the main experimental facility, a calorimeteric laboratory has been set up which is now fully operational [4]. Three main apparatus is used in order to gain basic knowledge of the chemical processes prior to their investigation in the FIRES reactor: a differential scanning micro-calorimeter, a small scale reactor and an adiabatic bench-scale apparatus for venting studies.

The chemical processes, on which attention is presently focused, are:
- toluene mononitration by mixed acid,
- suspension polymerisation of methyl methacrylate.

The main reasons for this choice are the industrial importance and high exothermicity of these reactions, and the fact that they have given rise to a relatively high number of incidents in the past [5].

Achievements

The following work has been performed in 1990:

- Assembly and characterisation of key elements of the FIRES facility, including commissioning of control and data acquisition systems and preliminary experiments to calculate heat capacities, heat transfer coefficients, heat losses, and stirring effects in the reactor vessel.

- Neutralisation experiments between hydrogen chloride and sodium hydroxide to study the dynamic behaviour of the installation and to adjust the simulator FISIM for the FIRES reactor. These experiments were carried out in semibatch mode under isothermal (see Fig. 5.1) and adiabatic wall conditions, modifying the feed rate of NaOH and consequently the power generated by chemical reaction [6].

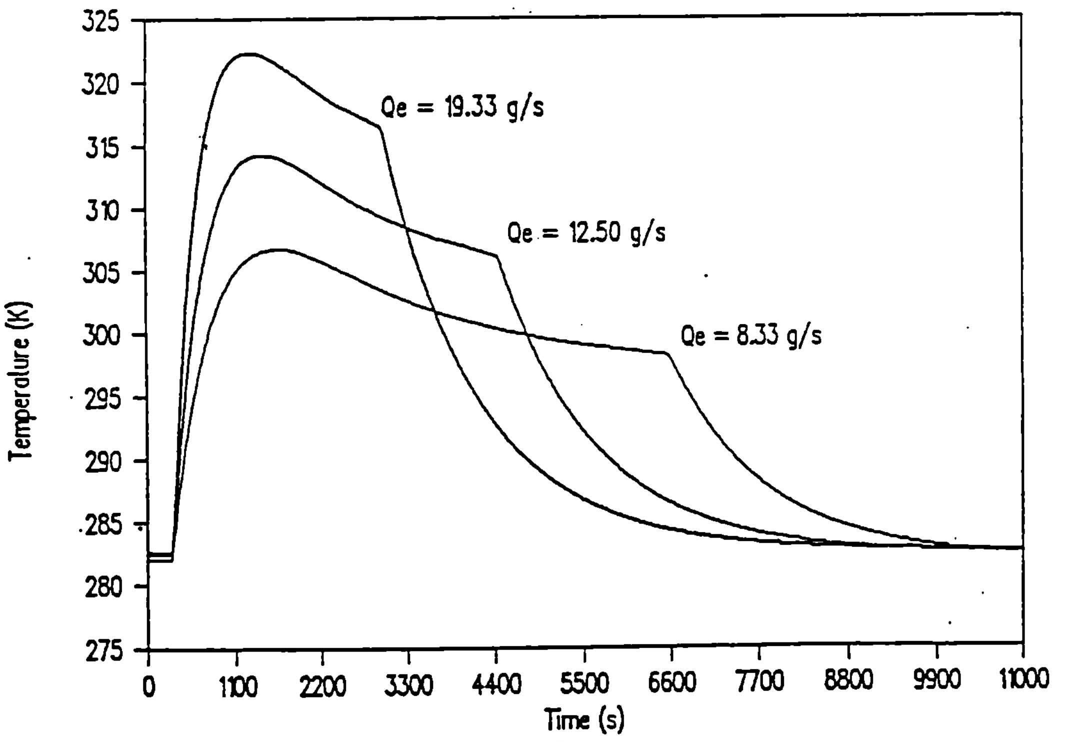


Fig. 5.1 Neutralization experiments between hydrochloric acid and sodium hydroxide in the FIRES reactor. The jacket temperature was maintained constant (at approximately 9°C) and a sodium hydroxide solution (30% in weight) was added at different feeding rates, Qe, to a hydrochloric acid solution (32% in weight) until complete neutralization.

- Esterification reaction experiments between 2-butanol and propionic anhydride were started at the end of February in collaboration with the UK Health and Safety Executive, Buxton Laboratory. The first experiments were carried out in the reaction calorimeter (RC1) and in the adiabatic vent sizing calorimeter (PHI-TEC) to obtain kinetic data and investigate runaway reaction phenomena, and early warning detection techniques [7].

  The esterification reaction experiments were subsequently performed in the 100 liter FIRES reactor in August 1990 (see Fig. 5.2). These experiments successfully demonstrated how an exothermic reaction can proceed under subcritical (controlled conditions) and supercritical (runaway conditions). Data from these experiments are being used to validate scaling criteria for heat transfer and runaway reaction predicton, as well as calorimetric techniques such as DSC, ARC, PHI-TEC, and RC1. Temperature-time profiles from the FIRES experiments are used to validate kinetic schemes from the small-scale tests (see Fig. 5.3), and for the adjustment of the FISIM code.

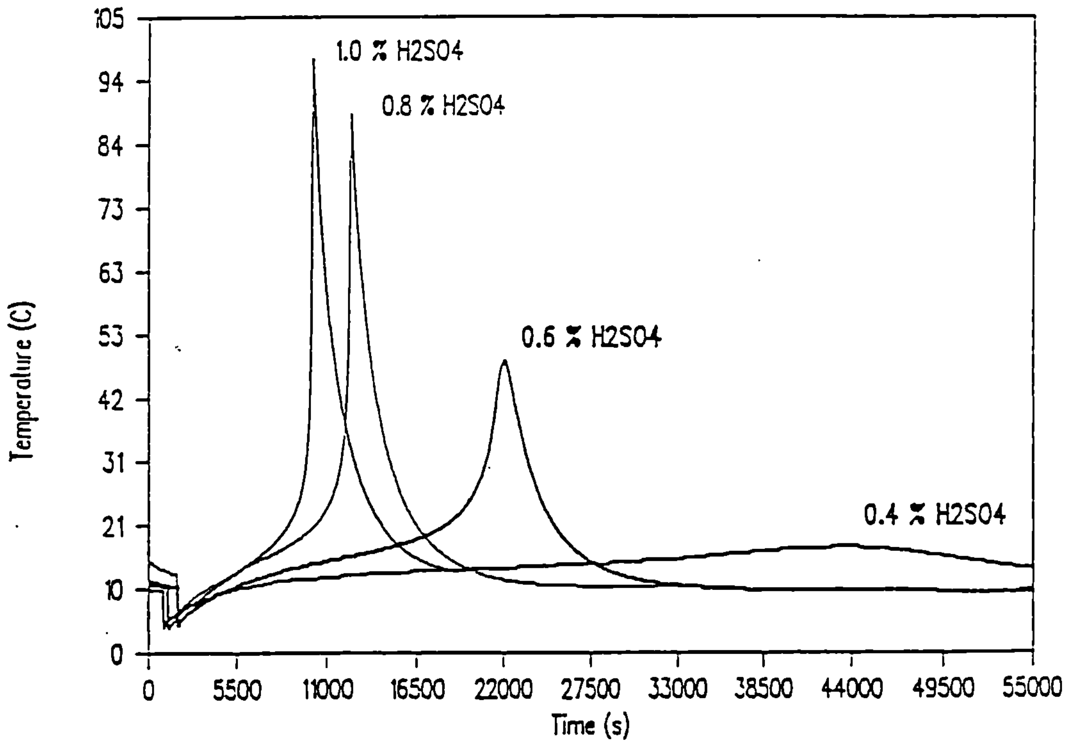


Fig.5. 2 Experiments on the esterification reaction between propionic anhydride and 2-butanol carried out using the FIRES facility. 2-butanol containing various concentrations of sulfuric acid was added to the reactor and allowed to reach thermal equilibrium, the propionic anhydride was then rapidly introduced (the initial drop in temperature is associated with endothermic mixing of the reagents). The catalytic effect of sulfuric acid on the rate of reaction can be seen from the changes in the reactor temperature-time profiles, with high acid concentrations leading to exothermic runaway.

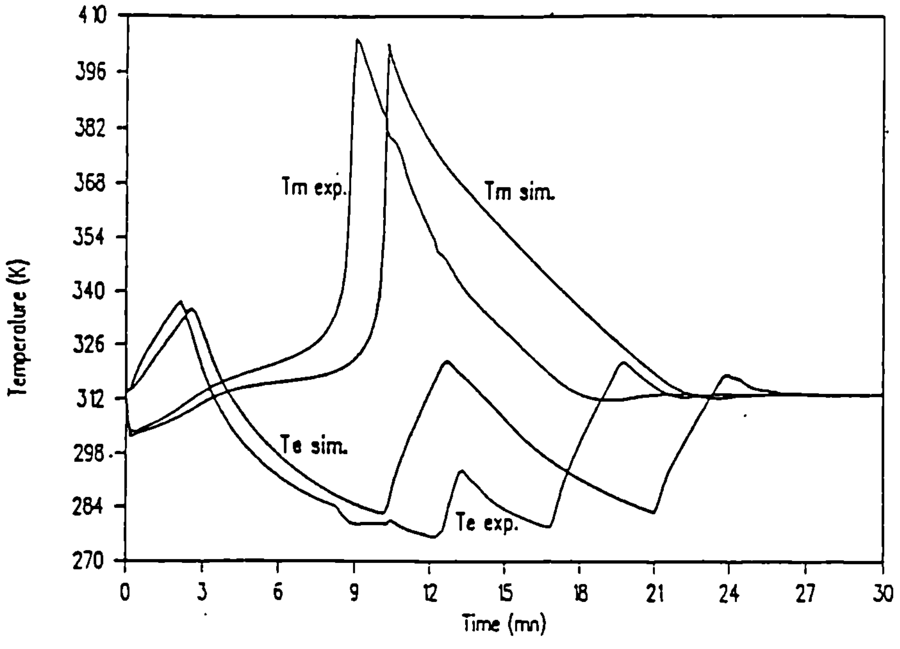


Fig.5. 3 Experimental and simulated temperatures of the reacting mass, Tm, and the heating/cooling jacket (Te) in a runaway scenario in the RC1 reaction calorimeter for an isothermal esterification.

- The experiments on toluene nitration in the small scale reactor were pursued in order to prepare those in the FIRES reactor [8].
- Modelling of fast equilibrium reactions have been introduced in FISIM.
- Model based applications for the on-line estimation of the state variables (temperatures, pressures, and concentrations), the early detection of runaway initiation, and the adaptive control of the reactor were tested [3, 7].

Near future

It is foreseen to start in 1991 the toluene nitration experiments in the FIRES facility, first of all with normal industrial conditions in order to characterize the influence of the operating conditions (concentrations, stirrer speed, starting temperature, stream feed, etc.) and to optimize the process from a performance and safety point of view. In parallel, study of methods of early detection of runaway initiation for this reaction will be carried out.

At this point the experimental results will be used for the adjustment of the heterogeneous two liquid phase kinetic model developed in FISIM, and for precalculations in order to help the experimental design of the second phase.

In a second step, there will be experimental simulation of failures: influence of the cooling system failure, of the stirrer stopping, of the speed of stream feed, of incorrect initial concentrations, of incorrect starting temperature. The objective is to assess safe operating conditions and criteria to avoid thermal hazards.

Finally, the study of different methods to stop the runaway: fast injection and emergency emptying will be carried out.

Concerning FISIM an interesting development will be its conversion into a general and user friendly simulation code able to deal with any type of batch installation.

Investigation of Multiphase Flow Phenomena in Reactor Relief Systems During Venting (project MPMC)

Experimental Work

The Multi-Phase Multi-Component test facility has been modified to allow a study of venting during a runaway reaction. A series of tests involving the decomposition of hydrogen peroxide was successfully completed in June 1990. For one of the tests, Fig.5. 4 shows the pressure variation in the 50 litre vessel during runaway and subsequent emergency venting through a rupture disc. Conditions for this test were: 80% initial vessel filling, 11.5% mass concentration of hydrogen peroxide in water and 80 g ferric sulphate used as catalyst. The results of the tests and their implications for safer relief system design are being discussed with industry.

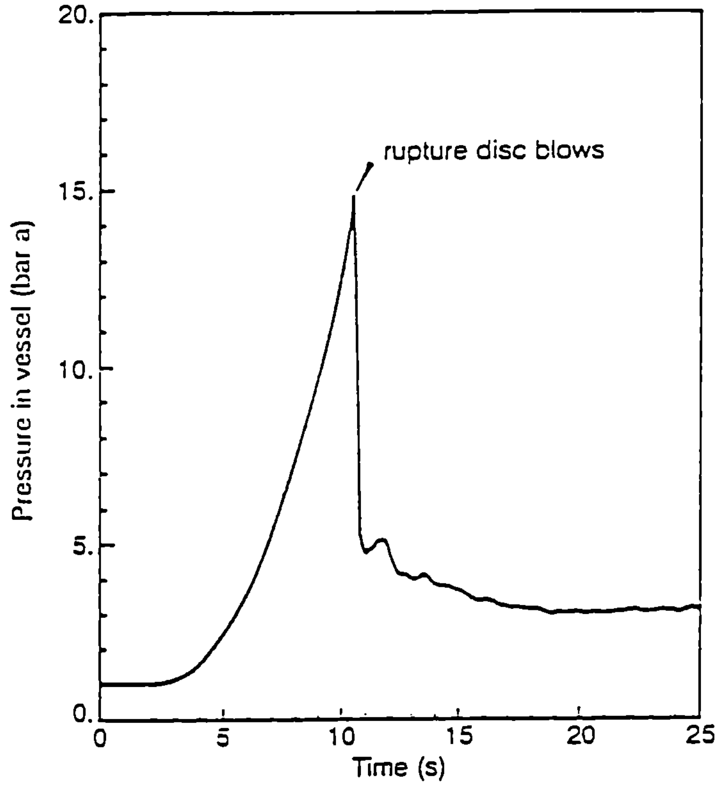


Fig.5. 4 Measured pressure in MPMC reaction vessel showing emergency venting during runaway (decomposition of hydrogen peroxide)

Currently, a series of tests is underway to study the possible effects of solid particles being carried over with the fluid during emergency venting. The industrial interest in these tests centres on the degree of carry-over of the particles as well as their possible effect on the rate of discharge of the fluid.

In addition, a number of small-scale flow visualisation tests have been conducted with a 13 litre glass vessel with the aim of providing some insight into the complex two-phase flow processes occurring during venting, particularly when high viscosity fluids and foams are involved. Measurements have also been made of the void fraction of air bubbling through high-viscosity liquids in a 400 mm diameter perspex vessel. Visual observations and measurements show that the void fraction, α_{total}, has two components: one component, $\alpha_{emulsion}$, is due to the formation of a microbubble emulsion and the other, $\alpha_{large\ bubbles}$, due to large bubbles rising quickly through this emulsion (see Fig. 5.5). Then

$$\alpha_{total} = \alpha_{emulsion} + (1 - \alpha_{emulsion})\, \alpha_{large\ bubbles}$$

These observations are now proving useful to the theoretical modelling activities.

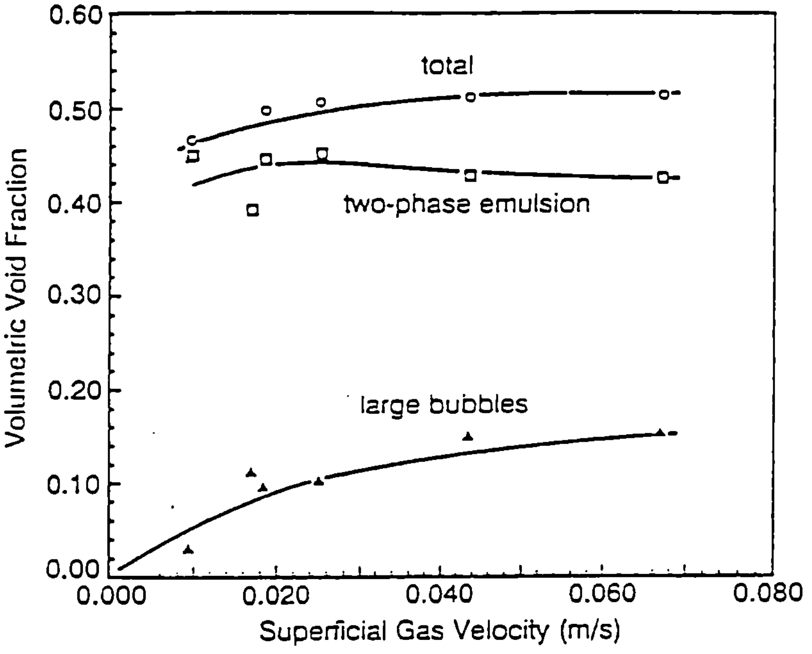


Fig. 5.5 Void fraction components (emulsion and large bubbles) during bubbling of air through a high-viscosity liquid (3000 mPas).

Analytical Work

This analytical work, which continues in parallel with the experimental work, has concentrated on three topics: (a) a study, through computer program predictions, of a number of depressurisation studies relevant to industry [9, 10], (b) development of a practical method for sizing safety devices under compressible two-phase flow conditions and (c) prediction of the effect of high viscosity on the void fraction during depressurisation [11]. Topics (a) and (b) above have been completed and results formally presented at conferences.

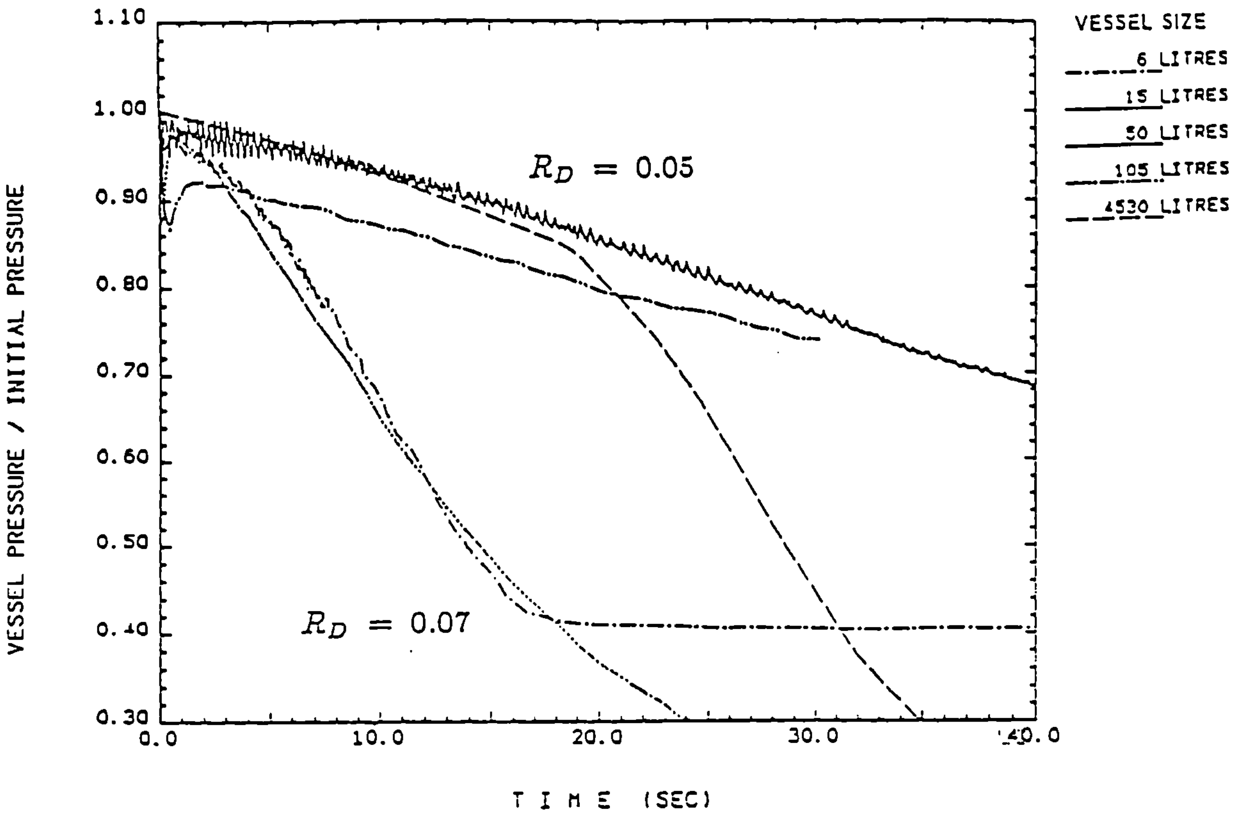
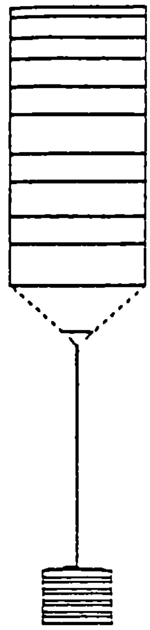


Fig. 5.6 Typical scaling comparisons for the pressure in the vessel; experimental data from different vessel geometries. R_D is the ratio of vessel diameter to vent diameter.

For the interpretation of experimental data, during 1990, the main attention has been given to difficulties associated with scaling from small size vessels to larger vessels [9, 12]. Fig. 5.6 is an example of the comparisons made with data from different test facilities for top and bottom venting of five vessels with a volume ranging from 0.006 to 4.53 m^3. As is shown in this figure, for test facilities with the same vent-to-vessel diameter ratios, the initial rates of depressurisation are approximately equal.

In addition an analysis has been made of the effect of liquid viscosity on vented mass [9, 13]. High viscosity liquids can lead to a flow regime similar to that of foaming fluids, where almost the whole vessel contents are vented. However, large increases in the viscosity may result in less mass being vented from the vessel. The experimental data obtained indicate that, for the understanding of these phenomena, further development of two-phase flow models is required.

Vessel:	
Volume:	0.050 m^3
Diameter:	0.40 m
Height:	0.40 m
Vent pipe:	
Diameter:	0.02 m
Length:	1.8 m
Quench tank:	
Volume:	1.0 m^3
Diameter:	0.8 m



Pre-Relief Conditions:	
Pressure:	5 bar
Void Fraction:	0.25
Back Pressure:	1.0 bar
Vessel cells:	10
Pipe cells:	9
Quench tank:	11

Fig. 5.7 The grid used for closed system calculations in MPMC.

A new programme of analytical work has recently begun, concerned with improving the design criteria for equipment downstream of vent systems, e.g. catch tanks, knockout drums, scrubbers etc. This topic is now viewed as a priority area by industry in expectation of more stringent regulations regarding the discharge of substances to atmosphere. Consequently, work on this topic will expand in the coming year. For the time being, and for the understanding of the hydrodynamic phenomena occurring downstream of the primary vessel, preliminary calculations have been carried out in simplified closed systems [9, 13]. The layout for the calculations in such systems is shown in Fig. 5.7 which includes the primary vessel and the dump tank. These studies will be supported by further experimental work on the MPMC facility.

Computational Models for Emergency Relief

Development of the emergency venting code RELIEF

For sizing emergency relief systems, required by safety rules, it is necessary to dispose of adequate and validated computational models which must be based on a correct description of the chemical conversion, of mass transfer between the liquid and vapour phases, of two-phase fluid dynamics and of the interactions among these processes.

The code RELIEF, formerly known as VESSEL [14], is currently being developed at the JRC. It is a two-phase transient thermohydraulic code and is based on a one-dimensional description of the governing processes. It is designed to handle an arbitrary number of chemical species (both inert and reactive) and can model ongoing chemical reactions of differing order.

The vent line dynamics are treated separately since different physical phenomena dominate this process. A choice can be made when determining the critical discharge rates between a rather simple one-node model (which are almost universally used by industry), and a multi-node model (under development) which computes the axial variation of component composition and includes the effect of an ongoing chemical reaction. Supportive fundamental work concerning non-equilibrium effects in critical flow has been performed in conjunction with the University of Louvain [15].

During 1990 the bulk of the effort has been directed towards the implementation of a one-dimensional treatment of the component concentration variation in the two phases. In this way the importance of axial component concentration gradients on the venting process can be assessed.

In parallel with this activity parametric studies have been performed to assess the relative importance of vent line location, scaling effects, interfacial drag forces, and reaction type on the vessel pressure history. A review of this work has been presented at the Eurotherm seminar on "Heat Transfer and Major Technological Hazards" [16].

Also in 1990 validation of the code has been performed using experimental data obtained from the Multi-Phase-Multi-Component test facility of the JRC.

A start has also been made on the development of a user-friendly, menu driven input processor.

To facilitate the easy access to thermophysical and transport property data the package PPDS [17] has been purchased and implemented on the departmental and central computers of the JRC.

Assessment of codes

The final report [18], for the Benchmark Exercises on the emergency venting of vessels containing non-chemically reacting fluids under high pressure, became available early in 1990. In these exercises it has been concluded that the phenomenology of the depressurisation transient is governed by the composition of the two-phase mixture discharged from the vessel. If this mixture is predominantly liquid with small vapour entrainment the initial depressurisation rate is small and high frequency pressure oscillations are observed in the vessel and in the ventline. These oscillations seem to disappear when a predominantly vapour mixture is expelled from the vessel. The occurrence of these processes and their significance during a blowdown transient is characterised by the various geometrical, operational and physicochemical parameters associated with each test facility.

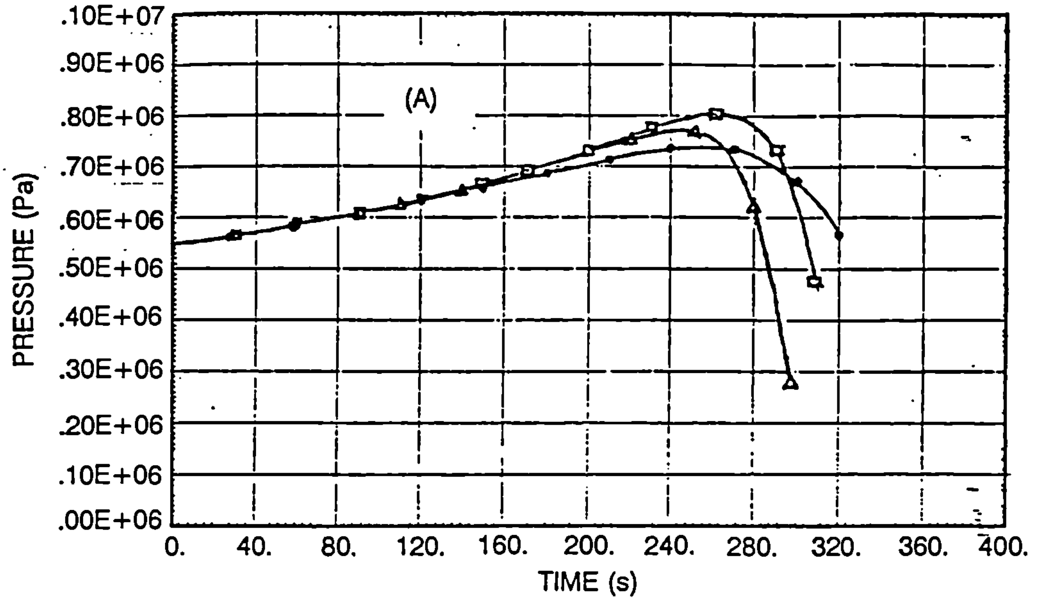
The main features of the codes used are :

Name of the CODE	Nodes in the Vessel	Nodes in the Vent-line	No. of Chemical Reactions	No. of Compo-nents	External Heat Fluxes	Two-phase Flow Models
RELAP5	Several	Several	-	1	Yes	According to flow regime
SAFIRE	1	8 or 50	10	10	Yes	Two drift-flux models
RELIEF	Several	Several	10	10	Yes	Drift-flux
DEERS	Several	Several	4	6	Yes	Drift-flux

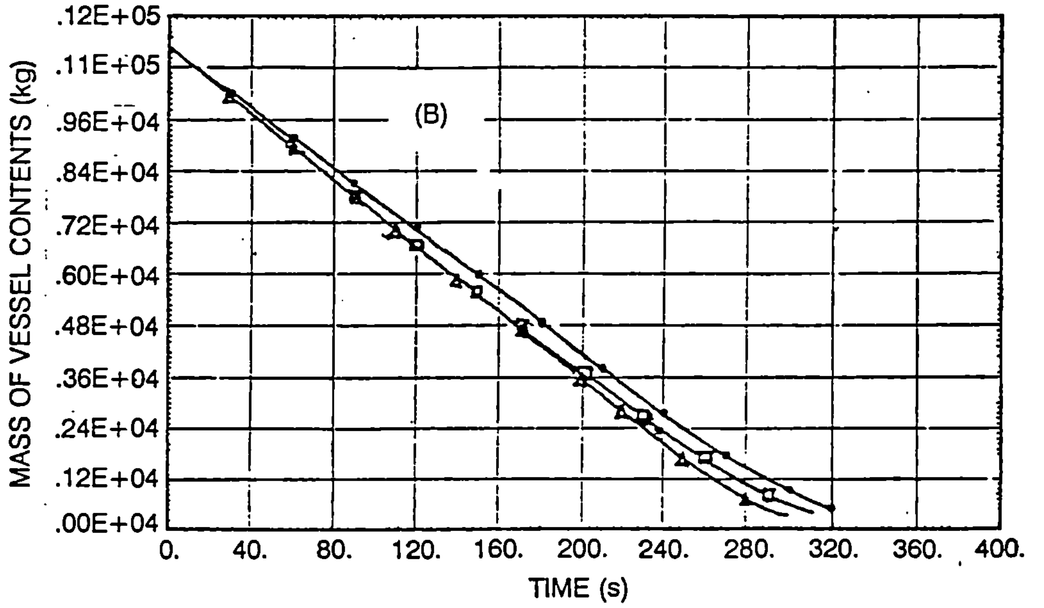
An additional aim of these exercises was to compare the code RELIEF developed at the JRC with the codes SAFIRE and RELAP5. Both these codes originated in the U.S., however, for the RELAP calculations the version EUR/MF, improved locally, has been used. The comparisons carried out have highlighted the need of realistic two-phase flow models and they demonstrated the significance of one-dimensional solutions at least in the vessel. During 1990, the same calculations have been carried out with the U.S. code DEERS [9, 10].

Preparatory Activities for the Implementation of the "Seveso Directive"

Invited lectures on batch reactor/storage tank safety issues have been presented at four Seminars (Université Catholique de Louvain, Louvain-ia-Neuve; Federchimica, Milano; Institut Químic de Sarriá, Barcelona; FAST-RICH 90, Milano).
In order to provide quick and inexpensive Emergency Relief System (ERS) design/verification service using simplified formulations of the DIERS type, an assessment of these methods has been performed. The scope of this exercise was to investigate the limitations and to evaluate the degree of accuracy of such formulations in different vent system geometries (nozzles, long pipes) and for various materials (toluene, butanol, methylpentane, methanol) submitted in a reactor tank to an external heating of 40 kw/m^2. In Fig. 5.8, the pressure and the reactor inventory time histories after vent opening (at time zero), calculated with the simplified formulation (Leung) and with the computer code SAFIRE, are shown for toluene (nozzle vent). The simplified methods have been found sufficiently adequate for providing conservative ERS sizing for this type of liquid.



Toluene: Nozzle model (external fire)



Toluene: Nozzle model (external fire)

Fig. 5.8 Pressure (A) and vessel mass (B) versus time in a reactor submitted to an external heating of 40 kw/m^2, and containing toluene in saturation conditions with a filling ratio of 90%, calculated with:

□ Simplified Leung formulation
△ Computer Code SAFIRE with constant material properties
● Computer Code SAFIRE with temperature-dependent material properties

Dispersion of Dense Vapour Clouds

The aim of this project is to provide enhanced numerical methods to predict the behaviour of heavy gas accidentally released to the atmosphere. Both the quasi-instantaneous release resulting from the complete failure of a containment structure and the more frequent small-scale continuous release are considered.

The research concentrates on the application and further development of the 3-D finite volume code ADREA-HF and a simpler computation tool based on the shallow layer approach. The work is performed in the frame of a collaboration with the Centre Demokritos of Greece and in association with the ongoing and future Shared Cost Action programmes on Major Technological Hazards.

A key feature of the ADREA-HF code is the capability of treating in an efficient and userfriendly manner the domain boundaries of highly complex terrain and to model directional time-dependent sources of a heavy fluid (gas, liquid or two-phase mixture) at arbitrary locations of the computational domain.

The main objective of the shallow layer model is to provide a more realistic substitute for the simple box-models, which at present are widely applied in industry. In the box-models all properties are assumed constant (or profiles are assumed a priori) within the cloud in both the vertical and horizontal directions, whereas in the shallow layer models the properties are averaged over the cloud height only.

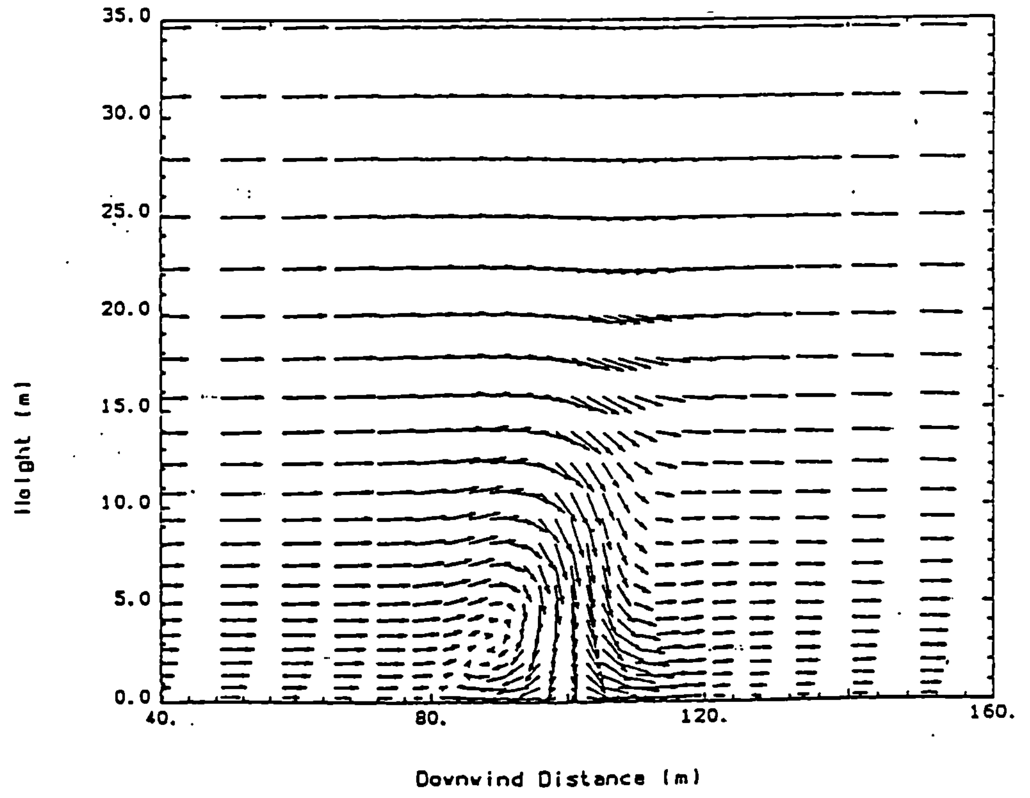


Fig. 5.9 3-D simulation of Thorney Island test no. 8 with ADREA-HF. Calculated flow pattern in the vertical plane at 2 seconds after the release. The initial gas cloud had approximately the shape of a vertical cylinder with a volume of ca. 2000 m³. The density relative to air was 1.63. The wind velocity at 10 m height was 2.3 m/s.

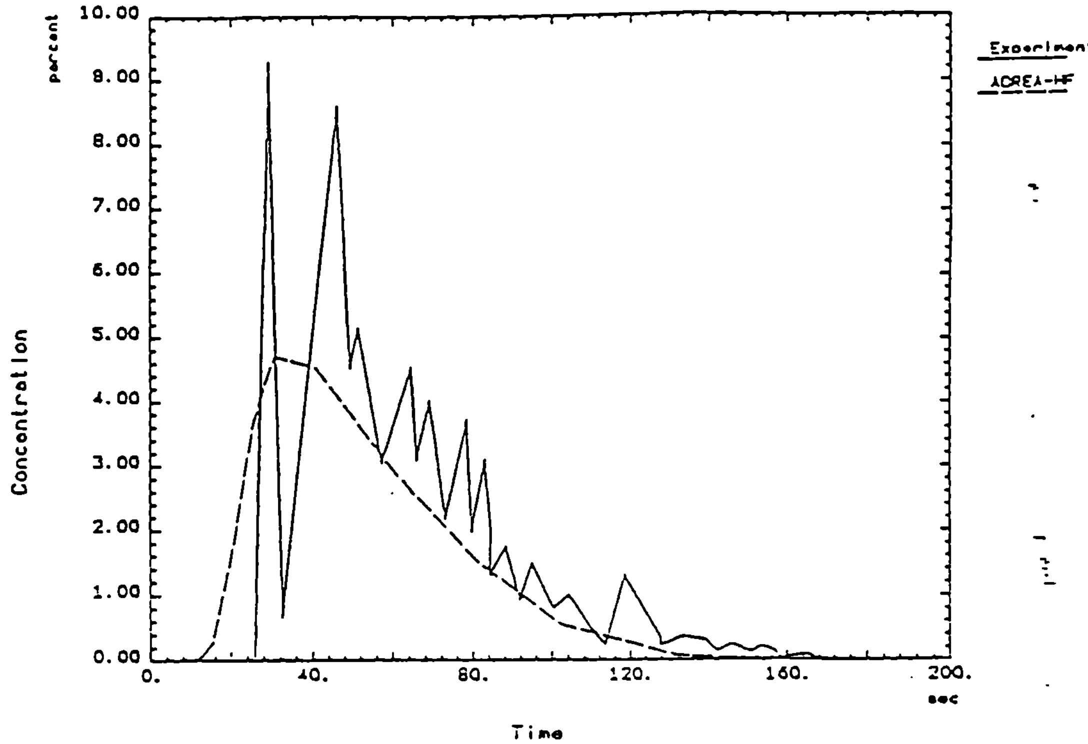


Fig. 5.10 3-D simulation of Thorney Island test no. 8 with ADREA-HF. Comparison between the calculated and the experimental concentration history at ground level ca. 70 m downwind of the release position.

During 1990 the main activity for the ADREA-HF code has been to examine different turbulence models by comparing the calculated results with experimental data from the Thorney Island field experiments [19]. In Fig. 5.9 is shown the calculated flow field in a vertical plane from a 3-D simulation. The cloud was initially contained in a vertical cylinder which collapsed instantaneously. The figure illustrates the characteristic slumping process of the cloud induced by the gravity. In Fig. 5.10 a typical comparison between the calculated concentration history and the experimental recording is shown. The figure illustrates the capability of the code to predict the time averaged concentration.

A 1-D version of the shallow layer model has been developed during 1990. This version has been applied to prediction of 2-D wind tunnel experiments with and without obstacles. In Fig. 5.11 is shown a comparison between experimental [20] and calculated values of the steady state concentration in the immediate lee of a solid fence for a continuous release. The influence of the fence height on the dilution of the cloud is seen to be taken adequately into account by this rather simple model.

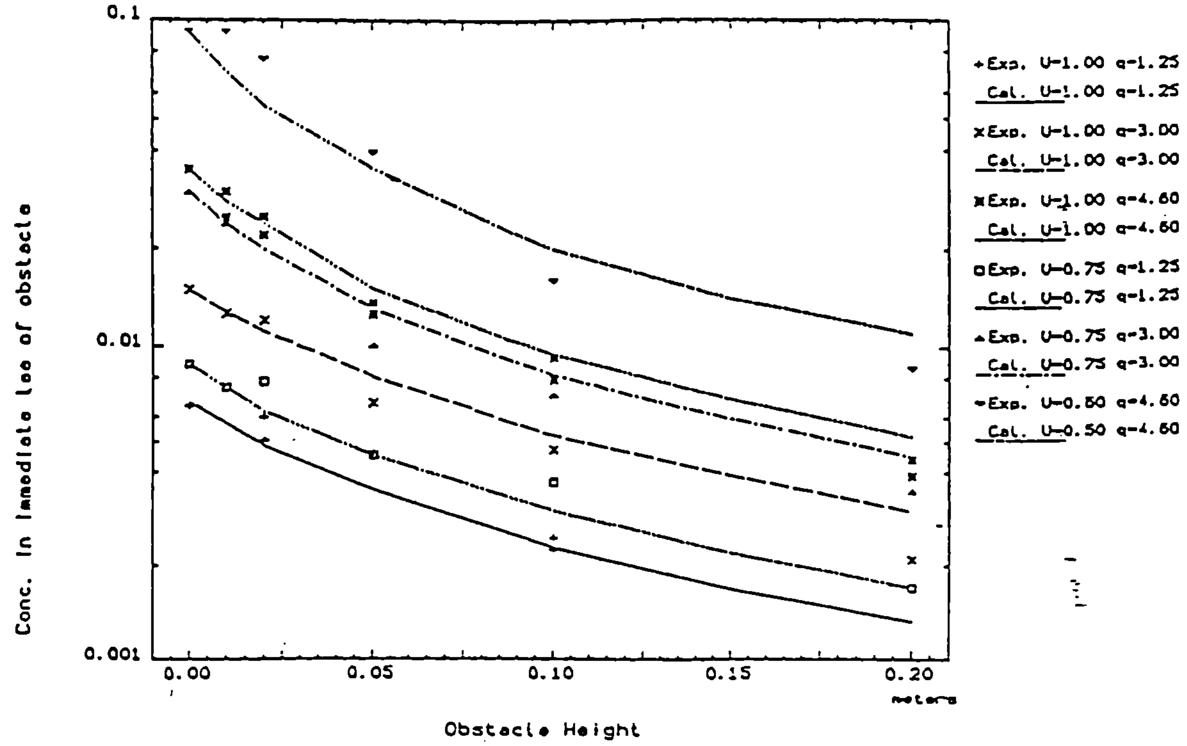


Fig.5.11 Predictions of 2-D Wind Tunnel experiments [20] with the 1-D shallow layer model. The fence was located 1.5 m downwind the continuous 2-D source. The experiments were performed with wind velocities (at 16 cm height) U of 0.5, 0.75 and 1 m/s, and source flow rates q of 1.25, 3.0 and 4.6 cm^2/s. The density relative to air was 1.52.

For 1991 is planned an extension of the shallow layer model to 2-D and an introduction of 2-phase flow capabilities (especially those related to release) in the ADREA-HF code.

Numerical Simulation of Reacting Gas Flows

Introduction

The numerical simulation of reacting gas flows represents a relative new research activity at the JRC Ispra. The work actually started in September 1989. The major objective is to provide numerical tools for the safety studies where detonation processes are of major concern: prediction of thermal and mechanical loads on structures due to the combustion of vapour clouds, flame front and detonation/blast wave propagation. In addition, the methodology applied and the computer program under development are of relevance also for a wide spectrum of applications in the area of numerical flow simulation.

Achievements

During 1990 a pilot version of a computer code was developed for the numerical simulation of two-dimensional multi-component reactive transonic flows. The code can handle the flow of gas mixtures with an arbitrary number of components which might chemically react according to an arbitrary number of elementary reactions. The chemical reaction kinetics is described by the Van't Hoff law. Due to the use of unstructured grids, even complex geometrical boundaries can be well represented. At the present stage of the code development, the major emphasis is given to those processes which are relevant for high velocity gas flows including the formation of shock and detonation waves. Models for diffusion processes and turbulence will be included in future code versions. Attention has been given to the selection of an appropriate numerical solution strategy. The method applied belongs to the class of "High Resolution Techniques" which allow the accurate tracking of flow discontinuities (e.g. shock waves, contact discontinuities). These techniques, well assessed for one-dimensional Euler solvers, were extended to multidimensional reactive flow processes.

The basic physical and numerical approach chosen has been verified by a number of test cases for non-reactive gas mixtures as well as for more complex flow conditions. An example is given in Fig.5.12 which shows the interaction of a shock wave with cylindrical obstacle. The figure clearly indicates the high resolution of the shock wave which has just passed the cylinder.

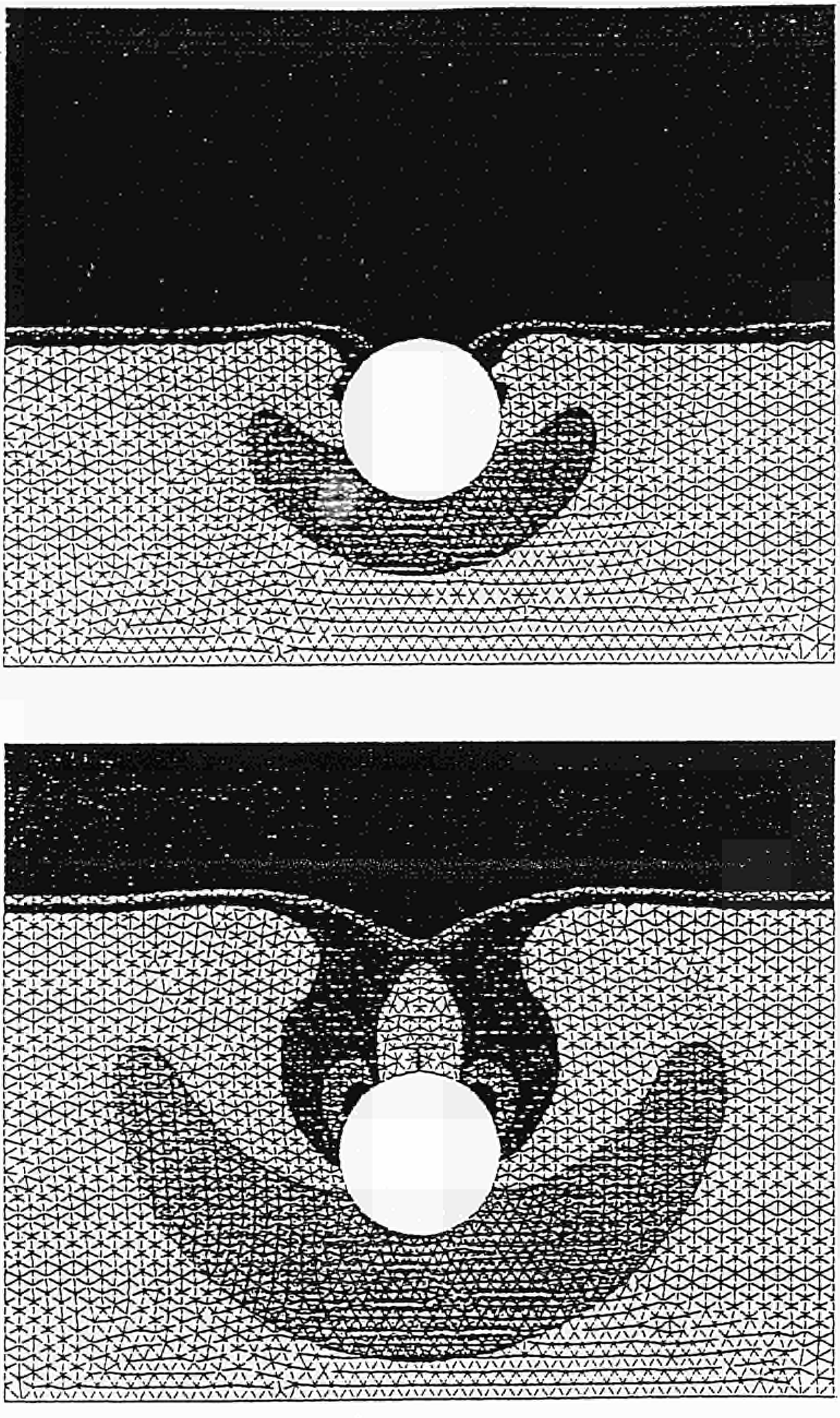


Fig. 5.12 Interaction of a shock wave with a cylindrical obstacle. Iso-temperatures are displayed at two successive times. Increasing temperatures correspond to the color sequence blue, green, yellow, red, magenta.

Measurement Techniques for Multiphase/Multicomponent Flows

Objective

Adequate flow measurement techniques are a key item for the investigation of the complicated multiphase/multicomponent flows usually encountered in industrial hazard studies.

Research on four topics is performed: mass flow measurement (1) by gamma densitometry and (2) by nuclear magnetic resonance (NMR), (3) investigations on the performance of Coriolis meters for two-phase mass flow measurement, and (4) flow velocity measurement by the temperature correlation method.

Achievements

1. Gamma Densitometric Mass Flow Measurement

A prototype device for the measurement of two-phase mass flow in a pipe of 72 mm i.d. has been developed. The instrument uses gamma densitometry in two planes with a 2-source/12-beam arrangement. By tomographic/correlative signal processing the local density and velocity can be determined, which provide the basis for the calculation of the total mass flow in the pipe. The system is expected to offer an improved accuracy for mass flow measurements under inhomogeneous two-phase flow conditions, [21, 22].

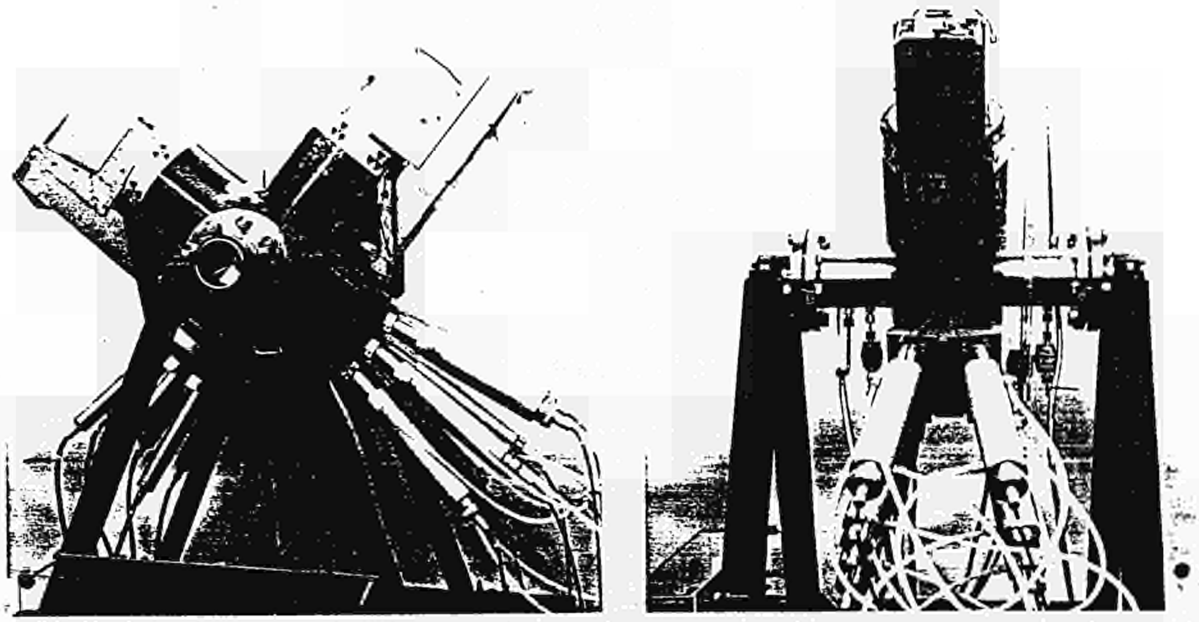


Fig. 5.13. Prototype of the gamma densitometric mass flow measurement device mounted for testing on the Air-Water Loop

The prototype apparatus has been built and installed in the Air-Water Test Loop for experimental testing, see Fig. 5.13; a novel design allows to combine the density correlation measurement and the tomographic reconstruction of the fluid density in two planes using 12 measurement beams with only 2 radiation sources, see Fig. 5.14. For this the instrument geometry has been optimized.

Major parts of the software, a key element of the system, have been developed. The software for tomographic reconstruction is ready and was experimentally verified. From different versions of the signal correlation software the final one will be chosen based on the experimental verifications underway.

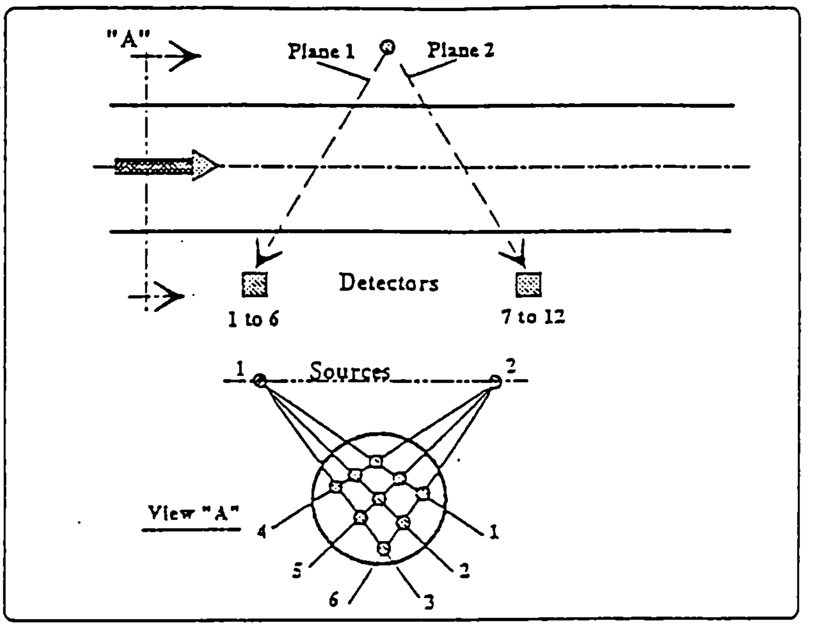


Fig. 5.14. Gamma densitometer arrangement in the mass flow meter using two sources and twelve detectors

2. Nuclear Magnetic Resonance (NMR) Mass Flow Measurements

For these measurements an oil-water-gas test loop has been set up and commissioned. The computer controlled NMR pulse spectrometer has been installed in this loop. It measures proton resonance in the liquid phase of the fluid at a proton resonance frequency of 4 MHz.

The principle of the NMR flow measurement method has been described in detail in [23]. The schematic arrangement at the loop tube is shown in Fig. 5.15. The oil-water-gas mixture is flowing through the NMR-RF-coil. The nuclear spins of the protons in this coil are tagged by a 90°-RF-pulse at time zero of a measurement. After this the amount of spins present in the coil at time t is measured by a Carr-Purcell-Meiboom-Gill spin-echo sequence. The spins which have left the coil during time t due to the flow no longer contribute to the NMR signal. At a certain time all the tagged spins will have left the coil and the NMR signal decays to zero. In this way the efflux curve of the tagged spins is obtained in dependence of time, from which the velocity probability distribution and the mean velocity of the liquid phase in the flow can be evaluated. The initial NMR-signal of this curve immediately after the 90°-pulse at time zero is proportional to the total amount of spins in the coil and hence to the mass of the liquid fraction of the flow. From this the void fraction can be obtained.

So far measurements of water-gas or oil-gas two-phase flow can be made. First commissioning experiments have been performed.

The software for the NMR spectrometer has been extended for noise and fluctuation averaging in two-phase flows with varying void fraction. A Fourier transform option has been included for the later analysis of the oil and water contents in mixed flows [24].This option includes normal Fourier transform from time dependence to frequency dependence as well as the back transform from frequency to time dependence.

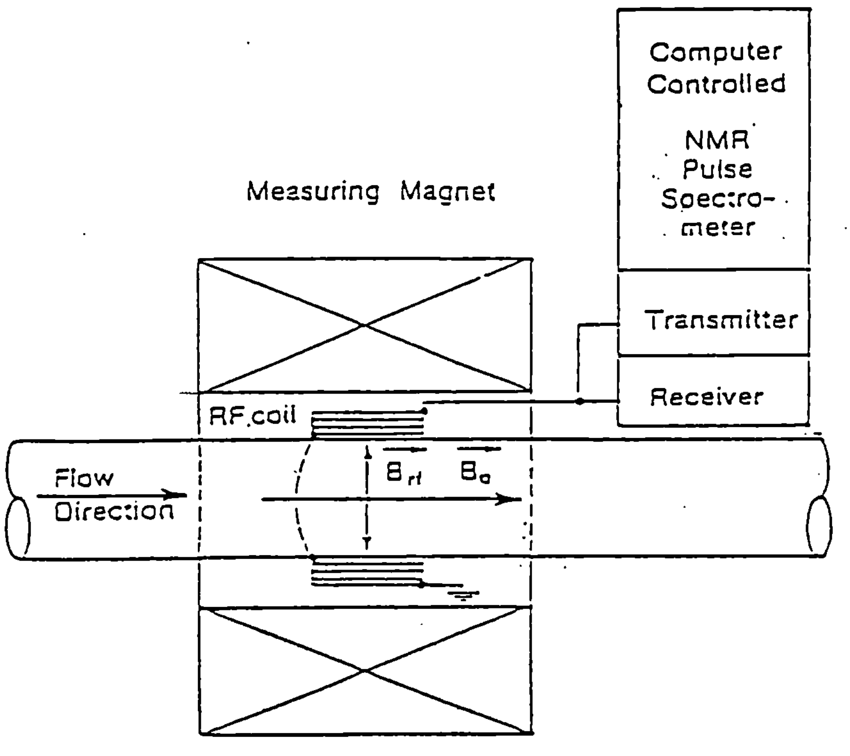


Fig. 5.15. NMR measurement arrangement at the loop tube

3. Coriolis Meter Investigation

This activity was started in September 1990. It aims at applying Coriolis meters to the measurement of two-phase (gas/liquid) mass flow. Existing instruments fail to measure such flows. Very little bibliographic information is available on this mode of operation.

First experiments with a Coriolis meter were started on the Air-Water Test Loop. These tests provide knowledge on the two-phase flow performance of a standard industrial instrument. It has become evident that to explain the meter behaviour, analytical models have to be developed which take into account the damping of oscillating pressure waves in two-phase media.

As an alternative approach the realization of a rotating Coriolis meter is investigated [25]. Construction of a prototype apparatus is planned.

4. Flow Velocity Measurement by Temperature Correlation

Flow velocities can be determined by correlating the temperature noise conveyed by the fluid flow. Temperature noise is present in most thermohydraulic flows encountered in the process and chemical industries: flows behind heat sources or sinks, flows in pipes with heat losses, and two-phase flows are typical examples. Temperature fluctuations in the fluid as low as 0.1 K provide useful signals.

The practical application of this method presents a number of problems concerning signal handling and data analysis. An advanced system was developed to measure flow velocities [26]. Different applications proved the maturity of this system and the reliability of the techniques used [27].

The apparatus comprises three essential parts:

- The sensor, which is made from two small thermocouples placed at two locations in the flow direction.
- The electronic part, which consists of a two-channel, high-gain/low-noise amplifier. Essential features are dc-suppression and the automatic gain control to manage wide signal ranges during transients.
- The signal handling system, which accomplishes the data acquisition, the correlation measurements and the final velocity data qualification. The whole system is controlled by a Personal Computer. An important step to obtain reliable velocity results is the automatic data verification and qualification, as correlation measurements may briefly fail because of a momentary low coherence of the noise signals. Such erroneous data must be eliminated from the final velocity presentations, see Fig 5.16.

An example of application is shown in Fig.5.17 In the main coolant pipe of the LOBI facility, a large test loop for reactor safety research, the flow velocities were measured in single phase (pressurized water) and two-phase (steam/water) conditions during transient experiments. The flow velocities could be determined also under conditions, where turbine meter measurements failed.

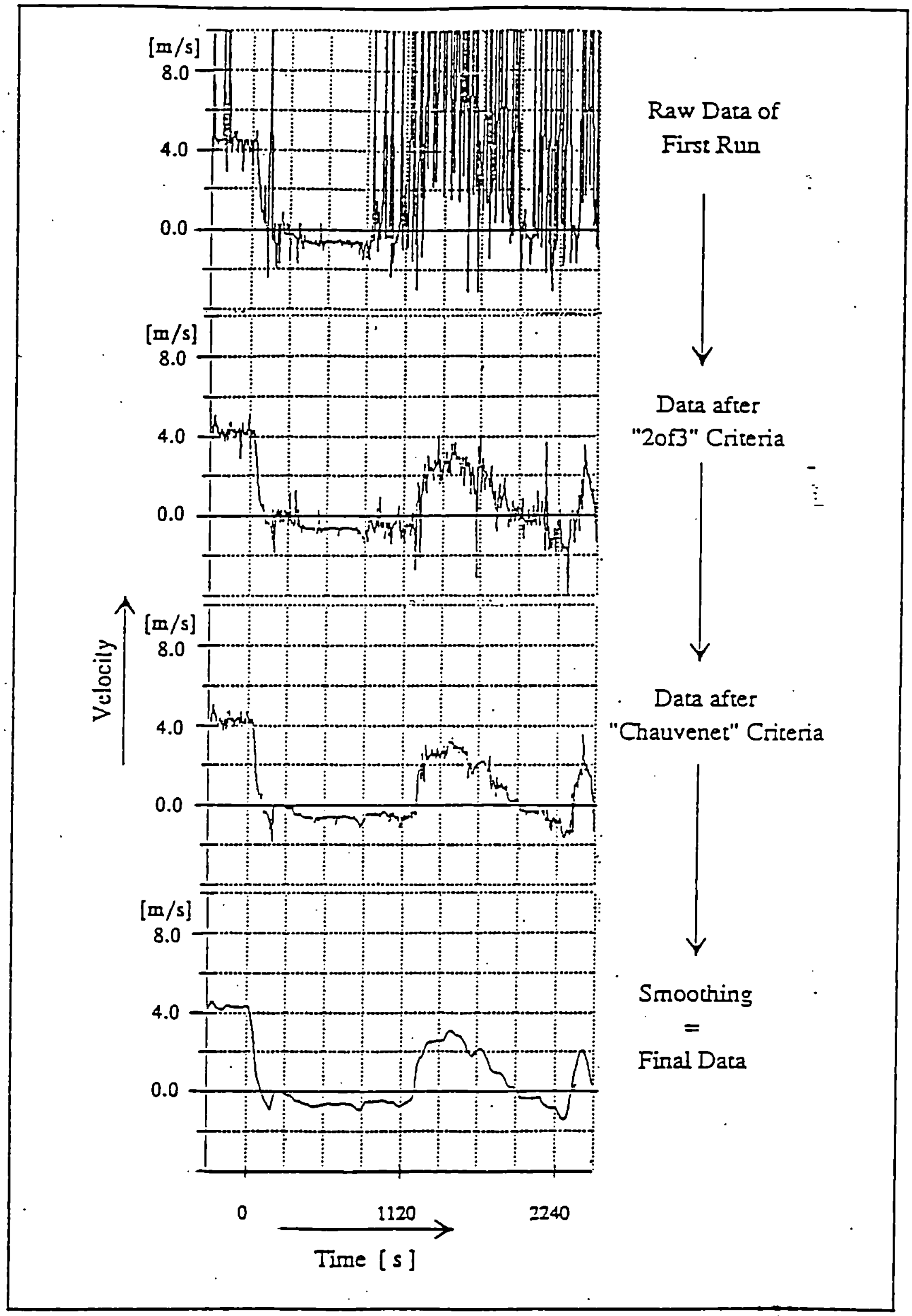
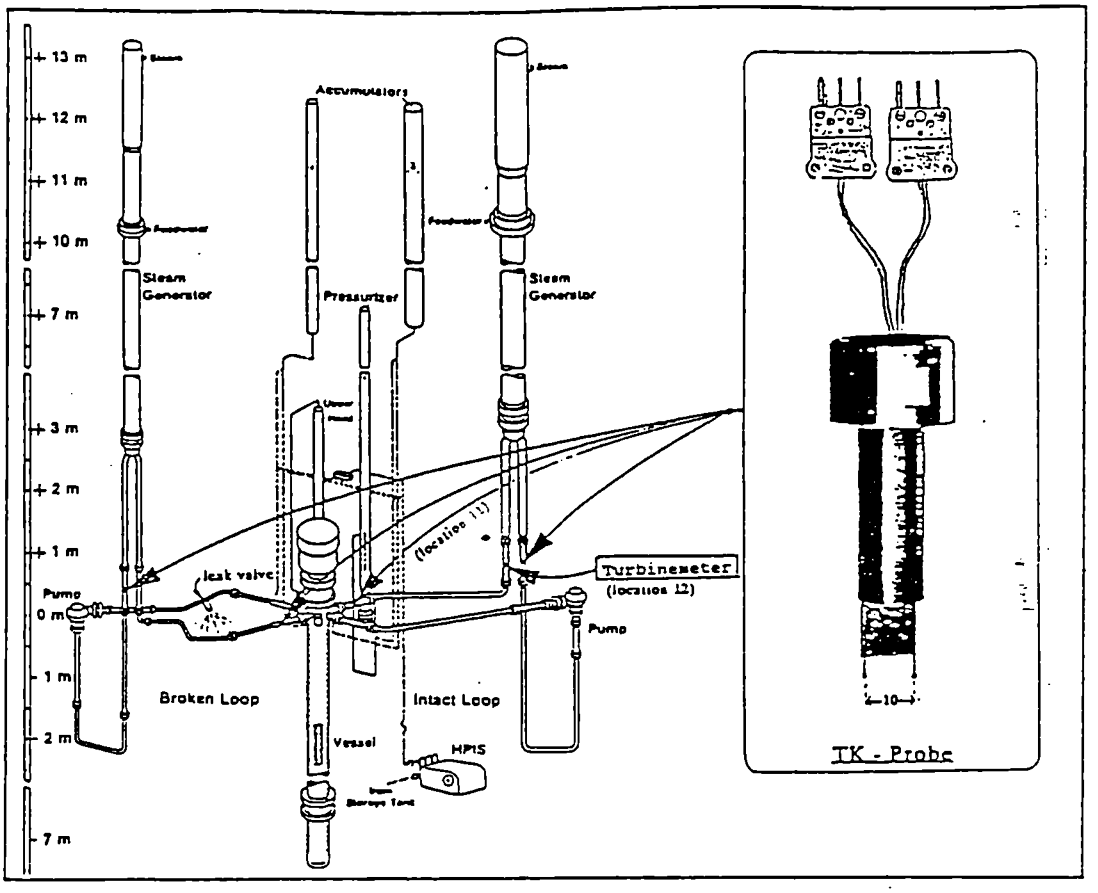


Fig. 5.16. Signal validation and correction procedure of the temperature correlation instrument;
measured and validated data of coolant pipe flow during LOBI Test BL-44



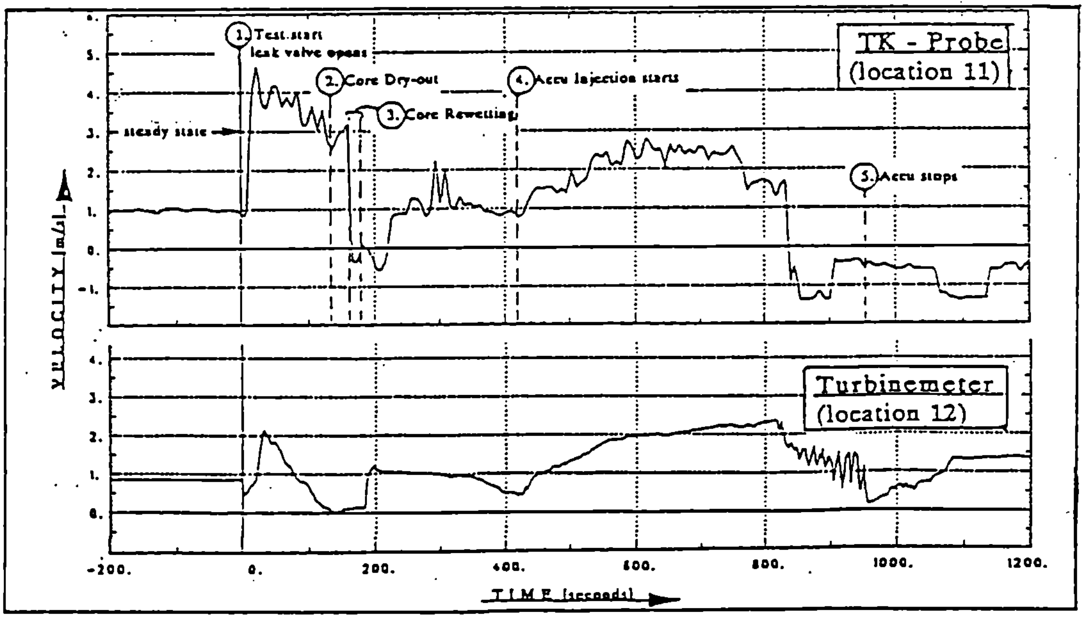


Fig. 5.17. LOBI primary loop flow velocities measured during test BL-34; data of the temperature correlation instrument at location 11 and of a turbine meter at location 12

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1.1.6. REFERENCE METHODS FOR EVALUATION OF STRUCTURAL RELIABILITY

The studies described below are preparatory and supporting activities in view of the operation of the large Reaction-Wall facility currently under construction.

Development and Implementation of the Pseudo-Dynamic Test (PDT) Method

Investigation of this new test method has continued, reviews have been made[1,2] and the requirements for the parameters of the Reaction-Wall PDT system have been identified. The numerical algorithm forming the basis of the on-line computer solution of the equations of motion has been written and implemented for use in development trials. It is of general form allowing the choice from a range of well-known time integration methods, both explicit and implicit, and will be used together with digital control to give a potentially powerful and flexible system.

In the PDT method the test structure is subjected to a displacement history which is calculated on-line by a computer and applied to the "lumped-mass" points of the structure via electro-hydraulic actuators. In the configuration envisaged each actuator will have its own digital control system. All the controllers will be connected via a Local Area Network (LAN) to a central computer. The computer will receive information from a load cell on each actuator, use it in the solution of the equation of motion for the structure for the next time step and output the new required displacement.

The LAN is now being finalised, but the digital control system has already been tried out succesfully in a number of experiments involving the cyclic loading of reinforced concrete columns. Conventionally, displacement measurement in the control loop has been performed using analogue devices, with consequent associated electrical noise. In order to eliminate this drawback, digital transducers are now employed which feed directly into the servo-controller.

Overall, the digital control approach opens up the possibility of trying out new control feedback algorithms which are not achievable with classical proportional/integral/derivative (PID) controllers. One area of interest currently being studied is the evaluation of the non-linear characterestics of the actuator (viscous and coulomb friction, slack etc.) for cyclic loading.

The major work to validate the PDT method is to be done within the framework of the European Association of Structural Mechanics Laboratories) making use of existing expertise and facilities in the field.

Research on Reinforced Concrete (R/C) Structures.

The experimental sector's main task for the transfer to the new laboratory housing the reaction-wall will be to upgrade in scale the methodology which at present is being implemented and/or developed. The transfer time from the present facilities to the new laboratory, once constructed, should then only be dependent on the installation of the major operational facilities (hydraulic system, data acquisition system, etc.). In the meantime, the major experimental features are being studied individually.

A new reaction rig has been constructed which can test full-scale R/C column-slab structures in biaxial bending by means of two pistons in the x-y plane with a third piston applying an axial load. The loading system now includes a digital controller for the axial load while the x-y pistons are commanded by a P.C-run package with added software developed in-house which includes facilities such as: command signal generation and data acquisition subroutines appropriate to the type of experiment being conducted, e.g. "stop-wait-start" data generation for relaxation tests, cyclic displacement ramp generation with alternate frequency cycles, piston locus geometric correction for large displacements etc.

A new specimen design has been prepared, in accordance with EUROCODE No.8, having dimensions of 250x250 mm.and a height of 1500 mm. as shown in Fig.6.1. With the experimental set-up described above, a further eight specimens have been tested, seven of which were of the new type.

The non-linear behaviour of column-slab specimens has been investigated in depth using the data available from the previous year's campaign on 300x300mm columns and continued with that from tests with the new EUROCODE No.8 type specimen. A variety of loading conditions have been investigated in order to determine the effects of axial load and both simultaneous and piece-wise biaxial bending on the degradation of the mechanical properties of the column. The results have provided useful data for the calibration of the member-type computer models mentioned below.

As a help in the design of experiments involving the vibratory behaviour of structures in the non-linear regime, a method is being developed whereby an equivalent damping and a natural-frequency degradation characteristic can be derived from measured force/displacement hysteresis loops in experiments on similar specimens. The results so far show that there is a consistent relationship between these two properties in all the results examined, and for which a parabolic curve has been found to fit reasonably well.

Concerning possible sources of experimental error in the implementation of the PDT method, of particular interest is the effect of strain-rate dependency of the stress-strain relationship of the structural materials. This could have a significant influence on the forces generated by the applied displacements in a PDT simulation (PDT time is typically two to three orders of magnitude greater than the real time of an earthquake for example). The experimental campaign has provided new data on this aspect. The current estimate of the rate effect is of the order of 3% load error for a real frequency of 0.2 Hz with respect to a test frequency of 0.002 Hz. (see Fig.6.2).

A further problem, related to the above, is the load relaxation that occurs during the hold-time periods of the imposed (step-wise) displacement history. An example of this is shown in Fig.6.3. It is estimated that a hold time of 2 seconds in a PDT step will typically allow load relaxation of about 3%. An effort is to be made to implement an algorithm which excludes the stop-start step to avoid this problem.

Modelling in Earthquake Engineering

Seismic signal analysis and generation

The design, analysis and testing of structures subjected to earthquake loading require the quantification of ground motion using different representations: response spectra, power spectra and accelerograms. These requirements have been reviewed and are summarised in Ref.[3].

Power spectra or response spectra quantifications are appropriate for linear analysis of structures where the superposition principle can be applied: e.g. the design codes are generally given in terms of response spectra. However nonlinear analysis and testing both require signals to be obtained as scaled versions of real earthquake accelerograms or which are artificially generated.

It is then important to provide the designer and the experimenter with tools allowing to pass from one representation to the others. These tools should include a convenient description of the nonstationary character of earthquake signals since this feature is considered relevant for the response of nonlinear structures. This aspect can be addressed by introducing an evolutionary power spectrum model. This model combines a stationary power spectrum and modulating functions which have to be identified.

A set of tools has been developed and implemented in CASTEM 2000. The main features (see Fig.6.4) are:

- Analysis and quantification of the nonstationarity of real signals for the identification of the modulating functions; an orthogonal wavelet decomposition technique was introduced for the analysis of the signals, further modelling of this decomposition being performed using a least-squares fitting technique.

- Power Spectrum / Response Spectrum direct and inverse trans- formations in the stationary and nonstationary case: various ways for improving the convergence and the robustness of the algorithms were studied and implemented.

- Generation of artificial accelerograms from a given Power Spectrum: the stationary case is treated using inverse Fourier transform with random phases whereas the nonstationary case is addressed introducing an orthogonal wavelet recomposition technique and a random sign generator.

- Correction of signals for preventing velocity and displacement shifts.

- Nonlinear response spectrum associated with a given stationary or nonstationary signal: a nonlinear single degree of freedom system featuring stiffness and strength degradation has been introduced.

This set of tools allows for instance the building of a data base of artificial signals possessing the same non stationary features as a recorded accelerogram but which match a given response spectrum. A generation procedure for EUROCODE 8 response spectra was also implemented.

A practical overview of the above topics was presented in [4] whereas some typical applications are presented in reference [5]. A detailed implementation document [6] including a summary of the various introduced algorithms was produced. A summary of orthogonal wavelet decomposition and recomposition techniques is in preparation [7] for general interest.

Structural Modelling

The design of structures subject to earthquake loading is normally made using sophisticated computational tools, such as finite-element based computer codes. This permits the calculation of the maximum stresses and displacements of the structure as required for checking the safety of the design. The calculations assume linear elastic behaviour although it is widely accepted that, in severe earthquakes, structures may be allowed to withstand considerable damage, providing they survive and are repairable. Thus the designer must be able to predict the non-linear behaviour beyond the design limit also. Accurate calculation of the response of real structures in the non-linear regime is however not yet feasible and approximate methods have to be used.

Eurocode No.8, the relevant design code, currently in draft form, restricts designs of structures for seismic zones to be regular, that is to have smooth variations of mass and stiffness in both plan and elevation. For such structures the non-linear response can be estimated from a linear analysis by means of 'behaviour factors' which allow the designed ductility of the structure to be used to reduce the calculated design loads. Validation of this simple but powerful approach for different types of structure is one of the aims of the work of the Association of Structural Mechanics Laboratories; development of simple non-linear computer codes for design purposes is another, as is improving and extending finite element codes to permit more accurate but less expensive calculations than are presently possible.

Modelling efforts are being made at several levels in support of the above aims.

(i) "Local" modelling of concrete and masonry is to be undertaken based on damage-mechanics concepts to derive finite elements suitable for simulating the response of these materials to repeated cyclic loading. These will be incorporated in the CASTEM 2000 finite element code system.

(ii) Detailed member models are being developed for structural components such as the "Fiber" model of a reinforced concrete column described below.

(iii) Global member models of the Takeda type ("macro-model")are to be derived for components such as columns, beams, masonry panels, shear-walls etc.

(iv) Global models of complete structures using the above members are also being used and/or developed to predict the non-linear behaviour of structures with the aim of producing practical design tools.

The "Fiber" model [8] is of the "finite filament" type and is one of the most fundamental models yet to be developed and used for the nonlinear analysis of the response of reinforced concrete members and structures to large amplitude reversed loading. Owing to the discretisation of the member both longitudinally and transversely, the use of realistic nonlinear uniaxial constitutive laws for steel and concrete (including the effect of stress reversals) and the variable flexibility scheme implemented, the model is able to reproduce the details of the complex physical behaviour very accurately. It can follow the spreading of plastification along the member length, can account realistically for the pinching of the moment-curvature hysteresis loops due to compressive axial forces and/or unsymmetric distribution of reinforcement, and takes properly into account the effects of axial load variation and of the biaxiality of bending on the response. The "Fiber" model works best where the assumption of flexure dominated behaviour is not violated. However, due to its extensive computational demand and storage requirements, it is, as yet, too expensive and cumbersome for use in everyday design practice. Fig.6.5 illustrates the typical discretisation of a column cross-section, the stress-strain laws used for the repeated loading of the steel and concrete constituents, and as an example of use, the prediction of the monotonic force-displacement curve for a R/C column under uniaxial bending compared with the corresponding experimentally obtained behaviour.

A review of masonry modelling has been performed [9] and an experimental programme proposed [10] to enable modelling of masonry members to be started. In addition, to derive experimental data and models for the effect of masonry infills on the behaviour of R/C frames, the Institute is collaborating in the SEISMIER (Studies and Experimental Investigations on Structural Models to Improve Earthquake Resistance) Programme. This originated from the Commission's Large Installation Programme which contributed to the funding of a new shaking-table facility at the National Laboratory for Civil Engineering (LNEC) in Lisbon. The facility is to be used, in the first instance, for collaborative research, twelve examples of which have been identified to date. The STI is involved directly in two of these sub-programmes which are relevant to its future work in the Reaction-Wall facility. The first phase of the collaboration concerns the testing of masonry-infilled reinforced-concrete frames on an existing cyclic loading rig at LNEC and later stages will involve the new shaking-table and the JRCreaction-wall. Combining LNEC experience from a previous programme of tests on masonry panels at low loading rates with recent JRC experience on testing reinforced concrete columns at various rates has enabled the definition of an agreed test matrix. The major parameters under investigation are the frequency of the (displacement-controlled) shear loading and the effect of super- imposed vertical load. The effect of a window opening will also be examined, but variations in its geometry and size will be left for the later study.

To assess our current calculation capability in both linear and non-linear analysis of reinforced concrete structures some of the benchmark calculations of the R/C working group of the Association are being performed. CASTEM 2000 is being used for the linear analysis, DRAIN-2D for non-linear prediction and SHEARQ (a very simple global model which simulates the building as a shear column) as a comparison. Fig.6.6 illustrates some CASTEM 2000 results - 1D modal analysis, 3D mode shape, linear analysis response spectra and includes SHEARQ results for a simulated earthquake input - top floor displacement history and maximum inter-storey displacements as a function of the work hardening slope of a bilinear frame material.

Dynamic Properties of Materials

1. Studies on plain concrete response to impact loading

This study is aimed at developing and validating strain-rate dependent behaviour models for concrete on the basis of experimentally measured stress-strain-strain rate relationships for plain concrete.

As a first step the stress-strain and fracture characteristics in tension have been measured at high loading rates using a modified Hopkinson's bar made of square aluminium bars with 6 cm side, to which a cubic concrete specimen is glued. Such stress strain curves (Fig.6.7) showed an ultimate tensile strength of 10 MPa with a corresponding deformation of 250 microstrain, both values being three times larger than the low strain rate values. However, the falling branch of such stress-strain curves, which corresponds to fracture propagation through the specimen, needs to be corrected by introducing in the analysis of the experimental results the true resisting cross section and the effects of stress and strain concentrations. The experimental measurements necessary for the evaluation of such corrections are under preparation.

These first results confirm that under dynamic loading the capability of plain concrete to absorb energy is greatly increased with respect to the case of low loading rate.

2. Studies on steel

The development and validation of constitutive models of steel describing the material response under impact loading, are based on experimental investigations. One of the crucial points for the experimental investigation of the steel response under impact loading is the conception and the analysis of a suitable specimen permitting the performance of tests in controlled conditions of stress, strain and strain rate.

In practice, most of the specimen shapes normally used fail to reach large strains due to geometric instabilities as well as very high strain rates due to the use of too large a gauge length to obtain a homogeneous stress distribution.

A double shear specimen has been developed (called "bicchierino") which should avoid the above mentioned difficulties for testing at large strains and very high strain rates, under simple and double shear loading.

Experiments in uniaxial shear have been performed [11,12] in the strain rate range 1×10^{-2} to 3×10^{4} s-1. The experiments at very high strain rate have been performed using a modified Hopkinson's bar set-up for shear testing. Typical shear stress-strain curves obtained for AISI 316H and ARMCO iron are reported in Fig.6.8. Such stress strain curves confirm that the new double shear specimen allows the deformation of the metal up to very large strains ($\sim$4) and very high strain rates (3×10^{4} s-1) in a well controlled manner. The flow curves measured for AISI 316H and ARMCO iron in this large strain-rate range are regular and show a strong reduction of ductility as the main effect of strain rate.Nevertheless, microscopical examinations showed that at very high strain rates the deformation concentrates in a band narrower than the initial nominal gauge length (shear band formation). This phenomenon demands further examination to gain more resolution of the real effects of very high strain rate on the mechanical properties.

Based on uniaxial viscoplastic experiments on pre-damaged AISI 316H stainless steel, constitutive equations have been calibrated for as-received, creep-damaged as well as low-cycle-fatigue-damaged specimens [13] covering stress-strain-strain rate relations and accounting for strain and strain rate hardening. The material constants entering the equations are found to be damage dependent.

Computational Mechanics and Code Development

Nonlinear solution strategies for plastic and softening materials

Quasi-static elastoplastic or stress-softening structural problems exhibit particular features such as limit loading or local/global bifurcation patterns which cannot be treated using conventional load control techniques. Therefore in order to address the local modelling of reinforced concrete structures, more sophisticated control strategies are to be set up.

An arc length control method using internal quasi-Newton iterations was implemented in the CASTEM 2000 code, starting from a previously implemented standard load control method using modified Newton iterations.

The algorithm possesses the following features :

- The arc length method allows control of the solution process by limiting the internal response of the system to a given load rate rather than imposing an external load step.
- Due to the nonlinear character of the equilibrium equations, an iterative algorithm is introduced in order to determine each new equilibrated configurations. These iterations are performed introducing an indirect approach safeguarding the linear solution format of the standard load control approach.
- The iterations are performed using quasi-Newton updates, improving the convergence speed and the robustness of the modified Newton update.

General references on these topics are available (see e.g. the references of [14]). A detailed implementation document including a summary of the various algorithms introduced and benchmark tests for elastoplastic problems was produced [15].

Development of the CASTEM 2000 code

All the previously mentioned developments have been performed within the same computer code framework: CASTEM 2000. This is an illustration of the potential of this generation of code for hosting rather heterogeneous developments.

CASTEM 2000 was developed by the CEA-Saclay. Through a collaboration agreement, it has been available at JRC Ispra for internal use for the last three years, and during this period its potential has been evaluated. This type of toolkit code built around sound data structures and offering a high level language (GIBIANE) appears to be a suitable environment for development activities. For instance the Arc Length method mentioned earlier can be applied to all types of problem dimensions (1,2 and 3-D), all types of elements in CASTEM 2000 and all types of plastic materials; at the same time it consists only of about 500 lines of coding in GIBIANE.

A collaboration contract for the common development of CASTEM 2000 has been negotiated and signed. The object of the collaboration covers various aspects of the seismic analysis of reinforced concrete structures. As a consequence of this agreement, CASTEM 2000 can be freely used at JRC and the CEA conceded the right to transfer it to third parties for internal use.

Fast transient dynamics

In the framework of the new collaboration contract with CEA on the development of PLEXIS-3C (contract N. 3504-88-11 TS ISP F) signed in July 1989, the implementation in PLEXIS-3C of the models originally developed in the EURDYN series of computer programs (EURDYN-1D, -01, -02, -03, -1M, -3M) has been completed with the exception of sliding models for 3D compressible fluids, which are being modified. Furthermore, the following actions were started :

- generation of general fluid-structure sliding models for 3D situations ;

- investigation concerning the application of the Arbitrary Lagrangian Eulerian formulation to structures undergoing very large deformations.

Finally, support has been offered for further developments in PLEXIS-3C of 3D models for advection-diffusion problems [16,17], based on the previous TRAFLU-2D and TRAFLU-3D models. This activity is being performed in the framework of a third party work contract with CISE and ENEL-CRIS, Milano.

Informatics Support

In addition to the above activities, the computational mechanics sector has provided informatics support on various topics:

- Use of a distributed working environment based on the X-Window System: the possibility of easily running standard applications (terminal emulations, window management, load informations, etc...) either at local or remote level has been made available through appropriate customizations. All the "smaller" UNIX machines (6 machines are currently concerned) can thus be used as improved X Terminals, allowing to host at the same time both local data elaboration activities and remote sessions on CPU servers. The details of the strategy are explained in reference [18]. This action generally aims at improving visualization and user control.

- Distributed data access facilities : a Network Based Indexed Sequential Access Manager (ISAM) function library was developed in order to facilitate access to distributed date files. The system serves as an intermediate layer between data base applications (e.g. EDF) and network connected UNIX platforms. The ISAM library was written in C+ + and thereby possesses the full potential for extension of an Object Oriented package. The details of this development can be found in reference [19].

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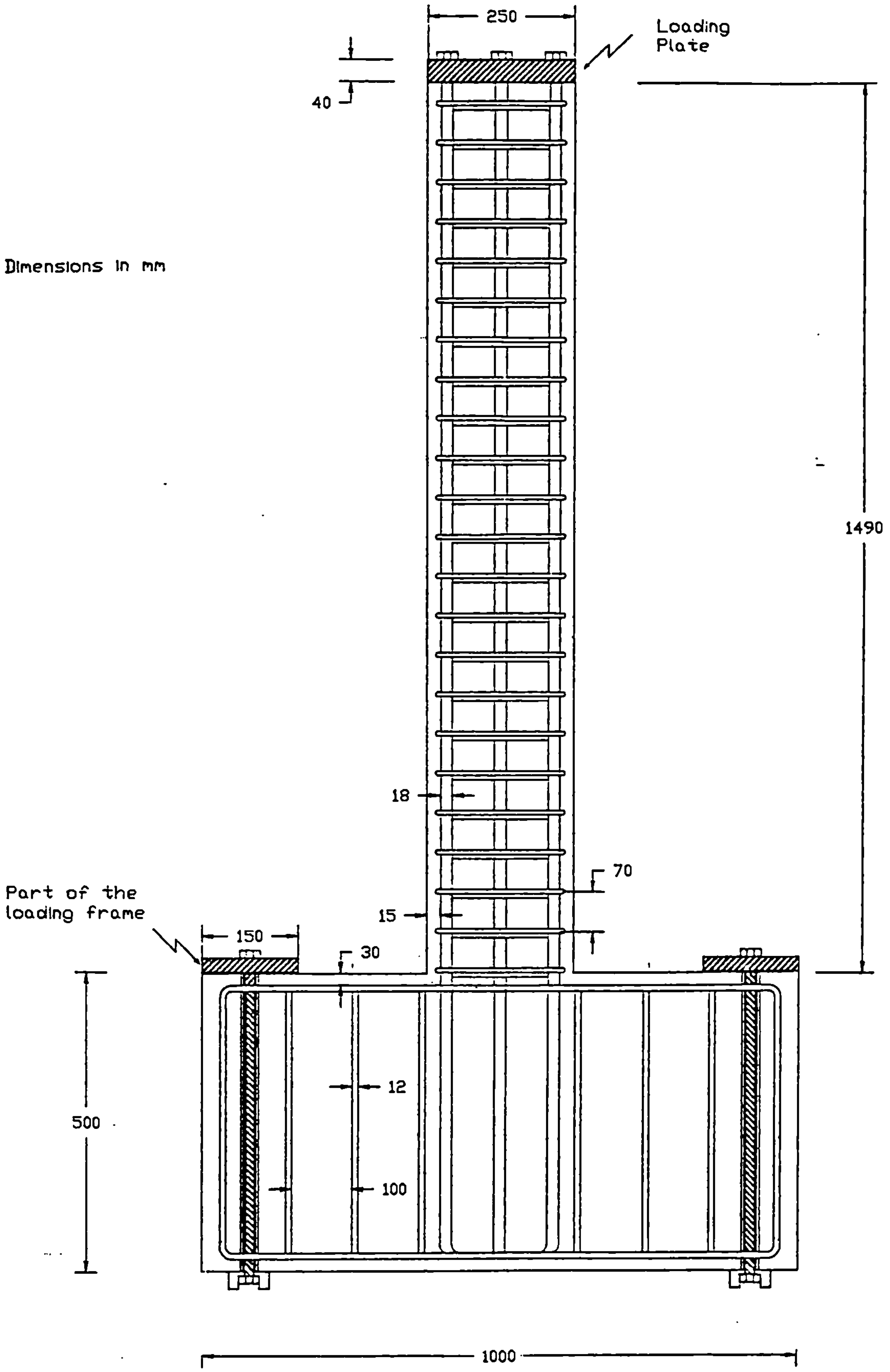


Fig. 6.1 Column-Slab Specimen Geometry

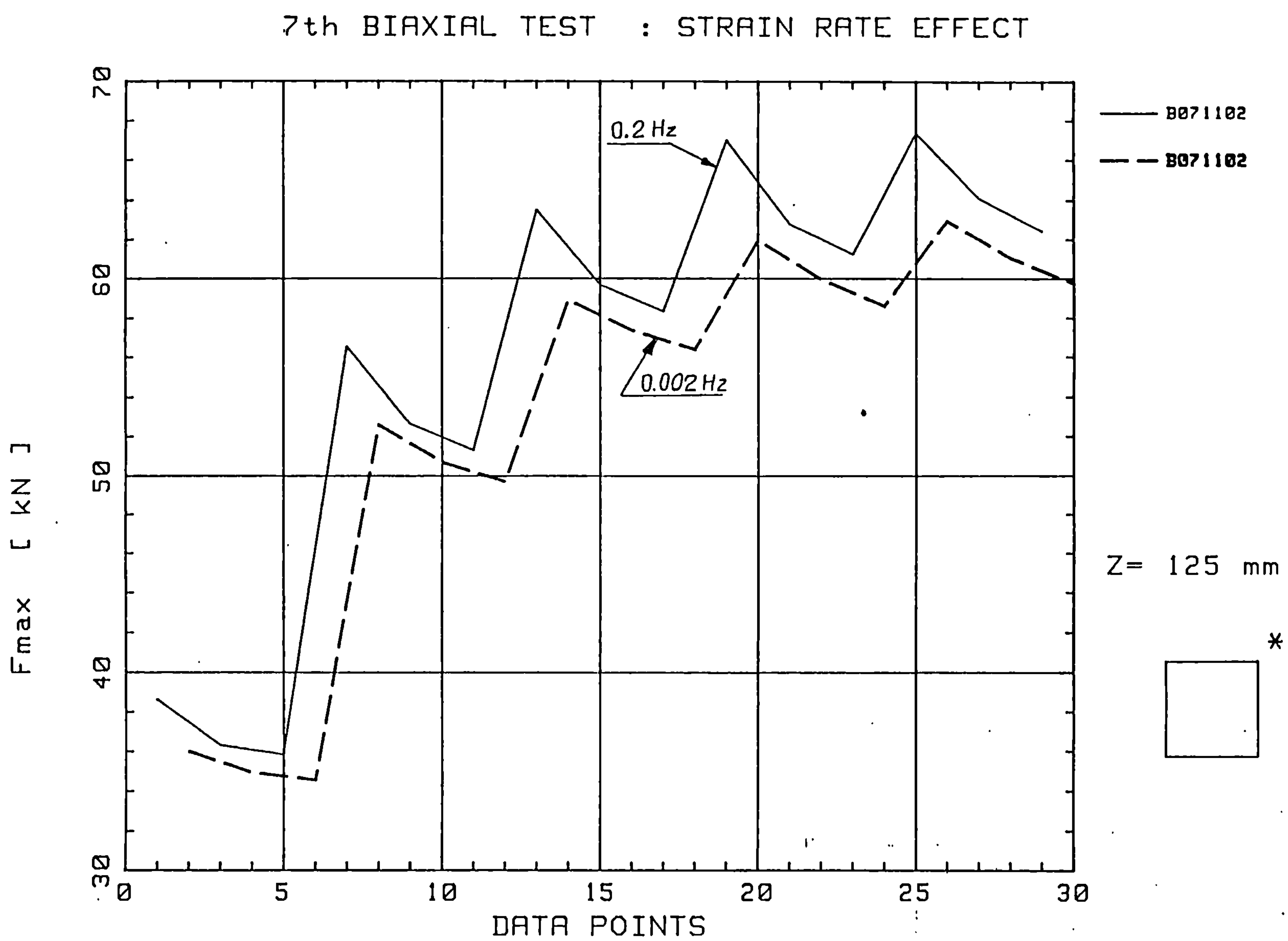


Fig. 6.2 Strain-Rate Effect on Maximum Load per Cycle

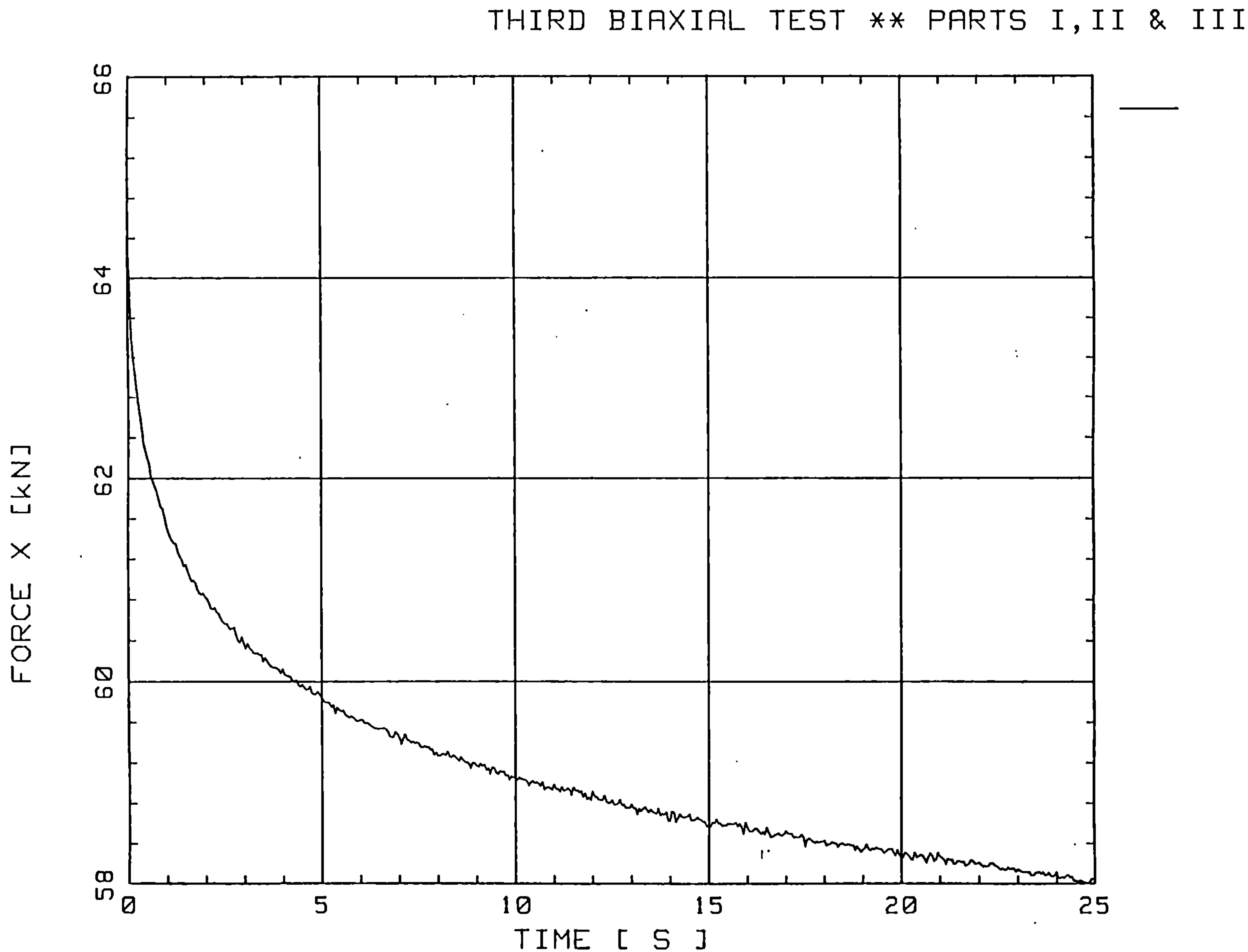


Fig. 6.3 Load Relaxation versus Time

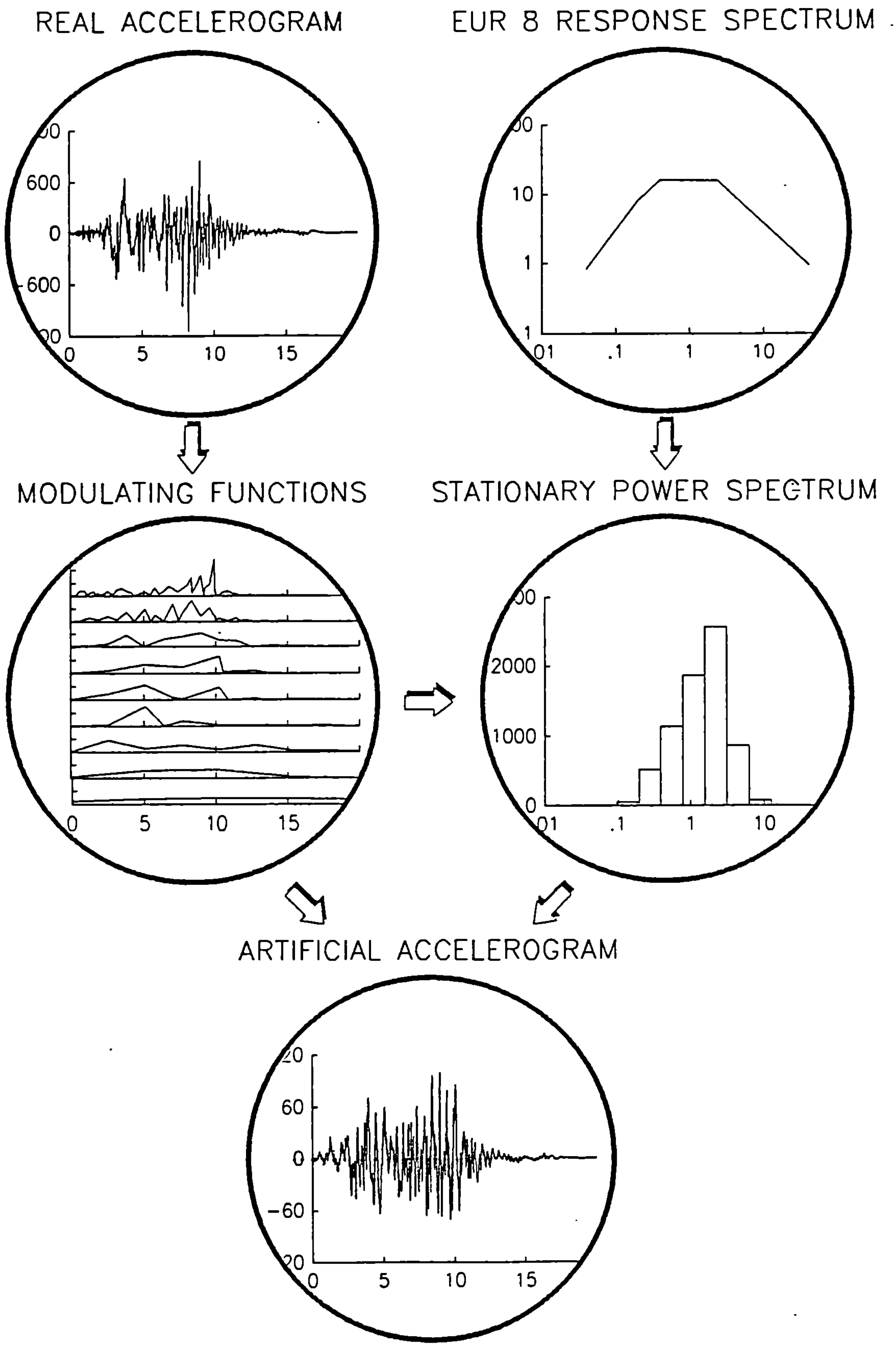
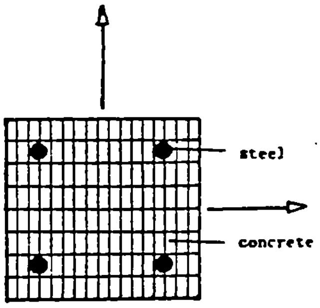
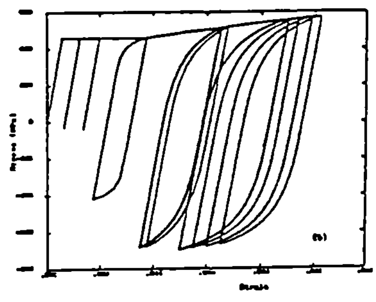
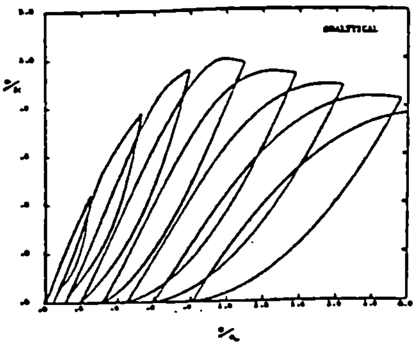


Fig. 6.4 Seismic-Action Tools in CASTEM 2000



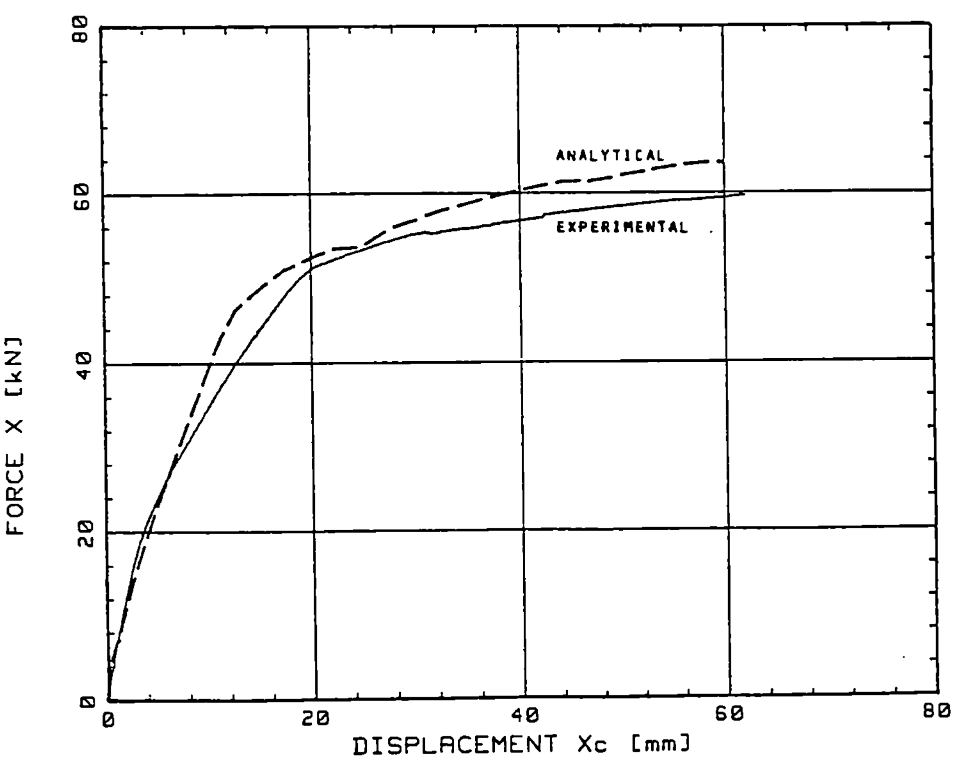


Steel



Concrete

Discretization Stress/strain curves under repeated loading



Uniaxial bending of R/C column

Fig. 6.5 The "FIBER" Model

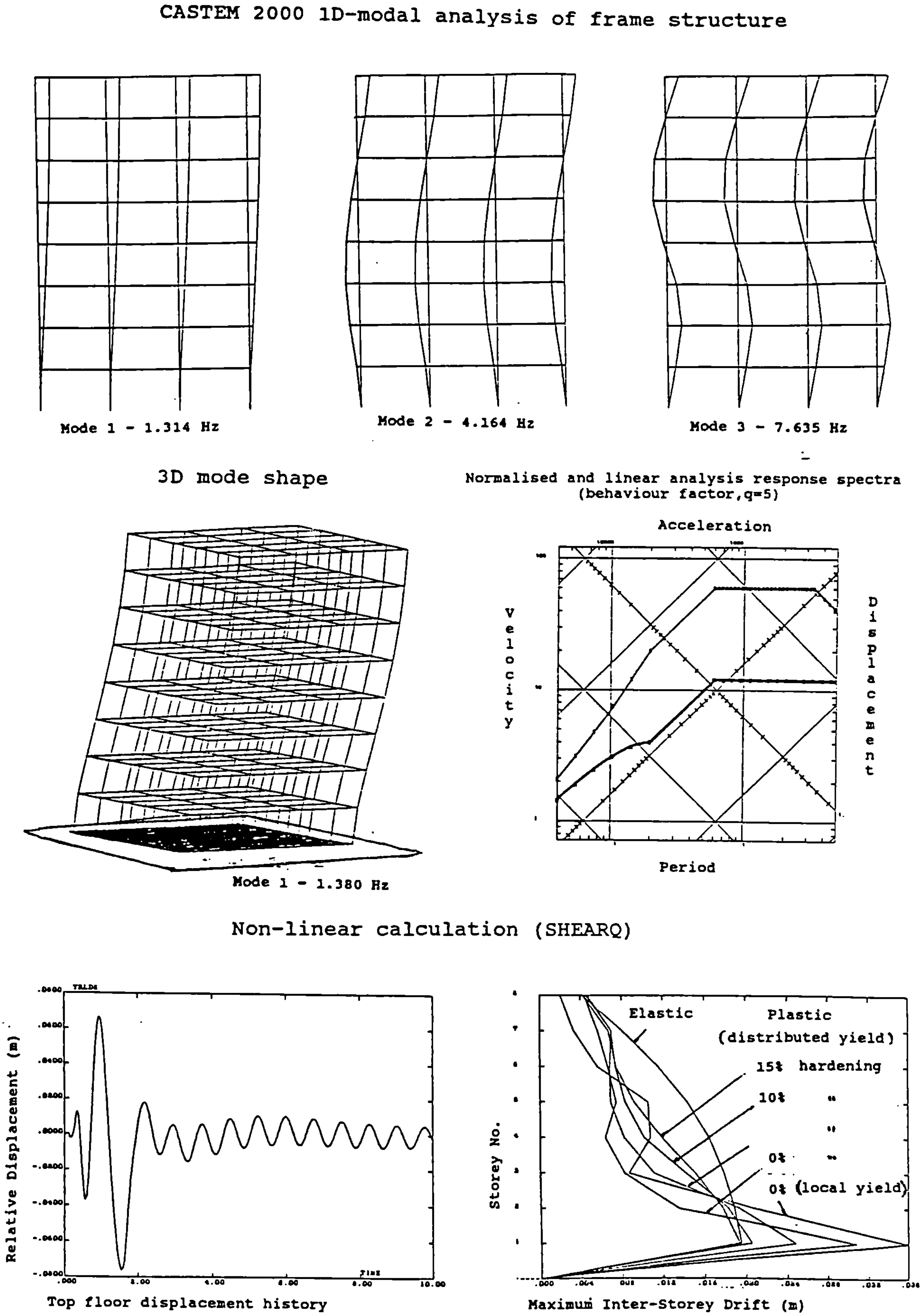


Fig. 6.6 Examples of Structural Modelling

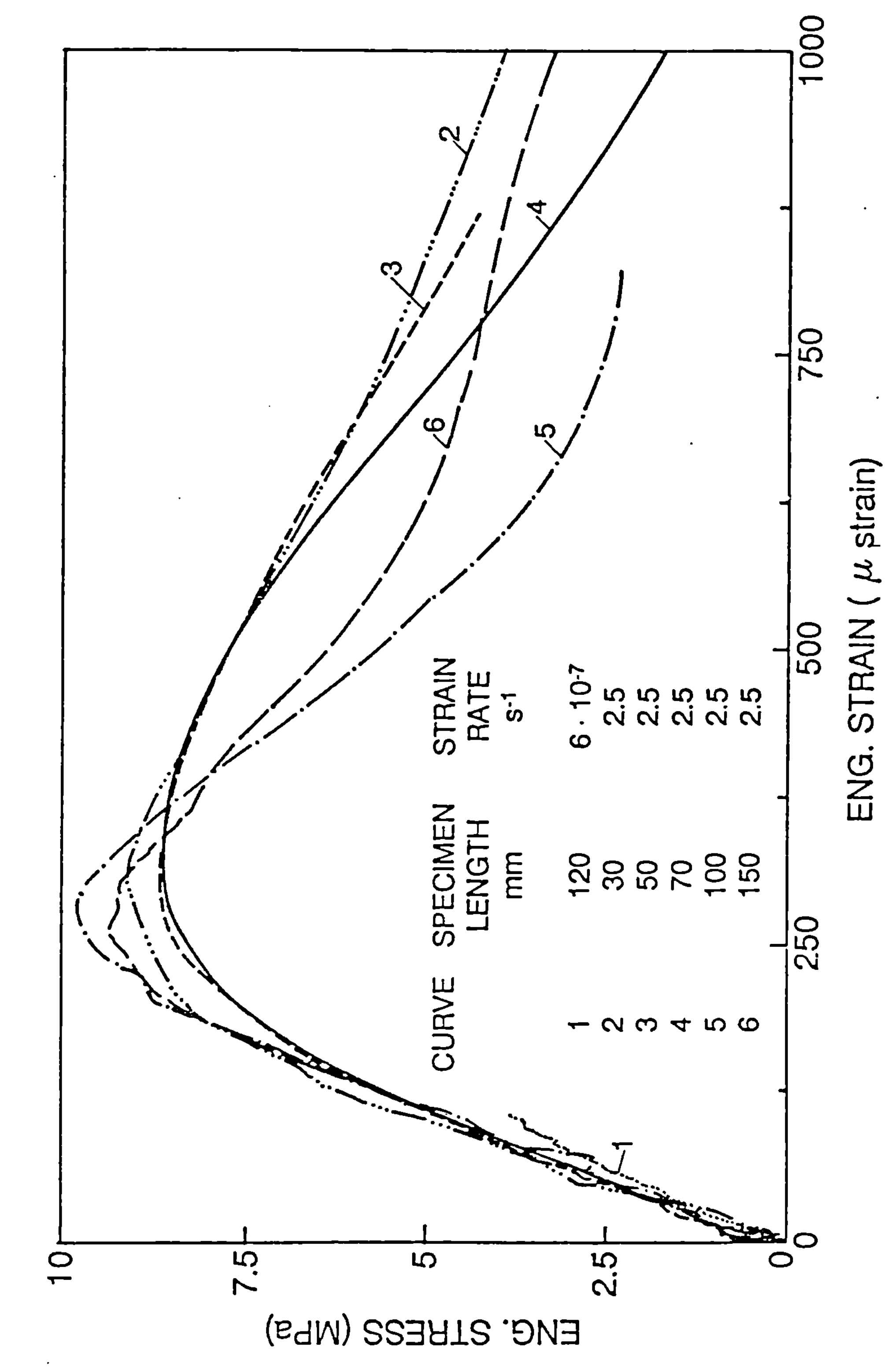


Fig. 6.7 Stress-Strain Curves of Plain Concrete at Low and High Strain Rate. Hopkinson's Bar Measurement of Stress and Strain

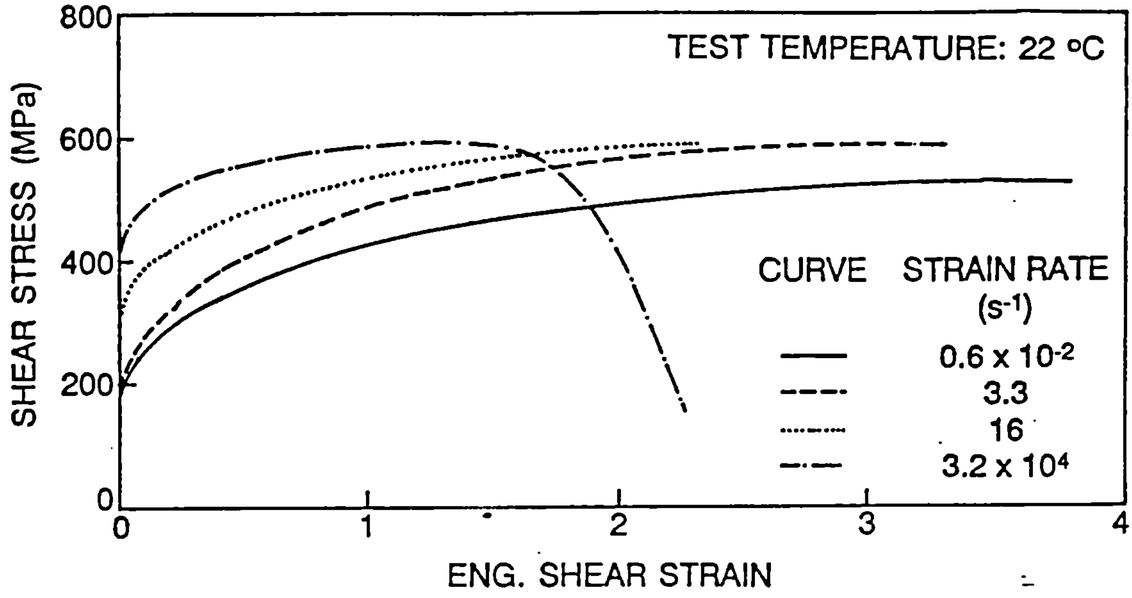


Fig. 6.8 (a) Shear Stress-Strain Curves at Different Strain Rates of AISI 316H Stainless Steel

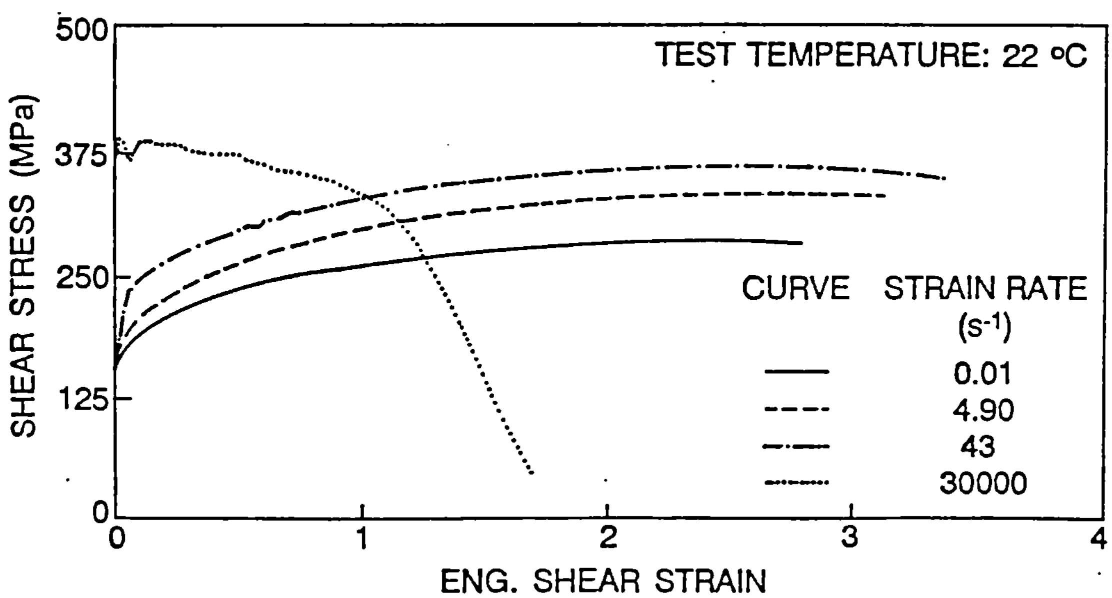


Fig.6.8 (b) Shear Stress-Strain Curves at Different Strain Rates of ARMCO Pure Iron

1.2. S/T SUPPORT TO COMMUNITIES POLICIES

1.2.1. SAFEGUARDS

SUPPORT PROGRAM FOR DG I

Since PRE-PERLA became operative, the IAEA has constantly used the facility for training of personnel and calibration of instruments.

In particular during 1990 an integrated Physical Inventory Verification (PIV) training course was given to IAEA and EURATOM inspectors. In the pre-calibration phase the High Enriched Uranium standard inventory of PRE-PERLA was measured to determine calibration parameters to be used in the field by the inspectors.

During 1989 the first international exercise had been carried out in PRE-PERLA with the participation of EC laboratories as well as DOE (USA) and Japanese laboratories with the aim of assessing the performance of different High Resolution Gamma Spectrometry codes, currently used by IAEA. The results were discussed in a workshop held in 1990 attended by thirtyfive scientists from all over the world. The conclusions will allow the IAEA to make its choice of software.

SUPPORT PROGRAM FOR DG XVII

The calibration and training laboratory PRE-PERLA has been extensively used in support to DG XVII.

Calibration and training exercises for inspectors and Safeguards laboratories'of EC member states, and performance evaluation exercises involving non EC laboratories have been continued during 1990.

Software and data bases for field instruments and Headquarter systems (PHONID, High Level Neutron Coincidence Counter, Active Well Counter) are undergoing continuous development.

Integrated NDA field instruments have been designed, developed and delivered to DG XVII (PHONID 3b, MTR gamma scanner, Pu-meters).

The training activities have been restructured and increased to provide :

-basic courses in gamma ray methods, neutron methods and statistics,
-instrument oriented training (HLNCC, AWCC, PHONID, Pu-U isotopics),
-plant oriented Physical Inventory Verification training.

Integrated gamma-neutron, gamma-calorimetry systems were examined with the customer in order to take in due consideration his needs already in the design and development stage.

Design and implementation of large Headquarter data bases compatible with the field instruments are under way to cope with the large quantity of field data collected in the future by the inspectorates.

1.2.2. Expert Analysis in support of DG XXI for scientific apparatus imported from Non-Community Countries

This activity deals with the study of scientific instrument dossiers imported from non-Community countries, which are exempt from custom duty when they are used for scientific research and have high scientific value, provided there is no equivalent instrument with the same characteristics made in the Community.
The dossiers analysed are those for which the customs of the Community countries refused the tax exemption on imported instruments.

The Institute's Nuclear Experience Division made available technical support and participated in meetings of the Custom Duty Free Committee, in which controversial cases were reviewed.

The decisions of the Committee are published in the official journal of the Community and became operative for the customs of all Member States.

In case of controversy between the countries, the scientific opinion expressed by our experts is determinant for the decision of the Committee.

The decisions of the committee can be contested at the Court of Justice in Luxembourg. In such a case a scientific support is supplied to the Juridical Services of the Commission. During 1990, 12 working days were spent during 6 meetings. of the committee.

In addition a continuous support was provided for the legal service in connection with the latest developments of jurisprudence in the field of UNESCO exemptions.

1.3. WORK FOR THIRD PARTIES

The Institute has been successful in selling the use of some of its major facilities. In particular contractual activities were executed in the hot cells of the nuclear isle and a contract was signed for the use of the FARO installation.

Equally important for the work of the Institute was the start of paid cooperation in the area of model and calculation codes development related to structure dynamics and fluid mechanics.

Finally the selling of special techniques has to be mentioned, e.g. for the construction of heat pipe furnaces and the use of Hopkinson bar type equipment to measure dynamic material properties.

1.4. ASSOCIATED LABORATORIES

EUROPEAN ASSOCIATION OF STRUCTURAL MECHANICS LABORATORIES

The work of the two sub-groups of the Association concerned with the earthquake response of civil engineering structures (reinforced concrete and steel/concrete composites respectively) is proceeding according to schedule.

The concrete-structure working group programme had as a first stage the establishment of a common ground of design and analysis among the various members. This is almost complete; benchmark designs have been performed according to the relevant Eurocodes and have shown good agreement in terms of linear analysis. A meeting to be held in November will compare the non-linear analysis results and define the experimental work of the next phase of the programme.

The first phase of the work programme of the steel/concrete structure group has resulted in agreed designs for the test set-up and specimens. Six types of specimen are to be used to cover two types of beam/column joint (bolted and welded) and three ratios between the steel and concrete load-carrying capacity within the shear panel of the joint. Specimens of each design are to be tested a) on a shaking table, b) quasi-statically and c) pseudo-dynamically. Detailed specimen drawings are in preparation and manufacture should start in November.

Work of the working group on test method development should start before the end of the year. The programme involves setting up a state-of-the-art version of the Pseudo-Dynamic Test (PDT) method allowing the use of both explicit and implicit solution strategies together with digital control techniques. This is to be followed by a series of experimental validation tests comparing the results with those of shaking-table tests for a variety of materials and scales.

A programme of work on masonry structures is still to be defined in detail. A problem is that perhaps the major concern is in the behaviour of existing masonry buildings, many of which are of historical interest but which differ in type between the various Member States. Thus it is not easy to define a representative structure. Also the interest for new masonry buildings is limited because their use for seismic zones is proscribed in several countries. Finally the PDT method is least suited to testing masonry buildings because of their distributed mass, their very high initial stiffness and their brittleness. The work programme, when finalised, will concentrate on these latter aspects of the problem.

2. HUMAN RESOURCES

Status December 1990

	Scient./ Techn. Staff	Admin. Staff	Authorized Recruitm. 1989-1990		People who left in 1990		Grantholders		Visiting Scientists		Experts Seconded		Auxil. Agents
			ST	Adm.	ST	Adm.	present	addit expected arrivals	present	addit. expected arrivals	present	addit. expected arrivals	
Direction (1)	3	4							-				
Thermodyn. and Rad. Physics	51	6	1	-	-	-	1	-	1	1	2	1	-
Process Engineering	82	6	1	-	7	-	7	-	-	2	2	1	-
Applied Mechanics	29	2	1	-	3	-	2	-	2	-	-	-	3
Nuclear Fuel Cycle	78	5	1	-	1	-	2	1	2	-	-	-	1
Nuclear Experiments	44	2	1	-	1	-	-	-	-	-	-	-	-
In Pile Tests	3	1	-	-	-	-	-	-	-	-	-	-	-
Technical and Adm.Support (2)	11	10	1		1								3
	301	36	6	-	13	-	12	1	5	3	4	2	7

(1) includes QA/QC
(2) includes: purchase of materials, contracts, infrastructure planning, fissile material control and transportation

ANNEX A

List of publication

I. Contribution to periodical and monographs

FUSION

F. Lanza, M. Cambini, M. Della Rossa, E. Parnisari
"Investigation on the Form in which Tc is retained in a Borosilicate Glass containing simulated High Level Waste", submitted for publication in J. of Nucl.Mat.

F. Reiter, J. Camposilvan, M. Caorlin, A. Perujo, S. Tominetti
"Recycling of hydrogen from stainless steel surfaces under ITER/NET conditions"
ICFRM-4, Kyoto, 4 - 8 December 1989. Proc. in J. Nucl. Material, in press

F. Reiter, "Solubility and diffusivity of hydrogen isotopes in liquid Pb-17Li"
Fusion Engineering Design, in press

C. Carretti, G. Gervasini, F. Reiter,
"The transport of hydrogen isotopes and helium in the NET first wall"
EVC2-AIV XI, Trieste, May 21 - 25, 1990, Proc. in Vuoto, in press

S. Tominetti, M. Caorlin, J. Camposilvan, A. Perujo, F. Reiter,
"Solubility and diffusivity of hydrogen and deuterium in TZM"
PSI 9, Bournemouth UK, May 22 - 26, 1990; Proc. in J. Nucl. Mater., in press

H. Dworschak, F. Mannone, A. Perujo, G. Pierini,F. Reiter, G. Vassallo, A. Viola, J. Camposilvan, K. Douglas, G. Grassi, P. Lolli-Ceroni, A. Simonetta, B. Spelta,
"Tritium research and technology facilities at JRC Ispra"
Fus. Eng. Design 12 (1990) 319-330

INDUSTRIAL HAZARDS

Skouloudis, A.N., K.I. Bell and H.M. Kottowski, "Venting of vessels containing reacting fluids; a parametric study with SAFIRE and DEERS"
J. Loss Prev. Process Ind., Vol 3(1), 1990, pp 13-16

G.J. Krüger, J. Haupt und R. Weiss: "A Nuclear Magnetic Resonance Method for the Investigation of Two-Phase Flow", IUTAM Symposium, Nancy/France, 1983, pp 435-454, J.M. Delhaye and G. Cognet
Edt's, Springer, Berlin/Heidelberg, 1984

STRUCTURAL RELIABILITY

Donea J., Jones P.M., Magonette G., Verzeletti G. "The Pseudo-Dynamic Test Method", in "Recent Advances in Earthquake Engineering and Structural Dynamics".
Co-ordinating Editor: Davidovici V. E.

Pegon P., Guelin P., "Implicit Finite Strain Analysis in Convected Frames"
Proc. 5th Int. Symp. on Num. Meth. in Engn., Springer-Verlag, Vol 1, pp 165-172, 1989

Donea J., "Generalised Galerkin Methods for Convection- Dominated Transport Phenomena"
to appear in "Applied Mechanics Reviews"

Donea J., Quartapelle L., "An Introduction to Finite Element Methods for Transient Advection Problems"
submitted for publication in "Computer Methods in Applied Mechanics and Engineering"

REACTOR SAFETY

Jones A.
Calculation of Fuel Penetration and Freezing in channels with a Two-Phase Flow Code.
Nuclear Science and Engineering, Vol. 105, N° 2 (1990) 105-122 - ART 28574

Jones,A., Benuzzi,A.
Modelling an Electric Furnace for the Preparation of Large Quantities of Molten Uranium Dioxide.
Computational Mechanics Communications
ART 29166

Magallon, D., Hohmann, H.,Schins, H.
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ANNEX B
Organisation Chart

- **SAFETY TECHNOLOGY INSTITUTE**
  Director:
  H.F.HOLTBECKER
  - Specialized Service for Technical Administration Support & Marketing :
    S.ZANELLA
  - Coordination & Secretariat :
    Secretariat : M.E.MARENGO
    Staffing : C.MAURY
    QA / QC : L.FERRARIO
  - **Thermodyn.& Radiat.Physics Div.** – P.FASOLI-STELLA
    - Severe Accident Studies – A.MARKOVINA
    - Radiation Physics – H.RIEF
    - Fluid Dynamics Modelling – A.BENUZZI
    - Thermomech. Tests – H.HOMANN
    - Fission Product Transport – A.JONES
  - **Process Engineering Division** – C.BUSSE
    - Computational Proc.Analysis – H.STAEDTKE f.f.
    - Ind.& Environm. Hazards Analysis – R.NIJSING
    - Experimental Fluid Dynamics – -
    - Integral System Experiments – C.ADDABBO
    - Material Properties – C.BASSANI f.f.
    - Measurement Techniques – E.OHLMER f.f.
    - Techn.Support – L.FRITZ
  - **Applied Mechanics Div.** – J.DONEA
    - Earthquake Engineering – Ph.JONES
    - Computational Mechanics – J.P.HALLEUX
    - Experimental Mechanics – G.VERZELETTI
  - **Nuclear Fuel Cycle Division** – H.DWORSCHAK
    - Tritium Techn. & Safety – F.MANNONE
    - Radioactive Waste Management – H.DWORSCHAK
    - Nuclear Material Management – W.HAGE
    - Instrumental Analysis – M.CAMBINI
    - Plant Design & Modelling – J.L.BOURDON
    - Decontamination & Waste Treatm. – R.GRITTI
  - **Nuclear Experimental Div.** – G.BARBERA
    - Safety Analysis & Licensing – F.TINAGLI
    - Operation Analysis – S.CARUSO
    - Technical Support – P.BASTIANINI
    - Hot cells Operation – J.CAUWE
  - **In-pile Tests Division (at Cadarache)** – P.von der HARDT

ANNEX C

List of Tables and Figures

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REFERENCE METHODS

ANNEX D

Glossary of Acronyms and Abbreviations

BMFT	Bundesminister für Forschung und Technologie
CATHARE	French Large System Thermohydraulic code
CEA	Commisariat à L'Energie Atomique
CONDIF	Computer Code Name (Molten pour behaviour)
DRUFAN	German Large System Thermohydraulic code
EAC	European Accident Code
EC	European Commission
EDX	Energy Dispersive X-ray
ETHEL	European Tritium Handling Experimental Laboratory
ENEA	Comitato Nazionale per la ricerca e per lo sviluppo dell'Energia Nucleare e delle Energie Alternative
ENEL	Ente Nazionale Energia Elettrica
FARO	Experimental Facility for Fuel Melting
FIRES	Facility for Investigating Runaway Events Safely
FISIM	FIres SIMulator
IAEA	International Atomic Energy Agency
IGSCC	Intergranular Stress-Corrosion Cracking
ITER	International Thermal Nuclear Experimental Reactor
KFK	Kernforschungsanlange Karlsruhe (FRG)
LDTF	Large Dynamic Test Facility
LMFBR	Liquid Metal Fast Breeder Reactor
LOBI	LWR off Normal Behaviour Investigation (installation)
LOCA	Loss-of-Coolant Accidents
LOFA	Loss-of-Flow Accidents
LWR	LIght Water Reactor
MDYN	Material Dynamics
MOX	Mixed Oxide Fuels
NDA	Non Destructive Analysis
NMR	Nuclear Magnetic Resonance
NET	Next European Torus
OM	Optical Microscopy

PDT	Pseudodynamic Testing Methods
PERLA	Performance and Training Laboratory (Nuclear Safeguards)
PETRA	Facility for Treatment of Radioactive Waste
PISC	Programme for Inspection of Steel Components
PWR	Pressure Water Reactor
SCA	Shared Cost Activity
SEM	Scanning Electron Microscopy
UKAEA	United Kingdom Atomic Energy Authority
USNRC	United States Nuclear Regulatory Commission

European Communities - Commission

EUR 13690 — Annual Report 1990 - Institute for Safety Technology

H. Holtbecker

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EN

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In the area of nuclear reactor safety studies, the Institute for Safety Technology (STI) concentrated its efforts in analysing experimentally and numerically phenomena which characterize highly-improbable but very severe accidents either for light water or for sodium cooled reactors.

In the STI nuclear isle, three new laboratories for waste (PETRA), fusion (ETHEL) and safeguards, (PERLA) activities are approaching completion and have made substantial progress in their licensing procedure.

The Institute started activities in the non-nuclear safety research area only a few years ago and has been able this year to present its first significant experimental and theoretical results in the areas of runaway reactions, accidental release of products and their deflagration/detonation.

Concerning Reference Methods for the Evaluation of Structure Reliability a better understanding was gained of the nonlinear cyclic and dynamic behaviour of materials and structures by performing experiments and developing constitutive and structural-member models leading to the computer simulation of complete structures.