YEARBOOK

CENTRAL RESEARCH INSTITUTE for PHYSICS

OF THE HUNGARIAN ACADEMY OF SCIENCES

1985-86

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MTA • KÖZPONTI FIZIKAI KUTATÓ INTÉZET

CENTRAL RESEARCH INSTITUTE FOR PHYSICS
HUNGARIAN ACADEMY OF SCIENCES
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P R E F A C E

The Central Research Institute for Physics of the Hungarian Academy of Sciences - generally known by the Hungarian abbreviation KFKI - is a research centre actively engaged in a multitude of fields of both basic and applied research. The five constituent institutes of the research centre have a certain degree of independence, but participation in joint projects is also important. Such projects can take full advantage of the wide range of expertise and instrumentation within KFKI.

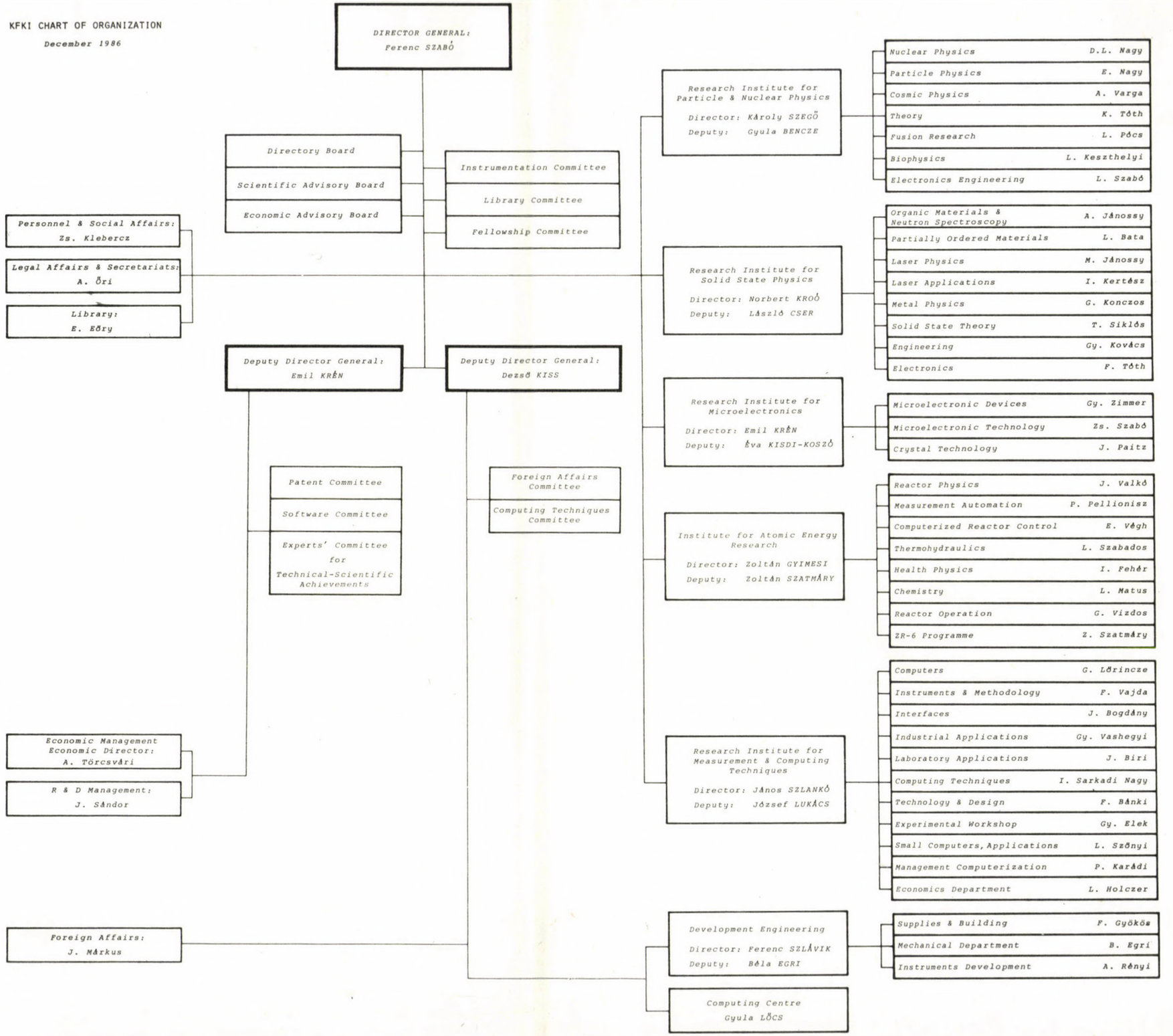
Two important examples of collaborative efforts will be described in some detail in this Yearbook. The first one is our active participation in the VEGA Mission, led by the Space Research Institute, Moscow. This project involved both very high technical requirements and strict deadlines. The final success of the encounter of the VEGA probes with Halley's comet and the scientific results of the mission have fully justified the efforts. The technical experience gained is an added bonus. The second example is the creation of a framework for collaboration in the field of theoretical physics. The Centre for International Workshops in Theoretical Physics (abbreviated as NEFIM) was founded in 1983, and has enjoyed a great measure of success.

The rest of the Yearbook summarizes the activities in 1985-86 of the five institutes of KFKI, and those of the Computing Centre and the Development Engineering Division.

Director General

KFKI CHART OF ORGANIZATION

December 1986



PARTICIPATION IN THE INVESTIGATION OF HALLEY'S COMET (VEGA MISSION)

Several institutes of the Research Centre contributed to the final success of the VEGA Mission. An extensive and exhaustive period of instrument design, mechanical and electronic construction work, and software development preceeded the launching of the two VEGA probes in December 1984. Experience gained during that preparatory period can be considered a valuable asset, and the long-term benefits for R&D work can hardly be overestimated. The period covered by this Yearbook was primarily characterized by the increasing stream of scientific data supplied by the instruments on board, as the two probes were hurtling through interplanetary space towards their destination - the encounter with Halley's comet. The moment of truth arrived in March 1986, and the quality and quantity of data gathered during the encounters fully justified the efforts. Although the evaluation and interpretation of data are still in progress, the results obtained so far have already provided a new, firm foundation to theories of cometary phenomena, and have brought to light some surprising facts as well.

After an introductory survey, some of the scientific results obtained with our participation will be summarized. Results on the imaging of the nucleus - never before seen by any instrument - will be described, followed by a summary of our present understanding of nuclear activity. The last part is devoted to plasma and high energy particle measurements in the wider environment of the nucleus.

SCIENTIFIC BACKGROUND, IMPLEMENTATION, MAIN RESULTS

WHY A COMET - AND WHY HALLEY'S?

On December 15, 1984 the first spacecraft in history to meet Halley's comet was launched from Baikonur, USSR. The second one followed on December 21, 1984. They - VEGA-1 and VEGA-2 - were also the first spacecraft built especially for cometary research and equipped for the comprehensive study of a comet. They were followed by the spacecraft SAKIGAKE on January 8, 1985, by GIOTTO on July 2, 1985 and SUISEI on August 18, 1985*.

Why a comet, and why should just Halley's comet be the target of this flotilla of spacecraft in which the efforts of thousands of scientists, engineers, and other scientific-technical personnel from many countries all over the world combined in one single goal?

One of the arguments might certainly have been that, since prehistoric times, comets have belonged to the most spectacular and mysterious phenomena in the sky, and no real progress had been made in understanding them until the discovery by Edmund Halley, who - in his book Astronomiae Cometicae Synopsis (Oxford, 1705) - first stated that comets were celestial bodies revolving around the sun whilst obeying Newton's law of gravitation. Although the rate of progress increased, basic questions such as size, composition, structure, surface properties - even the mere existence - of a solid core (nucleus), the chemistry and dynamics of the gas, dust and ionic environment, problems of interaction with the interplanetary environment remained unsolved. Seven planets and many of their satellites had been explored by spacecraft up to the middle of our decade leaving comets and asteroids as the major unexplored bodies of our planetary systems.

The strongest argument was, however, the insight that comets were formed at the time of the formation of the solar system and thus consisted of the primeval material from which the solar system evolved, conserved more or less in its original state, i.e. without having undergone the nuclear, chemical and geological processes suffered by the sun and the

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* The first encounter of a spacecraft with a comet was that of the s/c ICE with the comet Giacobini-Zinner on September 11, 1985. ICE was built to study the interaction of the solar wind with the geomagnetosphere and was equipped accordingly. It carried no imaging (video-) systems, no spectrographic equipment, no instruments to measure dust or neutral molecules. In spite of this, the ICE Mission was a great success and yielded valuable results relating to the plasma and magnetic field structure of the tail of the comet Giacobini-Zinner.

planets. The widely accepted view that comets arrive to the inner solar system from the Oort Cloud which is a reservoir of some 10^{12} potential comets revolving around the sun at distances of 10,000 to 100,000 astronomical units, does not mean, however, that future cometary nuclei were formed in the Oort Cloud itself. The supposed places of their origin vary from the asteroid zone to interstellar clouds. No matter how this question will be answered, knowledge of the physical and chemical properties and composition of cometary matter is certainly a corner stone of the future development of present theories of cosmogony.

Further very strong arguments were provided by the role comets played in evolving our present concept of the plasma structure of interplanetary space. It was on the basis of the properties of ionic cometary tails that Biermann postulated, in 1951, the existence of the solar wind which was subsequently first detected by the LUNIK II spacecraft in 1959. It is the interaction of the solar wind with the cometary ion population that makes the study of comets extremely interesting from the viewpoint not only of cometary physics, but also from that of plasma physics in general. Mass loading of plasma, formation and dynamics of various types of shock waves, various kinds of transient phenomena, especially nonlinear phenomena in strongly turbulent conditions, acceleration of ions are the main plasma phenomena connected with comets; the study of these plasma phenomena inevitably needs in situ measurements.

Halley's comet is one of the brightest of comets, and in fact is the brightest among those comets that have returned at least twice to the inner solar system. Its return in 1986 was the thirtieth recorded one, its orbital data were thus quite well known, and other requirements (visibility, activeness, etc.) were also well satisfied except that the orbital motion of Halley was retrograde and, as a consequence, the velocity of a spacecraft relative to the comet had inevitably to be very high. VEGA-1 and VEGA-2 flew by Halley's comet with relative velocities of 79.2 and 76.8 km/s, respectively. This reduced the time spent in the 10^6 km environment of the comet to about seven hours. Careful comparative studies of other possible candidates resulted in the choice of Halley's comet as the target of five spacecraft for the first concerted and comprehensive in situ study of a comet.

THE SPACECRAFT VEGA-1 AND VEGA-2: SHORT DESCRIPTION AND MISSION HISTORY

As is well known, both VEGA spacecraft visited, prior to their rendezvous with Halley's comet, the planet Venus which they flew by on June 11, 1985, and June 15, 1985, respectively. On doing so, each of them detached a module of a mass of about 2 t by means of which detailed investigation of

the atmospheric and surface properties of the planet was carried out. Gravity assisted by the planet, the remaining part (mass about 2.5 t) of each spacecraft continued its voyage towards Halley's comet.

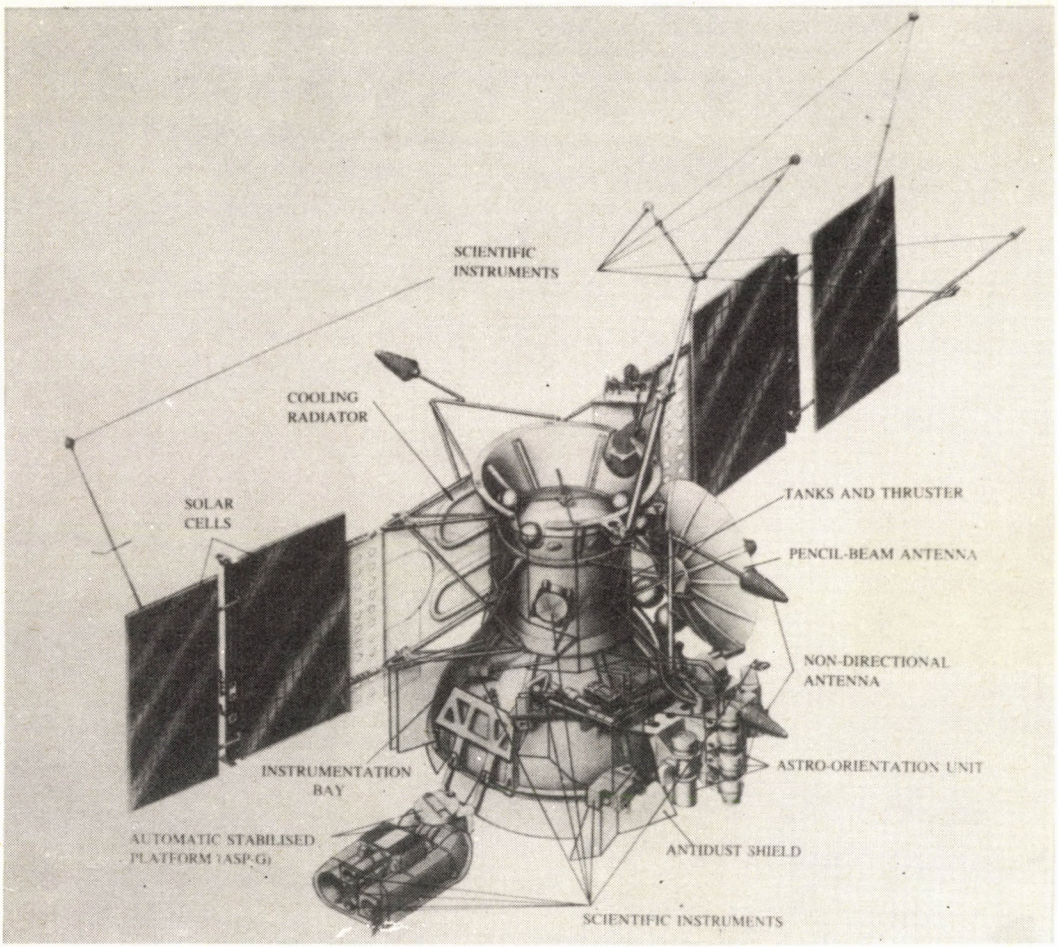

Fig. 1

Schematic drawing of the VEGA s/c without the Venus descent module

Figure 1 is a schematic drawing of the s/c VEGA (VEGA-1 and -2 were identical in all respects) without the Venus descent module. Table 1 shows the orbital data of both spacecraft, Table 2 contains a specification list of the scientific payload designed for studying Halley's comet (instruments of the Venus descent module are not indicated in the Table). The instrumentation of VEGA-1 and -2 was identical.

Table 1

MAIN PARAMETERS OF THE VEGA MISSION FLIGHTS

	VEGA-1	VEGA-2
Launch	Dec 15, 1984	Dec 21, 1984
Venus fly-by	June 11, 1985	June 15, 1985
Closest approach to the nucleus of Halley's comet:		
-time	07:20:06 UT	07:20:00 UT
	March 6, 1986	March 9, 1986
-distance from the nucleus	8890 km	8030 km

KFKI participated in five experiments of the VEGA Mission. These were TVS, DUCMA, ING, PLASMAG and TÜNDE-M. The biggest task was certainly the design and construction of the complete electronic system of the two CCD television cameras (TVS) together with devising and writing the software for the automatic tracking of the comet and controlling the rotation of the pointing platform (ASP-G). This was carried out in KFKI, in cooperation with the Space Research Institute of the USSR Academy of Sciences, and with CNES, France. The idea and the complete experimental setup of the energetic charged particle experiment TÜNDE-M was devised by the Cosmic Physics Department of RMKI. The corresponding instrument was built by the Technical Department of RMKI in cooperation with the Space Research Institute of the USSR Academy of Sciences, Max-Planck-Institute for Aeronomy (Katlenburg/Lindau, FRG). Essential parts of the PLASMAG Instrument were built in the Measurement Automation Department of AEKI. The Cosmic Physics Department of RMKI and the Max-Planck-Institute for Aeronomy also participated in this project which was led by the Space Research Institute (Moscow). KFKI also played an important role in the overall managment of the missions: one of the two vice-chairman and four of the thirteen non-USSR members of the International Scientific and Technical Committee of the VEGA Missions, one principal investigator (of TÜNDE-M) and two co-pi's (of TVS and PLASMAG), and a number of co-i's of the fourteen scientific experiments were from KFKI.

Table 2

SCIENTIFIC PAYLOAD OF THE VEGA SPACECRAFT

Acronym	Instrument	Goal and instrument parameters	Mass (kg)	Power (W)
Optical experiments:				
TVS	TV system	Inner coma and nucleus imaging. Two CCD cameras (fields of view 0.43^{o} x 0.57^{o} and 3.5^{o} x 5.3^{o})	31.5	50
TSK	Three channel spectrometer	Spectral mapping of coma emissions in the range $0.12<\lambda<1.9$ μm	14.0	30
IKS	Infrared spectrometer	Detection of infrared emissions of coma and thermal radiation of nucleus ($2.5 < \lambda < 12$ μm)	18.0	18
ASP-G	Automatic pointing platform	Pointing of TVS, TKS, and IKS at nucleus region	82.0	40
In situ dust experiments:				
PUMA	Dust mass spectrom.	Dust particle elemental composition	18.7	31
SP-1	Dust particle counter	Dust particle flux and mass spectrum ($m > 10^{-16}$ g)	1.9	1
SP-2	Dust particle counter	Dust particle flux and mass spectrum ($m > 10^{-16}$ g)	4.2	4
DUCMA	Dust particle detector	Dust partic. flux and mass spect. ($m > 1.5x10^{-13}$ g)	2.7	2
FOTON	Dust particle detector	Large dust particle detection (under anti-dust shield)	2.1	4
In situ analysis of neutral gas, plasma, and fields				
ING	Neutral gas mass spectrometer	Neutral gas composition		
PLASMAG	Cometary plasma spectrometer	Ion flux composition, energy spectra of ions and electrons	6.8	8
TÜNDE-M	Energetic particle analyser	Energy and flux of accelerated cometary ions	4.5	6
MISCHA	Magnetometer	Magnetic field	4.0	6
APV-N	Wave and plasma analyser	Plasma waves, 0.01-1000 Hz, plasma ion flux fluctuations	4.9	8
APV-V	Wave and plasma analyser	Plasma waves, 0-300 kHz, plasma density and temperature	3.0	2
		Altogether (without ASP-G)	125.3	178
		with ASP-G	207.3	218

MAIN RESULTS

Both VEGA spacecraft completed their tasks successfully. An extraordinary huge amount of unique scientific data was accumulated mainly during the two fly-bys.

The Giotto Mission was equally successful (fly-by was on March 13-14, 1986 at the smallest distance of 600 km), and has confirmed all the main results of the VEGA Missions.

Now, as a result of the VEGA and GIOTTO experiments, we know with certainty that there is a solid nucleus in Halley's comet. Its shape is irregular with characteristic dimensions of about 16x8x8 km, it has a dark cover with a very small albedo ($0.04 \begin{smallmatrix} + 0.02 \\ - 0.01 \end{smallmatrix}$) consisting mostly of carbonaceous chondrite-like material with strongly increased carbon content. We know that there is a strong mass loading of the solar wind in the region between distances of about 1 and 10 million kilometers upstream of the comet and, as a consequence, a bow shock exists in the solar wind plasma at distances farther than 0.3 million kilometers around the comet on the solar side. We know that, in addition to the bow shock, there are more boundaries around the comet in the cometary plasma region, e.g. the cometopause, the magnetic barrier, and the cometary ionosphere boundary. We now know that there is an energetic cometary ion population surrounding Halley's comet beginning at a distance of about 10 million km from the nucleus. Energies of these ions extend to more than 700 keV (much more than anticipated earlier), spatial distribution of their intensity shows distinct, complicated patterns.

These results were obtained by the TVS, TÜNDE-M, and PLASMAG experiments of the VEGA Missions, confirmed and in some aspects complemented by the corresponding experiments of the GIOTTO Mission. They will be dealt with in more detail in the subsequent two sections of this Yearbook.

Substantially new results were also obtained in practically all other experiments of the Halley missions. To mention only a few of them:

The first in situ measurements of gas production rate showed values between 0.7×10^{30} and 2×10^{30} molecules per second. Ionic species with masses up to about 110 AMU were detected. Surface temperatures of the nucleus were measured and were found to vary between 300 and 400 K - values much higher than anticipated. Fluxes, mass distributions, and compositions of dust particles were measured. It was found that dust particles of smallest masses ($<10^{-14}$g) were much more abundant than predicted on the basis of the light-pressure-depletion theory.

It should be noted that the results indicated here represent a tiny, very incomplete fraction of the results obtained during the first six or seven months after the encounters in March 1986. A large amount of data still awaits analysis which will certainly yield still more insight into the formation and development of comets.

THE NUCLEUS

The imaging experiment was very successful. This is true in spite of the fact that during the VEGA-2 encounter the orientation microprocessor failed and the system worked in a back-up mode transmitting only full-frame images with exposure times not optimized for nucleus observations.

Some further problems made the image processing difficult. In the case of VEGA-1, the linear response of the CCD matrix was shifted from zero by an offset of about 70 digital intensity values. Coherent noise was also present on the images. An additional high frequency noise affecting VEGA-2 images was removed using Fourier transformation.

As of today we have processed only those images on which the nucleus can be identified. This includes about 63 VEGA-1 and 11 VEGA-2 images taken around closest approach which were, respectively, on 6 March 1986 at 7:20:00 UT at a distance of 8889 km and on 9 March 1986 at 7:20:06 UT at a distance of 8030 km from the nucleus. *Figure 2* shows a reproduction of the best image of VEGA-2 taken at a distance of 8030 km from the nucleus with a resolution of 120x160 m^2, in the 740-900 nm spectral range.

Fig. 2

Image of the nucleus taken by VEGA-2 at a distance of 8030 km

Our first goal was to determine the size of the nucleus. Although only illuminated parts can be seen on the images, by iterating them, and by considering both the fly-by geometry and the rotation period, we reached the conclusion that the overall dimensions of the nucleus are $(16\pm1)\times(8\pm1)\times(8\pm1)$ km. On the GIOTTO spacecraft the camera could define only two sizes: these agree with our results. The nucleus is irregularly shaped, similar to a potato or an avocado; the closest geometrical body is a truncated cone capped at each end by hemispheres of 4 km and 2.25 km radii, respectively. The volume is about 500 km^3. On the basis of this and using the nongravitational force values, Rickman recently evaluated its density and found it to be about 0.1-0.3 g/cm^3, very much less than was anticipated.

The rotation period was obtained by reconstructing in space the major axis of the nucleus. From this, supposing prograde rotation, we obtained 53.5 ± 1 h period. This agrees well with ground based observation of the jet periodicity and brightness variations, and with the Lyman-α breathing of the hydrogen coma observed by s/c SUISEI. GIOTTO has no data for the rotation. We would mention, however, that some ground based astronomers obtained a period of 7.2 days. This is possibly connected with the nutation of the spin axis, but further analysis is necessary.

It was possible to obtain the position of the rotation axis too, assuming that it is perpendicular to the major axis. Its inclination to the orbit normal is 20 degrees. This result does not coincide with an earlier result derived from the ground based observation of jets; but the variation might be explained by the nutation of the axis. No differences could be found between images made by different filters so we conclude that the colour of the nucleus is neutral, grey.

At present we are in the process of defining the contour of the nucleus on individual images. This should be corrected by the illumination to obtain the limb of the dark side too, based on the fly-by geometry. At this stage preliminary limbs are available. Using these, in the Space Research Institute in Moscow an approximate 3-dimensional nucleus has been reconstructed, but this needs further improvement. The same group, using a similar technique as in medical tomography, reconstructed the 3-d light intensity distribution in the near nucleus region. The dust jets shield some part of the limb, so it was important for us to understand the jet geometry.

An important observation was that jets are observable mostly around the sunlit hemisphere, after dawn or before dusk the jet activity was limited. The VEGA-2 images made possible the 3-d reconstruction of most of the jet sources. On those images the jet boundaries and cores are clearly identifiable.

For 3-d reconstruction, we assumed that the jet sources could be approximated either by discrete points or by lines. (The edges of a linear source should appear as boundaries on several images.) By knowing the geometry, most but not all of the sources could be spatially reconstructed. One important discovery is that not only are many of the sources actually pointlike or linear, but they seem to be ordered to form an even larger quasi-linear structure along the surface. One part of this structure crosses the projection of the s/c trajectory onto the nucleus, which means that the s/c crossed this jet. This was actually observed by the SP-1 dust counter. We were able to identify a jet source on the dark hemisphere too, using the shift differentiation technique developed by Larson and Sekanina.

The GIOTTO HMC experiment concluded that the very active regions on the surface are less than 15-20% of the total surface. The Lyman-α imaging on SUISEI also identified localized sources on the surface: two strong (S1, S2) and four weak (W1-W4) sources were identified, resulting in periodic breathing of the Lyman-α coma. The conclusion was reached that VEGA-1 experienced the outburst of S2, whereas VEGA-2 did the same with W4, assuming a 7h time of flight for dust particles from surface to s/c. These conclusions agree well with the general features of VEGA-1 and VEGA-2 images. As GIOTTO encountered the comet when it was rotated by almost 180 degrees in comparison to the VEGA-1 situation, it explains why the GIOTTO images are relatively clear.

It is important to note that on the VEGA images the surface of the nucleus on the non-active parts is covered by optically thin dust: the optical thickness is less than 0.1. These measurements also revealed that the nucleus is covered by a dark material resulting in a low (4%) albedo.

Work is in progress to identify the observed surface brightness variation on the processed images with topographic features, dust sources, etc. At this stage from the VEGA images no surface feature has been identified unambiguously. The GIOTTO images show some crater-like structures on the surface.

The results of some other experiments are also relevant to understand the nucleus. The IKS experiment on VEGA measured the surface temperature of the nucleus and found it to be 300-400 K, in a region of about 5x3 km^2. This shows that the surface there can not be highly darkened normal ice. Both devices, the PUMA on VEGA and the PIA on GIOTTO measured the dust composition. They confirmed that dust particles fall into different classes: one is quite close to light organic material, another to silicates, the third is close to C1 carbonaceous chondrites but richer in carbon. Ten minutes before closest approach the dust material very frequently had the highest peak in carbon: closer to the

nucleus the highest peak was carbon or silicon. The density of the dust was very light, in the range of 0.03-0.4 g/cm^3. Both IKS and TKS on VEGA confirmed that the activity around the nucleus was asymmetrical, and confined to the sunward hemisphere. In different spectral ranges jet-like activities were observed.

What is our present understanding of the nucleus? At the advent of the space missions Whipple's dirty snowball model was the accepted paradigm. It was developed further e.g. by allowing an outgassed, friable sponge like mantle on top of the ice-dust core. As this model yielded a fairly homogeneous activity, special surface features were considered to explain jet activity.

After the space missions we have to conclude that the nuclear activity is much more inhomogeneous than was previously thought. The most active area is about 20% of the surface, being divided into active spots and so-called crisps, linear features. The inactive or less active areas are covered by dark, refractory material probably rich in carbon. (The IRAS experiment observed three comets all of which were very dark.) At some places the solid surface might be almost impervious to the escape of gas. The volatiles are either produced from jet sources or are emitted from the dust in the atmosphere but pure gas outbursts cannot be excluded. The surface material has probably low heat conductivity. If one compares the position of the jet sources of VEGA-2 with the active regions measured by SUISEI and as seen by GIOTTO, the activity is highest around noon and varies with the Sun angle. IKS on VEGA observed about 5-10 degrees of heat lag, corresponding to 1-2 hours of time lag. Having so many localized jet sources and small active surface, the active areas should be almost covered by ice to account for the observed total gas production rate. However, here we face some difficulty in understanding where the dust comes from. If it is just frozen-in material in the ice, dust analysis does not reveal the overall cometary composition. However, this is an unlikely situation, because to account for the total material lost during one apparition, the surface layer has to shrink about 1m, or - assuming 20% active areas - 5m deep crisps should cross the surface. But deepening decreases the possibility for the Sun to heat it, so the active areas should change from time to time. It will be interesting to see how the 1910 jet sources coincide with the present observations. If the position of the crisps is changing, this can be due to heat stresses. In this case the new crisps are covered by "fresh dust" from the surface layer and the dust will give information about the overall composition of the comet. In this picture the icy core is covered by a thicker layer of solid mantle.

If the position of the crisps does not change, then the nucleus may be similar to that described by the icy glue model. This means, however, that the crisps should be deep and wide after many apparitions, slowly leading to the disintegration of the nucleus. Some crisps should be big enough to be observable by our camera having about 200-300 m resolution. This type of analysis is still in progress. We would mention that in this case the missions give information about the composition of the icy glue, but not about the boulders glued together. The difficulty of this model is, however, that it is unclear how large-sized boulders could reach regions outside the big planets.

If we believe that comets were born in the Uranus-Neptunus region (though the low density favours more distant regions), it is conceivable that very big objects were also created with small likelihood. Some of the big ones could have been captured by the giant planets. It is tempting to claim that Umbriel, a satellite of Uranus recently observed by Voyager, is very similar to Halley albeit very much larger.

During the 20th ESLAB Symposium (Heidelberg, 27-31 October, 1986) Whipple suggested that the comets are made of smaller snow balls glued together. The surface probably underwent some changes due to irradiation, etc. while the comets were stored in the Oort cloud, and this yielded the less active or inactive areas. The friable sponge like mantle might be in work only in the active places. Further studies are needed to clarify this situation.

PLASMA AND PARTICLE ENVIRONMENT

The PLASMAG-1 instrument package observed the plasma component of lower energies on board the VEGA spacecraft. It had two hemispherical electrostatic analysers which measured the energy spectra of ions arriving from the spacecraft-comet relative velocity direction (Cometary Ram Analyser--CRA) and from the direction of the Sun (Solar Direction Analyser - SDA). The SDA had an acceptance angle of 38° x 30° and detected ions in the energy/charge range 50-25,000 eV/Q (Q is the charge state). The SDA observed the solar wind stream which has a very narrow angular distribution in undistributed interplanetary space and the average energy of the proton component is about 800 eV. The CRA had an acceptance angle of 14° x 32° and detected ions in the range 15 - 3500 eV/Q. The main goal of CRA was to observe cometary ions. In the vicinity of the nucleus where the particle velocity was negligible compared with the spacecraft velocity relative to the comet, the energy spectra of the cold cometary ions represented their mass spectra.

A cylindrical electrostatic analyser (EA) with an acceptance angle of $7^{o} \times 7^{o}$ was oriented perpendicular to the ecliptic plane to observe an angular section of the theoretically isotropic electron distribution in the energy range of 3 - 10,000 eV. The PLASMAG-1 instrument package also included two Faraday cups. The Solar Direction Faraday Cup (SDFC) measured the total solar wind flux. The Ram Faraday Cup (RFC) had four periodically changed modes of operation. Two of these modes provided information on the neutral particle flux from the comet by detecting secondary electrons and ions, produced by neutrals striking the metallic emitter. The other two modes measured the total charged particle flux.

During the normal cruise phase in interplanetary space, only the Solar Direction Analyser and the Electron Analyser were working. Before the encounter with Halley's comet, solar wind parameters could be determined for about 26 weeks from VEGA-1 ion spectra and for about 11 weeks from VEGA-2 ion and electron spectra, and several interesting interplanetary phenomena (high speed streams, plasma regions of enhanced temperature, etc.) were observed. The EA and also the CRA of VEGA-1 ceased working due to an operator's error in March 1985.

The Ram Faraday Cup began observing cometary neutrals at a distance of about 3 million km from the nucleus. The distribution of neutral gas density was determined for both VEGA spacecraft. In *Fig. 3* the thick solid line represents the theoretical dependence of neutral gas density on cometocentric distance as $n_n(r) = n_o(r_o/r)^2 \exp(-r/\lambda)$ where $n_o \approx 10^4$ cm^{-3} at $r_o = 10^5$ km, and $\lambda \approx 2 \times 10^6$ km is the ionization scale length. The thin lines present data measured on board VEGA-1. The total gas production rate was estimated as $Q = 4\pi r_o^2 n_o v_g \approx 1.3 \times 10^{30}$ molecules/sec where the neutral gas velocity was assumed to be 1 km/sec.

Figure 4 shows the trajectories of the two spacecraft around closest approach. As can be seen in *Fig. 3*, the density of neutral particles already exceeded 10 cm^{-3} at a distance of 2 million km from the nucleus. Part of the heavy cometary particles became ionized by photoionization and the interaction of cometary and solar wind plasma excited magnetohydrodynamic turbulence as was observed by the plasma wave experiment and the magnetometer on board the VEGA spacecraft. Here in the foreshock region, the temperature of the solar wind was gradually increasing while its velocity was decreasing as an effect of the "mass-loading" by heavy cometary ions. VEGA-1 observed a sudden drop in the proton velocity at a distance of about 1 million km. Approximately at the same time, the magnetic field and the electric field oscillations suddenly increased together with the proton temperature. Here the spacecraft crossed the bow shock where the supersonic solar wind flow became subsonic. All plasma instruments on board VEGA-2 observed the bow shock farther away from the nucleus at a distance of 1.3-1.4 million km.

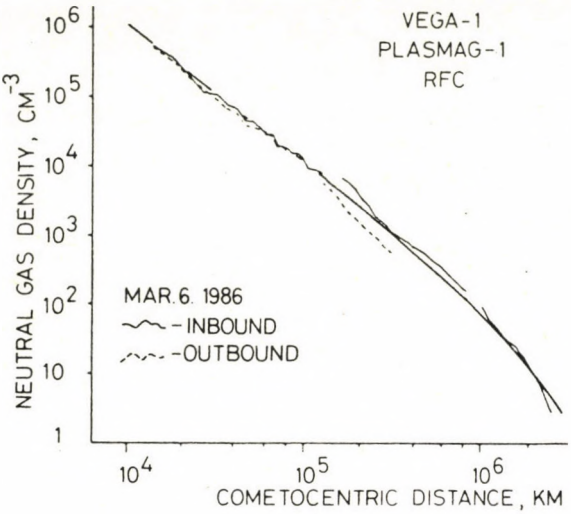

Fig. 3

Cometocentric density profiles for neutral particles measured by the RFC of PLASMAG-1 on board VEGA-1. The thick solid line shows a theoretical estimation

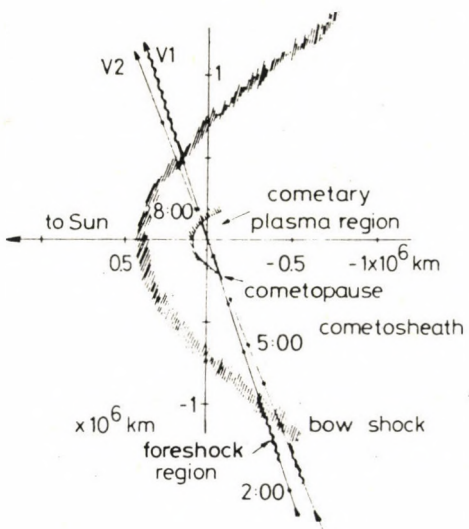

Fig. 4

The plasma environment of Halley's comet, as observed by VEGA-1 and VEGA-2, projected on the spacecraft orbital plane. Features of PLASMAG-1 data are marked with symbols along the spacecraft trajectories (V1, V2) which are marked at 1 hour intervals of Universal Time

Downstream of the bow shock, both VEGA spacecraft entered a region which was called the cometosheath. Here both SDA and CRA observed the decelerated solar wind flow simultaneously as shown by SDA spectra in *Fig. 5* (left-hand side branch) and by CRA spectra in *Fig. 6*. On the right-hand side of the SDA spectra, a more energetic branch can be seen which represents cometary ions belonging to the water group. These ions were picked up and accelerated by the solar wind.

At about 200,000 km from the nucleus (6:35 UT), the cometary ion population became comparable to the solar wind population as shown by *Fig. 5*. Afterwards the solar wind disappeared from the acceptance angle of the SDA and the cometary ions produced a peak around 1 keV in the energy spectrum. VEGA-2 observed similar changes at the same cometocentric distances. Between 6:43 and 6:45 UT (170,000-160,000 km) VEGA-2 intersected a relatively sharp boundary (with a thickness of about 10,000 km) called the cometopause which separated the cometosheath from the cometary plasma region (see *Fig. 6*). At the cometopause the proton velocity was still around 200 km/sec while the velocity of heavy cometary ions was estimated as a few times ten km/sec.

In the cometary plasma region between the cometopause and closest approach, the almost stagnating heavy cometary ions dominated (300-3000 eV range), but a minor proton population was also observed which was continuously cooled and decelerated. The velocity difference between the two populations could be explained by the fact that protons were not coupled to the slow heavy neutrals as much as heavy ions.

Around closest approach when ion velocities are small compared to the spacecraft velocity relative to the comet, E/Q spectra can be transformed into M/Q spectra. *Figure 7* presents 4 sec averages of ion energy spectra measured by the CRA at distances 17,000-14,000 km from the nucleus. The presence of H^+, C^+, CO^+ and Fe^+ ions is obvious in the cometary plasma region. The peak at $14 < M/Q < 20$ most probably originates from H_2O parent molecules and the contributing ions are mainly O^+, OH^+ and H_3O^+. The peak at $24 < M/Q < 34$ might originate from the parent molecules of CO/CO_2 or other molecules containing N or S and the contributing ions might be CO^+, N_2^+, H_2CO^+, HCO^+, CN^+, HCN^+, or atomic ions such as Mg^+, Al^+, Si^+, P^+ or S^+. The minor peaks at $M/Q \approx 2$, 8, 70 and 85 might be due to H_2^+, O^{++} and some heavy organic ions or ionized clusters, respectively. On the basis of the CRA measurements on board VEGA-2 the total ion density was estimated above 1000 cm^{-3} at a distance of 15,000 km (at 30,000 km it was about 200 cm^{-3}).

Unfortunately, the PLASMAG-1 instrument package ceased working on board VEGA-2 two minutes before closest approach (presumably it was hit by a cometary dust particle). About 25 minutes later all sensors except

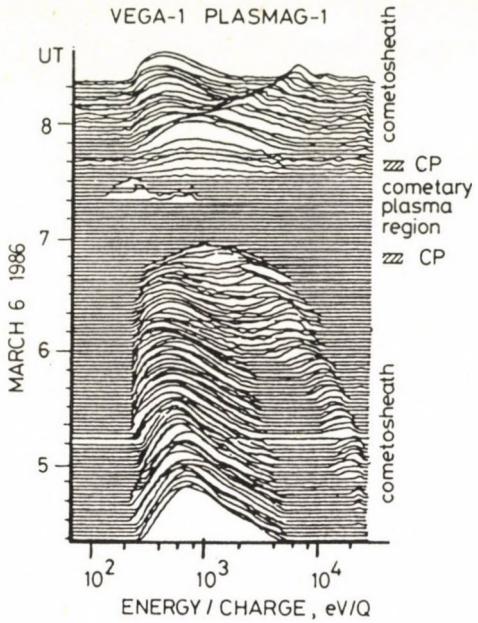

Fig. 5

2-min averages of high-time-resolution ion energy spectra measured by the VEGA-1 SDA of PLASMAG-1 during encounter

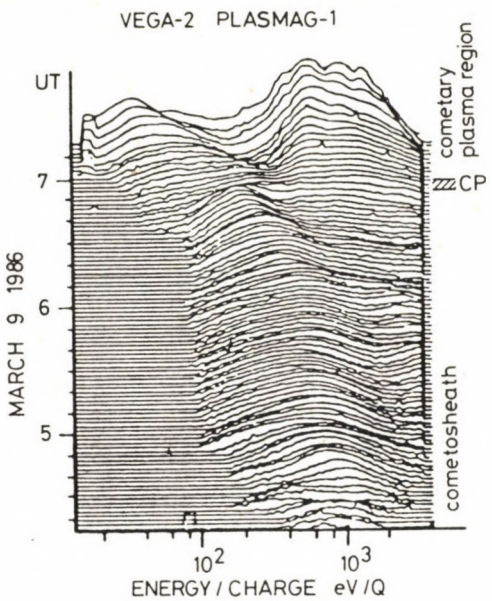

Fig. 6

2-min averages of high-time-resolution ion energy spectra measured by the VEGA-2 CRA of PLASMAG-1 during encounter

for CRA could be switched on again. By that time the cometopause had already been passed. VEGA-2 could not observe the outbound bow shock since it was switched off because of changing operation modes.

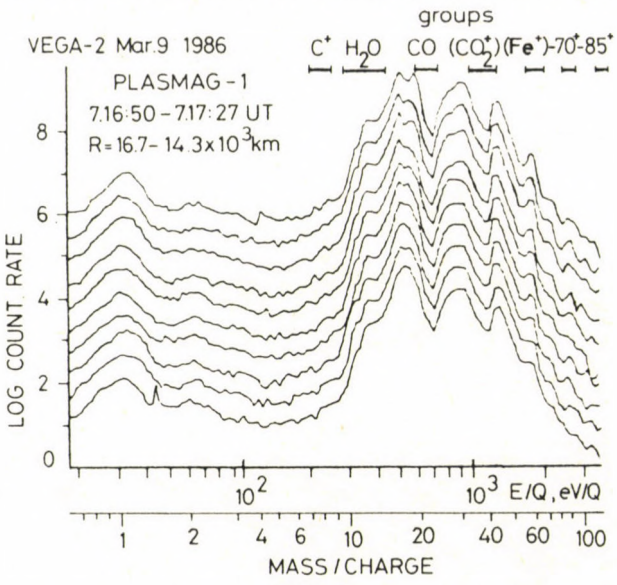

Fig. 7

Spectra of cometary ions observed by VEGA-2 CRA of PLASMAG-1 at distances 14,000-17,000 km from the nucleus (4-sec averages)

The cometopause and the characteristic changes in the cometosheath plasma were observed by the SDA of VEGA-1 on the outbound leg. As shown in *Fig. 4*, the bow shock was detected at a cometocentric distance of about 550,000 km where the proton velocity suddenly increased while proton temperature stayed high to a cometocentric distance of about 1.2 million km since the distribution of heavy cometary neutrals and ions was spherical and did not depend on the shock geometry.

The TÜNDE-M instrument was designed to study the energetic (40 to 600 keV for protons, 80 to 730 keV for water ions) particle environment around Halley's comet and, in the cruise phase, to observe the heliospheric background of the same energy, as well as to study solar and interplanetary particle acceleration up to energies of 13 MeV/nucleon.

In the phase between the Earth and Venus the instruments on both VEGA spacecraft observed several interesting interplanetary phenomena including a flare particle event on January 21, 1986 when a 2B flare appeared on the Sun followed by the sudden increase of the fluxes of electrons and high energy nuclei. During the event the profiles of particle

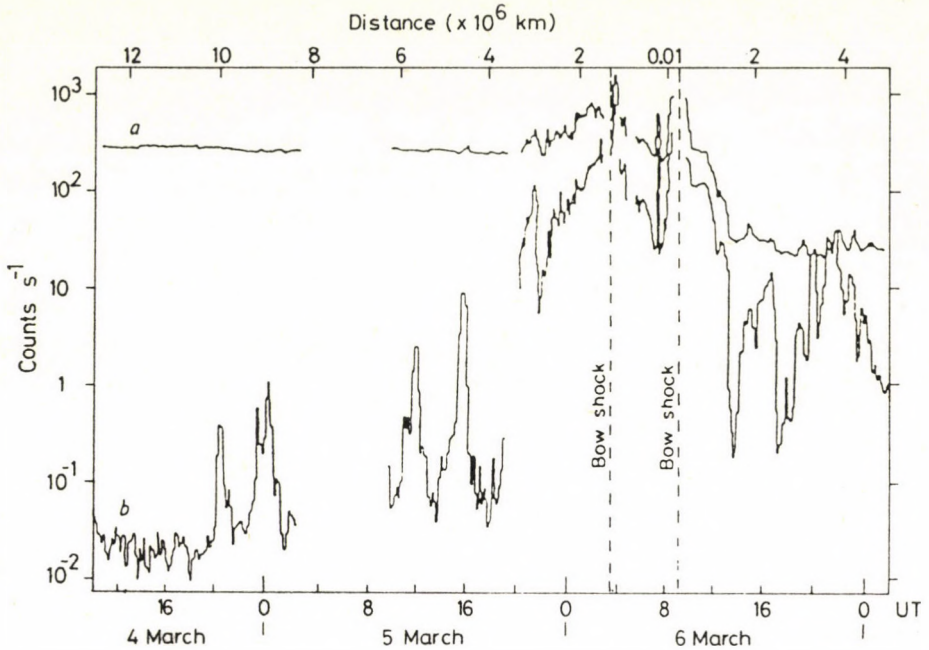

Fig. 8

Ion fluxes recorded on 4-6 March 1986 by the two lowest energy channels of the VEGA-1 TÜNDE-M. a) 40-50 keV; b) 50-60 keV. The upper horizontal scale is the distance from the comet nucleus

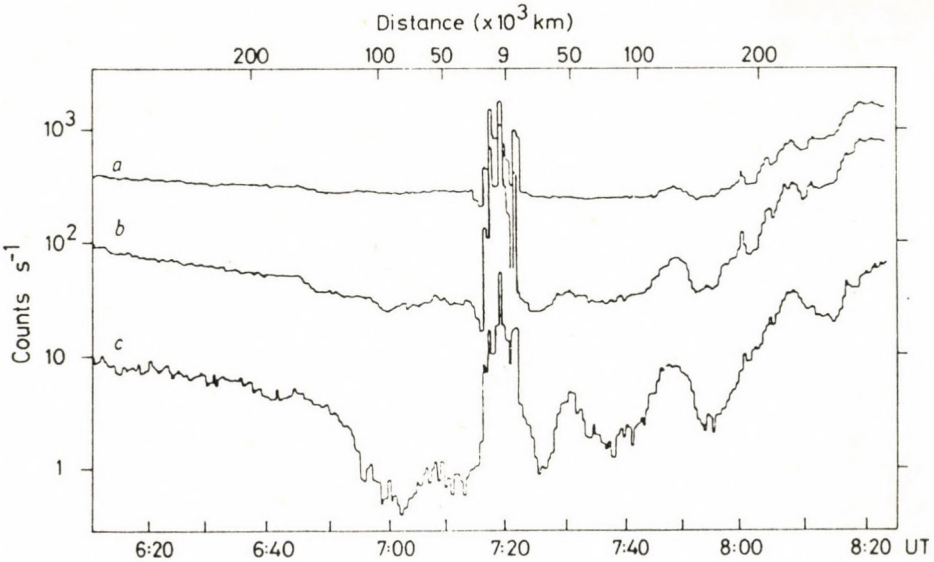

Fig. 9

Expanded version of the region of Fig. 8 near the time of closest approach to the nucleus. a) 40-50 keV; b) 50-60 keV; c) 130-140 keV

fluxes exhibited complicated structures including a sharp increase at 18:50 UT on January 22, interpreted as a crossing of a discontinuity in the interplanetary medium.

In the vicinity of the comet the TÜNDE-M aboard the VEGA-1 spacecraft detected intense fluxes of energetic heavy ions with energies above 80 keV starting at a distance of 10 million km from the cometary nucleus. Three regions with different energetic ion characteristics were identified *(Fig. 8)*: a foreshock region between 10 million km and the bow shock which contains ions picked up in the solar wind; a second region around the shock with the most intense fluxes; and a third region, downstream of the shock, showing a complicated structure which may be characterized as follows. Energetic ion intensities are decreasing with decreasing cometary distance. There is a sudden decrease of intensity of about one order of magnitude at about 150,000 km from the nucleus where the cometary ion population tends to overwhelm the solar wind ("cometopause", see above), and a narrow (32,00 $\pm$ 5,000 km) region centred around the point of closest approach showing a sharp increase (almost two orders of magnitude) of intensity *(Fig. 9)*. This increase may be a combined effect of adiabatic compression in the plasma slowed down almost to standstill in front of the magnetic barrier (with B as high as 70 nT) and a second order Fermi acceleration in the strongly turbulent magnetic field. Energy spectra of ions in the energy range 80 keV to 730 keV, as measured in 52 energy channels beginning at 04:19 UT until 07:15 UT (March 6, 1986) corresponding to distances 900,000 km to 20,000 km from the nucleus are shown in *Fig. 10*. The spectra are of power function type indicating that

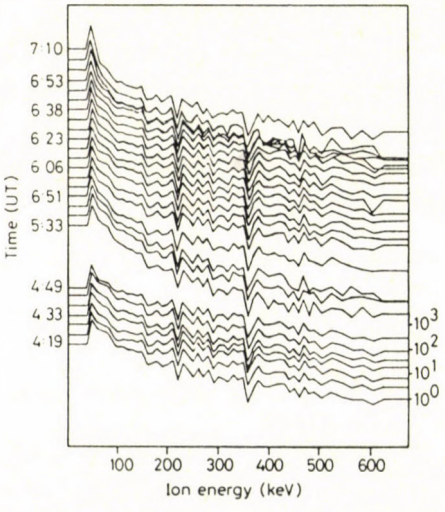

Fig. 10

Ion energy spectra measured by VEGA-1 TÜNDE-M before closest approach

the acceleration mechanism downstream of the bow shock is different from that in the foreshock region, where the spectrum is exponential.

The characteristics of ion acceleration in the foreshock region have been studied in some detail. Here the fluxes of ions (most probably water group ions) exhibit a constant increase towards the nucleus with large, quasi-periodic enhancements superimposed on it; these enhancements show no obvious correlations with the direction of the interplanetary magnetic field. Due to the viewing angle of the instrument the pick up mechanism alone is not able to produce ions with such large energies as observed; in other words, the ions observed by TÜNDE-M must have been picked up and accelerated. Here the distribution functions are approximately Maxwellian for energies about 100 keV while the derived temperatures vary from about 20 keV (at 10 million km) to about 4 keV (at 2.5 million km) with an increase to 6 keV at the shock. The latter effect is modelled by the temperature change derived from a Fokker-Planck type equation with a source term and a stochastic Fermi acceleration term. This mechanism was shown to be capable of explaining the temperature increase and is probably the mechanism responsible for the acceleration of ions in that region.

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CENTRE FOR INTERNATIONAL WORKSHOPS IN THEORETICAL PHYSICS (NEFIM)

The workshop centre of the Hungarian Academy of Sciences was inaugurated in 1983. In the past few years, new forms of international collaboration in theoretical physics have gained prominence. As an alternative to conferences with a large number of participants, a more active form - workshops - has developed. The idea is that in a workshop, a limited number of researchers get together and discuss in rigorous detail the current topics of their common interest. These discussions often lead to joint publications.

The Centre for International Workshops in Theoretical Physics (NEFIM) is supervised and sponsored jointly by the Hungarian Academy of Sciences and by the Central Research Institute for Physics, Budapest (KFKI), and has the purpose of fostering the exchange of information between researchers in Hungary and their colleagues abroad. The requisite infrastructure for workshop activities has been made available at KFKI, whose director general, along with the head of the Department of Mathematical and Physical Sciences of the Academy, have overall responsibility for the NEFIM. Hungarian theoretical physicists may take part in the activities of NEFIM, and (at their suggestion) researchers from foreign countries may be invited.

The physics community has responded to this new organization with vigorous interest. In the opening year, three meetings were organized with a total of 42 participants from various countries. The following year (1984), the number of workshops under the auspices of the NEFIM had grown to 6, and the number of foreign participants totalled 51 from more than 13 countries. In 1985 six and in 1986, three workshop activities were held, and seven more are planned for 1987. A complete survey of workshops since NEFIM made its debut, is appended here.

NEFIM has justified the expectations of theoreticians and has proved that leading experts from home and abroad are happy to take part. It will become apparent that this new and flexible form of cooperation has made it possible to organize meetings with a widely varying number of participants and on a variable timescale.

Activities of NEFIM

NEFIM acts as an institutional framework in organizing workshops (1-6 weeks) of Hungarian and foreign physicists with the purpose of solving problems in definite areas of theoretical physics by way of intensive exchange of information. In the intervals between these activities NEFIM prepares the forthcoming workshops. This is done in collaboration with various departments of KFKI.

From 1987 onwards, the activities of NEFIM will include two fellowships in theoretical physics. These fellowships will be advertised to foreign applicants each year, for a total period of six months. The posts will be available at KFKI and the Roland Eötvös University, Budapest (ELTE), depending on the research area of the successful applicant.

NEFIM reserves the right to publish the results of these scientific activities.

The structure of NEFIM

The scientific activities of NEFIM are coordinated by the Scientific Council whose members are elected from the theoretical physicists who are members of the Hungarian Academy of Sciences or Doctors of Physical Science. (Membership will be proposed by the Mathematical and Physical Department of the Hungarian Academy of Sciences.) The Scientific Council may, at its discretion, nominate other physicists, including foreign scientists. The duration of membership of the Scientific Council is one election period of the Hungarian Academy of Sciences.

The Scientific Council is directed by two co-chairmen, appointed from among members of the council by the chairman of the Department of

Mathematical and Physical Sciences of the Academy, for a period of two years. Conventionally, one of the co-chairmen is a physicist from KFKI, the other from ELTE.

The organizing and administrative duties are performed by the executive chairman appointed by the director general of KFKI for a period of three years. The executive chairman is responsible for the finances, the measures for carrying out the scientific programmes, and the work of the administrative staff.

Workshops organized by NEFIM are directed by the workshop director appointed by the two co-chairmen. It is the responsibility of the workshop director to select the participants for a given workshop .

Cooperation with other organizations

The Central Office of the Hungarian Academy of Sciences allots an annual allowance to cover the expenses of invited foreign researchers during their stay in Hungary.

These researchers are either actually employed by KFKI or work in the framework of a contract. KFKI secures an allowance in Hungarian Forints to partially cover the expenses of these visiting scientists while they are in Hungary. In addition, KFKI provides office rooms, a conference room and the requisite equipment for NEFIM which includes: a desktop IBM-type computer system and a copier. NEFIM is also able to use the infrastructure of KFKI such as the library, the publication service, the Department of International Relations and 150 hours/year of machine time on the central computer of KFKI.

Other institutes and universities provide help to NEFIM and its activities for instance by loaning conference rooms and other facilities.

LIST OF NEFIM WORKSHOPS

1983-86

Workshop on Relativistic Nucleus-Nucleus Collisions.
15-17 June 1983

Location: KFKI
Workshop director: J. Zimányi (KFKI)
Organizers: L.P. Csernai (KFKI) and G. Fái (ELTE)
Number of foreign participants: 13; Hungarian participants: 18

This workshop immediately followed the Conference on High Energy Nuclear Physics, Balatonfüred, 7-12 June 1984.

The discussions during the Workshop were focused mainly on the problem of formation and decay of matter with extremely high energy density and large baryon density produced in high energy heavy ion reactions. The basic assumptions and the details of theoretical approaches were critically discussed.

During and after the lectures, heated disputes developed. Later, the activities continued in small working groups. This Workshop gave the opportunity to bring to successful completion a number of multinational ventures initiated earlier and to start cooperation in new ones.

Electric Fields in the Cometary Environment
1-20 September 1983

Location: Budapest
Workshop director: K. Szegő (KFKI)
Number of foreign participants: 6; Hungarian participants: 6

The topic of the workshop was the structure of the electric fields arising in the cometary environment and their influence on space probe measurements. The role of the ambipolar electric field on the dynamics and thermodynamics of the cometary ionosphere was examined. This field both decelerates and cools the plasma in the outer ionosphere, while a shock may develop due to the deceleration. The consequences of electrostatic charging of cometary dust were also considered. They were shown to be minimal within the ionosphere and substantial outside. The

convectional electric field of inflowing solar wind as well as the Coulomb drag of this plasma on charged dust significantly affect the dynamics at the lower end of the dust mass spectrum.

Quantum Chromodynamics on the Lattice
18-24 September 1983

Location: ELTE and Visegrád
Workshop director: A. Patkós (ELTE)
Number of foreign participants: 40; Hungarian participants: 25

The current status of lattice-regularized quantum chromodynamics was reviewed by leading specialists (topics included string tension, and glueball spectrum). A European computer collaboration was initiated for high-precision investigation in the asymptotic scaling region.

Workshop on Charge-Density Waves in Solids
8-15 September 1984

Location: Budapest
Workshop director: J. Sólyom (KFKI)
Number of foreign participants: 15; Hungarian participants: 10

The workshop followed the conference on Charge Density Waves in Solids held in Budapest between 3rd and 8th September. A few participants, mostly theorists, who are most active in the field, were invited to stay for another week to continue discussions on the topics of the conference. The subjects included the properties of charge density waves formed in di-, tri-, and tetrachalcogenides. The main emphasis was on the discussion of the motion of CDW in these systems, the role of the contacts and of the impurities in the non-linear conductivity, memory effects, switching properties and the noise spectrum.

During the workshop a better understanding of the behaviour of these materials emerged.

Stochastic Systems: Mathematical Methods in Statistical Physics
31 August and 1 September 1984

Location: Kőszeg
Workshop director: D. Szász (MAKUTI)
Number of invited participants 12

Rigorous statistical physics has promoted intensive interaction of mathematicians and physicists. The workshop focused on the statistical physics of random media and disordered systems as well as on nonlinear dynamical systems. Deep discussions developed in these timely topics. The meeting helped the participants to get an insight into recent developments and into the perspectives of the subject.

Workshops on Chaos
Budapest, 1984 and 1985

Workshop director: P. Szépfalusy (KFKI)

Recent progress in the theory of chaotic phenomena indicates that the field is developing rapidly. To offer a possibility of discussing problems of current interest, as for instance whether all typical routes to chaos have been discovered up to now, what universal features they have, what the probability densities describing chaotic trajectories look like, in which way chaotic systems react to external perturbations, etc., two workshops, each lasting a week, were organized.
In September 1984, a workshop entitled "Properties of Chaos" was arranged to which five leading researchers were invited from Poland, the USSR, West Germany, and Denmark. Each of the participants held one or two lectures, the rest of the time was devoted to discussions. The Autumn 1985 workshop had the title "Chaotic Phenomena and Related Subjects" and fifteen participants were invited. Besides the seminars, emphasis was put on enhancing personal contacts and the effective cooperation of small groups.

Workshop on Topical Problems of Testing QCD in High-Energy Hadronic Reactions
2-7 July 1984

Location: ELTE and KFKI
Workshop director: G. Pöcsik (ELTE)
Organizers: F. Csikor (ELTE) and K. Tóth (KFKI)
Number of foreign participants: 22; Hungarian participants: 20

The Workshop was devoted to discussing topical problems of testing QCD in high-energy hadronic reactions such as fragmentation models, the validity of the parton model, the dependence on renormalization schemes, higher twist contributions, jets in pp and e^-e^+ collisions, W, Z events, hadronic corrections to weak processes, and related topics.

Dynamic Phenomena in Neurochemistry and Neurophysics
Theoretical Aspects
21-22 August 1984

Location: Budapest
Workshop director: P. Erdi (KFKI)
Number of foreign participants: 7; Hungarian participants: 10

The Workshop was devoted to discussing what the concepts of such theories as catastrophe theory, and the theory of dissipative structures and synergetics could offer to interpret neurophysiological phenomena. Some of the topics discussed were: kinetic theory of neural systems, chaotic phenomena in neurochemistry and neurophysiology, self-organization in the nervous system, locality and rationality in theoretical biology.

The participants agreed that concepts and methods originating from theoretical physics might penetrate usefully into neurobiology.

International Workshop on the Dynamics of Few Body Systems
10-14 June 1985

Location: KFKI
Workshop director: Gy. Bencze (KFKI)
Number of foreign participants: 14, Hungarian participants: 10

The aim of the workshop was to provide a frame of informal discussions and collaboration in the field of quantum dynamics of nonrelativistic few-body systems. The topics included nuclear, atomic and molecular few-body systems. Special interest was paid to the scattering theory of few-body Coulomb systems.

Participation was by personal invitation. Due to space limitations the number of participants was restricted. For a limited number of experts, financial support was provided by the workshop.

High-Energy Heavy Ion collisions
30 June- 5 July 1986

Location: KFKI
Workshop director: J. Zimányi (KFKI)
Organizers: I. Lovas (KFKI) and J. Németh (ELTE)
Number of foreign participants: 8; Hungarian participants: 15

The main concern of the Workshop was the applicability of various relativistic mean field approaches to describing nuclei and their collisions. The heated discussions between researchers working actively in this field led to a deeper understanding of the physics involved in these approaches.

Hadron Structure
17-19 September 1985

Location: Balatonaliga
Workshop director: E. Nagy (KFKI)
Organizers: A. Frenkel (KFKI) and A. Patkós (ELTE)
Number of foreign participants: 55; Hungarian participants: 35

The number of physicists from abroad included members of the European Muon Collaboration.

Recent developments in experimental and theoretical particle physics were discussed with particular emphasis on the EMC Effect.

Balatonszéplak Relativity Workshop
20-24 May 1985

Location: Balatonszéplak
Workshop director: F. Károlyházy (ELTE)
Organizers: B. Lukács (KFKI), Z. Perjés (KFKI) and A. Sebestyén (KFKI)
Number of foreign participants: 8; Hungarian participants: 14

As a first attempt to bring researchers of General Relativity together in Hungary, a Workshop was held on some developing areas of the theory such as inflationary cosmology, physics in the vicinity of black holes, current differential geometric approaches to gravity and Yang-Mills fields, and quantum gravity. The number of lectures was limited to 14 with the aim of promoting spontaneous activity during the meeting. The participants concluded that the idea of getting relativists together on this part of the globe should not be forgotten and a Second Relativity Workshop is currently planned for 1987.

Microcomputers in Science
19-25 May 1985

Location: Balatonalmádi
Workshop director: G. Marx (ELTE)
Number of foreign participants: 83; Hungarian participants: 42

The purpose of the workshop was to demonstrate the use of microcomputers in teaching physics. Among the subjects were the simulation of dynamic processes, cellular automatons and nonlinear phenomena. Partial support for the meeting was provided by UNESCO.

Infrared Divergences in the Physics of Condensed Matter
21 July-15 August 1986

Location: KFKI
Workshop director: A. Zawadowski (KFKI)
Number of foreign participants: 24

The first part of the workshop was devoted to systems of heavy fermions and valence fluctuations. Ten lectures were given, with participants from the Federal Republic of Germany, Japan and Czechoslovakia. The discussions focused on systematizing the various descriptions of the Kondo effect, but superconductors with heavy fermions were also considered.

The second session of the workshop dealt with the problem of tunnelling particles coupled to macroscopic systems with many degrees of freedom. The discussions were lively and the meeting proved to be of high value, with several topics ranging from metallic glasses to the measurement problem in quantum mechanics.

Nonperturbative Methods in Quantum Field Theory
1-7 September 1986

Location: Siófok
Workshop director: Z. Horváth (ELTE)
Organizers: I. Lovas (KFKI), L. Palla (ELTE) and A. Patkós (ELTE)
Number of foreign participants: 39; Hungarian participants: 37

Thirty-three lectures were given on two main subjects. One of the subjects was the quantum field theories defined on a lattice and the methods of statistical physics. The other major subject was the string theory of unified interactions. In addition, other non-perturbative methods were discussed.

RESEARCH INSTITUTE FOR PARTICLE AND NUCLEAR PHYSICS (RMKI)

The scientific profile of the institute is essentially characterized by the dominance of basic research even though considerable effort has been spent in the last few years on R&D work in various branches of applied physics.

Traditionally the main fields of research were both experimental and theoretical nuclear and particle physics. However, the scope has gradually been extended to cover a wide range of subjects.

At present, research is conducted in the following main areas:

1)experimental particle physics
2)experimental nuclear physics
3)materials science, applied nuclear physics
4)theoretical nuclear and particle physics and gravitation theory
5)plasma physics
6)cosmic physics and space research
7)biophysics.

The research personnel includes about 130 scientists as well as 12-14 postgraduate fellows working on their doctorate theses in physics. In addition there is a technical staff of highly skilled development engineers, technicians and an administrative personnel.

Our experimental activities in materials science and biophysics are centred around the institute's 5 MeV Van de Graaf accelerator where some work on nuclear spectroscopy is also conducted. The main item for our research in plasma physics is the MT-1 small tokamak.

Intermediate energy nuclear physics, experimental particle physics as well as space physics are being done in extensive international collaboration involving CERN, Geneva, and the Institute for Space Research, Moscow.

International contacts are also vital in theoretical physics, where the exchange of ideas is contributing directly to the results and the progress in the special fields studied.

The institute's engineering background has been especially important in our work in space technology as well as in the development of special nuclear electronics for various applications.

It is hoped that the following short description along with the rather extensive list of papers and reports will supply all the necessary information about the institute's activities.

EXPERIMENTAL PARTICLE PHYSICS

Our institute has been taking part in the European Muon Collaboration (EMC) whose aim is to investigate experimentally the nucleon as well as the nuclear structure and the hadron production in deep inelastic muon-nucleon scattering. The quark momentum distribution has been measured to a high precision and the functional form of the gluon distribution inside the nucleus has been determined. It was confirmed that the scale breaking properties of the nucleon structure function are well described by QCD.

In the study of hadron production the most important information is provided by the evaluation of the streamer chamber pictures of the EMC's detector system. The complete evaluation of all the pictures was finished only in 1985. A detailed study of hadronic final states confirmed the basic properties predicted by the phenomenological quark-parton model (QPM). However, there was also clear evidence for non-QPM-type behaviour in the hadron production.

Correlation effects have been studied in various kinematic hadron variables and the inclusive production of some specific particles in high-energy muon deep inelastic scattering was observed for the first time.

Considerable progress has been achieved in the construction of the L-3 detector devoted to investigating electron-positron annihilation at extremely high energies using the future LEP collider to be built at CERN, Geneva. The Budapest group has made a significant contribution to the development of the necessary software. The special software enables one to simulate the complex electromagnetic cascade processes on large computers as well as to perform Monte Carlo studies of various calibration methods of the electromagnetic calorimeter.

We are also involved in the European Hybrid Spectrometer (EHS) collaboration at CERN, Geneva. The 360 GeV proton-proton data have successfully been interpreted in terms of the Field-Feynman and Lund models amended by a quark-diquark distribution function. In this way a satisfactory description of experimental data is obtained with diquarks especially for the pp → lambda + anything process.

The RISK collaboration at the Joint Institute for Nuclear Research (JINR), Dubna, USSR, continued the analysis of the interaction of negative pions, kaons and antiprotons with nuclei at 40 GeV/c. The experimental data confirmed the A (atomic mass) scaling. The linear relation $D=a\langle n\rangle+b$ is satisfied for the distributions of secondary particles including also knocked out protons and the use of a modified scaling variable ensures scaling of the distributions in A at least up to the second moment.

At the end of 1985 a neutrino calorimeter was put into operation at the Serpukhov accelerator in the framework of a Dubna-Serpukhov-Berlin-Budapest collaboration. The first experiment which aims at the investigation of the existence of heavy neutrinos is under way.

On Lake Baikal, USSR, a deep underwater neutrino detector has been set up to investigate the existence of Dirac's monopoles. We have a team taking part in the experiment. The first measurements have already been performed and have enabled an upper limit to be set to the monopole intensity.

EXPERIMENTAL NUCLEAR PHYSICS

Nuclear fission is still a subject that is widely studied. Particular attention is paid to the energy spectrum of neutrons emitted in fission. The measurement of neutron energy spectra from thermal neutron induced fission of several nuclei has recently been completed. The results show that these spectra can adequately be described by a Maxwellian distribution for ^{235}U, ^{238}U and ^{239}Pu with nuclear temperatures T=1.32 MeV, 1.315 MeV and 1.38 MeV, respectively. The neutron energy spectrum of the spontaneous fission of ^{252}Cf has also been measured by using a ^{6}Li glass detector with known absolute efficiency. All these experiments have been performed in collaboration with the IPPE, Obninsk, USSR.

The angular and the energy distribution of fission neutrons from ^{252}Cf have also been determined in the energy range E_n=50 keV - 1.2 MeV

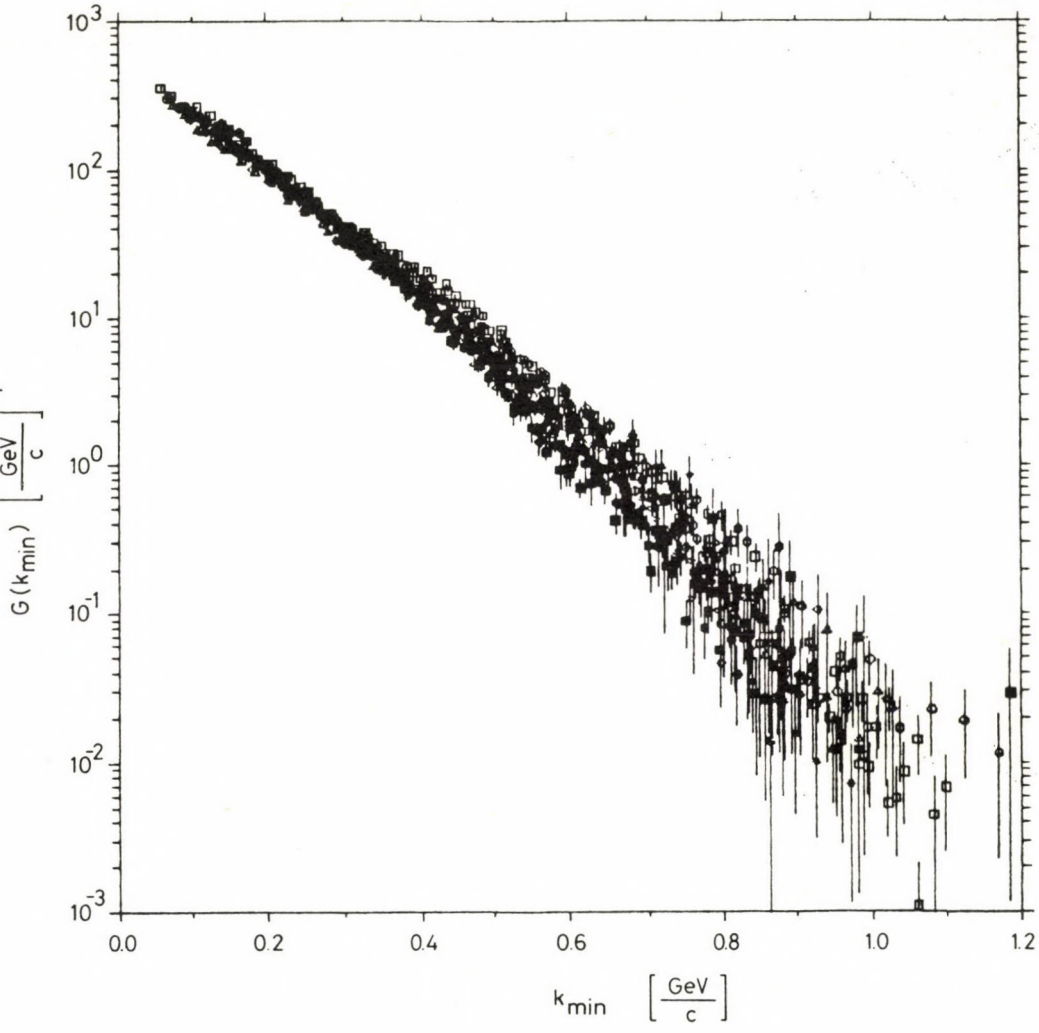

Fig. 1

Universal structure function $G(k_{min})$ for proton emission

by making use of a new experimental setup, which allows a simultaneous measurement in the whole angular region. This work has been carried out jointly with a team of the Technical University, Dresden, GDR.

The previous studies of the fine structure of the $g^{9/2}$ isobaric analogue resonances have been continued. In particular, a many-channel study of the decay of the IAR in ^{51}Mn was completed. Fine structure analysis in all open channels shows different spreading patterns in the various channels, which cannot be understood on the basis of the usual single-channel theories.

Further experiments are being carried out on ^{52}Cr, ^{54}Fe and ^{56}Fe target nuclei by measuring the first three proton groups in the elastic and in the inelastic scattering.

The strong coupling between collective levels of nuclei is known to produce important effects in both inelastic and reactive scattering processes. Since the amplitudes for single and multistep processes interfere with each other even a small admixture may have a large effect on the cross sections.

The single nucleon transfer reactions induced by 70 MeV ^{3}He particles on ^{28}Si nuclei were measured in collaboration with a team at the KFA, Jülich, FRG. The results were analyzed in terms of the coupled channel Born-approximation (CCBA) formalism. The reaction ^{24,26}Mg(d, ^{6}Li) at 80 MeV projectile energy was also studied and transitions to some members of the $K=2^-$ band were described also including certain forbidden transitions.

The mechanism of intermediate energy nuclear reactions is still the subject of extensive research. Of particular interest are inclusive production and quasi free processes.

In collaboration with a team of the Freiburg University, FRG, particle production by 300-550 MeV neutrons on ^{12}C nuclei was studied. The energy spectra of protons, deuterons and tritons were investigated in a wide angular range, from 51^{o} to 165^{o}. A scaling property of the inclusive proton spectra was established in the whole observed energy and angular range: the cross section is proportional to the product of the free N-N scattering cross section and a universal function shown in Fig. 1 in terms of the minimum recoil momentum. This function is very similar to that observed in the case of incident protons. Deuteron and triton spectra also show scaling behaviour and their properties can partly be interpreted in terms of the cluster excitation model.

The polarization of protons from the ^{2}H(p, 2p)n reaction was measured in an exclusive experiment using the 1 GeV proton beam of the Leningrad Institute of Nuclear Physics. The kinematic conditions were consistent with the quasifree scattering of protons on the constituent

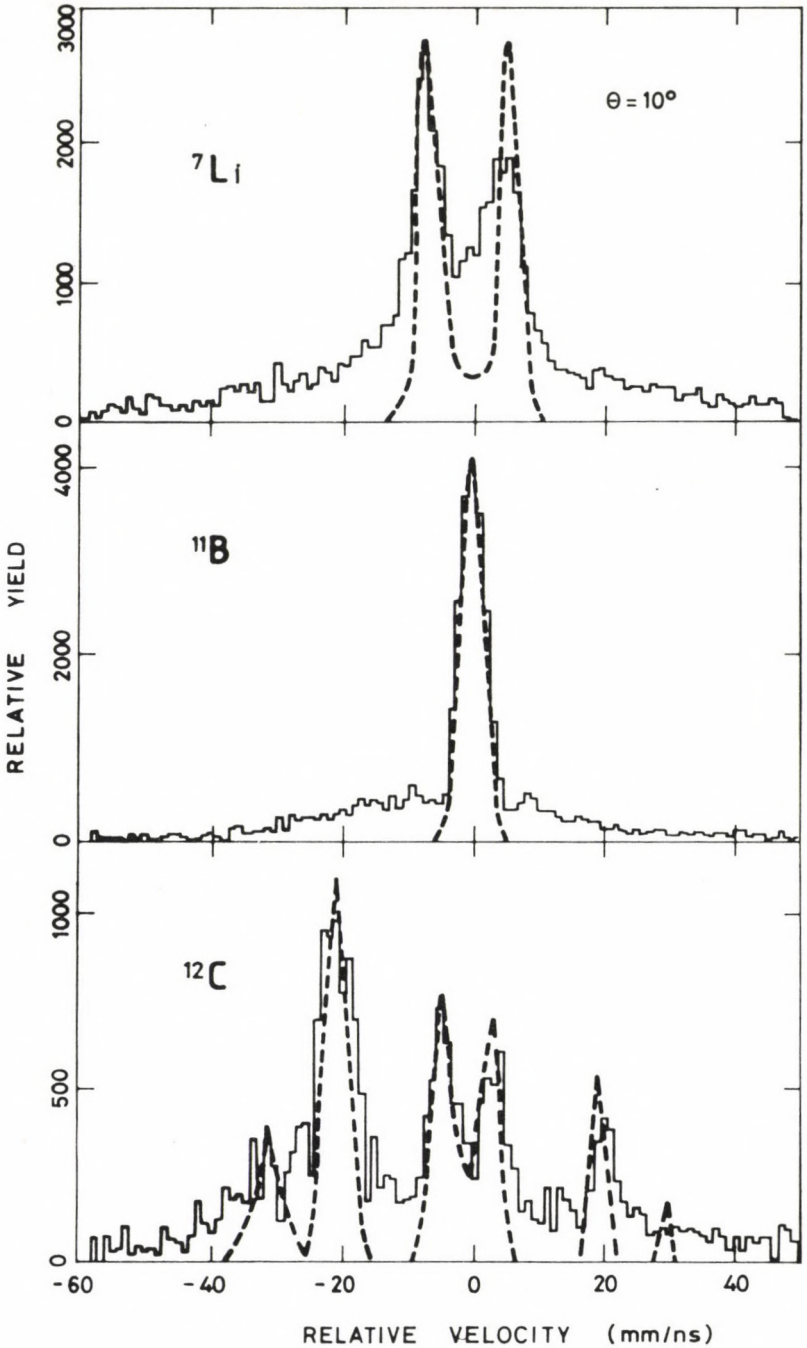
Θ = 10°
^{7}Li
^{11}B
^{12}C
RELATIVE YIELD
RELATIVE VELOCITY (mm/ns)
0
1000
2000
3000
4000
500
-60
-40
-20
0
20
40

Fig. 2

nucleons. The results show up to 150 MeV/c internal momenta the dominance of quasifree scattering in the process.

The experimental investigation of heavy ion reactions was being conducted in collaboration with Eötvös University, Budapest, and Michigan State University, USA. By utilizing moving source model predictions from the neutron distribution in coincidence with the light fragments, various physical characteristics have been estimated, e.g. rapidity source temperature, mass of rapidity source. The relative velocity interpretation of the contribution from a projectile-like source suggests the excitation of discrete, unbound neutron states (Fig. 2). For the investigation of sequential neutron emission a new experiment was performed on the MSU NSCL K500 superconducting cyclotron for the reaction ^{14}N + Ag.

MATERIALS SCIENCE, APPLIED NUCLEAR PHYSICS

The main directions of research can conveniently be classified on the basis of the nuclear technique applied. Correspondingly, research has been conducted in the following fields:

- -Rutherford backscattering spectroscopy (RBS) and elastic recoil detection (ERD)
- -Mössbauer spectroscopy
- -positron annihilation studies in solids.

$GdSi_2$ - probably the best silicide for microelectronics purposes - has been extensively studied. The sample was prepared under UHV conditions and prior to processing a clean interface was produced on silicon by using diluted HF dripping. It was found that the "critical temperature" for silicide formation reported earlier is an artifact and a correlation between the thickness of native oxide interface and the critical temperature has now been established. To determine the Schottky barrier height of this silicide a new method was elaborated. The oxidation behaviour was also investigated both in dry and wet ambience. During dry oxidation the silicide bonds were found to break up and a layer of $Gd_2.O_3.2SiO_2$ was obtained. For wet ambience a temperature dependence was found. At 500°C the composition of the oxidized layer was the same as for dry processing. At 800°C, however, more silicon atoms were oxidized and the layer composition was found to be $Gd_2.O_3.4SiO_2$. This type of oxidation behaviour results in a serious limitation in the various technical applications.

Utilizing the new heavy ion cascade implanter of the institute we have begun ion intermixing studies. The intermetallic compound formation of the Ge-Ni and GeAl-Ni systems has been studied. The Ge-Ni phases were produced by Ar and Xe ion beams. The presence of aluminum was found to cause phase separation. A comparison of ion beam mixing and furnace annealing was also made.

The method of elastic recoil detection (ERD) was installed and considerably improved. The recoil cross sections for both H and D in the case of alpha particle bombardment were measured in the energy range 1.6-3.4 MeV. For both isotopes a deviation from the Rutherford cross section was found. For deuterium a resonance was obtained at 2.15 MeV with a FWHM of 75 keV. In order to find the geometrical arrangement which yields maximum information on the probing depth and the best depth resolution in the energy range of 1-10 MeV extensive calculations have been performed. On the basis of these results instead of the generally accepted 30^{0} scattering angle we propose another configuration.

For the study of ion implanted systems by computational methods a Monte Carlo code (SEISM) was developed. The code calculates the three-dimensional distribution of the implanted atoms by using the Molière potential and the binary collision approximation. From the individual ion tracks, average data, e.g. total path length, SD of the projected range, the skewness of the distribution can be computed. The calculations were compared with the results of the RBS study of Sb implanted SiO_2/Si sandwiches.

The long-lived non-equilibrium population of the Zeeman sublevels of the ^{6}S ground state of FE^{3+} ions was also systematically studied in $LiNbO_3$: ^{57}Co single crystals in collaboration with researchers of the Universities of Erlangen and Mainz. The possibility of significant relaxation within the ^{6}S manifold was ruled out. The surprising dependence of the ^{6}S sublevel population on the angle between the crystal field axis and the external magnetic field was successfully described in terms of a nonradiative intersystem crossing process.

Hydrogen desorption during heat treatments of $Zr_3FeH_{5.5}$ has been studied by Mössbauer spectroscopy, X-ray powder diffraction as well as thermal gravimetry. It was found that if the heating rate is sufficiently slow all hydrogen effuses below 650K and no phase segregation occurs. If, however, some hydrogen is retained it induces phase separation at higher temperatures into Fe_2Zr (or more likely Fe_2ZrH_x) and zirconium hydride. The existence of a highly disordered f.c. tetragonal ternary hydride phase was also detected both by X-ray diffraction and Mössbauer spectroscopy.

Amorphous $(Fe_{1-x}Co_x)_{77}B_{13}Si_{10}$ ribbons were studied by Mössbauer spectroscopy and a significant decrease in the width of the hyperfine field distribution was detected with increasing Co content. These results could be explained in terms of structural changes and chemical ordering.

As a means of following the defect annealing characteristics in III-V semiconductors, positron lifetime measurements have been performed. Different samples of GaAs and InAs were irradiated at RT with 3.5 MeV electrons. The non-saturated, higher positron lifetimes after irradiation indicate a vacancy-like defect structure which annealed out at about 250°C. The remaining defects, presumably charged antisites, are stable up to 500°C. At about 700°C the bulk lifetime was registered again. In the case of a pure, dislocation-rich GaAs sample a new peak was observed at ca. 400°C, which can be attributed to vacancy agglomeration.

Amorphous and crystalline $LiNbO_3$ were studied both by Mössbauer spectroscopy and positron lifetime measurements. The results indicate that the short range order of the two systems may be similar. The higher positron lifetime of the amorphous phase could be attributed to the increase in the free volume.

Positron lifetime and Doppler broadening measurements were used to investigate Co-Si alloys in the whole composition range. The results show a linear correlation between the electron density of the alloy and the positron annihilation parameters. Around the Co_2Si composition an anomaly was observed which may stem from structural vacancies.

THEORETICAL NUCLEAR AND PARTICLE PHYSICS, GRAVITATION THEORY

In low-energy nuclear physics the exact methods of nonrelativistic few-body theory have successfully been applied to the description of three-nucleon scattering processes. The numerical solution of the Faddeev equations using separable representation of realistic nucleon-nucleon potentials yields a surprisingly good description of polarization observables in elastic scattering and breakup processes. This fact indicates that - contrary to previous claims - three-nucleon forces may have only a negligible effect on the scattering process at the energies considered.

The importance of Coulomb effects in p-d elastic scattering and breakup as well as in the alpha-deuteron collision process has been

studied by extensive numerical calculations based on the Faddeev equations.

Recently a controversy arose about the importance of electric polarization effects in low-energy p-d scattering. The controversy has been resolved by obtaining rigorous mathematical results. A new, long-range-modified scattering length has been defined and proved to have a finite zero-energy limit. It has also been shown that the extrapolation of experimental data to zero energy does in fact reproduce the newly defined finite scattering length.

As an interesting application of exact three-body methods an exactly soluble three-body model with separable interaction was constructed for treating the interplay between classical and quantum degrees of freedom in a dynamical system. The model has been used to calculate the probability of light particle emission in fission and heavy ion reactions.

In the field of heavy ion physics within the framework of the relativistic mean field theory the (presumably strong) influence of the sigma field on kaon production rate has been investigated and a significant enhancement was shown to exist.

The study of the resonance-meson coupling constants which cannot be extracted from ground state data suggests that the assumption of their proportionality to the masses removes the pathological features of the simple model which takes no account of symmetry breaking at the level of coupling constants.

A new type of phase coexistence region characterised by the finite range of the chemical potentials has been established in the rehadronization process of the quark-gluon plasma. In the mean field approximation a periodic gluon condensed phase was found in the quark-gluon plasma.

In theoretical particle physics, interest is concentrated upon gauge field theories and non-perturbative methods in understanding strong interactions. The study of non-Abelian anomalies and the corresponding Wess-Zumino effective actions has led to some new results. A rigorous proof of the uniqueness of the full non-Abelian anomaly has been given. By the application of the resulting Wess-Zumino Lagrangian it could be shown that the lambda parameter of the K_{l3} decay and the structure dependent amplitude of the decay $\pi \rightarrow e\nu\gamma$ are uniquely determined by the anomaly. By making use of the generating functional of the non-Abelian flavour anomalies in the QCD a gauge-invariant phenomenological Lagrangian was constructed for describing pseudoscalar and vector mesons. It is in fact equivalent to the Wess-Zumino Lagrangian in the low-energy approximation.

Efforts to understand the complicated problems of lattice QCD initiated the numerical study of critical phenomena in various simple models of statistical physics, such as the discretized version of the two dimensional O(3)-symmetric lattice theory as well as the icosahedral and dodecahedral vector models in two dimensions.

In general relativity, the research has been focussed on the study of space-times. The investigation of space-times whose three-space is conformally flat has been concluded and a complete solution based on a new method has been given. This new method uses the complex gravitational Ernst potential as a complex coordinate.

In the theory of the radiative Robinson-Trautman metrics it was shown that such space-times settle down asymptotically to the Vaidya metrics. This result was obtained by an extension of the Lyapunov functional method to homogeneous radiation-filled space. Also a programme was carried out to establish some bounds to space-time curvature which rely on causal principles.

Several aspects of relativistic cosmology, such as the thermodynamics of the early Universe, the implications of grand unified theories and the missing mass problem, were also studied.

PLASMA PHYSICS

The main goal of research in the field of plasma physics is to investigate the basic physical processes which underly high temperature fusion plasma phenomena. Our main possibility for studying confined plasma properties is the MT-1 small configuration tokamak of our institute.

In the last few years intensive research has been conducted along the following lines:

-plasma edge physics

-stability of the tokamak plasma

-plasma - wall interactions

-plasma diagnostics.

One of the most important tools for investigating the plasma edge is the spectroscopy of well defined amounts of certain impurities injected into the peripheral plasma. The laser blow-off process is designed to serve as a medium energy impurity atomic beam source. If a thin metal layer is blown off a substrate by a high intensity laser pulse, a small inflating plasma ball is produced, which is accelerated to a high velocity during the blow-off. This plasma ball of neutral

particles serves as a beam of neutral particles for edge studies. In the preliminary experiments the CM velocity and the thermal velocity of the plasma ball were measured in terms of the characteristics of the blow-off process (laser intensity, film thickness, etc.). Further investigations are under way.

In the case of soft disruptions the stability of the tokamak plasma is investigated by means of Mirnov coils and a soft X-ray pinhole camera. In the measurements a strong correlation was found between the plasma displacements and the signals given by the different detectors. The results can be interpreted in terms of the m=2 magnetic islands rotation.

The wall of the magnetic confinement device is exposed to a particle irradiation that affects the properties of the wall material. This interaction can conveniently be studied in model experiments where the surface of metals of potential interest for the future thermonuclear reactors of magnetic confinement devices is irradiated by an intense beam of charged particles. Of special interest are helium ions of a few MeV energy; these are produced in certain fusion reactions. It is found that during the irradiation severe surface deformations, e.g. blistering, exfoliation, and flaking, can occur. In some cases a peculiar wave-like pattern develops on the flaked surface. For the explanation a theoretical model has been suggested which attributes the phenomenon to the elastic instability of the implanted zone. In this simple model the characteristic wavelength of the patterns can be determined and has been found to be in reasonable agreement with the experimental data. The model works for homogeneous materials, e.g. metallic glasses and single crystals implanting helium, neon or argon ions. It is found, however, that the phenomenon does not occur on polycrystalline targets. A possible explanation may be that in this case the stress values reached during implantation are not large enough.

In the tokamak devices DITE and T-10 the properties of the edge plasma and the impurities were studied by erosion and deposition probes. Amorphous carbon and single crystal silicon collector probes were inserted into the bundle divertor on the electron drift side of the DITE. Onto the carbon probe a thin layer of antimony (2.7×10^{15} atoms/cm^2) was evaporated while into the silicon probe 5×10^{15} atoms of Sb were implanted prior to exposure to the plasma. Thus these probes not only collected impurities but were able to provide information on the material loss as well. By means of Rutherford backscattering (RBS) analysis the predominant specimens detected were identified as carbon, oxygen and components of stainless steel. Other impurities including Ti,

S, Cl, Mo, Cu and Pb were also found. On the evaporated probes a typical Sb loss of $3\text{-}5\times10^{15}$ atoms/cm^2 per plasma discharge was observed.

Similar probes were also used in the experiments with the T-10 device, but there the strong carbon deposition prevented any material loss.

The r.f. assisted glow discharge cleaning of the DITE device was investigated by single crystal silicon samples. The RBS analysis of these probes showed high deposition rates of carbon, oxygen and metals in both the hydrogen and the hydrogen plus methane discharges.

In order to be able to understand the physical processes that take place in the tokamak plasma, the information obtained by various methods of plasma diagnostics is of basic importance. At present several diagnostic devices (far infrared lasers, interferometers, X-ray detectors) are being developed in our institute. These devices are prepared for use at the T-15 tokamak device of the Kurchatov Institute, Moscow, USSR. During development, the laser physical processes are also being studied in FIR laser materials in order to be able to increase the laser power. For double frequency interferometers visible heterodyne interferometers are studied by using the red line of the HeNe laser.

Investigations of a high energy charged particle beam diagnostic method for studying the magnetic island dynamics is under way at the MT-1 tokamak. The preliminary results are not discouraging even though there are problems with the high resolution position sensitive beam detector.

COSMIC PHYSICS AND SPACE RESEARCH

The recording of cosmic ray muons of energies 10^{11} eV was finished in December 1985 at the Budapest underground muon telescope. The analysis of data collected over almost 28 years of continuous operation is still in progress. The aim is to further explore the solar modulation of galactic cosmic rays.

As for theoretical studies, the 22-year cycle of modulation has been investigated by computing particle energy losses along regular trajectories. The polarity reversal of the interplanetary magnetic field was modelled by the increase and overturn of the tilt angle of the neutral sheet. The energy loss model has also been used to obtain the heliolatitudinal variations of cosmic radiation. In collaboration with the University of Arizona, Tucson, USA, a three dimensional numerical simulation of solar modulation was applied in order to study anisotropies

and density gradients of galactic cosmic rays. The code includes diffusion, convection, adiabatic cooling and drift motion of particles in an interplanetary magnetic field containing a warped neutral sheet. The model reproduces the principal observations for a reasonable set of parameters.

The study of acceleration of energetic charged particles by interplanetary shock waves has been continued in collaboration with Imperial College, London, U.K. Loss-cone type particle angular distributions were clearly identifiable upstream of quasi-perpendicular shocks, characteristic of particle reflection by magnetic ramps. Upstream bi-directional distributions have also been observed in some events, and explained in terms of magnetic bottle field configurations.

For investigating comets a model of the build-up of the cometary nucleus was elaborated and a computer code describing gas diffusion through the pores of the nucleus has been developed. The motion of dust particles in the cometary environment was studied by taking into account solar radiation pressure and electromagnetic forces. It has been shown that the latter play a crucial role. Wavy features observed in the tails of certain comets were also reproduced. In a model of the inner cometary ionospheres, the thermalization of photoelectrons was investigated by taking into account several collision processes. The flow properties of the thermalized species were also studied with special emphasis on the possible occurrence of a shock transition. In another calculation the inner region of the coma, where gas-dust coupling is important, was simulated. The behaviour of the solar wind flow near comets and the shapes of cometary jets were modelled using simple dynamical assumptions. Values of the stagnation pressure and the magnetic barrier strength were estimated by including also charge exchange effects. The position of the ionopause was determined. Wave phenomena excited by the mass loading of the solar wind in front of the cometary bow shock were also studied.

The first multispecies (O^+ and H^+) time-dependent model of the terrestrial polar wind was developed in collaboration with scientists of the University of Michigan, USA. The observed large transient O^+ outflows from the polar ionosphere could be reproduced by numerical calculations.

A recent re-examination of a classic gravitational experiment, originally performed by Roland Eötvös and collaborators in Budapest, led a team of American scientists to suggest a new force of Nature, popularly known as the "fifth force". The relevant experiments were critically reviewed using archival information that is only locally

accessible. Moreover, a new series of measurements was started in collaboration with a team of the Roland Eötvös Geophysical Institute.

BIOPHYSICS

Nuclear techniques find very important applications in biophysical research. In particular, we have been engaged in the field of elemental analysis of biological samples. In addition to routine analyses a new method has been developed for localizing metal ions in proteins separated by SDS polyacrylamide gel electrophoresis (PAGE). The appropriately dried gel sections were directly bombarded by a proton beam of 3 MeV energy and the X-ray spectrum was measured at each position. This method has been found to be sufficiently sensitive for the determination of metal content (e.g. Fe, Ni) in the narrow protein bands along the gel. By providing structural as well as functional information the combination of PIXE and PAGE can make gel electrophoresis a more versatile and efficient tool. This new method has been used in collaboration with a group of the Biological Research Centre, Szeged, Hungary, to study the structure of the hydrogenase enzyme, which catalyzes the reversible formation and decomposition of molecular hydrogen.

In order to study the details of neural network formation extensive work has been carried out to construct a special printed microelectrode circuit system which may be operated in a biological environment. The gold microelectrodes were covered by a newly developed insulating layer which possesses good electrical and chemical characteristics under cell culture conditions. This work has been done in collaboration with scientists of the Research Institute for Microelectronics. The first test measurements were performed and electric signals of 200-300 microvolts produced by a monolayer chicken heart culture could be observed.

In addition to experimental studies theoretical neurobiological research has also been conducted. The basic aim is to investigate the developmental and functional mechanisms of the nervous system by means of mathematical models. Motivated by the fact that the information content of the genome is not sufficient for the specification of the synaptic connections between neurons it has been suggested that the external noise plays a positive role during normal development. Model calculations performed for different structures of visual systems confirmed the assumption. It was found that the mechanism which governs

normal development is also valid for the recovery procedure of neural elements after partial lesions in adults. It was also demonstrated that the normal rhythmic behaviour during neurochemical synaptic transmission can turn into "abnormal" and sometimes chaotic dynamics. This change may be associated with neurological disorders that may arise as a consequence of an even slight impairment of the control system of metabolism.

ENGINEERING BACKGROUND

The engineering and technological background for the scientific research of the institute is provided by the Department of Technology. More specifically the Department is responsible for the design and development of sophisticated and highly specialized electronic equipment for nuclear and high energy physics experiments as well as for related fields of research.

The main line of activity in electronics is the development of CAMAC units for various experimental purposes. Most of the instruments have been developed for plasma physics experiments with tokamak devices - including the institute's MT-1 small tokamak. The requirements of the physical measurements determine the common features of the units: fast digitizing of analogue signals, pre-processing and storing large amounts of data which arrive in many parallel channels. In connection with plasma physics two new versions of the phase meter module have been developed, which considerably improve the earlier design and facilitate the more accurate measurement of the refraction index of the tokamak plasma.

The development of a 16K memory module has just been completed and the first series of modules has been manufactured. This memory module enables the simultaneous measurements with several nuclear ADC-s to be performed. The development of the 64K memory module with many more versatile features is just under way.

For biophysics research a special low-noise amplifier was to be developed and built in order to amplify the extremely low level signals supplied by the extracellular recording electrodes from neuron cultures.

Multiwire proportional chamber development is also being continued. For the improvement of the spectrometer of the BIS-2 experiment carried out at the Joint Institute for Nuclear Research, Dubna, USSR, proportional chambers with X-Y-U signal wire planes and with 2x $1m^2$ active area have been manufactured.

Lately, image processing has become one of the main fields of development. The characteristics of the colour graphic display unit developed earlier for particle physics purposes have been substantially improved and the field of application of this unit has also been extended. As a byproduct of the work required for the processing of the pictures of Halley's comet in the frame of the VEGA space project, a new general purpose image processing system with the related large software package has been developed and manufactured.

The Department also takes part in projects supervised by other institutes or authorities if special expertise is needed. In particular a new data logging software has been written and implemented for the environmental monitoring system of the Paks Nuclear Power Plant.

The Department is also engaged in another important field of activity, space technology. The most important space programme of the past years, the VEGA mission, has successfully been completed, its results are, however, described in another part of this book.

More recently the most important activities in space research have been the further development of technology and basic services. With this in mind, an up-to-date laboratory for space technology has been built.

In the framework of the Intercosmos cooperation the development of an instrument complex to be launched on board the Phobos space probe in 1988 for the observation of Phobos, one of the satellites of Mars, has begun. The apparatus will analyse charged particles of low and medium energy. The engineering model has been built and tested. The international (Soviet-Hungarian) technical-scientific team - created for the development of the on-board computers of the Phobos probes as well as for the development of space technology and for its utilization in the national economy - was responsible for designing the on-board computer of the unit to land on the surface of Phobos. This computer controls the landing, the scientific and service instruments, the collection and processing of measurement data as well as their transmission to Earth.

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RESEARCH INSTITUTE FOR SOLID STATE PHYSICS

(SzFKI)

During the years 1985/86 this Institute dealt successfully with its traditional activities both in basic research and in applied R & D topics.

Research covers four main areas:

1. lasers and light spectroscopy
2. theoretical solid state physics
3. metal physics
4. partially ordered condensed matter.

The success of basic research is indicated by the attached publication list containing about three hundred titles.

Research - and - development includes a wide variety of activities: it starts from engineering work of applied electronics and equipment design (e.g. deep level semiconductor spectrometers); it continues with the technology of metallic glass production and the various applications, and combined dynamic neutron and gamma radiography for industrial testing; and progresses to the development of laser systems for industrial and medical applications.

One of the characteristic features of these activities is the tight link between basic and applied research.

The following pages offer readers a brief survey of our main results.

The higher order coherence properties (subpicosecond structures and frequency sweep behaviour) of mode-locked Nd:glass laser pulses (5 ps, 1 GW/cm^2) were investigated in a Michelson-type interferometer detecting them by the surface multiphoton photoelectric effect. The dependence of the time integrated nonlinear photoelectric current on the time delay between two parts of the same laser pulse furnishes information on those higher order coherence properties (e.g. chirp and picosecond substructure) which can be observed using multiphoton detection alone.

A new method was proposed to create and to measure the duration of femtosecond light pulses by means of nonlinear light beam deflection in a prism made of highly nonlinear optical material. The calculations predict 50 femtosecond pulses to be directly sliced out at 100 GW/cm^2.

We observed the predicted two sharp spontaneous Bremsstrahlung peaks at multiples of the laser frequency, superimposed on the continuous spectrum of laser excited metallic electrons.

The applicability of our MP-Q-003 miniaturized portable phosphate glass laser, developed earlier, was demonstrated by fast qualitative analysis of different (mostly archeological) materials using the spectrum of laser created plasma.

In the field of research on hollow cathode lasers the mode spectrum of a d.c. excited He-Kr laser operating at 469.4 nm was investigated in detail. It was found that in the case of TEM_{oo} transverse mode oscillation, the laser operates in a single axial mode without using any special mode selection technique. This single frequency operation was observed in the 25-40 mbar He pressure range. Using a three mirror Fabry-Perot resonator the oscillation bandwidth of the laser was measured to be 1.1 GHz. By changing the length of a two mirror resonator the laser could be tuned over a frequency range of 450 MHz. With transverse multimode oscillation, in accordance with theoretical expectations, a single frequency was observed when the optical resonator was exactly confocal. The spontaneous linewidth of the 469.4 nm Kr ion transition was measured to be 1.46 ± 0.05 GHz at 8 mbar and was found to increase linearly with increasing He pressure being 1.71 ± 0.05 GHz at 40 mbar. The probable explanation of the observed single mode laser operation may be ascribed to the large collision broadening due to the high He pressure used in the hollow cathode discharge tubes.

Electron-photon interaction in metal-oxide-metal structures was studied. It was found that the spectral distribution of emitted light is determined by the quality of metal in contact with the oxide while

the angular distribution is mainly influenced by the fast mode surface plasmons on the top of the diode. Consequently it is assumed that the soft (junction) plasmons pump the fast mode plasmons which are directly responsible for the light emission. Also on nearly-sinusoidal holographic gratings the interference of Bragg scattered fast surface plasmon waves was measured in order to study the effect of grating parameters on the momentum gap formation.

In the framework of Soviet-Hungarian cooperation a nonlinear optical phenomenon was observed (in 1980): molecules of a nematic liquid crystal (NLC) were found to be reoriented by the electric field of a laser beam of moderate power (~100 mW). Since that time, details of this effect have been further investigated; e.g. the role of reorientation at total internal reflection and the existence of light induced auto-oscillations in NLC.

A Nd:YAG laser equipment for medical purposes (MEDI-YAG) has been developed. The MEDI-YAG, incorporating a Nd:YAG laser, is adjustable to 100 W output power. The optical fibre with a gas flow possibility and the triple safety system ensure easy setting (power, time, gas flow) and safe operation giving the expected good results in therapy. After the first gastroenterologic device two urological, a pulmonological and a gynaecological system have been produced. The lasers are used to destroy tumours, to remove obstructing lesions, to control bleeding, to cause coagulation and for various other purposes.

A laser ionization time of flight mass spectrometer is being developed for the microelectronics industry; the purpose being the microanalysis of evaporated layers in integrated circuit manufacturing. This mass spectrometer combines a high precision optical system with a vacuum system. The optical system consists of three main parts: a Nd phosphate glass laser ionization source, a He-Ne pilot laser to direct the high intensity infrared ionizing laser beam, and a monitoring system which consists of a microscope combined with a television camera and a high resolution monitor.

In the field of optical thin films, as a means of improving the quality of evaporated coatings and for developing new types of optical coating our vacuum evaporation system was equipped with an optical process controller and an electron beam gun. Some new developments are: a wide band middle infrared filter for CO_2 laser wavelength, an FITC interference filter, near ultraviolet filters (360-420 nm), laser mirrors for a XeCl excimer laser at 308 nm, and a circularly variable optical attenuator.

SOLID STATE THEORY RESEARCH

Considerable interest has been attracted in the last few years by the motion of heavy particles interacting with a light degenerate Fermi gas. This has many important implications such as the diffusion of muons or hydrogen in metals, the motion of heavy ions in degenerate ^{3}He Fermi liquid, mass reduction of heavy d-electrons in transition metals and - very likely - in the heavy fermion systems. The question was how the fermionic heat-bath damps the tunnelling motion of the particle between the potential-wells of the lattice. In this sense the problem is strongly connected with a more simple one where the hopping motion is restricted to only two sites - this is known as the two-level system (TLS). Usually the latter model is studied even in the periodic case because here the strong electron-screening can be handled correctly.

We examined both models and found that the screening by the light particles results in a reduction of the spontaneus hopping rate; however, as we showed in the two-level case, the electron assisted tunnelling rate always exceeds the normal one.

The dissipative quantum systems are also interesting with respect to measurement theory: they are able to serve as measurement apparatus for the position of the particle. By switching the coupling between the fermions and the heavy particle with a large enough value but without assisted tunnelling the particle becomes localized and its position can be measured by non-invasive measurement.

The low-temperature coherent state of valence fluctuating and heavy fermion systems has been studied by seeking suitable variational ground state wavefunctions. A two-band version of the Gutzwiller method was developed for application to the periodic Anderson model. We solved the problem of minimizing the ground state energy with respect to a macroscopically large number of independent variational parameters. The results can be formulated in terms of an effective free-fermion Hamiltonian where, however, the parameters are renormalized. For small values of hybridization, the ground state is unstable against ferromagnetism. A generalization of the variational procedure to the site-diluted Anderson model shows that the Kondo exponent interpolates smoothly between the single-ion and lattice values.

We started to study the properties of quasi-periodic crystals. Analytical and numerical calculations have been performed for the spectral properties of a quasi periodic linear chain. Our conclusions indicate that the spectrum of a quasi-periodic one-dimensional lattice is a Cantor set of zero measure.

Statistical properties of the chaotic state arising in nonlinear systems have been studied. To characterize the degree of stochasticity in a quantitative manner, a new quantity has been introduced and its usefulness has been demonstrated in a wide range of the control parameter. For describing transient chaos a new method has been formulated in the framework of which the determination of the fractal dimension of a strange repeller amounts to the solution of an eigenvalue problem. On the basis of this method the fractal dimension characterizing the magnetization of an Ising chain in a random magnetic field has been determined.

PARTIALLY ORDERED CONDENSED MATTER RESEARCH

Ferroelectric chiral smectic C* liquid crystals have been investigated by several methods. New compounds were synthetized and phase diagrams of binary and phase diagrams of binary and ternary mixtures have been studied by polarizing microscope and differential scanning calorimetry (DSC) to optimize material parameters. A new method of alignment has been developed which allows measurement of spontaneous polarization, pitch, electro-optical and dielectric responses of room temperature mixtures. A new electro-mechanical effect has been discovered in these ferroelectric substances. An electrodynamic continuum theory has been suggested which interprets the phenomenon as the result of a new cross-effect.

Non-ferroelectric liquid crystals have also been investigated. The dielectric relaxation has been studied in nematic and smectic phases.

An empirical expression, relating molecular dipole moments, order parameter and transition temperatures, has been derived to describe the behaviour at the N-S_A phase transition. The changes of the relaxation times in the smectic phases have been interpreted by a generalization of the Maier-Saupe theory. A series of binary mixtures has been studied by X-ray methods and calorimetry for a better understanding of the role of molecular lengths in generating induced smectic phases.

A soliton-model has been proposed for the interpretation of NMR spectra of choelesteric and blue phases.

Nematic liquid crystals have also proved to be appropriate materials in the study of pattern formation.

Investigations on dependences between structure and transport properties of hydrogenated amorphous silicon (a-Si:H) have been continued.

A tight correlation between structural homogeneity and electronic properties could be proved. The structural investigations were enlarged by the ERD (Elastic Recoil Detection) technique which is well suited for determining the absolute hydrogen content and depth profile of H in a-Si:H thin layers. We managed to obtain 20 nm depth resolution and 1 μm probing depth by the optimization of the measuring parameters and using 3 MeV He^+ ion bombardment. By applying the time-of-flight method on a-Si:H we proved that the shape of the transient curves depends not only on the electrical properties of the amorphous silicon but on the measuring geometry as well. So the mobility and lifetime of charges calculated from these data are also dependent on the geometry - which might lead to false results. In conclusion the utilization of these techniques for amorphous silicon cannot be direct or, at least, the evaluation method has to be changed. Field-effect measurements on 3 μm thick a-Si:H thin films were also performed. The insulator was 25 μm thick kapton foil. Subsequent analysis revealed the non-exponential character of the relaxation processes and also the nonlinearity of the source-drain current versus driving voltage relationship.

The Ge-Se and As-Se family of chalcogenide glasses was studied. Transient effects have been observed in the photoluminescence (PL) of the Ge_xSe_{1-x} system after keeping the fatigued sample in the dark at low temperature. The intensity of the transient signal increases with the dark time. This effect suggests that band gap excitation inhibits the recombination of the PL centre.

Reversible photoinduced change of hole drift mobility was found in a-AsSe film. The drift mobility decreased by an order of magnitude due to He-Ne laser irradiation. The peculiarity of this effect - which differs significantly from the photostructural changes observed - is that thermal annealing at 80 ^{o}C, (well below the transition temperature) restores the initial larger drift mobility.

In accordance with the world-wide growth of interest in charge density wave (CDW) systems we, too, have continued our research in this field. We have extended the range of materials studied by $(TaSe_4)_2I$ and molybdenum bronzes. Methods of investigation have included (pulsed) dc, microwave conductivity and thermopower measurements, as well as NMR and optical spectroscopy. Part of this work was performed in international cooperation (University of California at Los Angeles, University of Zagreb, CNRS Grenoble, Max-Planck-Institut Stuttgart).

We have focused on two topics: the investigation of sliding CDW conductivity and the so called "narrow band noise", and the study of metastable states and relaxation processes. Our main results can be summarized as follows.

We have shown that the narrow band noise arising from CDW domains oscillates coherently. These experiments offer definite proof in the controversy of whether the narrow band noise is a bulk or an interface effect: the proof is in favour of the former.

By directly measuring the drift velocity of the sliding CDW (through detecting the line narrowing in NMR spectra of $Rb_{0.3}MoO_3$), fundamental experimental evidence for sliding CDW conductivity was given.

The most impressive new relaxation process investigated was the relaxation of dielectric polarization in $K_{0.3}MoO_3$. Direct measurements of discharge current in the time interval of 10^{-5} to 10^{3} seconds revealed a stretched exponential law for the time decay of polarization $P = P_o e^{-\{t/\tau(T)\}^{1-n}}$ where both the initial polarization, P_o, and the exponent ($1-n = 0.7$) are temperature independent *(Fig. 1)*. The time scale of the process, $\tau(T)$, was found to be temperature activated with an activation energy equal to the single particle Peierls gap. The glassy relaxation of randomly pinned charge density waves can be related to recent theories and experiments on spin glasses.

In the field of amorphous semiconductor research we have examined the solubility of the amorphous chalcogenide (As_2Se_3) layer and we found that it changes sharply after silver photodiffusion. A submicron ($\sim 0.35\ \mu$) optical grid was obtained by photodiffusion and a selective dissolving process utilizing visible monochromatic light interference phenomena. This process is also highly suitable for microlithography in VLSI (Very Large Scale Integration) technology.

Heat and momentum transport calculations have been performed in order to study the thermal history characteristic of the melt spinning procedure. The effect of casting conditions on the cross sectional inhomogeneities of metallic glass tapes was modelled.

A melt spinning apparatus working in an inert gas atmosphere has been installed in the metallurgical laboratory. Investigations on the laser quenching of alloys have been started.

Calorimeter experiments (DSC) on the thermal stability of amorphous alloys were continued. The composition dependence of relaxation energy was determined on the Fe-P-B amorphous system.

Studies on the short range order of metallic glasses were extended to Fe-Zr based alloys. The correlation between the atomic and electronic structure of melt quenched Fe(Zr,B) and (Fe,Ni)B alloys was examined by Mössbauer spectroscopy and photoemission measurements (in cooperation with the University of Basel).

In cooperation with the Solid State Physics Laboratory, University of Groningen, electronic structure calculations have been performed for iron-metalloid systems using the self-consistent, spin-polarized ASW

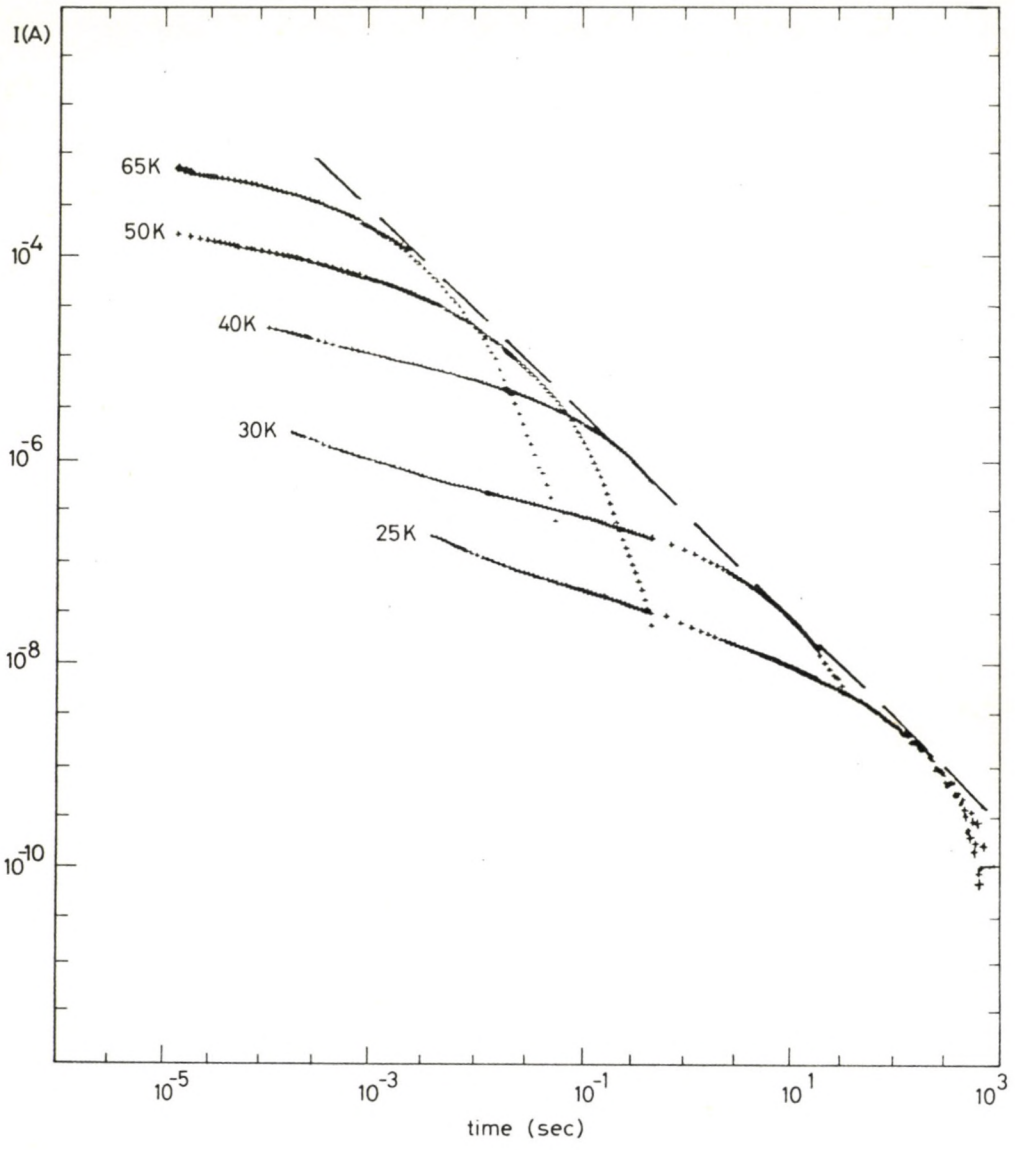

Fig. 1

Time dependence of depolarization current at different temperatures in $K_{0.3}MoO_3$

method; these calculations indicate that the electronic structure strongly depends on the atomic structure.

The short range structure of $Ni_{62}Nb_{38}$ and Ni_2B glasses has been investigated by means of isotope substitution high spatial resolution neutron diffraction. The partial structure factors and atomic correlation functions were determined with high accuracy. Strong chemical short range order was established for both glasses: this feature is reflected in the partial first neighbour distances, in the width of the atomic distance distributions, and in the coordination number values. From the results it can be concluded that the $Ni_{62}Nb_{38}$ glass is not a substitutional alloy as was supposed earlier.

Neutron radiography was used to investigate the heat transport circulation of the working fluid in heat pipes. The effect of pulsed boiling was discovered and it was analysed as a function of temperature. It was established that in heat pipes operating in the lower critical interval (where the pulsed boiling occurs), thermal and hydraulic equilibrium do not exist and, consequently, none of the usual heat transfer models for calculating the important working parameters should be utilized. Simultaneous neutron- and gamma radiography was used for several other industrial applications.

Small angle neutron scattering was used for the structure investigation of some ionic micelles. The concentration dependence of the average aggregation number was measured. The results have given a fourth-degree empirical rule both for Na-dodecylsulphate and for Li-dodecylsulphate. It was established that if the length of the hydrocarbon chain is changed, the average aggregation number increases by the squared values of the number of carbon atoms. Both observations were explained by considering the balance of hydrophobic interaction and electrostatic interaction between the head groups and between the micelles, neglecting the concentration dependence of the charge of micelles.

METALS RESEARCH

The study of amorphous alloys was continued. The statistical geometry of dense random packing hard sphere model *structures* has been investigated. The local order in the binary models was investigated via generalized Voronoi polyhedra. It has been shown that the use of an integer coordination number leads to inconsistencies in the binary models; this has also been investigated and it was found that the concentration

dependence is different below and above 0.18 metalloid content. The concentration dependence of the magnetic moment in iron-boron glasses has again been considered. A simple statistical description is presented; this yields non-monotonic behaviour of the iron moment - as was also observed experimentally.

Relaxation processes of Fe-Ni-B magnetic metallic glasses were investigated by measuring the Curie temperature in as-quenched and pre-annealed states. Three processes were found in as-quenched glasses whereas in pre-annealed processes there are two. Activation energies were determined for these relaxation processes. On comparing the results for as-quenched samples with those of pre-annealed samples, one can establish that the presence of an irreversible process facilitates the reversible processes.

Initial *permeability*, magnetic after-effect and power loss were measured along the length of an amorphous $Fe_{80}Si_6B_{13}C$ and $Fe_{7.6}Co_{54.5}Ni_{17.1}Cr_{42}Si_{3.4}B_{13.2}$ ribbon to investigate the homogeneity of the above properties. It turned out that in the case of the first composition having high magnetostriction the variation of the magnetic parameters is strongly related to the ribbon thickness whereas no significant effect was observed on the second composition having nearly zero magnetostriction.

In collaboration with Csepel Metal Works the different *anisotropy energies* determined by approach to saturation and torque measurements in polycrystalline and amorphous materials were reviewed. The earlier investigations concerning the effects of the process parameters on the physical properties have been extended to the zero magnetostriction on metallic glass $Co_{66}Fe_{4.5}Ni_{3.5}Nb_2Cr_1B_{14}Si_9$. It has been found that in the non-magnetostrictive ribbons ($\lambda_s \sim 10^{-8}$) the empirical cooling rate affects primarily the frozen-in anisotropy which in turn can be characterized by the in-plane anisotropy of the coercive force, and all the other properties depend dominantly on the anisotropy.

In the last two years a new laboratory for electron microscopy has been built in the KFKI. The most significant research result obtained during this period is the new magnetic domain detection method for investigating *magnetic domain* type II. By this method soft magnetic materials such as magnetic glasses, transformer materials, etc. can be investigated, and their magnetic properties on the basis of the domain structure can directly be understood.

The surface properties of ferromagnetic metallic glasses significantly influence their bulk magnetic properties. Therefore surface hysteresis loop measurements by magneto-optical hysterograph combined with domain observation measurements were used to investigate the sur-

face magnetic properties. It was shown that there is a great difference between the magnetic behaviour of the two ribbon surfaces (wheel side and air side). In spite of this feature, it was found that on both surfaces the magnetoelastic anisotropy plays a significant role in the determination of surface magnetic properties in all magnetostrictive amorphous materials. After proving this we determined the influence of tensile stress on the surface magnetoelastic anisotropy, coercive force and static hysteresis loss in a model material of $Fe_{80}Cr_3B_{17}$ ($\lambda_s=18.10^{-6}$).

The *transport properties* of the ferromagnetic amorphous system $Fe_{80}TM_3B_{17}$ were studied. The investigations were extended to Ni-based paramagnetic alloys. In the $Ni_{77}TM_3B_{20}$ amorphous alloy system, the influence of 3d, 4d and 5d transition metals on electrical resistivity, magnetoresistance and thermoelectric power was investigated between 1.5 and 300 K. The results cannot be properly interpreted in the framework of dilute magnetic alloy theories (Kondo effect), but magnetic contributions of clustering and effects from electron-electron interaction must be taken into account.

In an effort to obtain homogeneous foils of alloys (among others amorphous Ni-P alloys) by electrodeposition a new experimental arrangement was worked out. The measurement of the local P-content by the thermopower method and the local thickness of the deposited layers at the same point correlates well with the theoretical current density distribution and helps in selecting uniform parts of the samples which are very homogeneous not only on a macroscopic but on a microscopic scale as well.

For a better understanding of the bulk and local magnetic and electronic properties as well as their fluctuations in Ni-metalloid amorphous alloys we have performed - mostly in international cooperation - magnetization, NMR and low-temperature specific heat measurements on several metallic glasses of this type. It has been established that amorphous $Ni_{100-x}P_x$ alloys with $X \geq 18$ are Pauli paramagnetic with some magnetic inhomogeneities. The amount of these latter also depends on the preparation technique and it has been shown to be considerably smaller in our samples than reported previously.

For the amorphous $Ni_{80}P_{14}B_6$, $Ni_{78}B_{14}Si_8$ and $Ni_{75}TM_5P_{20}$ (TM=Ti to Cu) alloys very similar magnetic properties have been found. In the last of these alloy series the Pauli susceptibility has varied strongly with the TM element and correlated well with the previously reported ^{31}P NMR Knight shift in those alloys. It could be concluded from these results that in Ni-P type amorphous alloys a considerable electronic density of states exists at the Fermi level even at metalloid contents as high as 20 at%. This finding has been supported by the low-temperature specific

heat data obtained on $Ni_{81.5}P_xB_{18.5-x}$, $(Ni_{1-x}Cu_x)_{80}P_{20}$ and $(Ni_{1-x}Cu_x)_{77}B_{13}Si_{10}$ metallic glasses as well as by the ^{31}P and ^{63}Cu NMR data on the $(Ni_{1-x}Cu_x)_{80}P_{20}$ alloy series.

Besides amorphous alloys, some biological samples have been investigated by NMR spectroscopy. The water structure and dynamics in different biological tissues and organic hydrate systems have been investigated by means of various NMR techniques. A correlation between the NMR parameters and physiological properties has been established in brain, eye, muscle and cartilage tissues in connection with the nowadays expanding MR Imaging. The influence of water concentration changes on the macromolecular structure and dynamics has been studied in these tissues. The role of water H-bond networks in the structure and dynamics of organic hydrates was also investigated.

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RESEARCH INSTITUTE FOR MICROELECTRONICS (MKI)

The Institute for Microelectronics has continued its work on semiconductors, on mask production, on circuit design, on the research of new directions in support of R & D activity and on data storage using magnetic memory devices. (The last task was finished at the end of 1985.) Considerable progress was made in the field of understanding the physical background of semiconductor-technology, of crystal-growth and in the investigation of magnetic garnet layers.

The development of equipment for automating the used technologies was continued.

In the last two years the institute pursued its activity in connection with circuit design and the development of technology of semicustom integrated circuits. The technology developed for processing Al and silica glass layers was provided at the end of 1985, and proved to be successful on HT 001 CMOS master slices with Al gates. The technology of more complex silicon gate CMOS master slices was elaborated too and it has been proven on circuit designs according to the requirements of the customer.

Our work connected with circuit design includes:

- development and transfer of methods for computer aided circuit design,
- design of custom IC's,
- elaboration of computer aids necessary for designing silicon gate master slices.

Besides the self developed CG gate array circuits we designed circuits on HT 005 and HT 010 master slices. The first one consists of 560 gates while the other 960. The speed and complexity of circuits processed on silicon slices enable us to use them in the field of computer techniques. Circuits developed in the last two years are listed in Table 1.

Table 1

Circuit	*Master slice*	*Customer*	*Application*
APR 2	*HT 005*	*MSzKI*	*Dynamic memory control*
HDL	*HT 005*	*VIDEOTON*	*Printer control*
VDN8407	*CGB*	*VIDEOTON*	*Keyboard decoder*
TIC8412	*HT001*	*VKI*	*Power supply control*
VDK8602	*HT005*	*VIDEOTON*	*Baud-rate generator*
HMV	*CBA*	*FFMV*	*Metering of hot water consumption*

As a consistent piece of original research in materials science motivated by microelectronics, the extension of the ellipsometry method to detect thickness, regrowth and degree of amorphousness in implanted amorphous silicon layers is to be mentioned first. Thickness calibration was made by high-resolution Rutherford backscattering and channelling.

The formation and properties of titanium and gadolinium silicides were investigated with various methods including Rutherford backscattering, X-ray diffraction, electron spectroscopy and electrical measurements. A new phase transformation in the Ti-Si system was found and the best gadolinium silicide reported to date was produced in a UHV evaporation system.

Following joint studies with Cornell University (Ithaca, N.Y., USA) on pulsed ion implantation and anneal, a machine producing repetitive pulses was built.

Though the results themselves had been achieved somewhat earlier in joint research with California Institute of Technology (Pasadena, CA, USA) on a combination of double implantation and solid phase epitaxial growth processes for "perfect" doping of semiconductors, recent demands of VLSI R & D drew attention to these results and the applications in technology are becoming widespread. Similar success has been achieved in improving crystallinity by the implantation of silicon-on-sapphire structures.

The methodological arsenal of the Institute has improved during these years by virtue of a new high resolution scanning electron microscope (Jeol SM80) having been added to our existing facilities. Another important piece of new equipment for materials research in microelectronics is the 500 kV implantation machine operated jointly with the Institute for Nuclear and Particle Physics. Some other new techniques

to be reported are the equipment for rapid thermal annealing and low pressure chemical vapour deposition system.

In order to select the proper temperature distribution during Czochralski crystal growth, and to select the optimum crystal size to crucible ratio, along with the pull rate and the proper crucible shape, it is necessary to know the exact flow patterns. Therefore, our activity in the field of crystal growth was to study the flow pattern and the time function of the temperature distribution during the crystal growth by different model experiments. With the aid of fast Fourier analysis the hydrodynamic instabilities and the influence of the external magnetic field were studied, both in model experiments and during the growth of oxide crystals. By analysing the melt behaviour and crystal quality, a correlation between hydrodynamic instabilities and crystal quality was found for bismuth germanate.

Over ten years of experience in high quality crystal production and automation of the growth process as well as in the development of various items of electronic equipment led to the realization of the DIACONT crystal growth equipment. With this equipment crystals of predetermined shape can be reproducibly grown from a wide variety of materials. This work was performed in collaboration with the Institute of Crystallography of the Academy of Sciences of the USSR. In October 1985, an international working meeting was organized on ion beam modification of materials, as part of a biennial series of conferences on joint researches of the academies of the socialist countries. A Working Meeting on Ion Implantation in Semiconductors and Other Materials and Ion Beam Devices (1985, Balatonaliga, Hungary) covered problems of ranges, defects, defect annealing, implantation into semiconductors and metals and equipment. For the first time, papers of this series were published in a regular journal (physica status solidi (a) 94 (1986)).

INVESTIGATIONS OF THIN FILMS IN SEMICONDUCTOR TECHNOLOGY

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Ion implantation is a crucial processing step in semiconductor technology. Electrical, mechanical, magnetic and crystallographic properties of materials can be changed by ion implantation. The Physics Laboratory of the Research Institute for Microelectronics investigates the effects of ion implantation.

Ellipsometry (reflection polarimetry) is an attractive method for monitoring ion implantation induced damage due to its sensitivity and experimental simplicity. For VLSI applications, the checking of the amorphousness of the implanted layer is important. The evaluation of our measurements is based on programs written for personal computers. The programs can handle multiple wavelength and multiple angle of incidence measurements on multilayer samples.

It has been shown that Multiple Angle of Incidence (MAI) ellipsometry and spectroscopic ellipsometry can characterize ion implanted samples. The thickness of the amorphous layer in silicon following implantation with As and Sb ions and also the thickness of a native surface oxide layer were evaluated by MAI. The samples were investigated by high resolution Rutherford backscattering spectroscopy (RBS) to check MAI results. In this part of our work we have collaborated with the Humboldt University, Berlin, GDR, and the Central Institute for Physics, Bucharest.

During solid phase epitaxial regrowth of ion implanted silicon, not only the thickness of the remaining amorphous layer decreases but it is also different optically from the as-implanted one. We have established the so-called thermally stabilized amorphous state by ellipsometry at a wavelength of 632.8 nm. To obtain an appropriate optical model and to check thickness data obtained from ellipsometry, we again used high depth resolution backscattering spectrometry combined with channelling. Using special arrangements in backscattering spectrometry such as glancing detection and $^{16}O(\alpha,\alpha)^{16}O$ elastic nuclear scattering, we were able to construct realistic optical models both for amorphization and recrystallization experiments.

Ion implanted silicon and GaP were investigated by ellipsometry and channelling effect measurements to determine the validity of the Bruggeman theory for partially amorphous layers. It was found that an "effective medium" approximation gives a satisfactory description of the disordered layer for heavy ions and low doses. The thickness of the disordered layer and the degree of amorphousness are independent parameters and can be determined from ellipsometry alone.

Radiation damage in epitaxial layers of magnetic bubble thin films was investigated by backscattering spectrometry combined with channelling and $^{16}O(\alpha,\alpha)^{16}O$ elastic nuclear scattering. The magnetic parameters were modified by implantation and annealing. It was shown that the lattice damage was different for different constituents. Heavy ions were found more off-site than oxygen. A 350 ^{o}C annealing, showing optimum magnetic characteristics in bubble memory applications, leads to complete recrystallization of all sublattices down to a depth of 100 nm but leaves a disordered layer at depths between 100 and 300 nm.

The ion implantation process into germanium at room temperature is relatively less understood due to the observed peculiar surface morphology involving a black appearance. A yield deficit in RBS spectra is observed for Ge and Sb implants, a less pronounced, but observable effect was found for In implant and no change in RBS spectra was detected for Kr implant into Ge. More work is needed to clarify not only the nature of the yield deficit but also the inhibition mechanism of noble gases.

The electronic and structural properties of stable and metastable systems represent a crucial problem in condensed material research. The properties of metallic glasses and ion implantation induced amorphous Si and Ge were investigated by UPS and XPS methods. It was determined that the broadening of Fe "d" spectra characteristic for FeB and for the crystallization process is initiated at the geometrical surface. Ion implanted a-Ge has a valence band density of states strongly different from the data accepted for tetrahedrally coordinated amorphous semiconductors, thus indicating a strong modification of sp^3 hybridization.

Silicide thin films are very important in VLSI technology and represent an open field in intermetallic thin films. Because the thermodynamic data of the different silicide components are very similar, a wide range of stable and metastable phases could be formed by solid phase reactions. This formation process was investigated in Ti-Si and Gd-Si systems, demonstrating that the $TiSi_2 \rightarrow TiSi$ transition takes place at 800-900 ^{o}C, despite the fact that $TiSi_2$ is more stable than TiSi. The density of states of TiSi at the Fermi level is larger than for TiSi. The formation process of the Gd-Si system is strongly regulated by the surface oxide layer and the oxygen impurity. The oxidation process and the Schottky contacts of $GdSi_2$ show some peculiar characteristics.

Together with researchers at the Department of Materials Science and Engineering, Cornell University, Ithaca, USA, we investigated pulsed-beam ion irradiation on Fe/Al bilayers. Xe ion implantation of Fe/Al bilayers has resulted in very little material mixing. Pulsed-beam ion irradiation with much lighter ions and at much lower doses has resulted in a substantial amount of intermixing and the production of a non-equilibrium phase. Heat flow calculations have shown that the irradiation induced lattice heating causes a rise in the surface temperature and the melting of the Al.

A new technique for the fabrication of single crystalline thin films with a controlled variation in composition was attempted. Vacuum evaporation through a thickness controlling aperture onto a rotating substrate has yielded a sample with alternating wedge-shaped films in which the composition varies linearly with distance. Ni/Al, Pd/Al, Pt/Al samples were produced with this method, Rutherford backscattering was used to

investigate the films, while on the NaCl substrate X-ray energy dispersive spectroscopy and electron diffraction were used to study the self-supporting films on transmission electron microscope grids after dissolution of the substrate.

In collaboration with the Research Institute for Technical Physics, Budapest, we have studied a number of materials to be applied as candidates for electrical contacts on GaAs. Ion beam intermixing was found as a possible method to form good electrical contacts to GaAs. Mixing was done on a 500 kV heavy ion cascade using Ar^+ and Xe^+ beams. Intermetallic compound formation of Ge-Ni and Ge-Al-Ni systems by furnace annealing and ion beam intermixing were compared. By thermal annealing all stable phases of the Ni-Ge system were produced. Introducing aluminium into the system, phase separation and new intermetallic phases were obtained. By ion bombardment a comparable amount of mixing was found and the most stable Ni_2Ge phase formed.

Another investigated system was GaAs-Au. A comparison was made of thermal annealing and ion mixing + annealing on (100) GaAs-Au evaporated layers. The structures were investigated by SEM, X-ray diffraction, RBS + channelling and AES. Implantation and mixing by Xe enhanced, while mixing by Ar inhibited the interdiffusion of Au in GaAs compared to the pure thermal treatment.

The GaAs-Au ion mixed contacts were tested and their electrical parameters were measured. The interaction of Au with GaP and InP were studied by the same methods.

RESEARCH AND DEVELOPMENT OF CZOCHRALSKI GROWTH

Z. Juhász, Gy. Szabó

1. INTRODUCTION

Development of crystal growth is required by high technology which utilizes a wide variety of single crystals in large quantities and of top quality. As a result of research and development during the past decades Czochralski growth has been extended in different directions to produce homogeneous two- and more component crystals (i.e. semi-insulating GaAs). Further progress may be achieved by utilizing the better understanding of the fundamental phenomena which do not affect the crystal growth in simple cases such as Si growth.

In the Czochralski techniques the growing crystal is pulled out from the melt contained in a heated crucible. The growth process re-

quires a temperature gradient causing time-dependent flow and temperature distribution in the melt. Recently, an external magnetic field has successfully been applied to suppress these disadvantageous temperature oscillations in the melt at GaAs growth. In section 2 we briefly sketch our results obtained by simulating the magnetic Czochralski growth at room temperature.

The crystal quality is significantly affected by the temperature oscillations modifying the growth rate. To investigate this effect we have developed a computer controlled measurement system. Using this apparatus we have been able to study the relationship between crystallization and temperature variations (outlined in section 3) as well as the effect of any change in the boundary conditions. Analysis of the dynamic response of the crystal growth process is of interest in the design of computer control systems for Czochralski growth.

2. SIMULATION OF MAGNETIC CZOCHRALSKI GROWTH

Experimental apparatus was constructed to model magnetic Czochralski growth at room temperature [1,2]. Using this apparatus we could simulate all the essential phenomena appearing in semiconductor growth in a high magnetic field. Our model experiments, however, provide better conditions when studying the onset and the suppression of the temperature oscillations.

The working fluid was molten gallium contained in a double-walled glass crucible and the rotating crystal was modelled by a copper cylinder. The temperature of both the crucible and the crystal was stabilized by circulating water. We could vary the vertical magnetic field produced by a water cooled solenoid up to 480 A/cm. Using a computer controlled system the temperature of the working fluid was measured by a copper-constantan thermocouple inserted into the melt between the crystal and the crucible wall. We determined the standard deviation which was taken to be a measure of the amplitude of the temperature fluctuations.

The hydrodynamic instabilities appearing in the melt are analogous with the well known Rayleigh-Benard instability. The driving force of the melt flow is usually characterized by a Rayleigh number which is proportional to the temperature difference between the crystal and the crucible wall. In conductive melt the buoyancy driven flow may be damped by applying a vertical magnetic field. This damping effect is conventionally described by a Q number proportional to the square of the magnetic field. By analysing the time dependence of the melt temperature we could study the competition between the driving force and the damping effect. The results are summarized in *Figs. 1* and *2*.

We found that the temperature oscillations were completely suppressed when the magnetic field exceeded a threshold value which is strongly dependent on the temperature difference and the rotation rate. It is observed that the applied magnetic field significantly changed the melt stirring which is caused by the rotating crystal.

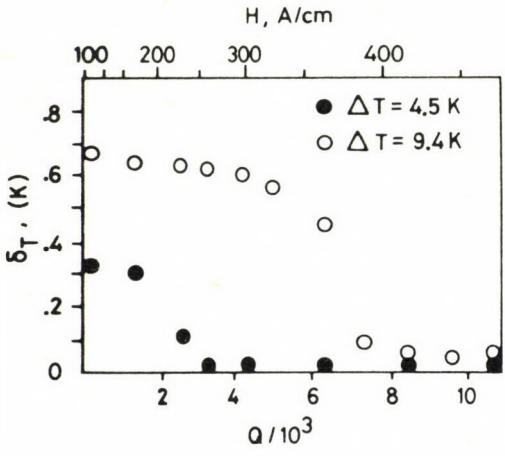

Fig. 1

Standard deviation of temperature fluctuations versus Q number at two different temperature differences for rotation rate of 20 rpm

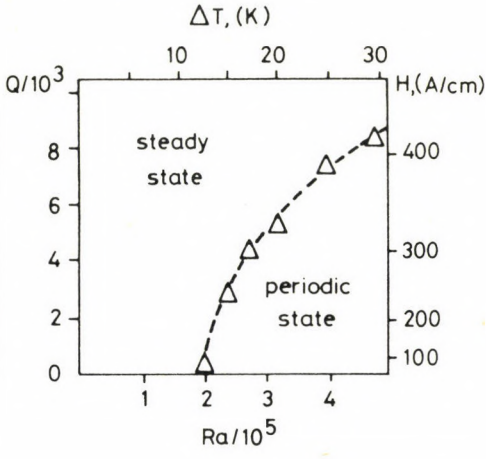

Fig. 2

Nature of time-dependent flow as a function of Rayleigh and Q numbers for a rotation rate of 30 rpm

In conclusion, these kinds of hydrodynamic investigations can provide valuable quantitative results enabling one to choose the optimum value of parameters for magnetic Czochralski growth.

3. DYNAMIC BEHAVIOUR OF THE CRYSTALLIZATION

The measurements of time-dependent crystal growth rate provide valuable and definitive information about the details of the growth process. We investigated this dynamic behaviour by simultaneously measuring the crucible weight and melt temperature near the solid-liquid interface during growth of $Bi_4Ge_3O_{12}$ crystals [3]. An electronic balance with a sensitivity of 0.01 g was used to weigh the crucible while a Pt-Pt 10% Rh thermocouple measured the melt temperature. The resulting temperature and weight signals were considered as an input and output of a linear invariant system, and the dynamic behaviour was characterized by the

transfer function and the spectral sensitivity determined by a complex frequency domain analysis. A typical response of growth rate (defined as the differentiation of weight signal with respect to time) following a temperature increase is shown in *Fig. 3*. The dashed line represents a correction to the numerical computation based on physical considerations.

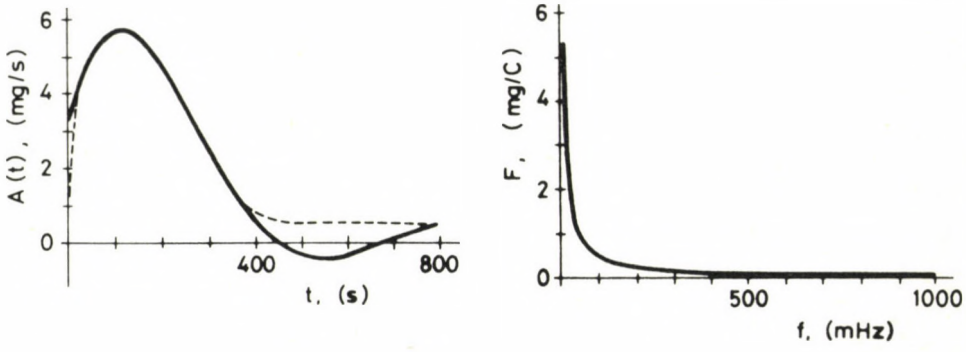

Fig. 3

Response function (left) relating growth rate to a temperature increase of 1 ^{o}C and the corresponding spectral sensitivity of weight (right) at a pulling rate of 2 mm/h

The periodic components of the measured signals were investigated by Fourier analysis. It is found that a characteristic peak in the power spectrum of the weight signal appears at the basic frequency of the actual temperature oscillation. As expected [4], the sensitivity of the growth process to the temperature oscillation increases with decreasing frequency. The results indicate that spectral analysis of the weight signal can be an efficient method for detecting spurious temperature oscillations in real time.

The results and the experience obtained during the present work are of considerable value in determining the design of future growth control systems.

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HCMOS - A LOW-POWER HIGH-PERFORMANCE TECHNOLOGY

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PROPERTIES OF CMOS INTEGRATED CIRCUITS

The basic element of the CMOS integrated circuits, the CMOS inverter, can be seen in *Fig. 4*. The CMOS inverter consists of an n-channel and a p-channel transistor. The source of the n-channel MOSFET is connected to the ground potential, while the p-channel's to the V_{DD} power voltage. The gates are connected together in the same way as the drains. The input signal reaches the gates and the output is formed by the drain electrodes.

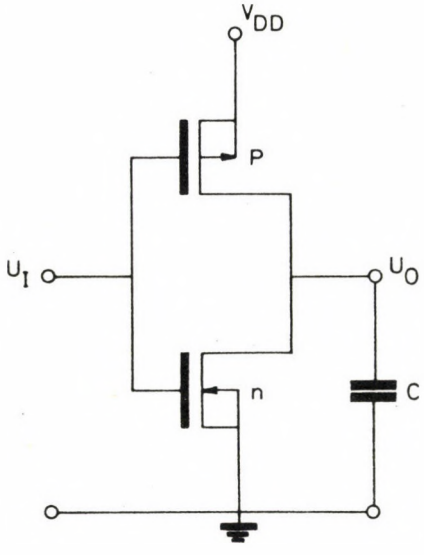

Fig. 4
Schematics of a CMOS inverter

The favourable properties of CMOS integrated circuits come from the operation of the CMOS inverter. In the static state one of the transistors is always closed so only leakage current flows between the power voltage and the ground potential, whose magnitude is below 1 nA. In this way, in static mode, a CMOS inverter does not consume any current, thereby resulting in the incredibly low power dissipation of the CMOS integrated circuits.

The next inverter is a capacitive load at the output of the CMOS inverter. The load capacitance will be charged through an open transistor resulting in fast switching, and the voltage difference between the

output logic levels and the ground or the power supply potentials will be in the order of mV's.

The advantage of CMOS integrated circuits compared with other MOS ICs is their low noise sensitivity. The reason for the good noise immunity is that the inverter will not be switched until the input voltage has opened the closed transistor.

The disadvantage of CMOS integrated circuits in comparison with the NMOS is that they need a more complicated technology and they occupy a larger area.

DEVELOPMENT OF THE CMOS TECHNOLOGY

The first CMOS integrated circuits appeared in the late 60s; they were used in quartz watches and pocket calculators. However, these CMOS integrated circuits had relatively low density. As a result of the great improvement of the semiconductor technology in the 70s, complicated integrated circuits were fabricated using CMOS technology. The increase of the power dissipation at elevated density also helped the distribution of the CMOS technology.

The development trend of the CMOS technology can be seen from Table 2, "L" is the channel length characterizing the given technology, t_{ox} represents the gate oxide thickness. The last column shows the largest static RAMs fabricated with CMOS technology of the given year.

Table 2

Year	*Name*	*L(μm)*	t_{ox} *(nm)*	*RAM*
1970	*CMOS*	*10*	*120*	-
1975	*CMOS*	*5*	*100*	*1K*
1978	*HCMOS-I*	*3*	*60*	*16K*
1981	*HCMOS-II*	*2*	*40*	*64K*
1983	*HCMOS-III*	*1*	*20-30*	*256K*

It can be seen from Table 2 that the first generation of the HCMOS (High Performance CMOS) technology characterized by a channel length of 3μm was prepared in 1978. Using HCMOS technology it became possible to fabricate high speed 16K static RAMs of low power consumption. The second generation of the HCMOS technology (HCMOS-II) with 2μm channel length was achieved in 1981. Recently, HCMOS-III technology has come into use where the characteristic channel length is 1-1.5μm. With these

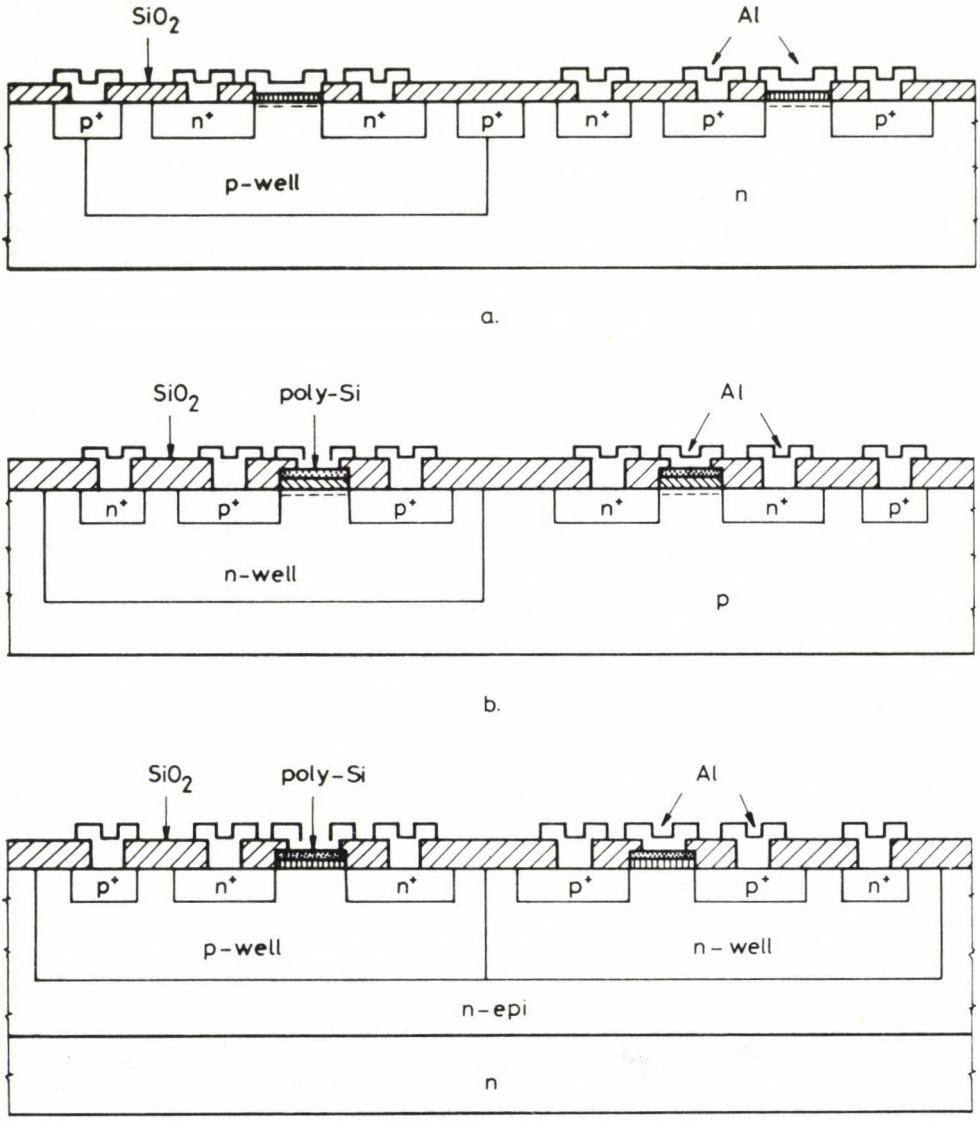

Fig. 5

a. p-well, metal gate CMOS structure
b. n-well, poly-Si gate CMOS structure
c. double well CMOS structure

technologies high speed static RAMs and gate arrays of high capacity can be fabricated. The most up-to-date technologies not only offer the advantage of small sizes but also the new techniques such as silicided gate, source and drain, multi level connection, different insulation techniques, etc.

Fig. 5 shows different types of bulk CMOS technologies. The conventional CMOS technology with p-well and metal gate can be seen in *Fig. 5a*. This type of CMOS technology is not suitable for fabricating VLSI circuits. Nowadays, the structures with an n-well are used, because of their lower parasitic capacitance *(Fig. 5b)*. In case of the double well structure the doping concentration of both transistors can be controlled, the distance between the p and n channel devices is decreased, thus requiring less space.

RESEARCH INTO HCMOS TECHNOLOGY

We have prepared a test circuit with poly-silicon gate, n-well technology in order to be able to measure different technological parameters, to examine n and p channel transistors with 3-12μm channel length, and to study the latch up phenomenon. The test circuit also consists of CMOS inverters, NAND gates and ring oscillators.

The most important steps and parameters of the technology can be seen in Table 3. In this experiment p type silicon wafers were used with 100 orientation and 20 Ohmcm resistivity. To prevent the formation of parasitic channels we applied the LOCOS technique. Contrary to the conventional method, we annealed the wafers after the B^+ implantation to decrease the segregation of boron atoms during field oxide growth.

The field threshold voltages in areas covered by poly-silicon satisfied the demand of $V_{TFn}>25V$; $V_{TFp}<-25V$. The V_{Tn} and V_{Tp} threshold voltages were set in one step. An implanted dose of 0.16 μC B^+ gave $V_{Tn}=1V$ and $V_{Tp}=-1V$ threshold voltages that are suitable for CMOS integrated circuits with 5V power voltage. We measured 30 Ohm resistivity for the polysilicon layer and 40 Ohm for the n^+ and 60 Ohm for the p^+ diffusion areas.

The effective channel length calculated from the transconductance characteristics of the MOSFETs were found to be 2.4μm shorter than the nominal values on the mask. The main reasons for this significant decrease are:

a) narrowing of the poly stripe during etching,

b) spread of the source and drain areas below the gate oxide.

Table 3

Process step	Thickness (nm)	Energy (kV)	Dose (μC)	Junction depth (μm)
1. Initial oxide	120			
2. P^+ implant. (n well)		60	0.5	3.5
3. N well drive in				
4. Si_3N_4 deposition	100			
5. B^+ implant. (field thresh. voltage)		60	2	
6. Field oxide growth	1200			
7. B^+ implant. (thr. voltage)		60	0.16	
8. Gate oxide growth	60			
9. n^+ poly Si deposition	500			
10. P^+ implant		40	480	0.5
11. B^+ implant		40	480	0.5
12. Source-Drain drive in				
13. CVD SiO_2 deposition	800			
14. Gettering				
15. Contact window				
16. Al(Si) metallization	1200			

Smaller changes can be achieved using anisotropic etch (like reactive ion etch, RIE) instead of isotropic wet chemical etch, and preparing shallower source and drain junctions. We do not have the necessary equipment for anisotropic etching, but we are able to decrease the junction depth by 0.2μm.

According to Table 2 the channel length of the MOS transistors prepared with HCMOS technologies is 3μm or below. MOS transistors with channel length L<3μm are called short channel transistors. With these devices we have to take into account many effects that are neglected in the conventional technology because of being non-essential, but now they became important, because the operation of the devices is greatly af-

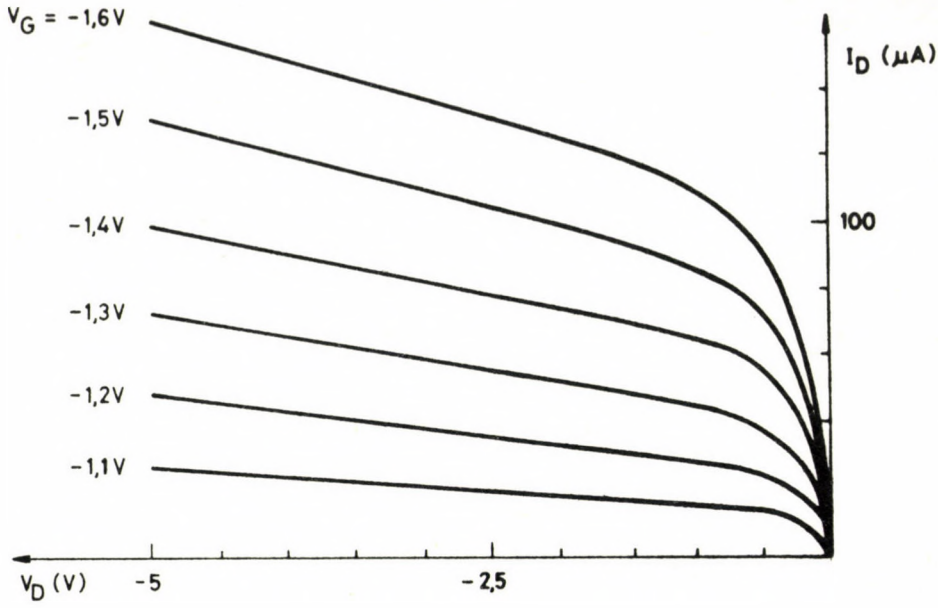

Fig. 6

I_D-V_D curves of small size p-channel MOS transistor (L_{eff} = 1.6 μm)

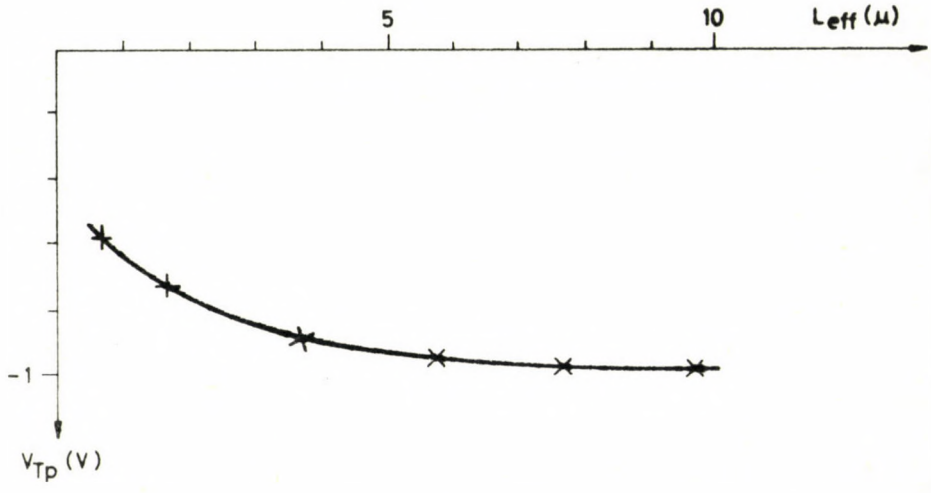

Fig. 7

V_{Tp} as a function of the channel length

fected by them. This is why the investigation of the short channel phenomenon is inevitable for developing HCMOS technology. We have carried out this kind of investigation on our test circuits too. As a result of channel length shortening the depleted regions of the source and drain of the transistors with L=3μm reach each other; this leads to a current between the source and drain even if there is no voltage on the gate. This effect is known as punch through in the literature.

p channel transistors with 4μm nominal channel length (L_{eff}=1.6μm) have strong channel length modulation, i.e. I_D-V_D curves do not have a saturation region as long as channel ones do (see *Fig. 6*).

The threshold voltage as a function of the effective channel length can be seen in *Fig. 7*. A strong change is found in particular when L_{eff}<3μm. This is caused by the spread of the depleted regions of the source and drain into the channel region, and charge of the gate electrode is partially compensated by the ions of the depletion region, this leads to a decrease of threshold voltage.

The results of these experiments have enabled us to develop a more advanced CMOS technology characterized by a 4μm channel length.

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INSTITUTE FOR ATOMIC ENERGY RESEARCH (AEKI)

REACTOR PHYSICS AND NOISE DIAGNOSTICS

Measurements on the ZR-6 critical assembly started in 1973 and are due to be continued up to the end of 1990. In 1985 the following measurements were carried out:

1. Noise diagnostics measurements

A. Investigations of the influence of water boiling on neutron fluctuation.
B. Study of the influence of vibration on the fluctuation of neutron flux.

2. Experimental determination of reactivity coefficients

The temperature coefficient of the reactivity has been measured in a lattice with the lattice pitch of 15.0 mm, 3.6% fuel enrichment, in the temperature range between 20 and 100 ^{o}C.

The summarizing report on the measurements performed up till 1980 was published as the first volume of the Final Report of the Temporary International Collective (TIC).

By the end of 1985 the period of serial investigations had been completed. The results will be published in the third volume of the Final Report of the Temporary International Collective, which can only be prepared after finishing a systematic and critical evaluation of the experimental data. With this work we shall have a suitable tool for testing the reactor physics codes elaborated for calculating WWER type reactors.

In 1986 a new period of investigations was commenced. In this period, problem oriented experiments are planned with the aim of clarifying special problems of WWER type (and to some extent other) reactors. In 1986 the following experiments were carried out:

1. Noise diagnostics measurements

In these experiments the effective range of sensitivity has been investigated for neutron detectors. The experiments have been carried out in configurations containing multi-core assemblies. The water gaps between the sub-cores have been varied.

2. Investigation of the influence of water-steel mixture as a radial reflector

Criticality parameters and energy-release distributions have been measured in configurations, where the radial reflector size and composition have been varied. The investigations will be continued in 1987, the neutron spectrum at the core - reflector boundary will be examined too.

The activities in the field of homogenization and the coarse-mesh method of the former years were continued. On the one hand new approaches to global calculations are sought. Theoretical investigations concerning the new calculational model proposed earlier are still in progress. Connections with other methods are discussed in several papers. A new formulation of the response matrix method was proposed. On the other hand a more efficient application of the traditional finite-difference method was also investigated. Recently the assembly homogenization has gained increasing attention. The homogenization is based on the solution of the diffusion equation in an assembly. The approximations of that calculation and ways of improving the accuracy have been developed.

The accuracy of parametrized few-group constants depending on burn-up, boron-concentration and temperatures has been investigated. It turned out that the usually used parameters are not able to describe the dependence with a satisfactory accuracy. A new parameter - the concentration of the isotope ^{239}Pu - had to be introduced.

The calculation of the power distribution inside the fuel assembly is important because of the maximum permitted power level of a power reactor. In the usually used codes many approximations are applied during the calculation. The influences of these assumptions were investigated in the case of the WWR-440 type reactor. This work led to the development of the new computer code MIKRO2.

The production of the isotopes ^{32}P, ^{99}Tc, ^{131}I, ^{125}I was studied in special irradiation channels. The multigroup cross-section library used for reactor physics calculations was completed by the constants of 18 new isotopes. The few-group constants of the irradiation channels and microscopic few-group constants were calculated by the spectral codes

GRACE and THERMOS. Calculation of the isotope production was performed by the diffusion code SNAP at the beginning and at the end of an equilibrium cycle with different arrangements of the irradiation channels. The arrangements of the irradiation channels had to satisfy many conditions relating to safety and economy. The work was performed in the framework of a research project coordinated by the International Atomic Energy Agency.

The economic significance of experimentally determining burn-up in the fuel assemblies of power reactors is by no means negligible. The work carried out in the years 1985 and 1986 gives a methodological base for such investigations. The aim of the experimental investigations was to examine the distribution of different isotopes in both types of WWR-SM fuel assemblies and to determine absolute burn-up values as well. Altogether five different fuel assemblies have been investigated. The results indicate that the axial and azimuthal profiles of fuel burn-up can be determined with an acceptable accuracy by means of the applied gamma spectrometric method. The absolute burn-up determination based on both measurements and fuel depletion calculations seems to be a straightforward and convenient method.

The work described here has been carried out in the framework of a research agreement between the IAEA and the KFKI (Examination and Documentation Methodology for Water Reactor Fuel (ED-WARF)).

Based on several years of experience with the measurement of low level fluctuating signals, a commercial noise measuring system has been developed. The system contains various preamplifiers and main amplifiers, power supplies, etc., and control electronics to facilitate off-line and on-line measurements and connection to micro-computer systems. Earlier versions of the noise measuring system have long been in operation at Units 1 and 2 of the Paks Nuclear Power Plant, the latest version is being installed at Units 3 and 4. Reactor noise analysis equipment is becoming part of the standard instrumentation of nuclear power reactors.

Noise measurements have been performed regularly at the operating units of the Paks Nuclear Power Plant. In the measurements in-core neutron detector signals, ionization chamber signals, temperature and pressure signals have been recorded and analysed. Analysis included methods with fast Fourier transform and auto-regression techniques.

A new method was introduced for determining reactivity coefficients by noise measurements. Perturbations traveling with the coolant were analysed using axially and horizontally placed detector pairs and a reliable indication of subcooled boiling was found. A sensitive diagnostic method for identifying thermal-hydraulic conditions inside the reactor is being developed. Out-of-core ionization chamber signals were evaluated and in-

terpreted for core barrel movement amplitude and direction. Analysis of in-core neutron signals revealed an occurrence of excessive control rod vibration, giving full evidence of the method's early warning capabilities. The existence of the vibration was later confirmed by independent means. For malfunction identification, a pattern recognition method is being used. With a view to its future integration into a new generation of reactor control systems, the development of a noise analysis expert system has been started.

The existence of a core-surveillance system is not yet general at most of the commercial PWR type nuclear power plants. However, it is regarded to be more and more important both for safety and economic reasons.

An on-line core-surveillance system, which is usually an add-on feature to the standard process-computer system, continuously provides information for the reactor operating staff about the detailed internal state of the reactor core. In other words, the task of the system is to monitor the three-dimensional distribution of the power within the core. Since the available measured information covers only partially the volume under examination, and the theoretical modellings are always based on several idealizations, the only possible way of solving the problem is to combine the measured and the theoretical information.

The VERONA core-surveillance system is one possible realization of this task. The basic parameters of the system are the following.

	Full-scale version	Extended version
No. of analog inputs	600	1000
No. of status inputs	100	200
No. of handled parameters	5000	7000
In-core measurement cycle	16s	16s
Fastest evaluation cycle	16s	2s
Two-dimensional reconstruction	16s	16s
Three-dimensional reconstruction	10min	2min
Finest trend resolution	-	2s
Longest trend expansion	-	burn-up cycle
Time span of integrations	reactor lifetime	reactor lifetime
No. of colour CRT units	2	2
No. of CRT pictures	12	32
No. of log forms	16	20
No. of real-time programs	45	55
No. of utility programs	20	30
Interactive operator support	no	yes
Applied CPU type	TPA 11/48	TPA 11/440
Disk capacity	10Mb	90Mb

The development of the system started at the end of 1982 and is still continuing. The installation of the system has been performed in three steps:

- a pilot version of the system was installed in Unit 1 in 1984;
- the full scale version installed in Unit 1 and Unit 2 in 1985, and in Unit 3 in 1986;
- an extended version, VERONA-plus is to be installed in Unit 3 in early 1987.

THERMOHYDRAULICS

Activities in this field have concentrated on reactor safety aspects of WWER-440 and WWER-1000 reactors that comprised both analytical and experimental investigations. Questions concerning the reliable operation of the Paks NPP also required considerable research efforts.

The integral-type test facility for WWER-440 reactors, the PMK-NVH loop, went into operation and, after a series of scoping tests, a small-break and a loss-of-flow test were performed. The former was a 7.4% cold-leg break experiment without accumulator injection and with only one high-pressure safety injection pump working. This test served as a basis for the first Standard Problem Exercise organized by the IAEA, with the participation of 17 institutions from 10 countries.

A new method has been developed for estimating the safety of WWER-440 type reactors. This renders possible the determination of the power reserves in the system, thus the net output could be increased. As a result of cooperation between Austria and Hungary, a two phase flow parameter measuring system has been developed. This system can be utilized for experimentally investigating reactor accidents.

A computer program module has been completed for calculating the safety margin and the hot channel in the VERONA program, which is used for the control of the Paks NPP.

The joint project with the Kurchatov Institute and Gidropress for the critical heat flux studies has been completed. Two different reactor core constructions were experimentally tested. In the first case the cassette walls were perforated, in the second there were no walls at all. Twelve test sections were used in the experiments, and both versions were found to yield a better performance than that of the closed wall version.

COMPUTERIZED REACTOR CONTROL

The activities of the Department for Computerized Reactor Control are divided into two main areas:

- reactor core monitoring,
- nuclear power plant simulation.

Relating to the first area, in 1985 the VERONA core monitoring systems were finished. These systems operate in Paks NPP in two blocks (Units 1 and 2). Each system calculates the 3D power distribution in the core and presents core maps on colour graphic displays in the block control room. Very many parameters are calculated from the power distribution, e.g. the location and the peaking factor of the most loaded fuel assemblies, the temperature rise in each fuel assembly. The development of the VERONA system was carried out in close cooperation with KFKI's Reactor Physics Department.

As a logical continuation of the VERONA systems, the so called "high level" block computer for Unit 3 of Paks NPP is under development. This TPA-11/440 based system provides core monitoring, core state prediction and technical/economical calculations. The core monitoring functions are the same as those of the VERONA system. Core state prediction provides a tool by which the block supervisor can determine the optimal rod position and boron acid concentration for a planned power change manoeuvre of the reactor. The technical/economical calculations mean different safety display functions (safety hexagonals, P-T state diagram, etc.) and trend analysis, moreover detailed analysis of the power balance of the whole block. By the end of 1986 the core monitoring part of the "high level" block computer to be used in Unit 3 will be finished, while the whole block computer is planned to be ready next spring (1987).

In the field of nuclear power plant simulation there are two projects in which the department is involved:

- the development of the full-scale simulator of the Paks NPP,
- the development of a basic principle simulator for WWER-440 power plants.

The detailed technical design of the full-scale simulator has been completed and at present the model development is in progress. For the basic principle simulator the dynamic modelling of the main technological units in the secondary circuit has been finished. The technical design of the control desk of the simulator is finished and its implementation is being carried out.

Fig. 1

The American astronaut, S.K. Ride carries out dose measurement with the PILLE TLD system on board the Challenger Space Shuttle during her flight. On this real space photo the PILLE TLD reader can be seen under conditions of weightlessness

Calculations and calibration measurements were carried out to evaluate the dose burden on board the Space Shuttle. Dose measurements were carried out by Sally K. Ride *(Figure 1)* on board the Challenger Space Shuttle during its flight in October 1984, with the Hungarian "PILLE" TLD system, based on $CaSO_4$:Dy bulb TL dosemeters and a portable, self-operated TLD reader; at the same time and at the same locations the dose values due to cosmic radiation were monitored on the Space Shuttle with the NASA ^{7}LiF TL dosemeters, and were evaluated after its landing in NASA's laboratory. The results show fairly good agreement between these measurements, as even the largest deviation between the results of the PILLE measurements and the NASA TLD measurements was less than 4%.

In the framework of the Intercosmos space programme, a new experiment was carried out in which the dose distribution in $CaSO_4$:Dy-Teflon rods, due to unshielded cosmic radiation, was investigated. The $CaSO_4$:Dy-Teflon rods exposed to unshielded cosmic radiation in space at an altitude of 300-400 km above the surface of the Earth, were recovered from the outer surface of an unmanned spacecraft, and were evaluated in our TLD laboratory utilizing a new measuring method: the $CaSO_4$:Dy-Teflon rods were sliced into ultrathin $CaSO_4$:Dy-Teflon discs (about 5-10 $mg \cdot cm^{-2}$) by a microtome. These ultrathin TLD discs were measured on our microcomputerized laboratory TLD system to establish the absorbed dose values at the different depth layers of the $CaSO_4$:Dy-Teflon rods. The results of these measurements showed that a large part of the cosmic radiation belongs to the soft cosmic radiation (having low energy) as the measured dose decreased to a large extent in the first few millimeters *(Figure 2)*.

To improve the energy response of bulb dosemeters, a version has been developed, based on LiF chips. The dosimetric properties of these new LiF bulb dosemeters are being studied.

The development of a semi-automatic TLD reader for routine monitoring purposes is in progress, this reader is to be connected to a microcomputer: the identification codes of persons as well as the code numbers of dosemeters and the measured dose values are to be written on magnetic discs during the on-line TLD measurements.

The development of a personal neutron dosemeter based on nuclear track detectors has been completed and tests for its reliability were performed at the Paks Nuclear Power Plant as well as by the oil industry, where the neutron dose is required to be monitored for workers dealing with neutron carotage investigations.

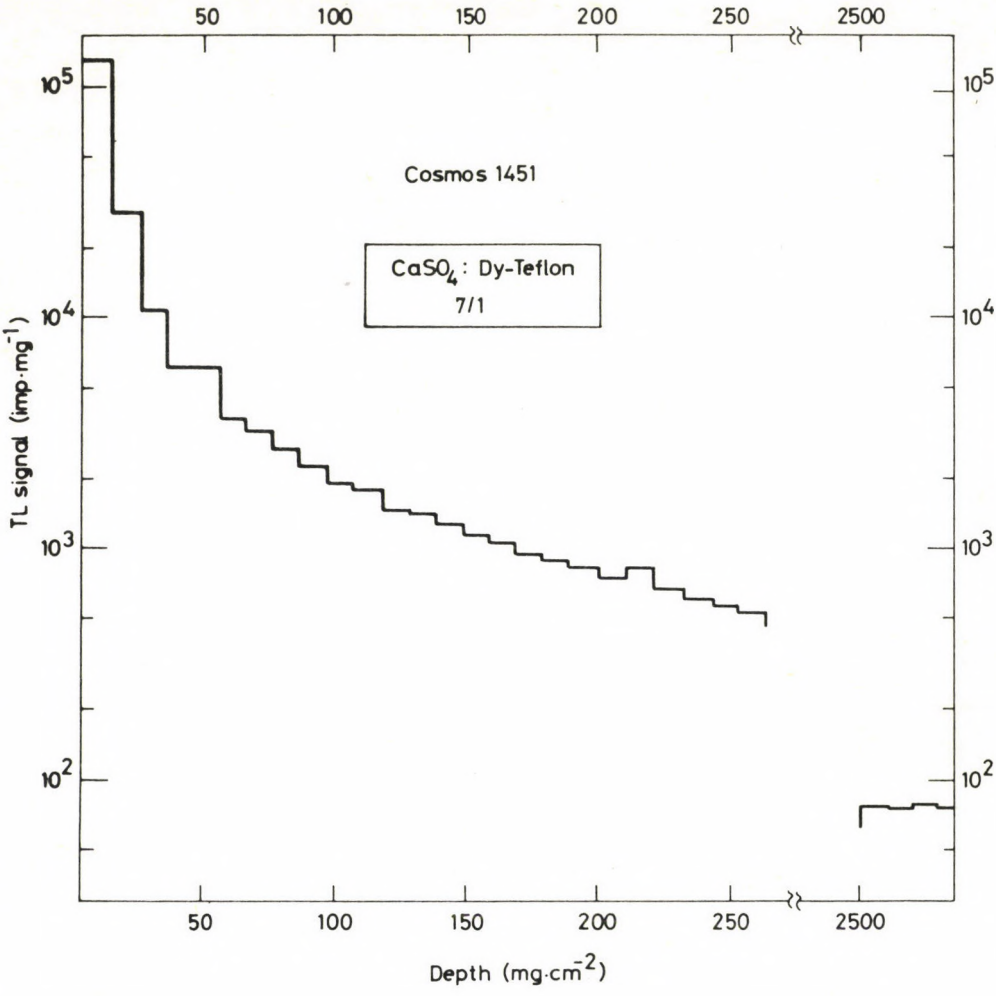

Fig. 2

Dose distribution in a $CaSO_4$:Dy-Teflon rod from the unshielded cosmic radiation

A medium-term project has been set up for developing a complete hardware and a software system suitable for organ dose determination by quantitative activity distribution measurement. Two methods were tested by means of which organ activities can be obtained after rectilinear scanning measurements. One of the methods is based upon the superposition of organ specific count rate distributions by least squares fitting; this proved to be very sensitive to the geometric differences in shape, size

and location of the organs between human and calibration measurements. The more advantageous method was when the count rates were simply integrated in a preselectable region of the count rate matrix. However, the use of the latter method is also limited (e.g. in the case of overlapping organs). With proper selection of the collimator, and the measuring and evaluating methods, the organ activity can be determined within ± 5% uncertainty.

A sophisticated calibration procedure has been carried out for the calibration of the phoswich detector of the whole body counter to determine ^{239}Pu and ^{241}Am deposited in the lung. The chest phantom used was developed at the Lawrence Livermore National Laboratory and was provided by the IAEA in the framework of an international coordinated research programme.

The deposition of aerosol particles in tubes was calculated and measured. Particle deposition is determined in the lung by gravitational settling, impaction and Brownian diffusion. An analytical solution to these fundamental processes has been derived. A program was written for calculating the deposition for mono and polydisperse aerosols in tubes. Measurements were carried out to examine the deposition of aerosols in horizontal and inclined, straight and curved, glass and silicon-rubber tubes. The particles were polystyrene spheres labelled with ^{99m}Tc.

A stochastic lung model and a computer code based on it has also been developed. The random walk, deposition and exhalation of particles inhaled into the human respiratory tract are computed by the code. In the first calculations the parameter sensitivities were studied. The calculated distribution pattern was compared with distributions measured by a gamma camera, and good agreement was found. The code is to be further developed, mainly in the modelling of the acinus regions terminating the bronchial tree.

Significant improvements have been carried out on the environmental monitoring and data acquisition system of the Paks Nuclear Power Plant in order to increase the number of measuring channels, to convert the measured counts into physical values, to improve peripheral units and to display simultaneously all measured parameters. All the measured data are printed out, displayed, and stored on magnetic discs by the microprocessor based CAMAC data acquisition system.

Calibration measurements were carried out on the on-line environmental GM counters and iodine monitors of the Paks Nuclear Power Plant (NPP), and statistical evaluations have been performed on the data measured by the on-line environmental GM counters and iodine monitors of the Paks NPP.

A portable semiconductor spectrometer (Canberra) was purchased for in situ, nuclide selective determination of environmental gamma dose rate and ground contamination. Calibration of the high purity Ge detector was carried out to obtain the energy and direction dependence of the sensitivity. A computer code was also developed for data transfer to the laboratory computer for automatic evaluation of environmental spectra. Test measurements were carried out in the vicinity of the Paks Nuclear Power Station and at Dukovany (Czechoslovakia) in the framework of an international intercomparison measurement. The results showed that in most cases good agreement can be expected between in situ and sample measurements. The minimum measurable dose rate was in the range of 0.03-0.05 $nGy \cdot h^{-1}$.

A more extensive environmental monitoring programme was carried out for assessing the radiation consequences of the Chernobyl accident. Starting from 29 April 1986 the following quantitites were systematically investigated:

- radionuclide concentrations in air
- fall out rate
- ground surface contamination
- dose rate.

In *Fig. 3* the variation of the excess gamma dose rate is shown against the time measured by a calibrated continuously operating GM monitor at

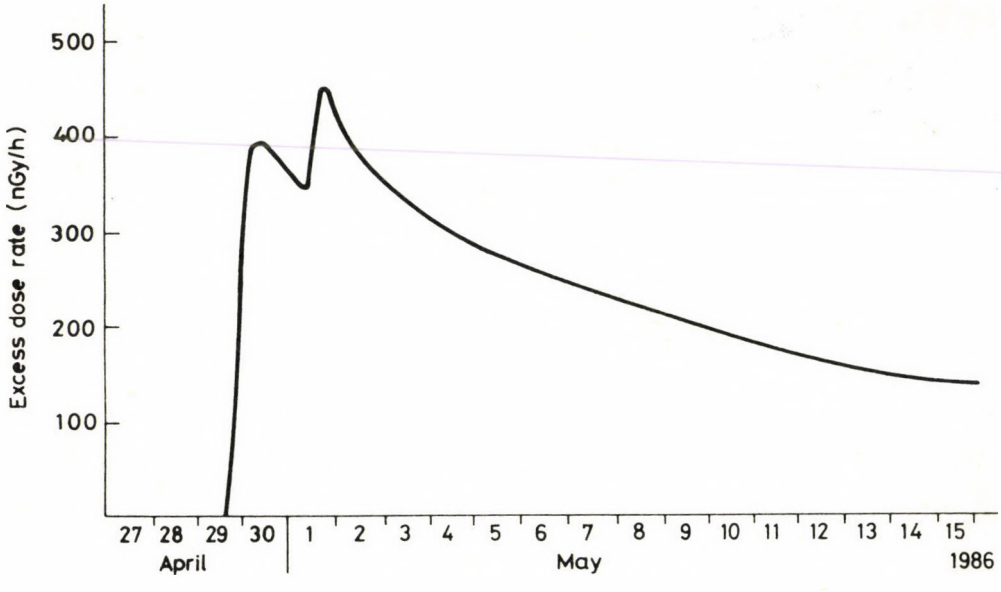

Fig. 3

Increase of the gamma dose rate in Budapest

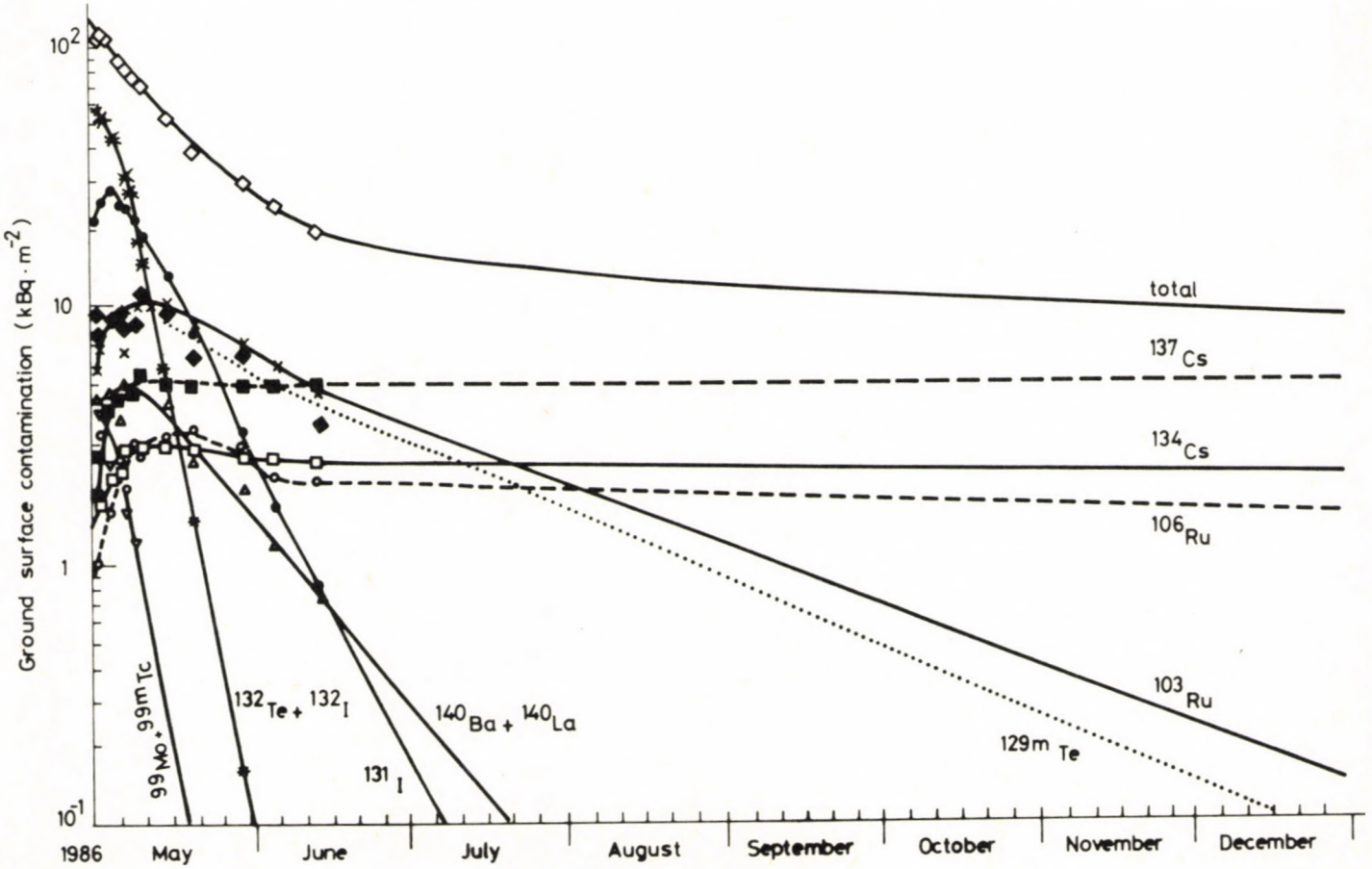

Fig. 4

Ground surface contamination of several radioisotopes measured by in situ gamma-spectrometry in Budapest and the values extrapolated to 31 December 1986

the site of the institute. The measured and predicted ground surface contamination of different radionuclides can be seen in *Fig. 4;* these were determined by in situ semiconductor gamma spectrometry in Budapest. *Figure 5* shows the distribution of the total ground surface contamination all over the country. The free-in-air doses were calculated from the measured ground surface contaminations. By the use of the free-in-air dose to effective dose equivalent commitment conversion factor given in the recent UNSCEAR report, the external effective dose equivalent commitment may vary from 70 to 720 μSv in different regions of Hungary.

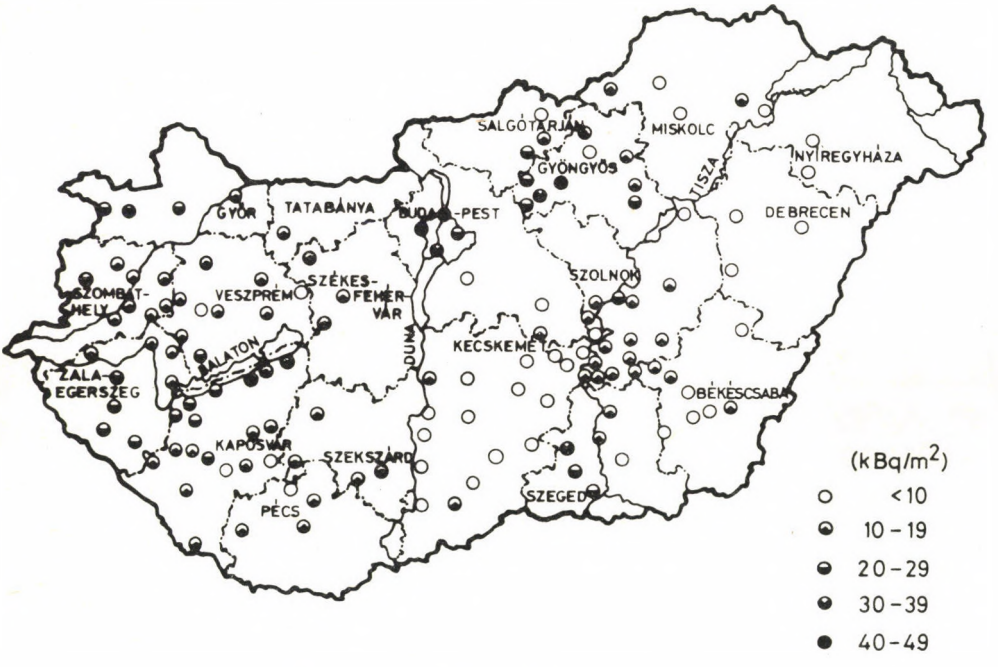

Fig. 5

Ground surface contamination - corrected for 15 May 1986 - measured at different locations in Hungary

Measurements were carried out by the whole body counter of the institute. The persons monitored represented a broad range of ages both for men and women. In the early period children from 4 to 16 years were also involved in the measurements. Activities of ^{131}I in the thyroid, ^{103}Ru in the lungs, ^{134}Cs and ^{137}Cs in the whole body were investigated. *Figure 6* shows the weekly averages of the thyroid ^{131}I activities found in children and in adults until the end of June. The whole body ^{134}Cs and ^{137}Cs activities in adults as a function of time can be seen in *Fig.7.*

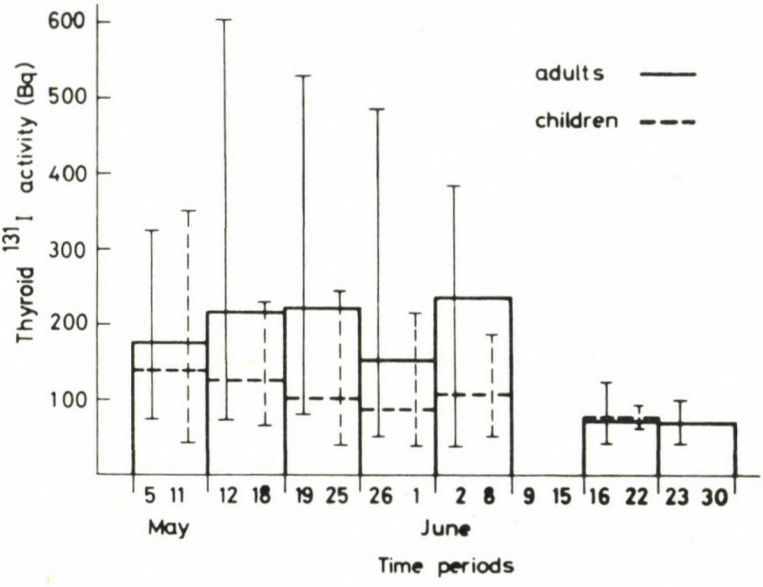

Fig. 6

Mean and range of thyroid ^{131}I activity during different time periods

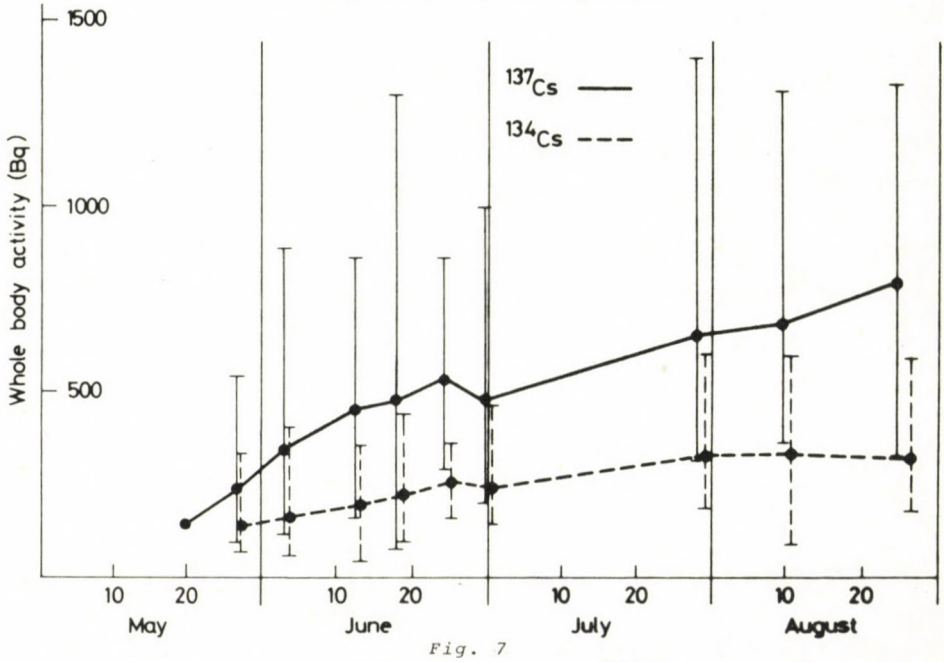

Fig. 7

Mean and range of whole body ^{134}Cs and ^{137}Cs activities during different time periods

The total internal dose could be estimated by direct activity measurements and calculations based on environmental data with conservative assumptions and it was found to be about 400 μSv committed effective dose equivalent.

CHEMISTRY

The study of charge transfer processes at solid/aqueous solution interfaces has been extended to some basic questions of electrode kinetics while semiconductor photoelectrochemisty has been pursued further and applied work on high stability corrosion layers has been performed.

The impedance spectroscopy of fractal metal surfaces was treated both theoretically and experimentally, establishing a relationship between the phase angle of the complex impedance, $\alpha \cdot \pi/2$, and the fractal dimension of the surface, D_f, as

$$\alpha = 1/(D_f - 1).$$

The method was generalized to provide a description of diffusion controlled processes.

The existence of a cathodic photoeffect on hydrogenated Na-tungsten bronzes, $H_yNa_xWO_3$, has been established. By kinetic arguments it has been shown that atomic H is produced during illumination.

The composition, crystalline structure, electrochemical stability and adsorptivity of stainless steel oxide layers were measured by Auger and Mössbauer spectroscopy, electrochemical and radiochemical methods in relation to the safety of nuclear power plants.

The influence of the chemical reactivity and long range order of the medium on the reactions of recoil ^{38}Cl atoms has been investigated in dichloroethanes and their mixtures with ethyl alcohol and hexafluorobenzene in liquid, crystalline and glassy phases. The extent of hot Cl and H replacement as well as of the excitation decomposition of newly formed products has been determined. A rare phenomenon of 1,2-hydrogen shift has been established for 1,1-dichloroethane in crystalline and for 1,2-dichloroethane in crystalline as well as in liquid phases. Addition reactions of HOAt with ethylene have been studied in cooperation with the JINR, Dubna.

In order to study the nature of hydrophobic hydration and interaction the thermodynamic excess properties of various aqueous solutions were determined as a function of temperature and concentration. The

systems included urea, 1,3-dimethyl urea, tetramethyl urea, tetrabutylammonium bromide, tetrabutylammonium butyrate and sodium lauryl sulphate in normal and heavy water. In cooperation with the Max Planck Institut für Chemie (Mainz, FRG) the theoretical interpretation of vapour pressure isotope effects of aqueous electrolyte solutions has been started by using the results of molecular dynamics simulation studies.

Positron lifetime spectra arising from micellar solutions have been interpreted in terms of a microscopic diffusion model. Micellar aggregation number and o-Ps diffusion coefficient in the solvent vs. temperature were determined; aggregation numbers show a qualitative agreement with those obtained from small angle neutron scattering experiments carried out in JINR, Dubna. The results of nuclear methods are complemented with high precision density- and equilibrium vapour pressure measurements.

Various ferrocene derivatives were studied by cyclic voltammetry and ^{13}C NMR techniques. Good correlations of the oxidation potential values with the Hammett constants as well as with the ^{13}C chemical shifts for carbon atoms of these molecules were found. The change of electron density distribution at the carbon atoms of cyclopentadienyl rings as well as of vinylene groups was given numerically as a function of the electron- donating or electron-withdrawing strengths of the substituents. Mössbauer parameters, oxidation potential values and ^{13}C chemical shifts were measured in mono- and di-ketone derivatives of [3]-,[4]-,[5]- ferrocenophanes. The effects of the changes in molecular geometry on the electron-withdrawal of the carbonyl group were clearly demonstrated by these measurements.

Laser ionization is a new and fast developing method for generating ions in mass spectrometry. Our purpose was to construct and investigate laser ionization ion sources and a time of flight mass spectrometer with an ion reflector for energy focusing. The first version of the instrument is working and provides the basis of plasma expansion experiments. Our plasma expansion studies cover hydrodynamical modelling too.

An AEI MS-702R spark source mass spectrometer with a photoplate detector is used for trace element analysis. The photoplates are evaluated by a Carl Zeiss Jena type G2 microdensitometer modified in our laboratory for fully automatic work.

In order to improve the reliability and accuracy of measurements two main lines of development have been followed. A laser plasma ionization method has been introduced by using a 3 mJ, 50 Hz YAG giant pulsed laser (manufactured by our Institute's Optical Department). The improved accuracy has been attained through the improved plasma reproducibility and more precise sample averaging. The second line has been to elaborate a more sophisticated computer program for evaluating concentrations from the optical density of isotope lines.

Numerous radioanalytical characterization techniques have been developed to qualify the primary cooling circuit of the first two units of Paks NPP. Thus RNAA, gamma-ray spectrometry particle sizing and microphotography were used to investigate the construction materials of the primary circuit, and the amount and composition of the mechanical contaminants. The investigations have been extended to studying the amount of corrosion radioactive isotopes and fission products which may occur both in solid particle form as well as in dissolved ion form.

High purity ground materials, electronic grade chemicals, and solvents used for producing microelectronic devices were checked for purity.

The neutron activation analytical method has been applied to determine the concentration of the trace elements Cu, Fe, Zn, Rb, Sc, Mn, Co, Mg, and V in medical and biological samples in connection with different diseases (Wilson's disease and schizophrenia).

For geochemical purposes an activation analytical method has been developed, too. A simple instrument has been constructed for simultaneous radiochemical separations.

Parallel measurements have been carried out to measure the nuclear constants k_o and Q_o and other related nuclear data in order to extend and improve the use of a new standardization method developed in cooperation with the activation analytical laboratories of the KFKI and the INW (Gent, Belgium). For some problematic (n,gamma) reactions, measurements have been also done at the DR-3 heavy water moderated reactor of Risø, Denmark. Calibration of the different reactor channels was accomplished using a new set of neutron flux monitors as well as by approximating the actual epithermal neutron fluxes by the $1/E^{1+\alpha}$ function. Results obtained for 112 nuclides of interest in reactor-neutron activation analysis have been compiled and published.

A neutron generator activation analysis method has been developed for the instrumental determination of oxygen, nitrogen, aluminium, silicon and iron in coal and in fly ash and clinker. The possibility of employing characteristic X-rays for analytical purposes in 14 MeV neutron activation has been investigated.

The X-ray fluorescence laboratory has two Si(Li) detectors with independent electronics and microcomputers. The exciters are annular radioactive sources. Main activities: theoretical examinations on particle size effects, elementary analysis in coal and fly ash, and geometrical optimization in special XRF applications.

The lifetime of PWR reactor vessels depends on the neutron irradiation embrittlement of the structural steel and its welding. A computer controlled instrumented impact testing system has been elaborated to

test irradiated steel and alumina specimens. This is a fundamental step towards participation in the IAEA coordinated material research programme CRP-3. We participated in the evaluation of the surveillance results of the 1st and 2nd unit of NPS Paks, too.

WWR-SM REACTOR

The WWR-SM type nuclear research reactor served as a wide range research device for solid-state physics, nuclear physics, activation analysis, material tests and biological research for 27 years and at the same time it ensured activation capacity for all the isotope requirements of our country (and for export purposes).

In time this reactor became obsolete not only in the technical sense, so its reconstruction became urgent. During the final years of service of the reactor - parallel with the usual operational activities - a total reconstruction plan was elaborated in cooperation with associated organizations and other institutions, and the reactor was shut down at 18^{00} hours on 25 April 1986.

This reactor had produced 13.1 GWday between 25 March 1959 and 25 April 1986, and had performed its operational time to 99.99% by its "Schedule", and its capability to meet the requirements was satisfactory.

From 2 May 1986 the dismantling of the reactor was started with a view to total reconstruction. The disassembling of the parts "hottest" from the point of view of radiology (the core, the primary cooling system, the small and big reactor vessels), and of the control and radiation protection system, and the heavy-current power system were performed by the staff of the Reactor Plant. The disassembling was completed within schedule and within this 6-month period (from May to October) none of the workers received the maximum permissible one-month radiation dose, and whole-body counting measurements showed there to have been no detectable incorporation at all.

The planned start-up of the reconstructed reactor is May 1988.

Parallel with the above work the installation of our correlation flowmeters was continued at the Nuclear Power Plant in Paks. In this period one flowmeter was set up in block III, and another flowmeter was produced for block IV. After the setup of the latter equipment correlation flowmeters will control the water circulation in the primary circuits of all four blocks of Paks Nuclear Power Plant.

In addition, a special two-channel noise generator was developed. The purpose of this generator is mainly for the attestation of the above-mentioned correlation flowmeters; moreover it could usefully be applied to other fields of stochastical gauges.

ACOUSTIC EMISSION TECHNIQUES

The acoustic emission technique as a modern, material testing method is becoming the method of choice in research and in industry. In previous years a mobile, computerized 32-channel acoustic emission laboratory was developed and manufactured for investigating large structures. With this laboratory numerous measurements were carried out in various fields of industry (power plants, petrochemical stations, etc.). Besides this laboratory a portable instrument was also developed and manufactured in small quantities. The instruments were distributed among potential users in the country to promote the more general usage of this technique.

A special multichannel acoustic emission instrument for leakage control is being developed which will be utilized at the PAKS Nuclear Power Plant.

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RESEARCH INSTITUTE FOR MEASUREMENT AND COMPUTING TECHNIQUES (MSZKI)

The Research Institute for Measurement and Computing Techniques has two main projects on its agenda. The first one is to provide new computer constructions and computational devices for the experimental and theoretical physicist in the research centre. This activity involves minicomputers and mega-mini computers being supplied to the measuring centres throughout the research centre and interfacing computers being installed around the mainframe computer.

Our second project can be called a small enterprise: in cooperation with a number of partners from outside the research centre we have established a small production line. Within a limited number of years we have earned a fairly good reputation as a computer supplier and as an application system-house too. This small scale production serves several useful aims. The experiences of our customers provide a stimulus for new developments. In this way the development-application feedback loop is closed to the benefit of the user and of the supplier. Last, but not least, this enterprise could add a decisive contribution to the financial stability of the whole research centre.

Our most remarkable results of the last two years are:

- new computer developments;
- computer control of a nuclear power station;
- participation in the VEGA experiment.

TPA-11/400 MINICOMPUTERS

The powerful TPA-11/400 series computers are fully upward compatible with the widely used PDP-11 systems, with the unified minicomputer system of the socialist countries and earlier TPA machines.

Although these machines are basically general purpose computers, they are particularly recommended in a multi-user environment for both office systems and scientific engineering applications. The advantages of the UBUS peripheral philosophy - used and well known in the TPA-11 family - are exploited in the TPA-11/400 models thereby enabling TPA-11 systems installed earlier to be used without restrictions.

The skeleton of the architecture of the TPA-11/400 family is based on a previously introduced Interconnecting System Bus - Xbus - which provides the TPA-11/400 machines with a higher I/O potential than that of other members of the TPA-11 family.

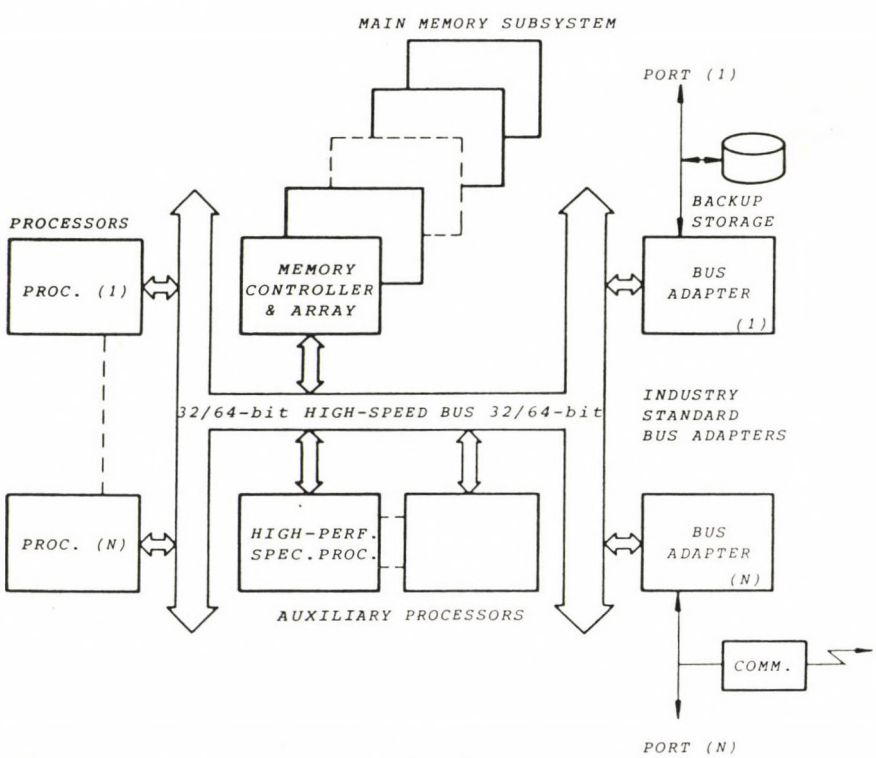


Fig. 1

System architecture philosophy of the TPA-11/400 family

The Xbus is a synchronous backplane bus. It has a highly encoded structure of functions, a unique priority scheme, an optional 64 bit read mode reserved for future use, and a four level vectored interrupt system. The maximum transfer rate is 16 Mbyte/sec. The priority arbitration system enables the units to occupy Xbus within a very low latency time of 62.5 ns on average. Occupying Xbus is an easy and short process that does not require any time consuming hand-shake protocol for selecting the next bus user. More than one I/O subsystem port can be configured at the same time. These adapters serve as outlets to industry standard buses where wide range of peripheral interface modules can be connected to the system. Details of the system concept are depicted in *Fig. 1.*

The maximum memory capacity for TPA-11/440 and TPA-11/420 computers is 4 Mbyte and it can be extended by .5 or 2 Mbyte per module. Reliability of the memory modules is enhanced by the built in error correcting code.

In view of the favourable features of the architecture and instruction set for the TPA-11/400 series, RSX-11M, RSX-11M PLUS, or UNIX operating system environments are recommended.

TPA-11/440

In this computer the central unit can be extended by a second UBUS adapter allowing the realization of powerful configurations. The second UBUS adapter has a co-called DMA cache function which upgrades the I/O potential - an attractive result of the Xbus. - The TPA-11/440 can be used especially advantageously for the FORTRAN-77 and COBOL programming languages because of its floating point processor and commercial instruction set. This commercial instruction set supports COBOL with special character string options and decimal arithmetic operations.

TPA-11/420

A VLSI processor lends an extremely good price/performance ratio to this computer. It has essentially the same instruction set as the TPA-11/440 - though without the commercial instructions. The 420 machine has a very compact construction with up-to date components so it easily covers a wide field of applications. For system enlargements a second UBUS adapter can easily be installed.

TPA-11/428

This is a special version of the TPA-11/420 machine which improves the processor and I/O performance of older, TPA-1140 and TPA-1148 models. It has the same processor, memory and I/O architecture as that of the 420 machine. Moreover, there is no need to change the UBUS peripherals and interfaces when the older central processing unit is replaced by the 428.

MEGAMINI COMPUTER TPA-11/540

This is the newest member of the TPA computer family. With its 32 bit instruction system it opens a new dimension to applications. In view of its full compatibility with a widely known, industrial standard computer family the program system background is firm and highly reliable.

The effective instruction set of the TPA-540 computer is realized by the central unit based on a bit slice microprocessor. The data format covers the range from one bit to 128 bit floating point numbers. The 32 bit virtual address range assigns a field of four gigabytes, enabling big, interdependent programs to be run. A built in floating point processor considerably improves the speed of data processing. The memory control logic ensures a highly effective virtual address handling. The physical address range is of 15 megabytes *(see Fig. 2)*.

The operator's console subsystem employs another microprocessor. This subsystem loads the diagnostic programs in and carries out the operator's instructions.

A 16 bit wide bus system UBUS - which has been used already in the TPA-11 family - serves for interconnecting peripheral units.

As regards software the TPA-11/540 is characterized by full compatibility with the VMS operational system.

CAMAC SYSTEM

We have a long and highly useful past in developing and applying CAMAC systems. This activity has been continued during the last two years. Some of the results are enlisted here:

- new modules have been realized (high accuracy D/A converter with 16 bit accuracy; contour searching device for TV pictures; LAN link module; real time peripheral module for the EURO-86 system etc.)

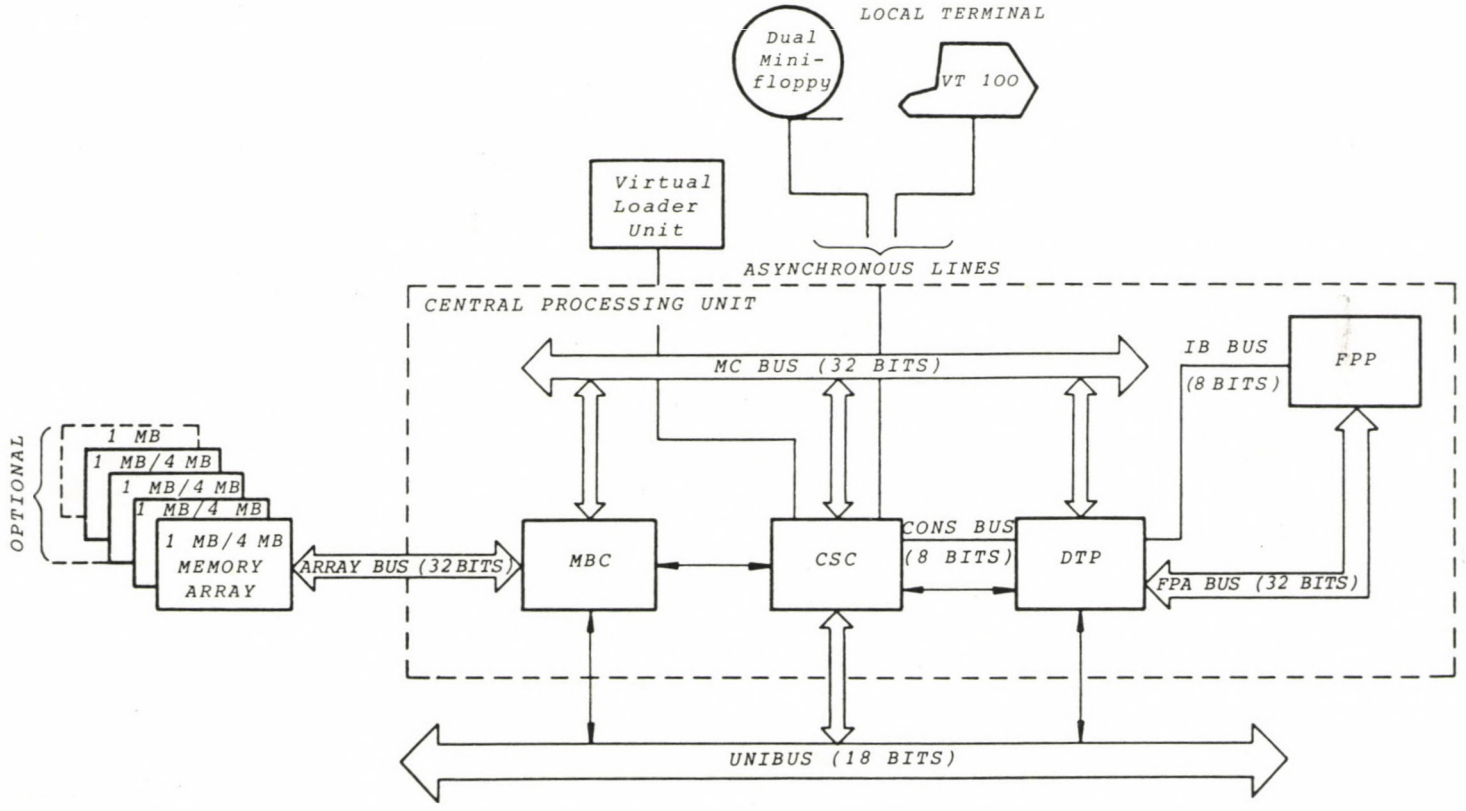


Fig. 2

Block schema of the TPA-11/540 computer

- new applications have begun (extension of a system to interrogate aeroplane black boxes; adding automatic pin control and slice device to our already existing gate array measuring device)
- new systems are under construction (subsystems for large scale TOKAMAK measurement control, intelligent data acquisition branches, LAN units of these branches, various means for the diagnostics and testing)
- new extension for our ICA-80 multichannel analyser has been developed (special biomedical and signal processing converters, e.g. one with pre-trigger averaging).

COMPUTER CONTROL OF THE NUCLEAR POWER STATION AT PAKS

The PAKS nuclear power station with its four blocks is a major contributor to Hungary's electrical energy generation. Blocks #3 and #4, each of 400 MW, are due to run under a highly sophisticated computer control.

The nucleus of the system consists of an on-line/stand-by computer configuration. The extremely critical task of controlling a nuclear power station calls for elements of utmost reliability. By virtue of the double computer stand-by system, dropouts of useful service time are practically absent. So unforeseeable hardware errors or regular system checks will not interfere with the normal running.

Figure 3 gives a general overview of the system. The problem which has to be solved was transformed to three levels:

- at the lowest level, data acquisition is performed. There are some 3000 analogue, and 4000 digital inputs and interrupts to be handled;
- the medium level takes care of the various processing tasks of the input signals and provides the means for complex display facilities. Measurement protocols and break-down registrations are prepared at this level too;
- the highest level computer basically makes reactor physical and background calculations. The results provided by this level are sent to the medium level, where computed data are compared with real signals.

At almost all points of the system devices with intelligence are employed. By "intelligence" we refer to the fact that these devices are more or less self-controlled computers with autonomous working possibilities. Such devices are the Intelligent Front-End Processors (Protocol

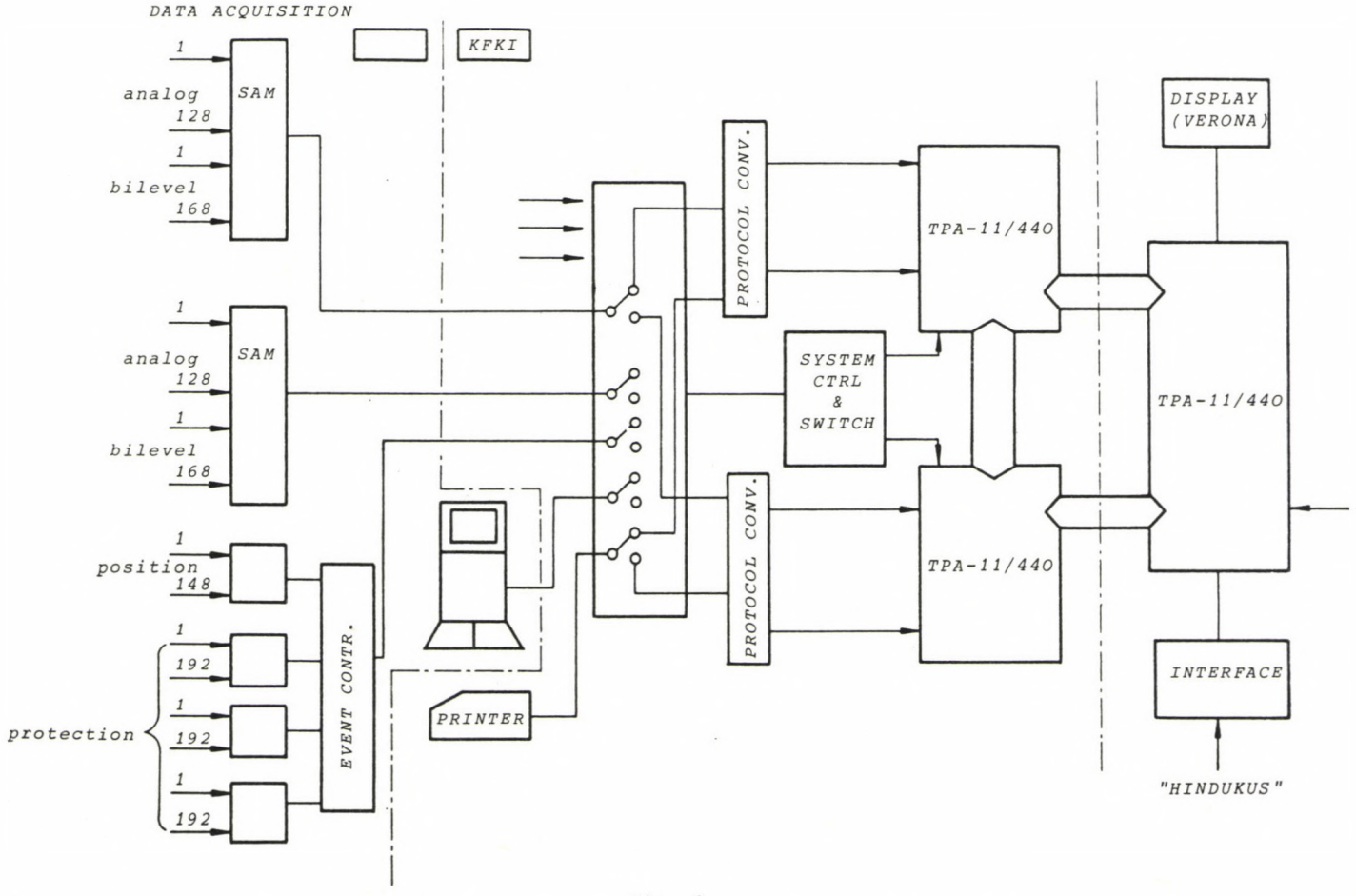


Fig. 3

General overview of the computer control for a nuclear reactor block

Converters), the Intelligent Switching System, the Intelligent Display Stations. These devices usually have operational memories, system peripherals, and specific programs of their own.

The on-line computer of the double system in normal working conditions behaves as an operational centre. All of the input/output lines are going into this computer and the technological connection is realized through the protocol converters.

The stand-by computer has identical construction and performance to its on-line counterpart. By changing the status of the switching relays the stand-by system will do the operational duties of the on line computer without restriction.

In *Fig. 4* the logical overview of the block control computer system can be found. The general system philosophy and data of the TPA 11/440 computers developed and manufactured by MSZKI have already been discussed.

A number of other organizations, in particular AEKI were involved in the planning and realization of the whole process control system.

IMAGE PROCESSING

Within the framework of an R & D contract with the Hiradástechnika Organization we have been taking part in the hardware/software development of an image processing display system.

The system is capable of real time (here it means video speed) manipulation and display of multispectral and multitemporal remotely sensed imagery. In an autonomous, stand-alone configuration all processing work is performed on a built-in microprocessor using the special hardware features of the system. Images are input in digital form via magnetic tape. In the near future it will be working also as a terminal of a high power special host system. For fast data I/O two 32 bit wide near video speed channels are available.

The image store consists of up to 16 memory modules, each containing two 512*512 pixel image planes. Even a 2K*4K pixel gray-image can be stored and any 512*512 window displayed. The so called pipeline processors (one for each primary colour) are capable of driving the RGB monitor channels with any combination of up to 16 input image channels and of varying the "colouring transformation" all in real time.

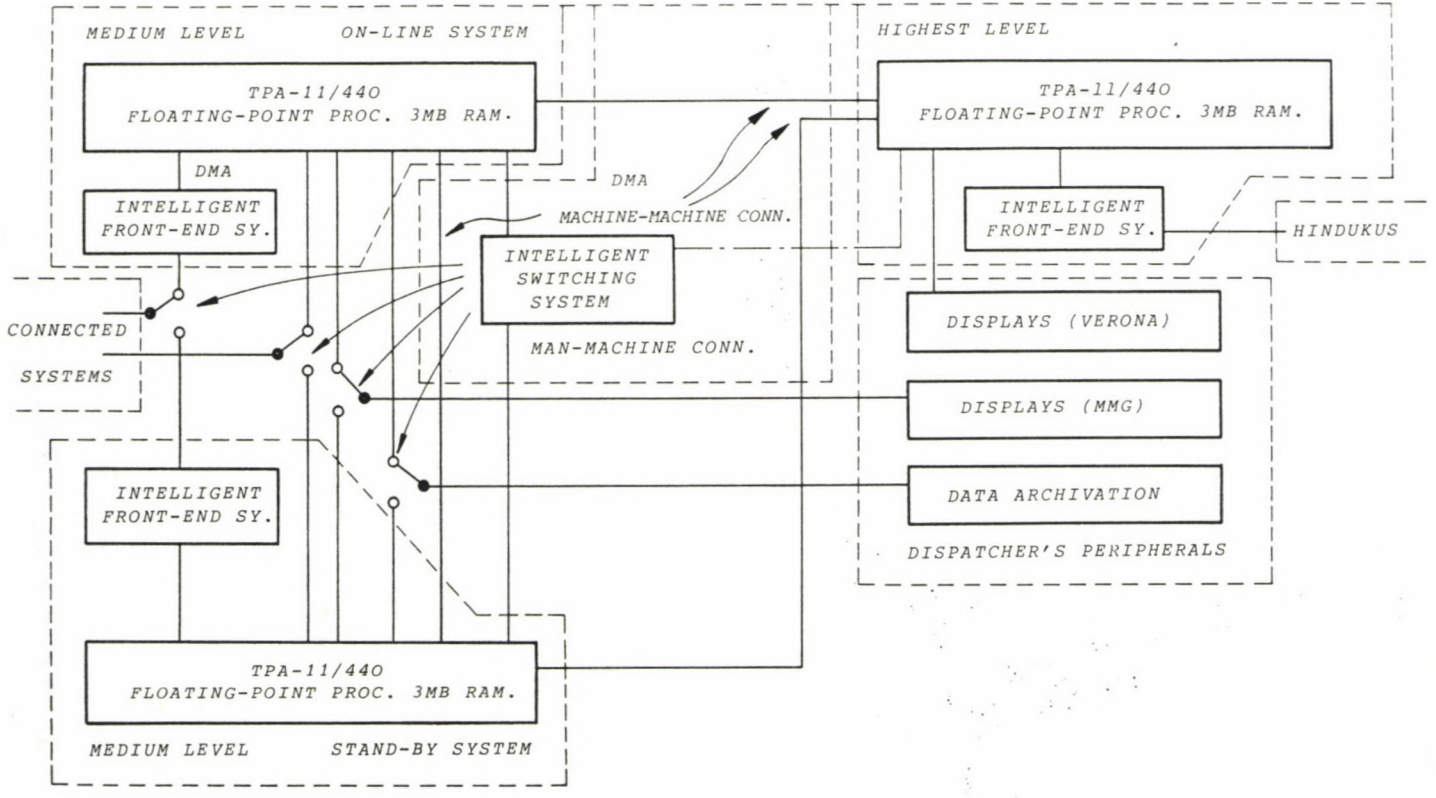


Fig. 4

Logical overview of the on-line/stand-by computer control

Other salient features of the hardware are:

- zooming by pixel replication
- scrolling in single pixel steps
- split screen display even with different zoom factors
- two programmable cursors
- track ball, joystick, light pen etc.
- merging coloured alphanumeric and graphic data
- real time image statistics (gray-level histogram, min/max values).

As can be seen in *Fig. 5* basically three main parts of the system can be distinguished:

- general purpose user microprogrammable controlling computer
- intelligent image memory subsystem
- pipeline processor and display subsystem.

The operating environment is UNIX-like, programs should be written in C language, and in certain time-critical cases microprogrammed segments have to be included. The operator - usually not a computer specialist - has two means of interaction at his disposal: either to use the menu or the options of the command system. If the command mode is selected, then job-stream sequences of complex commands may be given as immediate input or they may be stored for later execution.

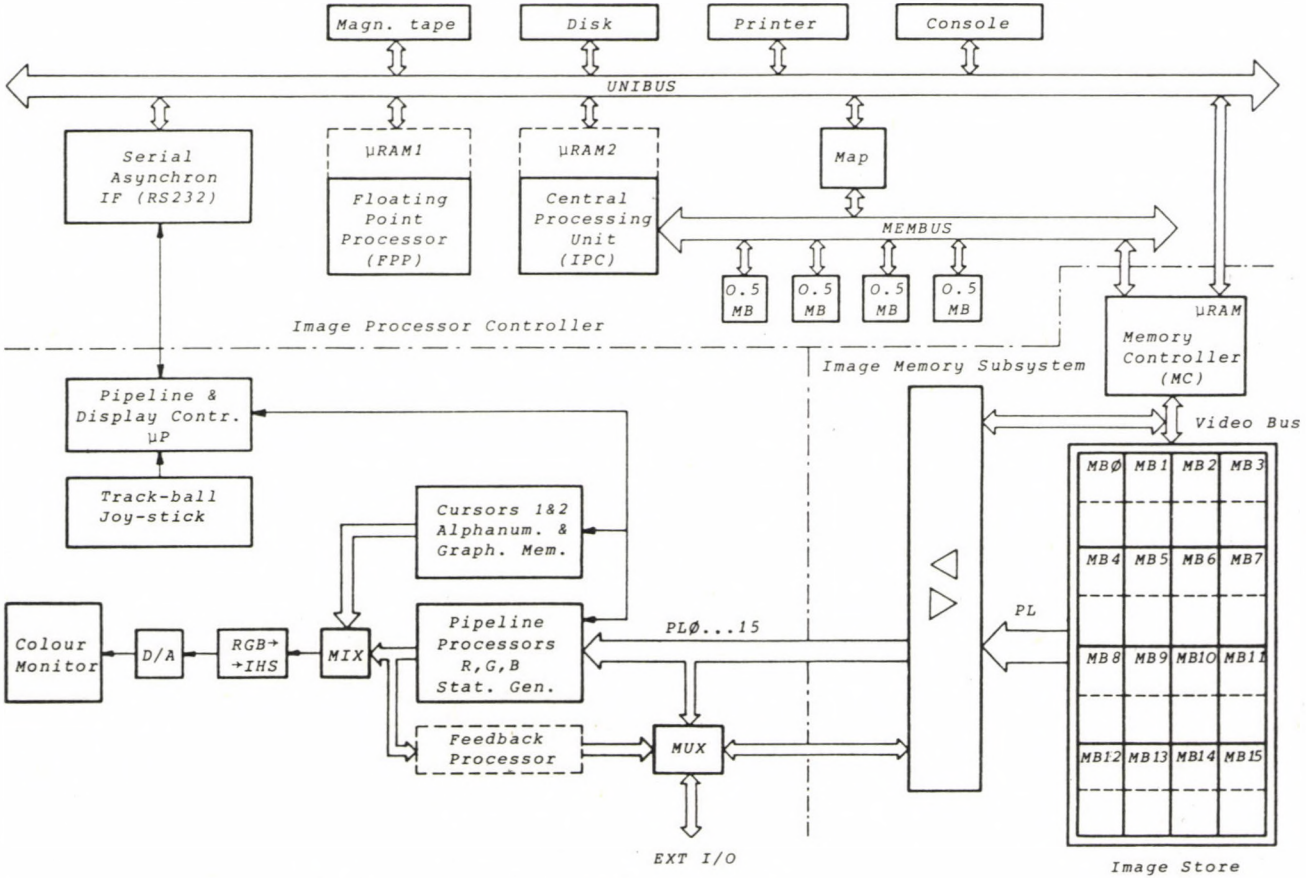
COMPUTER CONTROL OF THE CITY'S WATER SUPPLY

In the southern region of Budapest at Csepel some vital elements for sourceing and distributing of water are placed. There are wells, low and high pressure pipelines, storing pools, and other means for the control and improvement of water quality.

Naturally a complex system calls for sophisticated control. The allocation of production wells, the control of the pressure in the pipelines to match the consumption, the determination of the optimal level in the pools, the continuous checking of water quality and production cost are tasks which cannot be done properly without computerized process control.

The telemechanical part of the water supply is connected to a TPA-1140 computer configuration (UBUS extender, 3 disc units, displays and printers). The complete control is multilevel, hierarchically built up. Its main services are:

- data processing (about 1000 input signals with a measuring time of 10 sec)



Pipeline Processor and Display Subsystem

Fig. 5

Image Processing Display - stand-alone configuration

- protocol preparation (continuous and summary-type, hard copies from display screens)
- dispatcher's functions (technological pictures with measured and calculated values on colour displays, base values modifications)
- engineering functions (presentation of control algorithms, their modification, supervision)
- process control (check ups of the technological line, control of pumps and wells).

MEASUREMENTS ON A LOCAL AREA NETWORK

In our institute a unique local area network has been developed. The network, called LOCHNESS, was designed according to the layered structure of the ISO Open System Interconnection architecture, but we treated the recommendations as guidelines only. We deviated from the reference model in all cases when some gain was expected either in efficiency or in the simplicity of the implementation. Some layers are not implemented, others with strongly reduced functionality are incorporated into neighbouring ones. Our protocols are clearly different from the OSI protocols.

Our recent network measurements were aimed at getting information on data throughput between two connected hosts. In some respects these results could be more important than overall traffic characteristics. The experimental setup consisted of four TPA computers, connected by a coaxial cable running at 1 Mbit/s. During the experiment no other activity was taking place in the computers.

We have made numerous measurements on the network, e.g. compared the disk to disk transfer times within the same computer and between two different computers. In both cases the same file and disk utilities were used. Some representative results:

Measurement description	*Total time within the same computers*	*Total time between two different computers*	*Approx. data rates byte/s*
Copy of a complete cartridge disk (about 2.5 Mbytes)	*92 s*	*186 s*	*13200*
The same with special network utility (about 2.5 Mbytes)	-	*35 s*	*70200*

From the results of the measurements we conclude that between two computers a 1 Mbit/s coaxial cable can offer similar throughput rates as a 10 Mbit/s Ethernet cable, the CPU speeds and the software overheads being more decisive factors than the transmission speed. A 10 Mbit/s Ethernet cable can, however, support many more simultaneous connections than a slower cable. But whereas the Ethernet is designed for up to several hundred nodes, in a laboratory environment only 5-20 nodes are connected to the local area network.

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COMPUTING CENTRE (SzK)

COMPUTING SERVICES

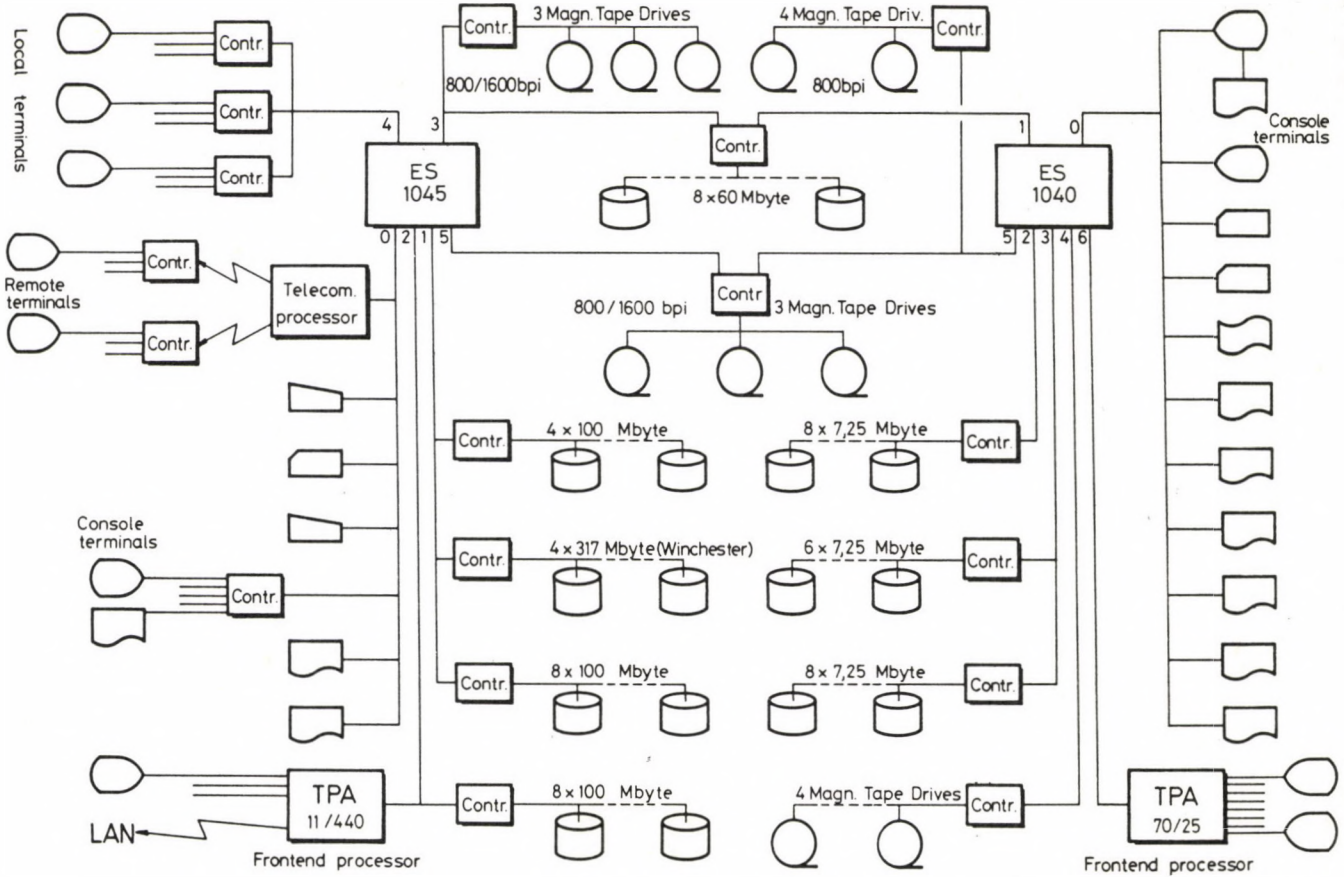
The Computing Centre runs the central computing facilities, maintains and develops their software systems, and also does scientific research in the field of numerical analysis and computing science. It also cooperates with the different institutes of the research centre in solving problems in computational physics and applied mathematics.

The ES 1040 computer installed in 1977 was running full time round the clock, but its computational power was insufficient. The average number of jobs processed per month in 1985 was about 6000, and reached 7000 in certain periods. About 75 per cent of the computer time was consumed in the field of atomic energy and nuclear physics. The complete utilization of the machine prevented the Computing Centre from providing services for other institutions. This situation, however, is likely to change in the future.

The main event within the period covered by the yearbook was the installation, in 1986, of a fully IBM 370-compatible ES 1045 mainframe with 4 MByte memory. The ES 1040 computer is still in operation and our two mainframe computers have shared disc and magnetic tape units. The main data of the configurations are as follows (see the figure):

ES 1045 configuration:

- 4 MByte memory;
- 2 byte multiplex channels;
- 4 block multiplex channels;
- 20 disc units (100 MByte);
- 6 magnetic tape units (800/1600 bpi)
  (3 units shared with the ES 1040);
- 2 line printers;
- TELE-JS telecommunications processor;
- 30 display terminals (20 local and 10 remote).



ES 1040 and ES 1045 configurations

ES 1040 configuration:

- 1 MByte memory;
- 1 multiplex channel;
- 5 selector channels;
- 16 disc units (29 MByte)
  (8 units shared with the ES 1045);
- 8 magnetic tape units (800 bpi);
- 4 line printers;
- TPA70 front-end processor;
- 18 display terminals.

The ES 1045 runs under the OS/VS1 operating system and the Gothenburg University Time-sharing System (GUTS).

The operating system of the ES 1040 computer is OS/MVT with HASP. Its teleprocessing system is driven by the Conversational Editor and Remote Users Support (CEDRUS) developed in our Institute.

Several programs and GUTS command procedures have been developed to support the transfer of programs and data files from the ES 1040 to the ES 1045. This is possible as the ES 1040 is upward compatible with the ES 1045 and files on the shared disc units are accessible both to CEDRUS and GUTS users.

The program library of both computers contains compilers for the languages FORTRAN, COBOL, PL/I, PASCAL (AAEC version). The program libraries of the ES 1040 such as the CERN library, IMSL library, EISPACK, Harwell and Rutherford have also been transferred to the ES 1045.

Under the GUTS system interactive compilation and execution of programs are possible. The following interactive compilers and interpreters are available:

- BASIC interpreter,
- Waterloo FORTRAN compiler for the debugging of FORTRAN programs,
- REDUCE 3.2 computer algebraic language,
- a program package for statistical analysis of data in medical and other laboratory research.

User programs can also be compiled and run interactively under GUTS.

Several computer algebraic language systems have been installed on the ES 1045, among others the AMP algebraic manipulation program.

FILE TRANSFER SYSTEM

By the end of 1986 a TPA 11/440 minicomputer had been installed and interfaced to the ES 1045 by means of a channel-channel adapter serving as a gateway between the central computing facilities and the experimental local area network (LOCHNESS) of the Institute.

A file transfer system (FILe TransfER system, FILTER) has been developed in cooperation with the Research Institute for Measurement and Computing Techniques. The system enables the users to

- send files from the TPA computers in the local area network to the ES 1045 and vice versa,
- submit jobs for execution on the ES 1045,
- fetch the results of the jobs to the printers of the TPA minis.

The FILTER system contains a subsystem emulating the terminals of the ES 1045 on the TPA terminals making available the full set of GUTS services for the users of minicomputers. A system for checking file access rights of users of the FILTER system is under development.

There is a file transfer service between the ES computers and the connected personal computers, too.

NUMERICAL MATHEMATICS AND SYMBOLIC COMPUTATIONS

Generalized Padé approximations have been investigated for some special functions. A table of integer-valued coefficients has been computed for elementary functions, for confluent hypergeometric functions and other auxiliary functions of mathematical physics. A method for investigating the transfer rate of a magnetic field in a spheromak plasma has been developed.

A computer program for calculating molecular force field parameters has been utilized for solving several problems relating to molecular structure. The program has been used by the researchers of the University of Chemical Industry in Veszprém, too.

Two general recursive methods have been found for generating conjugate vector pairs with respect to an arbitrary matrix. The first variant, called direct recursion, is a generalization of the classical conjugate gradient method. The other one, called orthogonal recursion, is capable of minimizing the residual vector at each step when finding the solution of a system of linear equations $Ax=b$.

Newton's interpolation method has been generalized to the Hermite interpolation problem in R^n by rewriting it in a recursive form. It has been shown that the general interpolation problem can be reduced to the

problem of constructing Newton multinomials, i.e. polynomials in n variables which vanish at the support abscissae. As a special case, recursive formulae for multivariate rational interpolation can be given. Formulae for numerical and symbolic computations have been presented. When applied in linear algebra, the method leads to a variant of LU-decomposition of matrices, which compares favourably with the traditional LU-decomposition in certain cases.

Methods of computer algebra have been applied to solve a number of problems in rational approximation of functions and in theoretical physics, especially in heavy ion physics.

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DEVELOPMENT ENGINEERING (MSZI)

The Development Engineering Division, the central technical base of KFKI, continued its activities in developing and manufacturing high-quality mechanical equipment and electronic systems in the years 1985-86. The maintenance of a part of KFKI's infrastructure, including energy supply, investments and upkeep of buildings, is also the responsibility of this division. Apart from these activities, fundamental and applied research are also being carried out in certain fields of technology.

In the period covered by this report, the manufacture and installation of a neutron velocity selector stands out from among the items of equipment development. The selectors installed in the spin-echo measurement laboratory of the nuclear research centre CEN de Saclay, France, are highly thought of by the users. The unique research results achieved in the field of measurement techniques proved to be of great importance in the development and manufacture of an experimental model of a 160 Mbyte magnetic disc store unit. Industry has purchased the licence to mass produce a digital drum plotter developed here too. This device, which is in fact a high-resolution drawing machine, can be used as a computer peripheral unit.

In the framework of computer-aided ECG diagnostic research activities, improved versions of the "BUDAPEST" automatic ECG diagnostic system and a real-time body surface mapping system "CARDIPLOT 64" for the measurement and interpretation of human body surface potentials have been developed.

Also in the framework of technology research, a vibration diagnostic method has been developed that will enable the immediate employment of statistical energy analysis for the study of the dynamic properties of mechanical structures. The so-called multi-sine technique is soon due to be utilized in practice: for vibration and reliability tests of agricul-

tural machines as well as for tests to prevent the loosening of the rims of railway wheels.

In the following, some of the more prominent work done during the past two years is detailed.

DEVELOPMENT OF A HIGH CAPACITY WINCHESTER DISC DRIVE

B. Egri

In 1984 the State Office for Technical Development commissioned the design and construction of a background store whose capacity can be increased up to at least 120 Mbyte and can be connected to a computer.

To solve this complex task, an R & D team was recruited comprising research fellows from the various institutes of the research centre, and the activities involved required well coordinated cooperation between the participating institutions.

The work was performed in three phases. As a result of the first phase, an experimental model was elaborated, essentially to test the available technical facilities and those created during the given period of development. A subsequent second model served for working out the requirements of the later industrial production with special regard to the supply of the necessary components and the industrial technologies to be used.

In the third phase, the tasks connected with the introduction into mass production were required to be solved in cooperation with the future industrial partner. (The home production of magnetic discs does not form part of the development task.)

The development of Winchester-type stores demands a new construction philosophy and new manufacturing and measuring technologies. With considerable effort a new measurement technology was elaborated for the qualification tests, i.e. "in-vivo" diagnostics of the experimental models produced during the construction phase. The testing methods that were used were based mainly on vibration diagnostics in order to eliminate any disturbing effects on the read-write process. In this manner the mechanical parameters and the influence of corrections could be evaluated.

One of the tasks to be solved was to design a thin film head (pole dimensions and gap width are 35x5 μm and 1 μm, respectively) by using vacuum technologies, among others the solid state technologies developed and utilized in KFKI for several years.

For the development of mechanical units, the manufacturing technologies had to be improved at several points. From among these the most

significant achievement was - also by its volume - the establishment of a clean-room which then enabled the assembly of the disc enclosure in a dust-free environment of class "100". The clean-room can, of course, also be utilized for other tasks requiring top technology conditions. The construction of electronic circuits employing multilayer card technology meant a problem for the designers mainly because of the novelty of the task and of the restricted assortment of available parts.

The technical level achieved by the above R & D activities is well characterized by the following parameters:

Store capacity	160 Mbyte
Number of discs	3
Recording density	6 580 Bpi
Track density	680 Tpi
Recording mode	MFM
Transfer rate	1012 KBit/s
Interface	Standard SMD.

The experimental models that have been realized up till now belong to the most up-to-date "mechatronic" devices and can well illustrate the potentialities available within KFKI.

DEVELOPMENT OF INSTRUMENTS FOR DIGITAL SIGNAL ANALYSIS

F. Nagy, A. Formanek, I. Simon, L. Zeke

Digital signal analysis is becoming increasingly useful in measuring techniques. In the framework of developing instruments and devices for measurement techniques, a microprogrammed fast Fourier processor (FFT processor) has been developed.

During the hardware design and when compiling the instruction set, the requirements of digital filtering were also taken into consideration beyond the main task of carrying out high-speed real-time spectral computations. To this end an architecture was chosen which enables the address generation for the five memory blocks used, the data transfer and the arithmetic operations to be performed with a 166 ns cycle time simultaneously *(see Fig. 1)*. The system structure allows the input and output of data blocks without interrupting the operation of the FFT processor. This enables the real-time processing of analog signals of up to 200 kHz.

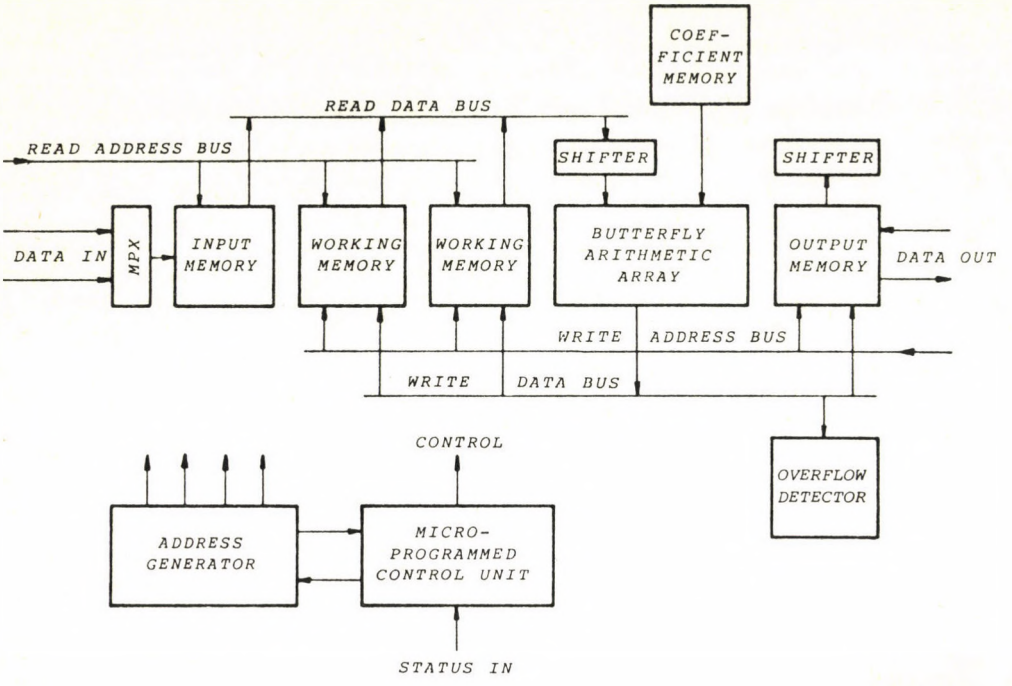

Fig. 1

Block diagram of FFT processor

The FFT processor can easily be interfaced to any arbitrary computer and high-speed analogue channel.

The following operations can be performed:

- FFT (fast Fourier transformation)
- IFT (inverse Fourier transformation)
- Spectrum smoothing (multiplication by an arbitrary window function)
- FFT and IFT on overlapped segments
- Triggered sampling (pre- and post-trigger possibility)
- Digital filtering

Main specifications of the processor:

Word length	16 bit, two's complement
Operating speed	30×10^6 operations/s
Data block size	0.25k, 0.5k, 1k, 2k

TYPICAL OPERATION TIMES

Block size	*FFT, IFT*	*Digital filtering*
	Operation time, ms	
0.25k	*0.36*	*0.72*
0.5k	*0.82*	*1.65*
1k	*1.8*	*3.6*
2k	*4.0*	*8.0*

VIBRATION METHODS AND FATIGUE INSTRUMENTATION

M.F. Ránky, G.T. Endrőczi

The Vibration Diagnostic Laboratory has designed a new type of low-frequency multichannel exciter controller. This low-cost, portable instrument is adaptable to any existing analog or digitally controlled multishaker system and serves as a complete measuring, data acquisition and control unit.

The application of this instrument complements and up-dates work of earlier type hydraulic exciter systems used in random load fatigue testing.

The basic idea of the instrument stems from statistical energy analysis and applied space-research methods.

Generally under fatigue testing a prescribed load as a function of time is forced against the test-object. The exact simulation of loads with a multishaker system requires a real-time spectrum correction technique because of the cross-effects between the input points and the structural nonlinearity. The developed new type of controller is based on the behaviour of the random vibrations of structures. The special feature of the instrument is the narrow band swept true Gaussian excitation mode, which allows the use of statistical methods with an extremely simple computational background rather than multichannel real-time spectral estimations.

USES: Multipoint fatigue and vibration tests of agromachines, all types of vehicles and mechanical structures.

FEATURES: Adaptable to any hydraulic or electrodynamic exciter system.

The exciters are controlled individually by the microprocessor based modules (CAMAC standard).

CAMAC coded command language for

- waveform selection
- module start/stop
- servo control
- interrupt handling

Out waveforms

- swept-sine (1 Hz - 20 Hz)
- narrow-band (max. 4 Hz) swept Gaussian
  - random
  - peak-minimized random
- user defined (periodicity max. 4 sec.)

Servo control

- parametric PID for DC
- parametric PID for average value of AC

Interrupt handling

- user defined function (e.g. emergency stop)

The modules are under Intelligent Crate Controller supervision. The ICC with a high-level programming language (BASIC) serves as the data acquisition equipment for data storage, handling and statistical analysis.

The modular architecture of the exciter controller with special ICC programs is able to control several different tests simultaneously.

The controller has standard interfaces for peripherals (display terminal, matrix printer, floppy disc) and for computer networks.

The controller has successfully undergone tests at VISHOM (Research Institute for Agro-machines Moscow) and MEFI (Research Institute for the Development of Agricultural Machines - Budapest).

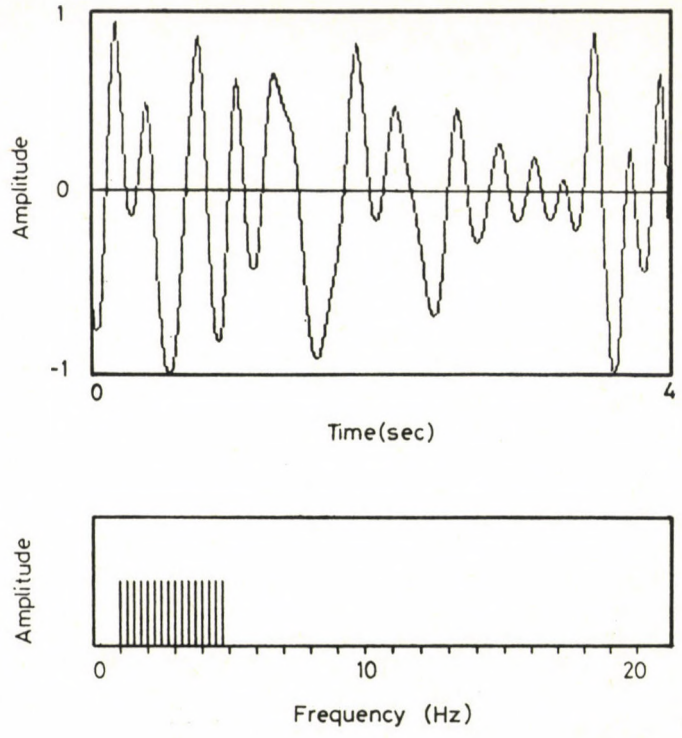

Fig. 2

Typical narrow band random multisine excitation function

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