RISØ

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Department of Energy Technology Annual Progress Report 1 January - 31 December 1989

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DEPARTMENT OF ENERGY TECHNOLOGY
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B. Micheelsen and C.F. Højerup

Abstract. The general development of the Department of Energy Technology at Risø during 1989 is presented. This year was the last one for the department, as organizational changes at the beginning of 1990 caused a split-up of the sections of the department.

The activities within the major fields are described in some detail and lists of staff and publications are included.

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1. DEVELOPMENT DURING 1989

1.1. The Department of Energy Technology

The annual progress reports of the department have described major organizational changes in the Department of Energy Technology in the years of 1988, 1987, 1984, and 1982. In the same period there were changes in the work of major subject fields in 1986, 1985, 1983, and 1982. In 1981 all sections of the department were critically re-evaluated, and in 1982 the resulting substantial changes in the work priorities led to the change of name from the Department of Reactor Technology to the Department of Energy Technology.

The year 1989 did not bring any organizational changes, but the Department of Energy Technology was terminated at the beginning of 1990. This annual progress report is for that reason the last one.

The Department of Reactor Technology was created in 1973 by assembling major reactor technology sections at Risø, and it consisted of the sections of reactor physics, reactor engineering, thermo-hydraulics and heat transfer, reactor dynamics, and the Danish reactor no. 1.

During 1976 it was understood that there was no chance of nuclear power being accepted in Denmark, and the staff of the department began a diversification process to allow the skill of the staff to be utilized in fields outside nuclear technology.

During the years the following fields have been explored:

1) Neutron radiography
2) Reactor economy analysis, - leading to
3) Energy systems analysis
4) Reliability analysis
5) Underground heat storage
6) Solar heating

7) Windmills
8) Oil-gas reservoir modelling
9) Oil-gas basin modelling
10) Combustion technology
11) Process simulation
12) Environmental models

The fields 2, 3, 4, 5, 7, 11, and 12 were taken out of the department to form new Risø departments, and 3, 4, and 7 are still vigorously pursued, while 1,2, 5, 6, 11, and 12 have been terminated.

Towards the end of 1989 major working fields still in the department were: Combustion technology (10), oil-gas reservoir and basin modelling (8 and 9), and reactor physics which was maintained as a small group during all the years.

At the beginning of 1990 the departments of Risø were re-organized. The purpose was to make it easy for the Danish society to see and identify what the tasks of the Risø departments were.

The large section of combustion technology was augmented by staff from the Chemistry Department to create a new Department of Combustion Research.

The oil-gas reservoir and basin modelling group was closed down. The work of the group was to a rather large extend based on financing coming from research programmes outside Risø or commercial undertakings. However, low oil prices gave in general a difficult situation for new research projects, and the work of the group was for that reason stopped.

The reactor physics group including the Danish reactor no. 1 - was merged with the health physics section of the earlier Health Physics Department, and the Risø (radioactive) waste treatment plant to form a new Department of Nuclear Safety Research.

The following annual report for 1989 of the Department of Energy Technology describes the work as performed during 1989 without any interference from the tremors of 1990.

1.2. The Reactor Physics Group

The main activities in the Reactor Physics Group have been:

- Verification calculations on the QUAD CITIES reactor for testing the COSIMA core simulation code
- Development of a new method for dealing with "control rod history" in COSIMA.
- Changes in the LEWARD cross section generating programme related to the above mentioned change in COSIMA.
- Supporting calculations for other departments, mostly in connection with DR 3 utilization.
- Modification of codes for calculation of aerosol behaviour, and the application of these codes, mostly within the Nordic AKTI research programme, and, commercially, for the Finnish Nuclear Regulatory Authorities.
- Participation in the Danish work of collecting data on power reactors in the vicinity of Denmark.

The core simulator programme COSIMA has been used for core follow studies on the QUAD CITIES reactor, for which detailed operating documentation exists.

These calculations showed a slowly increasing reactivity with time. It should, of course, be constant (=0), as the reactor is critical, and the increase seems to indicate a wrong (too fast) removal of the burnable poison, gadolinium.

There has been a continued development on the subject of "control rod history". A new method has been developed, which possesses the two (usually contradictory) features of being more accurate <u>and</u> much faster. In section 2 this new method is described in more detail.

A large number of calculations with different reactor physics codes have been performed in support of:

- DR 3 fuel management
- Silicon irradiation in DR 3 for semi-conductor production (design of a new horizontal irradiation facility).
- Fission gas release examinations of highly irradiated specimens of power reactor fuel.
- Fission gas release examinations of power reactor fuels, containing residual gadolinium amounts.

The code TRAP-MELT3 of the Source Term Code Package has been applied in a commercial project to a hypothetical LOCA in the Finnish LOVIISA reactor. The code calculates fission product behaviour in the primary system. During the calculations it was found to be necessary to correct the code at a number of points. The main results obtained in the project were the deposition of the fission product aerosols and vapours and the release to the containment of fission products.

The study of power reactors of interest for the Danish society is carried out in cooperation with the Danish Technical University. During the year reports describing technical data and safety related functions were made of the Swedish BWR and the East German VVER, while reports on Swedish and German PWR's were being prepared. Furthermore, the working group held seminars on: Fast reactors, nuclear powered satellites, Russian RBMK, and naval (sub-marine) reactors.

This work of collecting data and maintaining knowledge on reactors of interest was taken up as a Nordic collaboration project towards the end of the year.

1.3. Section of Combustion Research

Based upon the experience gained from the 2 MW circulating fluid bed at Risø National Laboratory it has been decided to build a 20 MW circulating fluid bed located in Aalborg at the utility company Midtkraft.

The plant which was built during 1989 is expected to go into operation at the beginning of 1990. It is a cooperation project between Aalborg Boilers A/S, I/S Midtkraft and Risø National Laboratory. Risø is responsible for the instrumentation, the measuring system, and the analysis of the measurements.

In 1988 a coal fired furnace was constructed and built at Risø. This facility was commissioned in the beginning of 1989. During the remaining part of 1989 a large number of measurements was performed in the furnace. In one project the aim was to characterize the near-burner-field, and in another the goal was to conduct laser measurements in coal flames. The laser measurements were performed in cooperation with AEA TECHNOLOGY (Harwell Laboratory) in England.

As part of fundamental combustion research a laminar entrained flow reactor was built, and it has been demonstrated in 1989 that the flow after a few hydraulic diameters is laminar. Experiments have been performed on char particles, and rate coefficients have been found and compared to rate coefficients found in other Scandinavian reactors.

At the same time work has been going on developing a pyrolysis model for the Danish Utilities and the Technical University of Denmark. Experimental data are obtained both from Risø and Arizona State University.

During the year a literature study concerning the optimal conditions for a dolomite cracker has been performed. The result indicates that 1-2 kg of dolomite per kg/h of biomass gives an acceptable level for the performance of the gasturbine.

A project for development of a stationary turbulent 3D gas-particle flow has been finished. An extensive number of reports has been published describing the different results which were obtained. This project has been performed as a cooperation project between the Laboratory for Heating and Air Conditioning at the Technical University of Denmark and Risø National Laboratory.

A combined experimental and theoretical study of the transition from stratified flow to slug flow in the two phase flow has been performed. The result has been very satisfactory.

1.4 The Reservoir Group

The work has been concentrated on two subjects of interest for hydrocarbon exploration and recovery, i.e. basin modelling and reservoir technology.

Basin modelling is directed towards a computer simulation of the history of sedimentary basins, based on basin analysis, including a description of the amount of organic matter, its conversion to hydrocarbons, the migration of the oil and gas and their accumulation in the reservoir rocks.

The Danish Modelling Group (DMG), with participation of the Geological Survey of Denmark, Dansk Olie- og Gasproduktion A/S, and Risø National Laboratory, has concluded the present series of basin studies for the Danish territory in 1989 with a study of the hydrocarbon potential of Northern Jutland. Studies for southern Denmark and for part of the North Sea Central Trough were done in 1987-1988. The work was partly done in collaboration with the consultants, Gordon S. Speers and Arif M. Yükler, using the basin simulator developed by A.M. Yükler.

At the same time a further development of the tools for basin modelling, i.e. basin simulators, as well as an investigation of the market for basin modelling services have been undertaken, partly financed by the Danish Ministry for Industry.

The development work on the reservoir simulator, COSI, has been continued with special emphasis on the user interface for interactive computing, including menu driven input facilities and extensive graphics output facilities. At the same time a COSI-version especially suited for parallel computers is being developed. This work is done in collaboration with MATH-TECH Aps. and Cowiconsult A/S and is partly financed by the EEC ESPRIT program.

For some reservoir studies, especially for the study of a some improved oil recovery schemes, a compositional treatment of the reservoir fluids is needed. A compositional simulation may, however, be very costly as to computer time if a large number of components is used. A procedure for the determination of the minimum number of components needed for the specific reservoir problem being studied is therefore under development. This procedure will be suitable for use in connection with a number of compositional simulators, including the above mentioned COSI. This development is performed in collaboration with Cowiconsult A/S and J. Reffstrup from the Technical University of Denmark.

Computer assisted methods for the determination of relative permeabilities from transient core experiments have been developed in collaboration with the Geological Survey of Denmark and the Laboratory for Energetics at the Technical University. These methods are now under implementation and testing at the Geological Survey.

Two Pd.D.-studies titled: "Development of analytical and numerical methods for the calculation of oil displacement in fractured reservoirs" and "Sediment subsidence and compaction, temperature development and maturation of kerogens" have been going on during 1989.

1.5. Danish Reactor DR 1

The reactor has been used for educational purposes only. A number of students from technical universities in Denmark and Sweden have carried out experiments at the reactor over periods of 1-3 weeks, and 52 high school classes have carried out one-day experiments. The total number of students has been more than 1000.

2. ACTIVITIES OF THE DEPARTMENT

2.1. A New Method for Taking "Control Rod History" into Account

In a core simulation programme, like COSIMA, the neutron cross sections at each point of the reactor are obtained by interpolation in large precalculated tables.

The entries of these tables may be:

1. Fuel type (characterized by e.g. enrichment, gadolinium poison)
2. The burn-up
3. The life-time averaged void content
4. The actual void
5. The moderator temperature
6. The fuel temperature
7. The power level
8. The control rod position (in or out)
9. The control rod history. (For how long, and at which times the control rod was in).

As to the two last parameters a new method has been implemented in the LEWARD program, which generates the cross section tables for COSIMA (HØJERUP, 1989). The old method required n^2 calculations, where n is the number of burn-up steps, whereas the new method only requires 2 n calculations, and, more important, gives even more accurate results than the old one (NONBØL, 1989).

The method requires 2 burn-up calculations, one where the control rod is in all the time, and one where the rod is out all the time. At each of the burn-up steps, the nuclear cross sections etc. are calculated both with and without the control rod. Thus the following 4 sets of data are obtained:

Burn-up with CR in	CR instantaneously in CR instantaneously out
Burn-up with CR out	CR instantaneously in CR instantaneously out

As interpolation weight, the accumulated burn-up that has taken place with the control rod in divided by the total burn-up, was first used, but it was found that a slight modification which would place an increased weight on the "latest" history, gave better results. When the new modifications were introduced in LEWARD also a new mode was established, enabling the programme directly to simulate a given time sequence of control rod movements.

Thus, in Fig. 1 a directly simulated control rod sequence has been run and the obtained k_{inf}'s are shown, and also the k_{inf}'s as obtained by the old and the new interpolation methods are shown. The above mentioned 4 curves (burn-up with/without CR, CR in/out) are indicated as well.

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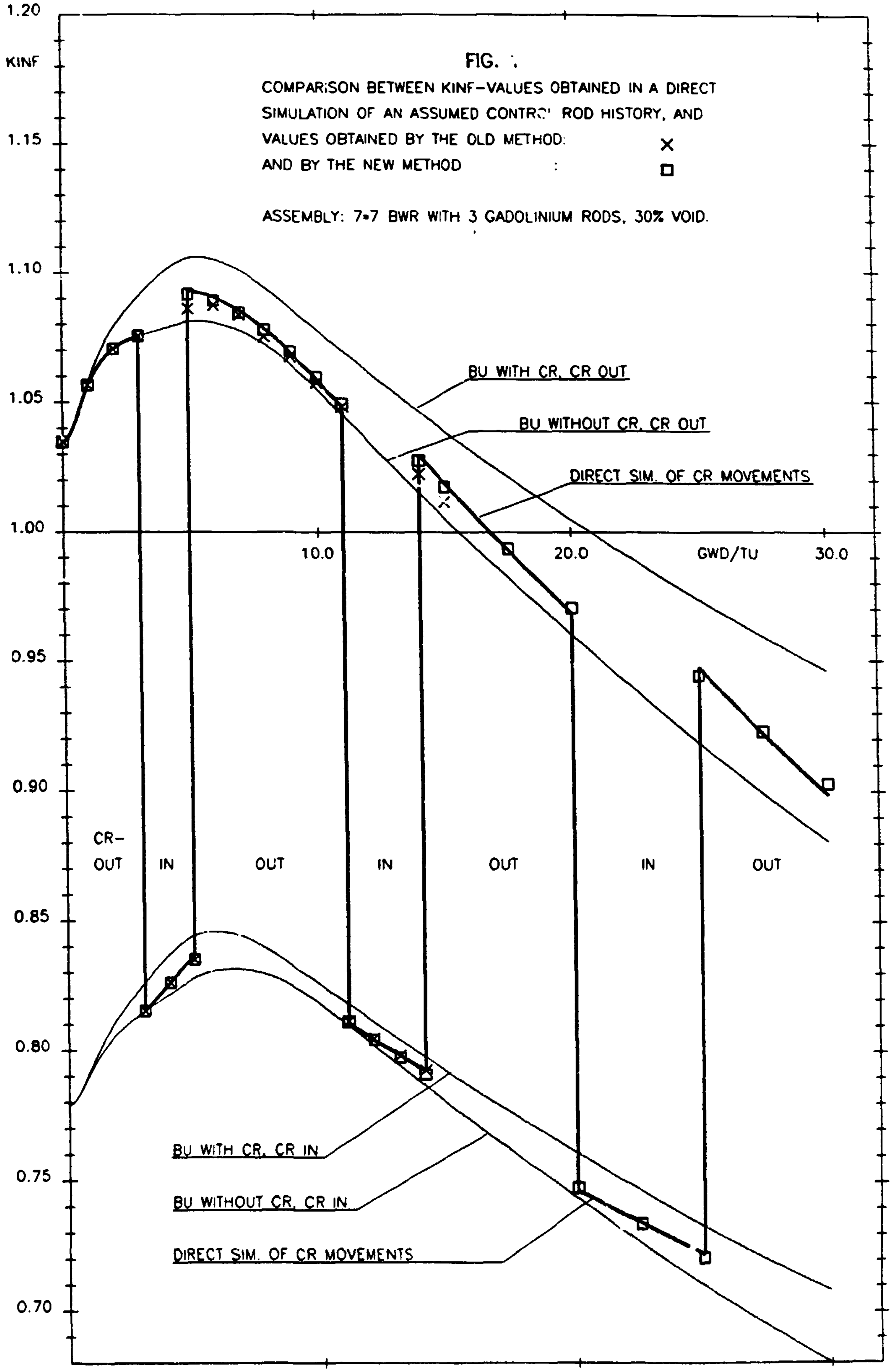
Frank Højerup


1.20
KINF
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
FIG. `.
COMPARISON BETWEEN KINF-VALUES OBTAINED IN A DIRECT
SIMULATION OF AN ASSUMED CONTROL ROD HISTORY, AND
VALUES OBTAINED BY THE OLD METHOD: X
AND BY THE NEW METHOD : □
ASSEMBLY: 7*7 BWR WITH 3 GADOLINIUM RODS, 30% VOID.
BU WITH CR, CR OUT
BU WITHOUT CR, CR OUT
DIRECT SIM. OF CR MOVEMENTS
10.0
20.0
GWD/TU
30.0
CR-
OUT
IN
OUT
IN
OUT
IN
OUT
BU WITH CR, CR IN
BU WITHOUT CR, CR IN
DIRECT SIM. OF CR MOVEMENTS

2.2. Reactor Physics Support in Fission Gas Release Examinations of Power Reactor Fuels

In the reactor DR3 several burn-up tests have been made with power reactor fuel pins of high burn-up. The purpose of these tests has been to examine pellet-cladding interactions during different over-power conditions. The detailed investigation of the exposed fuel pins has taken place at the hot cell facility at Risø.

The purpose of the reactor physics calculations has been to determine the power level of DR 3 which corresponds to a wanted power level in the test pin.

The calculations have been performed in two steps:

- First the axial power distribution has been calculated with the code DR 3/SIM for the reactor period and test pin positions in consideration.

- Then the radial fission distribution in the considered fuel element including the test pin is calculated with the collision probability code CCCMO. An important input parameter in this step is the isotopic composition of the highly burned test pin. This composition is being provided by the owner of the fuel pin.

On the basis of these two calculations it is possible to deduce the axial power distribution in the test pin for a given power level of the DR 3 reactor. A scaling factor of the reactor power then provides the wanted average power of the test pin.

The validation of this two-step method has been made by comparing the calculated axial power distribution with the power distribution measured by Lanthanum-scan of the test pin.

Erik Nonbøl

2.3. Calculation on a Hypothetical Intermediate Loss of Coolant Accident (LOCA)

The release of fission products from the primary system to containment has been calculated for a hypothetical intermediate (143 cm^2) LOCA with loss of electric power (accident category S_1B). The reactor considered was the Finnish Loviisa reactor, a VVER-440 (Soviet-type PWR), equipped with a containment.

The code applied was TRAP-MELT3 of the Source Term Code Package. TRAP-MELT3 had to be modified at a few points. The most important ones were:

- removal of an programming error in the thermal-hydraulic iteration routine. The error produced oscillations and led to excessive consumption of CPU-time or abortions of the runs.
- correction of the model for the treatment of particle diffusion in laminar flow.

The results of the calculation show that also in the primary system retention of fission products (apart from noble gases) takes place to a considerable degree. In particular, this is the case for the volatile fission products, which condense on the walls.

Peter B. Fynbo

2.4. The Temperature Calibration Laboratory

The Temperature Calibration Laboratory was accredited in 1978 by the Danish National Testing Board to carry out certified calibrations of temperature sensors in the range -150°C to 1100°C according to the International Practical Temperature Scale IPTS-68. (From 1 Jan 1990 according to the new International Temperature Scale ITS-90). In 1986 the accreditation was extended to cover calibration of electrical resistances up to 1000Ω and d.c.

voltages in the range 0V to 1.1V. The standard thermometers, the standard resistors, and the voltage standard cells in the Laboratory are traceable to the National Physical Laboratory, England.

The number of calibrations for customers has increased steadily during the years, but seems to have stabilized in 1989. In 1989 the Laboratory has performed 208 jobs for external customers and 16 for other Risø departments. In all 780 thermometers ranging from liquid-in-glass models to advanced digital types and 8 thermostats have been calibrated during the year. The calibrations have been made in the range from -150°C to 1100°C which covers the whole range accredited.

A series of temperature measurements has been performed for external customers on site. Temperatures have been measured in two waste incineration plants and in a power plant furnace.

F. Andersen / N.E. Kaiser

2.5. Large Scale Laboratory Tests of Two-Phase Phenomena

A combined experimental and theoretical study of the transition from stratified flow to slug flow in two-phase flow has been carried out as a joint project between Risø National Laboratory, LICconsult Consulting Engineers Ltd. and the Institute of Hydrodynamics and Hydraulic Engineering at the Technical University of Denmark.

The experiments have been made in a test rig located at the Technical University. The rig is about 50 m long including a test section of 36 m with an inner diameter of 90 mm. The test section is partly made of transparent tubes, which makes it possible to determine the flow regime visually.

All experiments have been performed with air/water mixtures in horizontal flow. Using a special liquid level meter the wave pattern has been recorded just before the start of slug flow. The shape of the slugs has been recorded at different flow conditions.

This work was carried out in 1988-89 for the Danish Ministry of Energy.

In 1989 a new project has been started as a continuation of the above mentioned work. The main purpose of the new programme is to study the slug flow regime. The experiments in this project will be carried out in a new bigger test rig with a length of 100 m and a diameter of 90 mm. The whole test length of the new rig is made of transparent tubes.

This work is also carried out for the Danish Ministry of Energy.

L. Christiansen / N.E. Kaiser

2.6. Risø Pulverized Coal Fired Tunnel Furnace

Through 1988 a coal fired furnace was constructed at Risø. During the start of 1990 the facility was commissioned.

The complete facility consists of a horizontal calorimetric tunnel furnace, a coal mill, and a flue gas treatment system. The furnace is dimensioned for a maximal input of 1.5 MW, and was in 1989 equipped with a simple swirl stabilized 0.6 MW burner. Fig. 1 shows the experimental facility.

The furnace is well suited for measurements of local parameters such as velocity and gas composition. The location of measuring ports and the free space around the furnace makes it possible to conduct forward scattering laser measurements in the furnace.

The facility was used in several different experiments during 1990.

In one project the purpose is to characterize the near burner field of a pulverized coal burner. Burners are often built as a double concentric, with the primary flow containing the coal in the middle and surrounded by a swirling annular secondary flow. The swirl induce a recirculation zone in front of the burner. The recirculating zone stabilizes the flame by mixing of the fuel with the flue gas. In 1989 measurements have been conducted on the 0.6 MW burner. Global measurements of carbon loss and fluegas composition were performed, and the local measurements of velocities were made by LDA.

In other projects the possibilities to conduct laser measurements in coal flames are investigated. Measurements with LDA (CLAUSEN et al.) and with CARS (CORTZEN) has been performed. CARS is a spectroscopic technique to measure temperature.

Finally the Danish boiler manufacturer Vølund has conducted flue gas cleaning experiments to reduce the emission of SO_x and NO_x.

P.A. Jensen

CLAUSEN, S. et al. (1989). Afprøvning og verifikation af laserbaserede metoder.

CORTZEN, F.W. (1990). Laser Based Measurements of Tempertures with CARS in the Risø Furnace. (To be published).

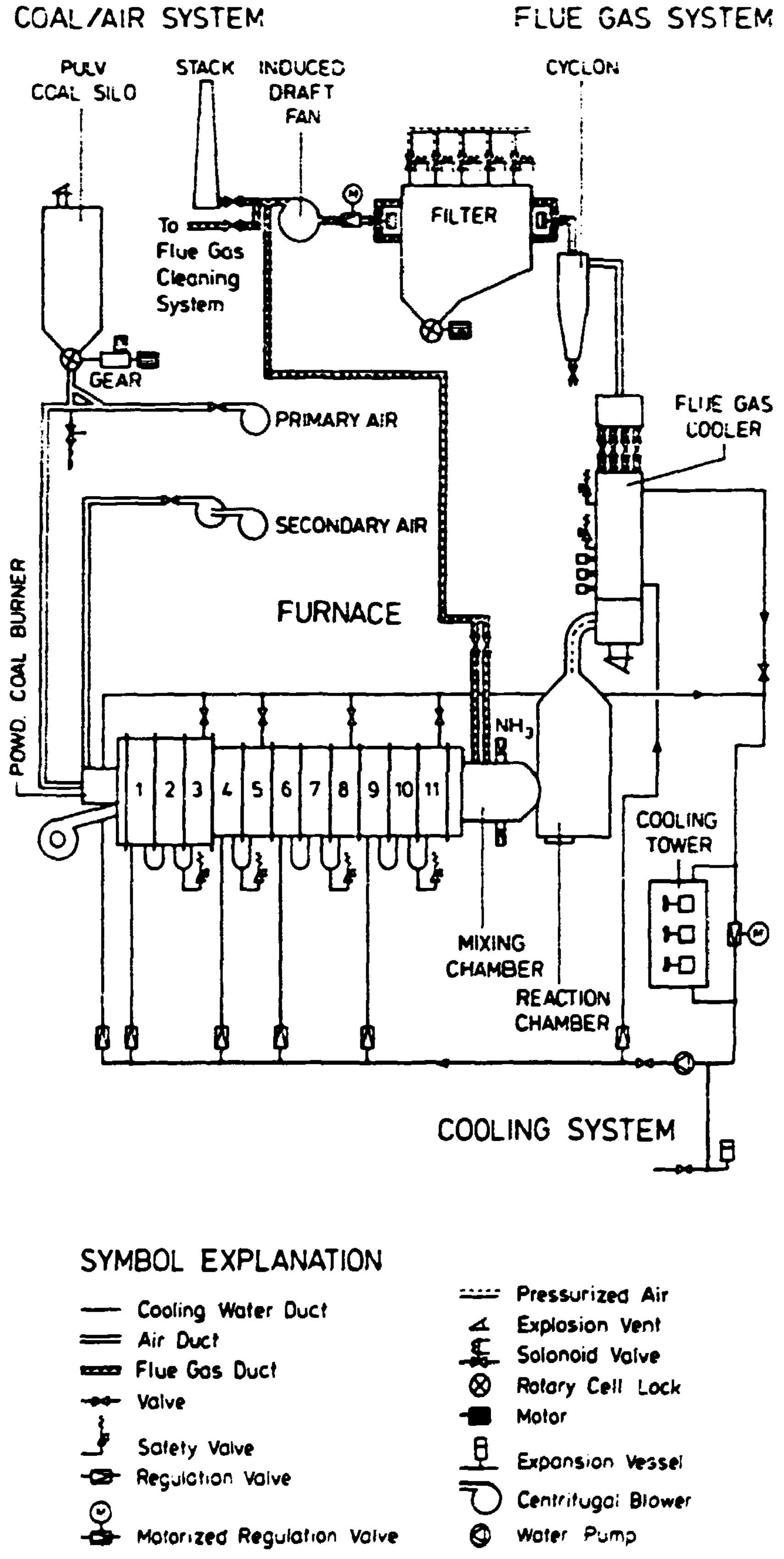


Fig.2. Pulverized Coal Fired Experimental Tunnel Furnace.

2.7. Computer Modelling of Coal Gasification Systems

Integrated Coal Gasification with Combined Cycle (IGCC) Power Plants have become a promising coal based generation option for electric utilities. In an IGCC system coal is gasified in a high pressure gasifier using oxygen and steam/water. The resulting fuel gas is cooled and cleaned (for H_2S) and combusted in a gasturbine system, and the hot exhaust gas is used to produce steam which feeds a steam turbine. As can be seen, an IGCC system contains several processes such as air separation, gasification, heat exchangers, gascleaning, combustors and turbines, which must all be included in an IGCC study. An integrated process like this is most easily simulated using flow sheating programmes among which we have acquired SEPSIM from the Department of Chemical Engineering, DTH.

To use SEPSIM to simulate IGCC plants, it is necessary to add several process modules such as gasifiers and turbines, which are not included in the module library. An equilibrium gasifier model based on minimization of Gibbs energy, has been constructed. The model is used to predict mass and energy balances for entrained flow gasifiers.

Further a turbine model, using an isentropic efficiency, has been constructed. These models, together with models for air separation and gascleaning will be combined, and the total IGCC process will be simulated.

J. Fjellerup

2.8. Optimal Process Conditions for a Dolomite Cracker

This is the last part of an EFP 88 Project, Optimal Process Conditions for a Dolomite Cracking of Tar from Gasification of Biomass. The EFP project is carried out as a cooperation between Aalborg Boilers A/S, dk-TEKNIK and the Section of Combustion, Risø. In connection with combined cycle gasification of biomass, where the gasifier exhaust gas is feeding a gasturbine, the tar content in the gas must be kept at a minimum, in order to protect the gasturbine. Recent results have shown that calcined Dolomite can be used as a catalytic tar cracker, and a litterature study was initiated to find optimal process conditions. The study has shown that the tar content can be reduced to a level acceptable for a gasturbine, if 1-2 kg of Dolomite is used in a fixed bed reactor per kg of biomass feed per hour.

J. Fjellerup

2.9. Computer Modelling of Biomass Gasification

The purpose of the project is, through application of existing data, to provide enough knowledge of gasification of biomass, especially straw, so that the effectiveness of the individual gasification reactors can be evaluated.

The aim is to set up models for fluid bed gasification of straw as well as countercurrent fixed bed gasification.

A.D. Helme

2.10. LDA Velocity Measurement in a 500 kW Pulverized Coal Flame

Pulverized coal burners are often constructed as a double concentric with a central primary flow containing the coal particles and a swirling secondary flow in the annulus. This induce a flow with a central reverse zone which stabilizes the flame near the burner exit. To characterize this flow it is desirable to measure the velocities with a non-intrusive method as LDA.

To verify the precision of the LDA measurements two main problems must be taken into account:

- Influence of particle size distribution on measurements.
- A reasonable stable stationary flow must be achieved.

LDA velocity measurement is based on the light scattering from particles passing the measuring volume. As no reliable sizing technique of coal particles in a combustor have been demonstrated in back scattering, we are forced to accept theoretical evaluations together with experimental observations.

Fluctuations in air and coal flows may influence on reproductivity of the LDA measurements.

The tunnel furnace is built of eleven circular calorimetric sections. All sections have measuring ports for optical access for laser measurements in forward and back scattering at several positions along the furnace. The furnace have a inner diameter of 1.2 m and a length of 4.5 m. The furnace is equipped with a simple 600 kW swirl stabilized pulverized coal burner. The swirl number for the actual burner is calculated to 5.6.

A two-beam laser Doppler anemometer with a Bragg cell for frequency shifting was used to measure the local velocities in back scattering. The green line (514.5 nm) of a 5 W Ar-ion laser was used. The laser, optics and traversing system is placed on a moveable wagon shown in Fig. 3. Optical access to the furnace is possible from both sides through ø100 mm water cooled ports with quartz windows.

Signal processing was done by a counter. For each measuring point 2000 individual velocity samples were taken. The velocity measurements were, due to the high turbulence level in the swirled flow, residence time corrected. Measuring time was larger than 10 seconds to secure reproductivity of mean velocities.

Velocity measurements were performed in two cases, without combustion at 20-30 °C and with coal combustion without preheating of the combustion air. The primary and secondary flow to the burner was fixed at 105 and 480 Nm^3/h in both experiments.

The experiment with combustion was performed with a coal loading of 67 kg/h ie. 490 kW. The mass density of the coals was 1268 kg/m^3 and the content of ash 9.0%. The size distribution from a standard sieve cut is shown in Table 1.

Table 1

70%	less than	45 μm
91%	"	63 μm
99%	"	90 μm
99.7%	"	125 μm
99.9%	"	180 μm

LDA measurements were taken when a stable stationary operation of the furnace was achieved.

The reproduction accuracy of the LDA measurements is illustrated in Fig. 2, measured at port B i.e. 499 mm from the burner. Within 5 hours after start, 5 velocity profiles were measured. After 1 1/4 hours the temperatures are not yet stable and a relatively low gas flow is streaming forward near the wall. 30 minutes later a stable flow is observed. It is seen that the mean velocities can be reproduced to better than roughly ±10%.

RMS velocities can, except in the near-burner field, be reproduced to the same degree of accuracy as expected statistically.

Successful LDA velocity measurements have been demonstrated on a 500 kW swirling coal flame in back scattering. Axial and tangential velocity profiles were measured at five positions. The flow is slightly asymmetric.

The data rate dropped below 3 Hz in a zone about 100 mm from the centerline immediate after the burner outlet. It was not possible to penetrate the centerline essentially at the first section. As the furnace has optical access from both sides, it is in principle possible to scan the hole furnace.

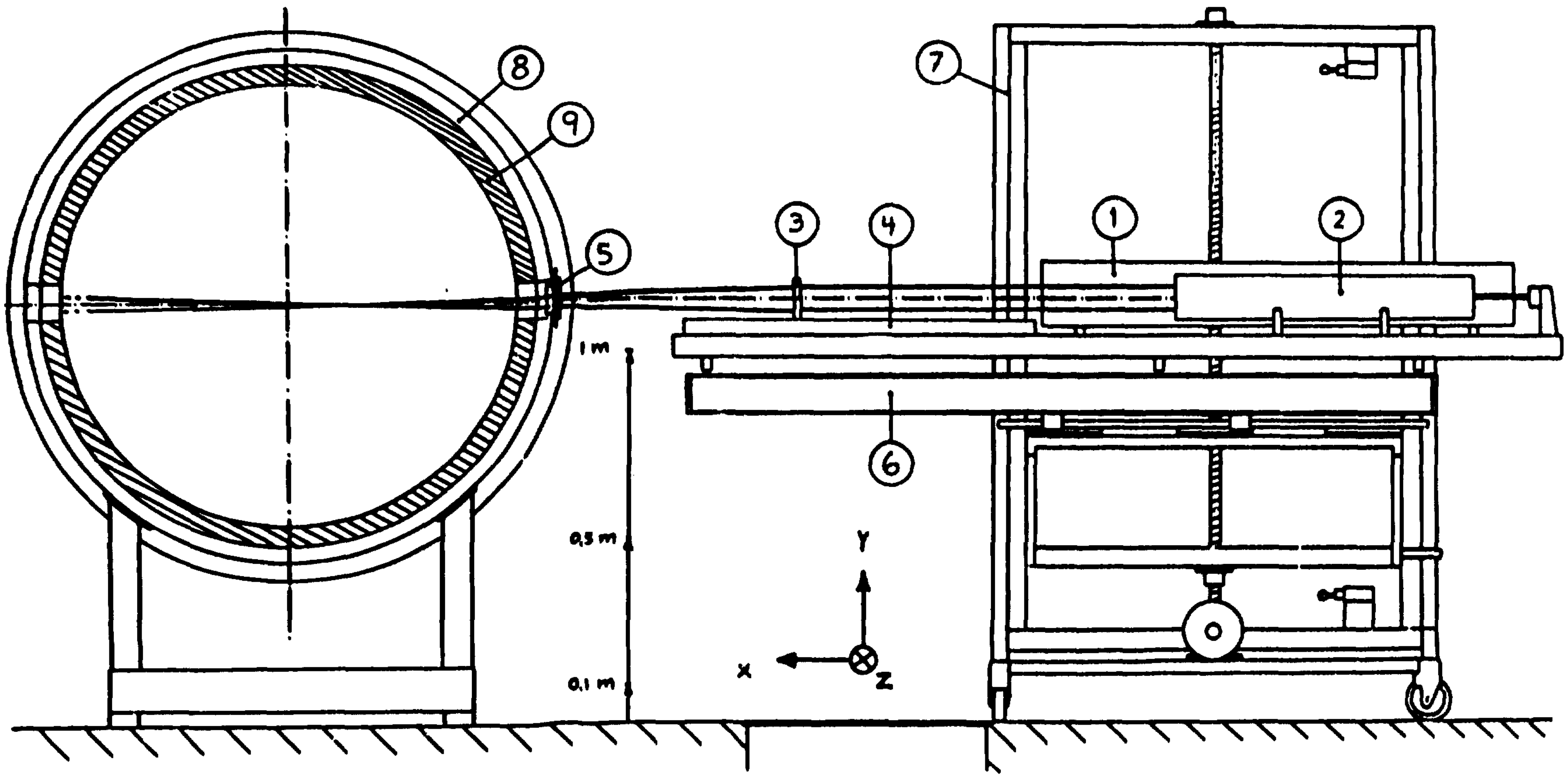


Fig. 3. Experimental LDA set-up seen from the burner. 1: laser, 2: optics, 3: 1200 mm front lens, 4: traversing system, 5: purged optical access to furnace, 6: sandwich plate, 7: wagon, 8: furnace and 9: refractory lining.

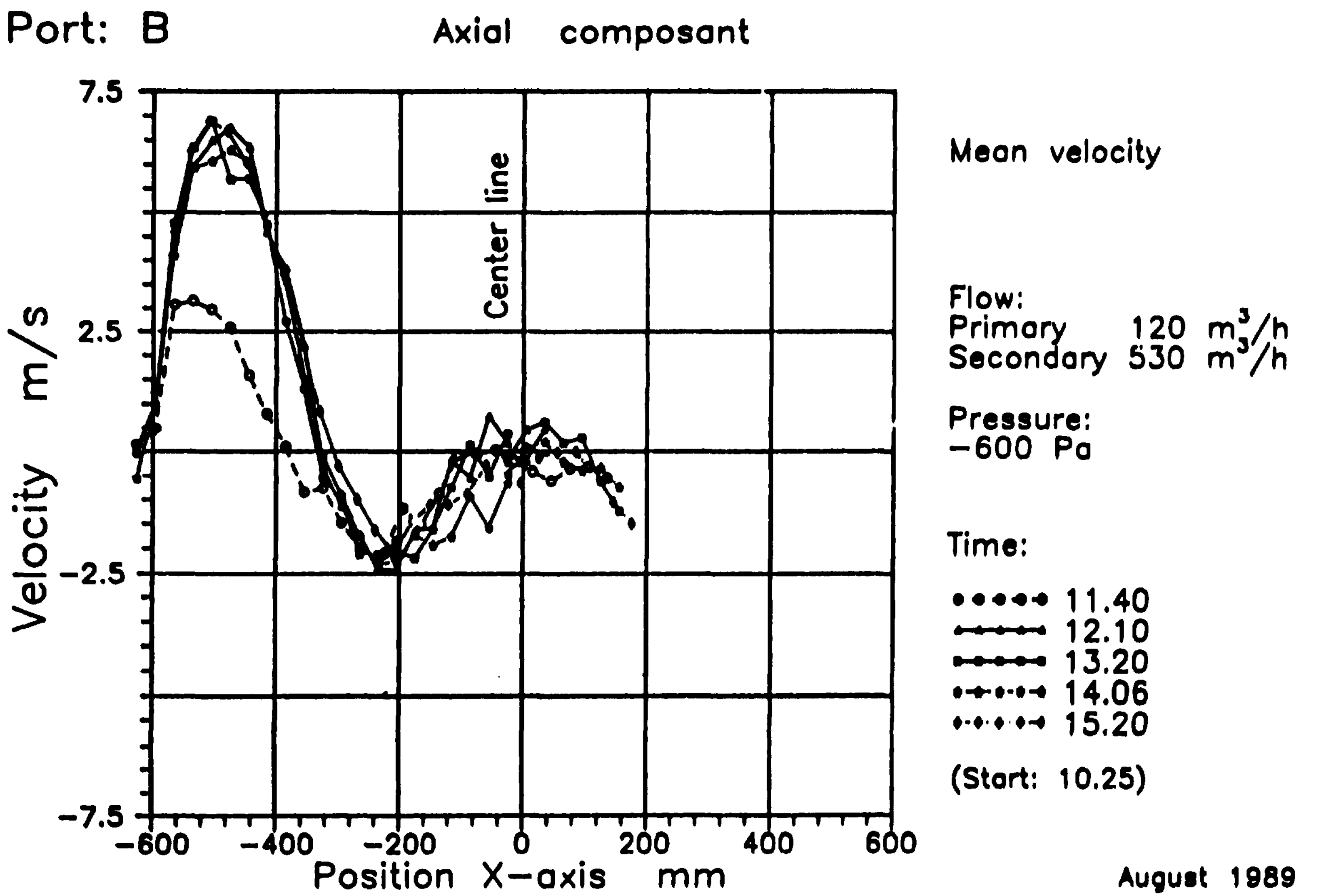


Fig. 4. Axial velocities at port B with coal combustion. The experiment was started at 10.25.

The LDA measurements with combustion could be reproduced within ≈±10% in the flame. Statistically 5-6% error could be expected on the LDA measurements. The error on the mean gas velocity due to the size of the coal particles seems relatively low ie. less than 10% with the actual burner and particle size distribution.

The overall combustion flow pattern shows similarities to the corresponding cold flow field except in a zone in the immediate vicinity of the burner outlet. The combustion mean and RMS velocities were found to be about a factor 2 larger than in the cold flow case, except for the axial mean flow after the recirculation zone. The recirculation zone with combustion was found smaller than in the cold flow case. The project ended November 1989.

S. Clausen

2.11. 20 MW Circulating Fluid-bed Demo Plant

A 20 MW circulating fluid-bed demo and test plant was built at the utility Midtkraft Power Company in co-operation between the boiler manufacturer Aalborg Boilers A/S, Midtkraft, and Risø. Risø is responsible for the test instrumentation, measuring system, and analysis of the measurements. The facility will use a fuel mix of straw and coal, ranging from 0-40% straw (on energy basis). The boiler will produce 24.6 t/h of superheated steam at 92 bar and 530°C.

At the end of the year the erection was almost completed and the first functional test was planned to take place in February 1990. A major test and research program is planned for 1990. Continuous flue gas measurements, including nitrous oxide N_2O and in-bed flue gas sampling probes, are new instrumentation features.

This instrumentation makes it possible to measure the formation and reduction of CO, NO, SO_2, and N_2O in various parts of the reactor.

L.K. Hansen

2.12. 6 MW Pressurized Circulating Fluid-bed

Aalborg Boilers A/S, in co-operation with Risø, Kemiteknik, DTH, and Universidade do Porto, Portugal, have applied EF for financial support to build a pressurized circulating fluid-bed test facility. To get a better understanding of in-bed conditions, some supplementary coal combustion and desulphurization tests were performed on the 2 MW, CFB at Risø. A prototype of an in-bed flue gas sampling probe and a commercially available probe were tested.

The commercial probe was unfit for use at high temperature due to chemical reaction in the ceramic filter. The prototype probe quenched the flue gas and consequently the chemical reaction in the ceramic filter. In spite of leaks of false air in the prototype, it seemed in principle to be a better solution.

A new and slightly modified probe has been designed and installed on the 20 MW demo facility at Midtkraft.

L.K. Hansen

2.13. Determination of the Thermal History of Rocks from Fission Track Measurements

One of the most important goals in geology is to describe dynamical processes of the Earth such as uplift and erosion of mountains and transportation and burial of sediments in basins. A rock sample may have experienced a complicated history of burial and contemperaneous heating. Understanding of these processes are of utmost importance for mineral and hydrocarbon exploration.

Fission tracks are created in minerals by spontaneous fissioning of ^{238}U. The track length is sensitive to temperature and time and therefore holds information on the thermal history of the rock. (GLEADOW et al.).

Risø has, in cooperation with the Institute of Petrology (Copenhagen University), developed a mathematical model and a computer code which calculates the thermal history directly from the fission track length distribution. An example is given below for a rock sample from Bornholm.

Fission tracks are lines of crystal defects created by natural fissioning of ^{238}U which is present as a trace element in most minerals. The defects are believed to appear as a result of mutual repulsion of mineral atoms (Coulomb explosion) after they have been ripped of electrons by the passing of positively charged fission fragments (FLEICHER).

The tracks may be seen in transmission electron microscope. They have a diameter of 10 - 30 Å and a length of around 16 μm (for apatite). The tracks are made visible in light microscope by etching. The acid has the highest etching preference in the tracks and in natural fractures (Fig. 5). Only tracks with a connection to the surface of the mineral are etched.

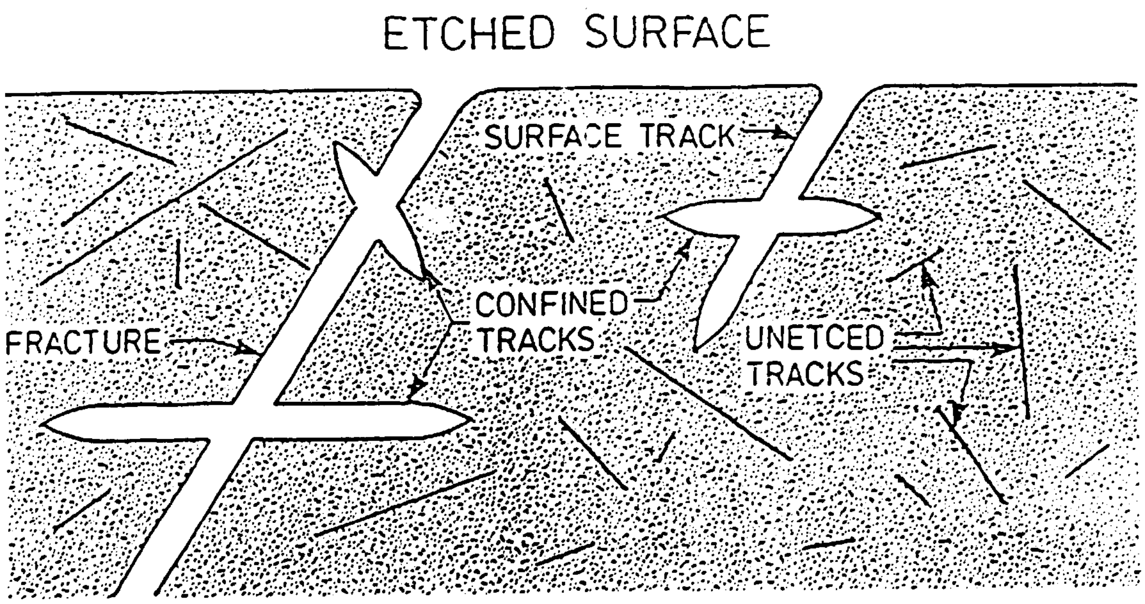


Fig. 5. Fission tracks are made visible in light microscope by etching.

A track length distribution histogram is constructed for near horizontal tracks (Fig. 6).

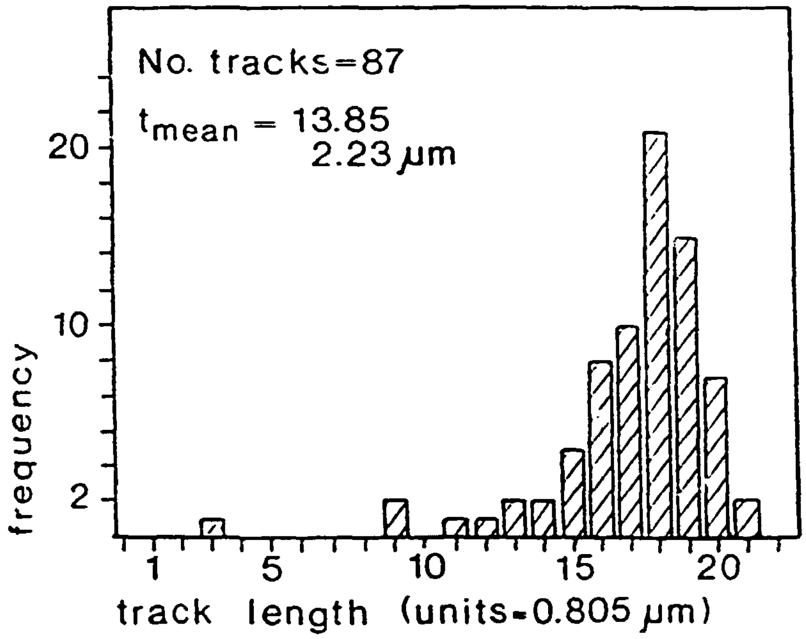


Fig. 6. An example of the length distribution of horizontal tracks. The sample is from Bornholm and has been measured by K. Hansen, Institute for Petrology, Copenhagen University.

The circumstance that only etched tracks are seen introduces a bias in the histogram relatively to the original unetched tracks. Thus long tracks have a higher chance of reaching a connection to the surface than short tracks. Another bias enters when only near horizontal tracks are chosen for the histogram. Statistical calculations performed at Risø have shown that the total biases are limited except for very short tracks.

Fission tracks are annealed as a function of temperature and time due to migration of vacancies and interstitials. The tracks are generated through time and are annealed to different stages. Each tracks has its own thermal history. Providing we have an annealing model the thermal history of a rock may be uncovered from the length distribution histogram. Risø has developed the necessary theoretical background for a computer program which uses the length distribution histogram as the main input data and determines the thermal history of the sample as an output. Other important input parameters are the uranium content and constants determining the annealing of tracks.

As an example the computed thermal history of a rock sample from Bornholm is shown in Fig. 7. It is seen that the temperature is steadily decreasing as the rock is lifted from a depth of about 3 km to the surface during a time span of about 260 mill. years. The uplift is connected with contemperaneous erosion.

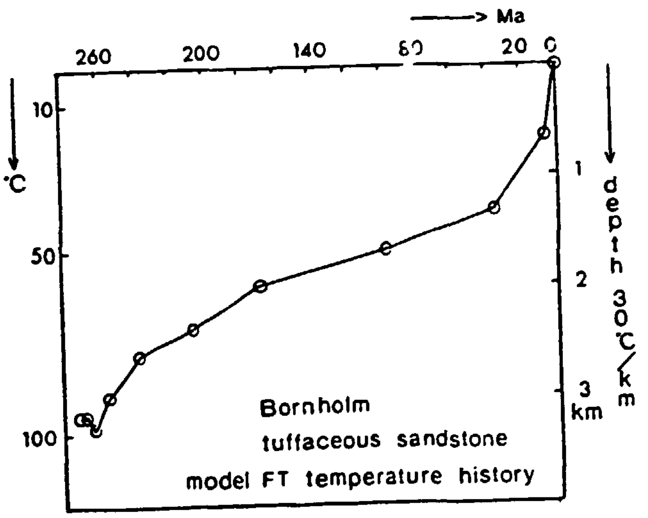


Fig. 7. Computed thermal history of a rock sample from Bornholm. The temperatures are converted to depth with the assumption that the geothermal gradient is $30^{o}C\ km^{-1}$ and the surface temperature is $0^{o}C$.

The fission track method seems to be a very promising thermal indicator. It has several advantages relative to other methods as measurements of vitrinite reflectance and biomarkers. First of all, fission tracks may provide us with detailed information during uplift and erosion in contrast to the other mentioned methods. Second, fission tracks do not migrate as is the case of biomarkers. There is a high potential for further research in fission tracks. F. ex. a more physical sound model for track annealing is needed. Further, improvements of the track observation method should be considered to increase the number of tracks measured, reduce the rock material needed, and reduce biases in the observations.

Peter Klint Jensen

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2.14. Saltwater Intrusion into Fresh-water Aquifers

The oil and gas reservoir simulation programme COSI has been developed by the Department of Energy Technology at Risoe National Laboratory in cooperation with the Laboratory for Energetics at the Technical University of Denmark and Cowiconsult, Ltd.

COSI (COmpositional SImulation) is a 3-dimensional, 3-phase, fully compositional, isothermal oil and gas reservoir simulation model. The simulator contains a dual-permeability option for the description of naturally fractured reservoirs.

The area of application covers natural depletion, gas and water injection for pressure maintenance, cycling of gas condensate reservoirs and other miscible recovery methods.

During the development of COSI it has been considered a major objective to design a flexible programme in which new features compatible with the overall scope are easily incorporated. As a consequence, the code is well suited to serve as a basic framework for the development of special-purpose simulators.

The programme COSIWTR for the simulation of saltwater intrusion into fresh-water aquifers is a special-purpose simulator developed from COSI. This work was initiated by a request to Cowiconsult from Oman's Ministry of Agriculture. The development of the first version of COSIWTR required 75 man-hours.

COSIWTR has been tested against a standard benchmark problem known as Henry's seawater intrusion problem, HENRY (1959). This example concerns groundwater flow and salt transport in a coastal confined aquifer. The problem as stated in Fig. 1. is taken from REFSGAARD et al. (1989). They also present their solution to the problem together with solutions referenced in the literature. (See also HUYAKORN et al. (1987)).

In the example the following parameters are given:

Hydraulic conductivity	:	1.16 e-5 m/s
Porosity	:	0.35
Relative density difference between salt and fresh water	:	0.35 e-1
Dispersion coefficient	:	7.64 e-7 m2/s

The specified boundary conditions are:

1) At the left boundary:
   - Specified Darcy velocity, U = 7.64 e-8 m/s
   - Zero saltwater concentration
2) At the right boundary:
   - Saltwater concentration equal to unity at the lower 80 meters
   - Lateral concentration gradient equal to zero at the upper 20 meters

The steady state solution obtained by COSIWTR is compared in fig. 2 to results published in the literature. (HUYAKORN et al. (1987)). The figure shows 0.5 isochloride lines obtained by different models.

Niels Bech

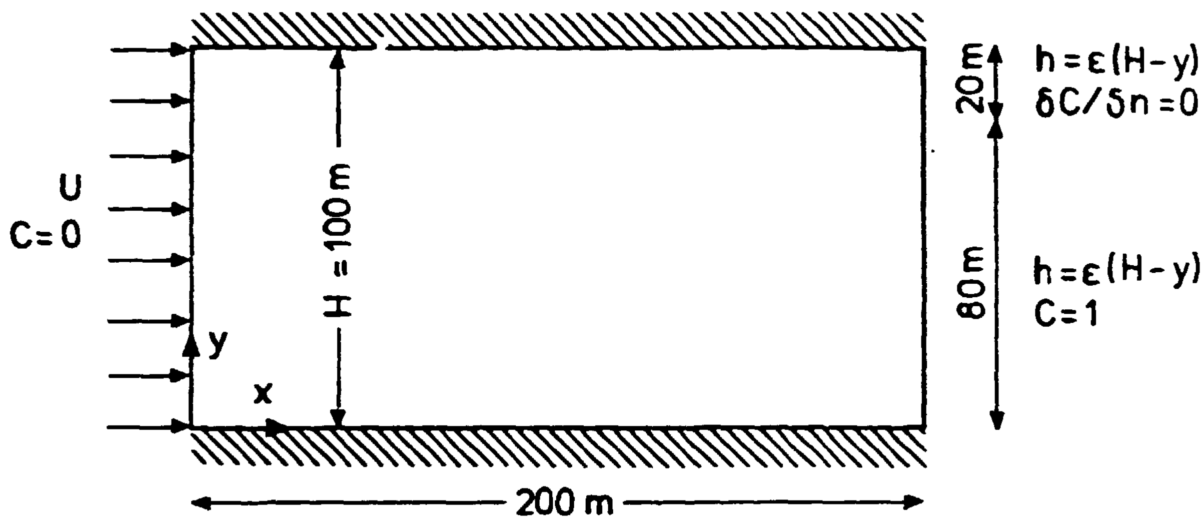

Fig. 8. Seawater intrusion in a coastal confined aquifer. Solution domain and boundary conditions.

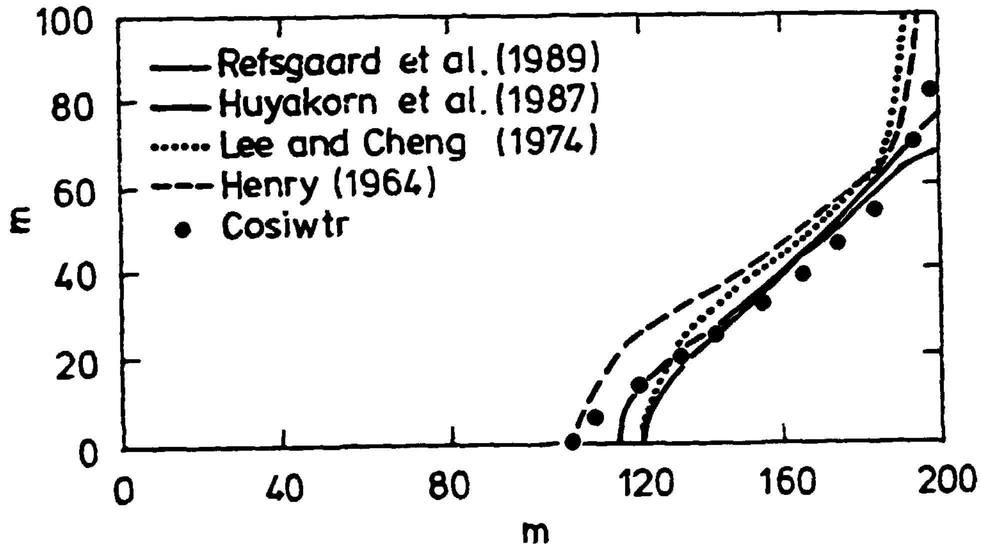

Fig. 9. Comparison to results published in the literature, HUYAKORN et al. (1987). The figure shows 0.5 isocloride lines calculated by different models.

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2.15. Development of a Computer Model for Stationary Turbulent 3-D Gas-Particle Flow

Due to the increasing use of pulverized coal fired boilers in power stations and industry and to the increasing demands to the environmental harmlessness of the furnace wastes, the need of reliable furnace analysis tools also increases.

The goal of this project, funded by the Danish Minister of Energy due to contract: "EFP-85, EM Journal no. 1433/85-10", has been to develop a computer programme, able to simulate the conditions in a pulverized coal fired furnace in reasonable detail, and usable as a base for more advanced models as needed e.g. for simulation of NO_x production.

Such a programme shall include models for turbulent gas and particle flows, for species concentrations, coal heat up and devolatilisation, homogeneous and heterogeneous combustion and convective and radiative heat transports.

The project has been carried out in cooperation with the Laboratory of Heating and Air Conditioning at the Technical University of Denmark. This laboratory has made the gas flow model including turbulence, species diffusion and homogeneous combustion and they have developed a new method for radiative exchange calculations. At Risø we have made the particle flow model, and we have tested the gas and particle flow programmes against data.

The gas flow programme is called TUFCA (TUrbulent Flow CAlculations). It is a finite element program, allowing so called body fitting. It applies the well known k-ϵ model for the turbulence modelling and controls the homogeneous combustion by turbulent mixing as well as by chemical kinetics.

The particle flow programme PAFCA (PArticle Flow CAlculations) tracks a statistical significant number of particles through the flow domain, the particles interacting with the TUFCA given gas flow and with the turbulent eddies, here modelled stoichasticly from an assumed gaussian distribution with a variance given by the TUFCA calculation.

The NIMREX model (Numerical Integration Method of Radiative EXchange) formulates the radiative problem in a new way that allows numerical integration methods known from finite element theory to be effectively applied.

The gas and particle flow programmes have been tested against a German channel flow experiment with very good results for the gas flow prediction and reasonable good results for the particle flow prediction, fig. 10.

P. Astrup og E. Gjernes

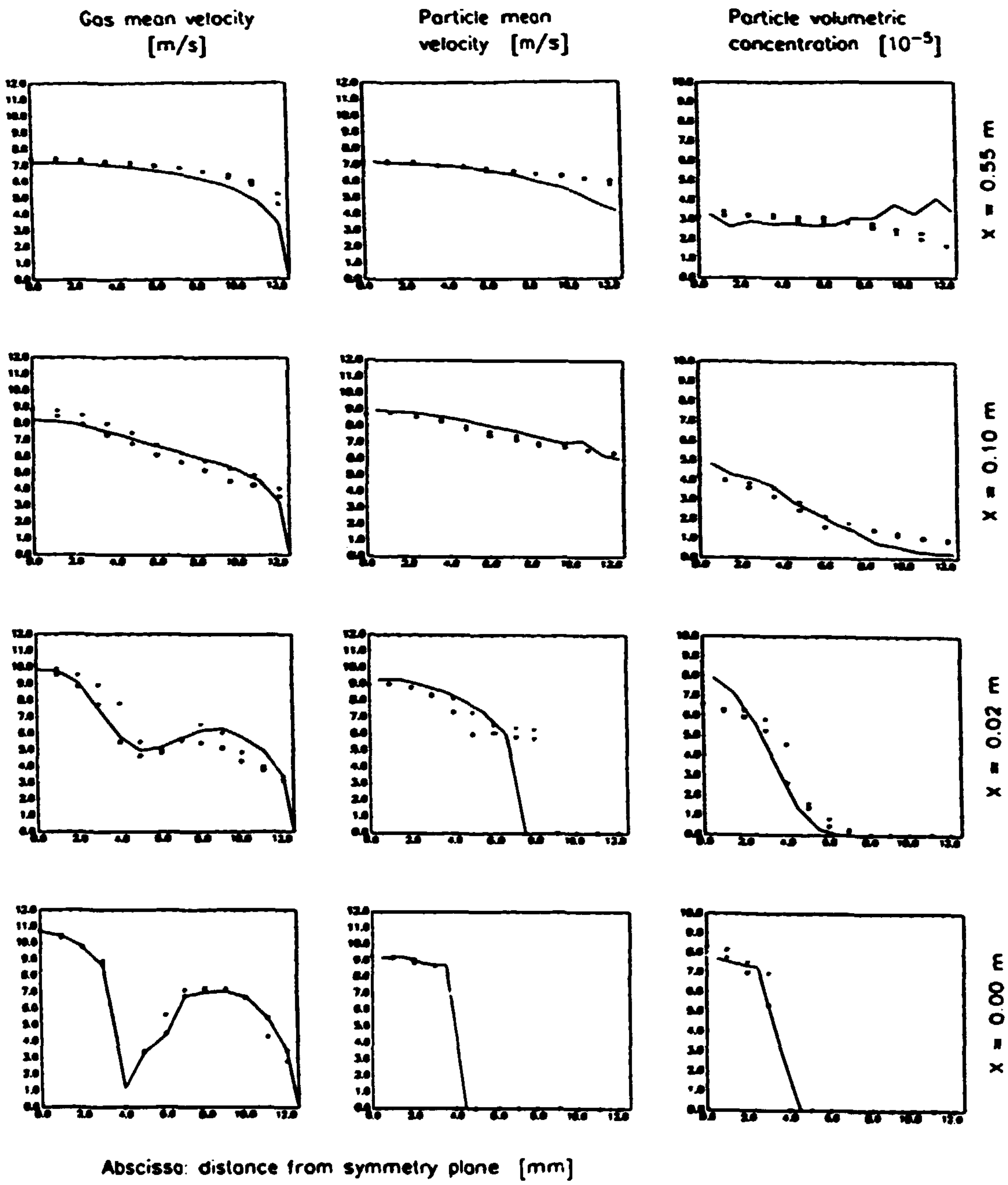

Fig. 10. Experimental and computed values for mean velocity of gas and particles and particle volumetric concentration are given for the right half of the duct. Particles were released in the center of the duct, and profiles are given for the inlet (X = 0.0) and three downstream positions.

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Abstract (Max. 2000 char.)

The general development of the Department of Energy Technology at Risø during 1989 is presented. This year was the last one for the department, as organizational changes at the beginning of 1990 caused a split-up of the sections of the department.

The activities within the major fields are described in some detail and lists of staff and publications are included.

Descriptors - INIS

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