At present several forms of probes for the simultaneous measurement of local velocity and temperature fluctuations are tested.

## 3. Possibilities For Future Work Involving Modifications of the Test Section

Thermohydraulics of electrically heated rod bundles, detection of flow obstacles and other disturbances, transfer functions for heat current fluctuations.

## 4. Publications


H. Fuchs, S. Fäsch: Measurement of Eddy Conductivity in Sodium. International Seminar "Heat Transfer in Liquid Metals", Trogir YU, 1971, Paper No. 47

H. Fuchs: Wärmeübergang an strömendes Natrium , ETH-Dissertation und EIR-Bericht Nr. 241 (1973)

H. Bunschi, W. Seifritz: A Fast Response Thermocouple for Temperature Fluctuation Measurements in Sodium Coolants
Annals of Nucl. Energy 2, 415 (1975)
Nuclear Technology 27, 523 (1975)

J. Bunschi: Turbulente Temperaturschwankungen in flüssigem Natrium.
ETH-Dis. No. 5890
Inst. für Reaktortechnik ETHZ-AF-NST-13 (1977)

J. Bunschi: Transfer Function of Temperature fluctuations for liquid metal slug flow
Atomkernenergie 31, 23 (1978)




# COMMISSION OF THE EUROPEAN COMMUNITIES REVIEW OF FAST REACTOR ACTIVITIES, MARCH 1981


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## 1. Introduction

The Commission continued its fast reactor activities essentially in the frame of the Fast Reactor Coordinating Committee (FRCC) and by the execution of a Reactor Safety Programme at its Joint Research Center (JRC).

## 2. Activities performed in the frame of the FRCC

The study performed jointly by the Commission and UNIPEDE (*) on the penetration of fast reactors in the European Community which I have already mentioned at the previous meetings is being concluded. An extract from the final report will be presented at the BNES International Conference on Fast Reactor Fuel Cycles (9-12 November 1981 in London).

### 2.1. Safety Working Group (SWG)

The Safety Working Group continued the elaboration of preliminary safety criteria and guidelines for typical fast reactor accidents. Three of five accident categories are now terminated, namely primary reactivity accidents, general cooling accidents and local cooling accidents. Two accident categories have still to be considered, these are accidents outside the core and accidents external to the station.

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(*) UNIPEDE = Union internationale des Producteurs et Distributeurs d'Energie Electrique

It should be mentioned that the progress in elaborating safety criteria and guidelines was slightly slowed down due to problems resulting from the different development stages of the reactor projects in the European Community.

The SWG continued its discussion on specific safety issues. The intrinsec safety features constituted a topic of particular interest. The Loss-of-Flow (LOF) accident analysis performed for a large commercial reactor which was presented to the group was an excellent demonstration of the potential of inherent safety features. With regard to accident prevention the use of microprocessors in the reactor control and surveillance system was another item of interest.

In the frame of an evaluation of the consequences of severe hypothetical accidents, the SWG concluded in collaboration with the PAHR expert group of the ACMP (^) the review of current activities in the field of post accident heat removal (PAHR) and made proposals for a reinforcement of work in specific areas.

2.1.1. Whole Core Accident Code Subgroup (WAC)

Comparative calculations for a mild overpower transient (TOP - 10 c/s) for an irradiated core are nearly concluded. The publication of the results is foreseen by the end of 1981.In a next step a loss of flow accident (LOF) for an irradiated core will be considered.

The first version of the European Accident Code (EAC) which was developed by the JRC-ISPRA in the frame of the WAC group activities, is used for the current comparative calculations. The results obtained are in good agreement with the results from other codes. The WAC group is confident that the EAC will become a competitive code system. Its modular structure makes the code particularly suited for the comparison of different modules for the same physical phenomena. The future development of the code foresees the incorporation of more modules from national programmes and also the development of new modules for phenomena for which the existing modules are not fully satisfactory.

2.1.2.Containment Loading and Response Subgroup (CONT)

The CONT subgroup continued its work on the lines described earlier, consisting essentially in an exchange of information on the activities performed in the frame of the national programmes and at the JRC ISPRA in the field of development and validation of codes used to assess the consequences of severe accidents on core structures and the reactor tank.

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(^) Advisory Committee for the Management of the Reactor Safety Programme

Recently the group performed a review of the phenomena determining the radioactivity release from a fast reactor in case of an accident which has led to partial core melting. All problems including the formation of a bubble in the core containing fission products, the fission product release into the secondary containment, the aerosol behaviour and possible event sequences which could lead to a radoactivity release into the environment were considered.

From this review resulted several proposals for activities by which the group could contribute to some outstanding problems.

2.2. Codes and Standards Working Group (CSWG)

Since 1980 the Commission disposes of funding to support the activities of this group. The budget allocations in 1980 were 300.000 EUA, in 1981 they are in the order of 400.000 EUA. (^)

The funds allowed to conclude a number of study contracts with different national organisations and industries with the scope to analyse in detail the existing national codes and standards for fabrication, quality control, and material specification. Also calculation codes used for the structural analysis are compared.

A number of reports were produced in the frame of these studies, which will be partially published. Another achievement of the CSWG is the elaboration of a classification system of LMFBR mechanical systems and components for safety and availability which is under review by the competent national organisations.

The Commission is confident that the work of the codes and standards working group will provide in the European Community a solid basis for the construction of fast reactors according to equivalent safety standards and open the market for reactor components.

3. R & D Activities Performed by the JRC

These activities fall into two main areas, namely LMFBR reactor safety and LMFBR fuel and fuel cycle safety. A description of the activities was given at earlier meetings, this presentation is therefore limited to some highlights only.

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(^) 1 EUA = 1,4 US

## 3.1. LMFBR Safety

### 3.1.1. LMFBR Core Accident Initiation and Transition Phase

#### European Accident Code

The first pilot version of the European Accident Code (EAC) - a modular system of computer programmes to study postulated hypothetical accidental situations in LMFBRs - has been terminated. In the EAC the various abnormal occurrences which could possibly lead to core melt-down in LMFBR are described by mathematical models (modules) developed and/or to be developed by the JRC or by national research centres within the European Communities. Activities for the creation of this integrated system have involved collection and intercomparison of the various modules and their inclusion into a single network available to all users within the European Communities.

Results obtained by the code have been analyzed and compared with those of the other participants in the WAC Comparative Analyses. The comparison has shown that the EAC is competitive both from the point of view of physical results and of fast memory and computing requirements.

#### Subassembly thermohydraulics, code development and validation

The computer code THARC-S - describing LOF type situation in subassembly until inception of coolant boiling - has been released to a number of research organizations in the Member Countries of the European Communities. On request of CEN, Cadarache (F), additional computations have been carried out to predict the thermohydraulic behaviour of SUPER PHENIX subassemblies under LOF conditions.

The computer code VELASCO-3D - treating steady flow conditions in failed subassembly - has been further developed in order to eliminate deficiency in the flow field modelling. The modified code is well suited for analysing experiments with pin bundles with helical wire spacers.

Experimental studies have been carried out on flow behaviour in partially blocked pin bundles - in collaboration with CEN, Cadarache (F), and on flow redistribution effects caused by a local boiling zone. Data obtained have been used for validating the VELASCO-3D code.

Experimental and analytical studies on the single phase flow characteristics of a 12-pin sodium boiling test section have been terminated.

#### Liquid metal boiling studies

Boiling behaviour of sodium has been studied in porous blockages formed by granulates of stainless steel, $UO_2$, and mixtures of stainless steel and $UO_2$. The JRC experimental set-up and approach have shown to provide an adequate picture of the boiling pattern beyond the onset of boiling. The experiments have been terminated and the results described in detail.

A 12-pin bundle test section with spacers has been prepared for studies on the thermohydraulic behaviour of grid and wire spaced subassemblies.

#### Fuel-coolant interaction

The development of the computer code SAMI - treating the case of coolant impact onto molten fuel and assuming intact subassembly - has been terminated, i.e. the code has been tested and is available for application. The special feature of the code is the possibility to calculate - with non-uniform mass and temperature distribution - coolant motion, vapour space growth and collapse, and pressure history as a function of time.

A literature review of melt/water stratification instability which could lead to vapour explosions has been carried out. Stratification tests have been initiated using tin-lead alloy at melting temperatures up to 1000°C and water at temperatures 5 to 50°C.

Model developments on shock wave hydrodynamic fragmentation processes and on other phenomena - such as fragmentation by deformation, and capillary wave stripping - are completing the JRC effort in the field of analytical description of molten fuel - coolant interaction.

The simulation experiments with NaCl (1.2 kg, 1200°C) - water vapour explosions have been continued in order to study the effect of pressurization on vapour explosion cut-off (system pressure varied between 1 and 20 bar).

### 3.1.2. LMFBR Accident Post Disassembly Phase

#### Post-accident heat removal

In the field of molten pool cooling and related structure problems, theoretical studies have concentrated on molten pool interacting with catcher structures. The experimental support to this activity is given by a 100 kg $UO_2$ melting rig, FARO. This multipurpose facility is also designed to study the problems of thermomechanical loads on catchers, fuel-coolant interaction, and freezing

and plugging of fuel in cold reactor core structures. Presently, the furnace housing of FARO is near completion, other important components are in an advanced stage of manufacture.

To predict the melting processes in FARO, the computer codes CONDIF (finite element) and MACONDO (finite difference) are being developed.

In-pile experiments - supported by several organizations in the European Communities - are planned to study particulate bed cooling and its transition to a molten pool; i.e. to predict criteria for the adequacy of particulate bed cooling by sodium within the bed, and to develop models for the transition of the bed into a molten pool following sodium boiling and dry-out. Feasibility studies have been carried out by the laboratories of CEN, Mol (B), CEN, Cadarache (F) and UKAEA, Harwell (UK), and analyzed with the aim to select a European in-pile site. Experiments are foreseen with no remelting, remelting of stainless steel, and remelting of stainless steel and $UO_2$.

A cooperation contract has been signed with the NRC (USA) and PNC (J) to execute additional in-pile test at the SANDIA National Laboratory (USA). In the European tests substantial remelting of the bed will be investigated; the US-tests - with smaller bed diameter - do not allow to study phenomena like substantial stainless steel and $UO_2$ remelting.

As analytical support to the above, sensitivity studies have been carried out with the ASPAB code for mixed stainless steel-$UO_2$ particle bed in 1D steady state conditions. A 2D code for studying the transient particle bed behaviour is being developed.

Another support to the above activities is the JRCs research on materials properties - which has concentrated on studies on suitable crucible material in which stainless steel and $UO_2$ will be molten. Experiments have been carried out at temperatures approaching 2800°C with complex materials, viz. $UO_2$-stainless steel, $UO_2$-Mo, $UO_2$-Nb, $UO_2$-stainless steel-mixture of fission elements like Zr, Nb, La, Ce-oxides.

Dynamic structure loading and response

Experimental results from the COVA and COVAS programmes have been used for further development of the computer codes SEURBNUK and EURDYN-1M - which are 2D hydrodynamic structural codes. Fluid dynamic algorithms have been developed or refined to simulate special situations related to complex geometries. Futher studies have been initiated on the interface motion in Eulerian coordinates and on the coolant roof impact.

Concerning the experimental programme, further COVA experiments have been carried out using newly developed electromagnetic flowmeters. Special tests have been added to the COVAS programme to verify the accuracy of structural calculations.

The efficient cooperation between the JRC and European institutes has resulted in an agreed research activity on LMFBR containment study.

Multiflow-multiphase hydrodynamics related to core disruptive accidents

The SIMMER-II code in its point-kinetics version has became fully operational at JRC. The code has been employed on a variety of 1D and 2D test problems.

### 3.1.3. Safety Related Material Properties

Material constitutive laws and dynamic loading properties

Research on materials dynamic properties is under way. Constitutive law models for materials submitted to fast transient are developed. Phenomenological models have been implemented in the EURDYN code. Identification techniques have been studied for the correlation between experimental data and mathematical models for dynamic material behaviour.

Stress-strain curves have been determined for 20% cold worked AISI 316 using specimens taken from a hexcan. Finally, uniaxial tests have been prepared on large specimens for extreme dynamic loading conditions. These tests will take into account the effects of increasing thickness, real weld points, and defect distribution.

Fracture mechanics

In order to study the effects of irradiation on fracture toughness of stainless steel, 24 irradiation experiments have been carried out at temperatures 350 to 550°C approaching fluences of approx. $1.5 \times 10^{20}$ n/cm$^2$ (E > 0.1 MeV). 24 other irradiation experiments are under preparation. Techniques are being developed for the study of elastic-plastic fracture mechanics.

Mechanical tests

Non-linear fracture mechanics concepts have been applied to study creep crack growth. Tests have been conducted on AISI 304 at 550°C. Results obtained have been analysed and compared to other data - which were obtained by more elaborated procedures - to evaluate "J" integral.

## 3.2. LMFBR Fuel and Fuel Cycle Safety

### 3.2.1. Operation Limits of Plutonium Fuels

#### Swelling of advanced fuels

The model on swelling of advanced fuels has been further elucidated : laboratory experiments have been performed under controlled temperature and mechanical load conditions to investigate the thermal conductance of advanced fuel-stainless steel contact interface. Mechanical properties of ceramic fuels - such as fracture strength, inelastic behaviour, crack formation, acoustic emission - have been studied up to approx. 1700°C. Theoretical activities have been concentrated on thermo-elastic stresses in fuel pellets and pellet fragments. A model describing the in-pile performance of advanced fuels based on four standard fuel zones has been incorporated into the fuel pin code TPROP and tested against experimental data.

#### Fuel behaviour under transients

Experimental and theoretical studies have been started to investigate the behaviour of oxide fuels and fission products under power or temperature transients. Irradiation experiments in the HFR reactor of the JRC have been prepared. A novel approach to the problem of measuring fuel-cladding gap conductance in-pile has been attempted.

#### Equation of state of nuclear materials

Work on equation of state of nuclear materials has been continued : experimental activities have been directed to verification of gas dynamic considerations for binary mixtures of monoatomic and polyatomic gases in temperature ranges from 2800 to 5000°C. Theoretical activities have been concentrated on an assessment of the available thermodynamic data, and on studies of the vaporization mechanism at extreme rates of evaporation.

#### Cladding corrosion

Irradiation experiments have been carried out, and the oxygen potential across sections of irradiated fuel have been measured by a microgalvanic cell developed by JRC. The results obtained have been used to verify the previously proposed model on the mechanisms of reaction between mixed oxide fuel and stainless steel cladding.

This activity approaches its end.

### 3.2.2. Plutonium and Actinide Aspects of Nuclear Fuel Cycle

#### Formation of actinides

In the frame of the Isotope Correlation Experiment, correlation technique has been applied to calculate the formation of actinides in LWR. Irradiation experiments are being prepared to study the formation of actinides in a fast reactor. U-Am mixed oxides have been fabricated by co-precipitation and gel supported precipitation. The thermal conductivity of these oxides has been determined from diffusivity measurements. The TPROF code has been applied to Am containing fuel to analyse heat generation and temperature variation during irradiation in fast fluxes. Work has been carried out on systematics in fast fission yields.

#### Safe handling of plutonium fuels

This acitivity deals mainly with aerosol research. Size distribution of Pu-aerosols has been determined by a combination of electron microprobe and quantitative spectrometry. Methods have been tested for autoradiography of aerosol particles. Aerosols from simulated glovebox fires have been sampled.

#### Aspects of head-end processing of carbide fuels

Various aspects of head-end processing of advanced fuels have been studied, e.g. U-Pu segregation during controlled oxidation of unirradiated fuel, diffusion of U-233 in $U_3O_8$ during reduction, direct dissolution of unirradiated fuel in nitric acid, etc. Residuals have been identified from the reprocessing of irradiated LMFBR fuels. The work on the controlled oxidation of irradiated fuels has been continued : residual carbon has been determined in combustion products.