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Fusion Technology Programme

Semi-annual Report April - September 1984

Compiled by
D. Finken
Projekt Kernfusion

Kernforschungszentrum Karlsruhe

KERNFORSCHUNGSZENTRUM KARLSRUHE

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Preface

The KfK-Association has continued work on 17 R&D contracts of the Fusion Technology Programme. An effort of 94 manyears per year is at present contributed by 10 KfK departments, covering all aereas defined in the Fusion Technology Programme.

The dominant part of the work is directed towards the need of the NET design or supporting experiments. Some additional effort addresses long term technological issues and system studies relevant to DEMO or confinement schemes alternative to tokamaks. Direct contribution to the NET team has increased by augmentation of NET study contracts and delegation of personnel, three KfK delegates being at present members of the NET team. In reverse, specifications and design guidelines worked out by NET have started to have an impact on the current R&D-work in the laboratory.

At the beginning of this year, planning of the 85/89 programme necessitated many expert discussions. KfK has contributed to this programme by proposals which have since been elaborated in more detail. In particular, a study on experiments of MHD effects has been performed, a proposal for the "Common Test Facility for Remote Handling" has been prepared and conceptual design of the KfK tritium laboratory has advanced. Some technology contracts, which were limited in duration to 1983/84, have been proposed in a revised form for prolongation to 1986.

Particular progress has been achieved in the reporting period in the field of superconducting magnets, by successfully terminating the LCT pretest in the TOSKA facility. After extended discussions on development and irradiation testing of ceramic materials (MAT 6 and MAT 13 tasks) a consistent complementary programme has now been established in collaboration with the involved associations. The discussions on blanket concepts, have had input from interlaboratory discussions including the US BCSS-study. Besides the ceramic breeder blanket, a new concept of a liquid metal blanket has been studied, and will be subject to further investigation. The development of ceramic breeder materials was extended to include silicate materials in glass form and sintered material with compounds of higher lithium content. The release of tritium from solid breeder materials still poses many questions. Special efforts have therefore been initiated to determine the solubility and diffusion properties of irradiated and unirradiated samples.

Relations to international fusion technology laboratories have been maintained and extended. Beyond the collaboration within the EC, cooperation existed with Japanese and, in particular, US laboratories in the field of superconducting magnets (LLNL, ORNL) blanket technology (ANL) and nuclear testing (UCLA, University of Wisconsin). The latter subject has been extensively discussed in a workshop, hosted at KfK in May 84. Testing needs in a preconstruction phase of NET and the role of NET as a testing tool have been reviewed at this occasion.

J.E. Vetter

M 1 The LCT-Project

The European LCT coil was tested successfully as a single coil in the Karlsruhe test facility TOSKA. Operation at design conditions (10 kA, 5.6 T at 4.8 K and 6 bar) was achieved without any problems. Cryogenic, mechanical and electrical performance was in agreement with predictions. Due to the high stability, the coil could be operated close to its critical parameters by heating the supercritical helium up to about 6 K. The coil stayed superconducting even after a fast dump (7 s) from full current. Good performance is also expected for operation in the 6 coil toroidal array of the LCTF.

The test results have already been reported at several international conferences (ICEC, ASC, SOFT), which took place in the last months (V 20 266). In the following the main results are summarized.

1. Cryogenic Performance

The coil temperature during the whole testing period is shown in figure 1 for some typical sensor locations. Both, cooldown and warmup, of the 40 ton magnet could be achieved within about 10 days by circulating helium gas in a closed loop through the coil. Smooth performance with small temperature gradients (40 to 50 K) was reached by computer control of the gas temperature. No cold leaks showed up during the whole test.

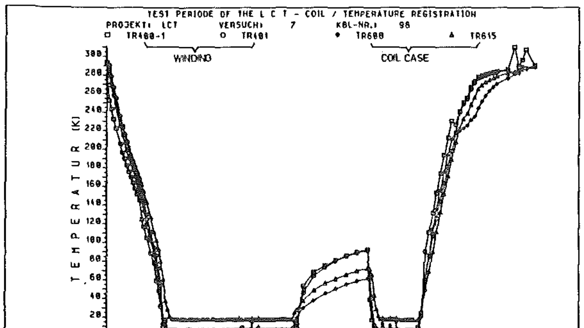

Fig. 1: Temperature of the coil over the testing period (the intermediate bump is due to suspension of active cooling over Easter holidays).

The vacuum was $2 \cdot 10^{-6}$ mbar at operational temperature. Coil cooling during magnet operation (4.8 K, 6 bar) or during 5 K stand-by conditions was done by cold helium pumps. Two types of piston pumps, which had been developed for that purpose, were operated alternatively without problems, each generating a He-mass flow rate up to 100 g/s (V 20 219, V 20 029). The warm gas produced by the eddy current losses during the intentionally initiated coil dumps could be safely handled without helium losses by a cold intermediate storage tank inside the main vacuum vessel.

2. Mechanical Measurements

During the whole testing period the overall deformation of the coil, the stresses in the coil case and the relative displacements between coil case and winding were monitored. The readings of the strain gauge rosettes on the coil case were converted to main strains and stresses and finally to van Mises equivalent stresses. The maximum equivalent stresses were about 150 MPa in good agreement with Finite Element structural analysis. Figure 2 shows a comparison of the van Mises stresses measured and that one calculated by FEM. Also the high stress level area near the large apexes symmetry and agreement with calculations are satisfactoring. Rosettes on the side walls of the straight section show higher values and a more unsymmetric orientation than expected, a fact not completely understood yet.

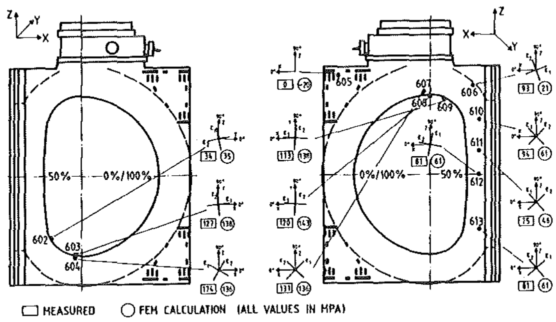

Fig. 2: Van Mises stresses and main strain orientation measured by strain gauge rosettes on both halves of the coil case.

The relative displacements between case and winding were measured with specially developed displacement transducers. Figure 3 shows that gaps are opening at the interface between case inner ring and winding due to the "breathing" of the winding as a function of current. The amount of these gaps is in agreement with compressive tests at dummy winding packs. At all locations other than the inner ring, the winding is pressed against the case providing the intended frictional coupling.

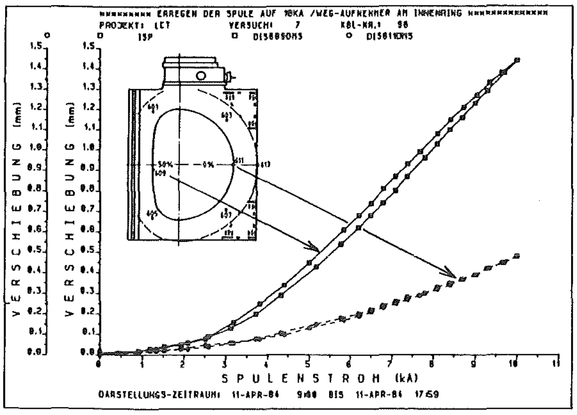

Fig. 3: Gaps between coil case inner ring and winding pack as a function of coil current.

As can be seen from figure 3, deformations and strains are depending essentially quadratically on coil current. But there are deviations from the exact quadratic behaviour which can be explained by non-linearities introduced by load-dependent moduli of the winding and load-dependent coupling of coil case and winding.

3. Electrical and Stability Measurements

After initial charging to and dumping from smaller currents to characterize the coil's and system's behaviour and to test the safety system, the coil was routinely operated at 10 kA. This corresponds to a maximum field of 5.6 T and a stored energy of 78.5 MJ. Operating temperature was 4.8 K at a helium pressure of 6 bar. Maximum charging (and slow discharging) rate was 3.3 A/s (50 min total charging time) with both, rated and maximum current, being limited only by the available power supply.

The possible occurence of transient normal conducting zones was carefully watched by monitoring the compensated voltages across each pancake on a fast transient recorder and on multichannel plotters. In no case any indication of a transient voltage could be seen. Maximum sensitivity was 0.4 mV corresponding to a normal conducting length of 2 cm of the cabled conductor.

Due to the obviously low internal disturbance level the mass flow through the coil could be kept small. Besides the flow of about 15 g/s through the case required to remove the 100 W steady state heat load, typically 35 g/s were circulated through the winding. This corresponds to about 1.2 g/s per each of the 28 250 m long conductor cooling channels. The Dittus-Boelter heat transfer coefficient was 0.015 W/cm^{2}K. Together with the other conductor parameters a Stekly number of about 8 results, which means that the coil could be stably operated far from full cryogenic stabilization.

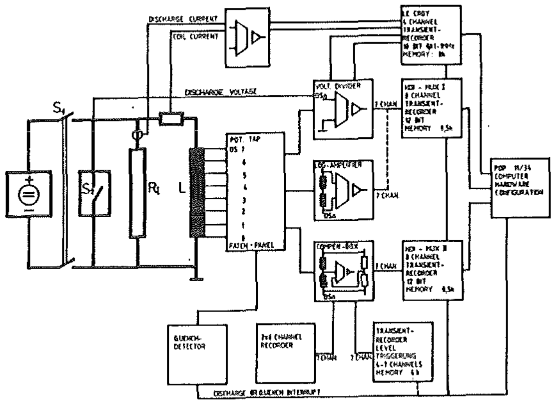

Fig.4: Block diagram of the safety discharge circuit and for the recording of transient data.

The electrical safety system consists of a fail safe quench detector and a switching system to dump the energy of the coil into an external resistor (fig. 4). The quench detector never indicated a quench and all dumps were initiated intentionally. A total of 5 dumps were performed from 10 kA with a time constant of 7 s resulting from the coil inductance of L = 1.59 H and the resistance value of R = 0.22 Ω. Discharge voltage was 2.2 kV giving an instantaneous power of 22 MW. This voltage could safely be accomodated because of the excellent insulation characteristics of the epoxy impregnated winding pack. At the test voltage of 10 kV for ground insulation a leakage current of typically 4 μA was measured.

During a dump currents and voltages of the coil were stored by 4 different transient recorders. Three of these recorders were connected to the PDP 11/34 computer to which the data were transferred after the dump. The forth transient recorder essentially was used to store the discharge voltage and current for calculation of discharge power and efficiency. Preselected temperature and pressure sensors were recorded by the multiplexing system and the PDP 11/34, as for normal operation, buth with enhanced scan rate and therefore reduced number of channels (40 instead of 370).

The temperature of the winding increased to about 6 to 7 K and to 15 K for the coil case, respectively, due to the ac losses. The corresponding pressure rise in the helium system was limited to 10 bar by relieving the gas into the cold storage tank.

From these measurements it could be concluded that during a 7 sec dump 98 % of the stored energy were extracted from and 2 % were dissipated in the coil. For a dump from 10 kA this means a dissipation of 1.5 MJ. More than 1/3 of this energy were dissipated in the coil case, the rest was dissipated in the conductor. For the coil case this is in good agreement with calculations. The time constant of the case for the eddy currents to be considered is about 0.1 s, leading to an expected dissipation of 1.1 MJ. The losses in the conductor seem to be about a factor of 2 to 3 higher than calculated, a discrepancy which is not yet understood. By increasing the dumping time to 15 s the losses were roughly halved, confirming that the losses are essentially due to eddy currents.

During and after all dumps the coil stayed superconducting.

To find out the stability limits of the coil the helium gas to one half double-pancake (corresponding to two hydraulic paths) was heated leading to a temperature of 5.7 K and 6.0 K, respectively. With these increased temperatures the coil was charged, operated and dumped two times from 10 kA. No deterioration of coil performance and stability was observed, although the temperature margin to current sharing was only about 0.5 K. This further proved the finding that the coil could be operated far from full cryogenic stabilization and very close to its critical data. This leaves additional margin, e.g. for nuclear heating produced in a real tokamak environment.

4. Further Project Schedule

The coil has been removed from the TOSKA-facility now and is prepared for shipment to ORNL which will start around Oct. 19. The coil will arrive in Oak Ridge on Nov. 15.

At the test facility at ORNL (LCTF), the "2 1/2 coil test" has been carried out successfully in August and September, thus an immediate installation of the Euratom-LCT-coil after its arrival can be expected. Several KfK-experts will come to ORNL for that task.

5. The Laboratory Torus Coil Experiment "TESPE"

A second three-coil test has been performed. Strain measurements (cf. Fig. 5) at several positions in the sides and the outer ring of the casing were partially in good agreement with calculations, there were other parts, however, where the FEM calculations overestimated the stresses by a factor of two.

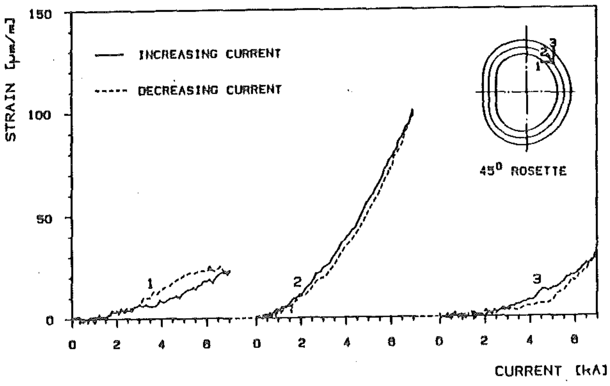

Fig. 5: Strain in the side of the casing at the marked position.

The stability investigations have been pursued further. All three known stability behaviours could be observed in the TESPE magnets depending on the operating current level. The comparison with calculations gave good agreement for the limit of unconditional stability and for the critical length of the minimum propagating zone. Taking into account the heat conduction along the conductor the calculated values of the critical energy come to acceptable agreement with measured data. Based on all these measurements a common theory of stability of bath-cooled magnets has been proposed combining the known theories on the basis of the normal state heat generation (V 19 877, V 19 597).

At fast discharges, the current transfer was measured in detail. After a heater simulated a disturbance the quench detection system registrated a quench when the normal zone reached 0.5 m length, what happened after 112 ms. Another interval of 77 ms was found from this detection to the opening of the current breaker and finally roughly 15 ms were observed for the actual transfer of current leading a voltage over one coil as plotted in figure 6, followed by the decrease of current and voltage with a time constant of 1.3 s. While 90 % of the stored energy was extracted, the remaining 350 kJ led to maximum temperatures in the windings and the casings of 28 K and 17 K, respectively, and to a helium pressure of 0.27 MPa. The cryogenic system recovered to stable operation within 15 minutes.

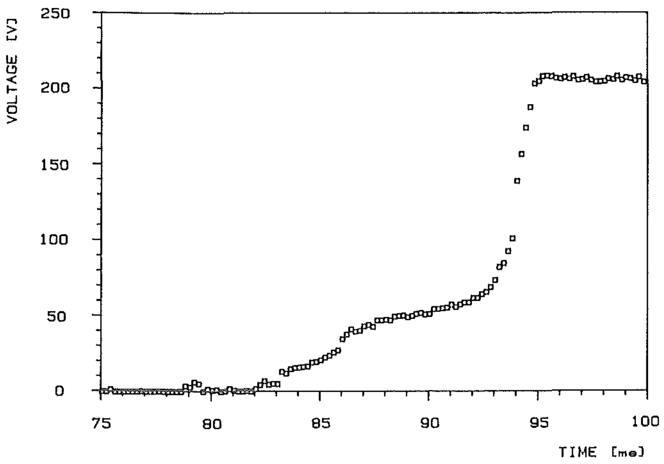

Fig. 6: Voltage of one coil during current transfer to the discharge circuit.

After completition of the three-coil tests the assembly of the full torus (Fig. 7) was carried out. A first cooldown of the torus has been performed until stable cryogenic operation was achieved.

The next steps are the operation of the complete torus to the design values and preparation of the first magnet safety experiments.

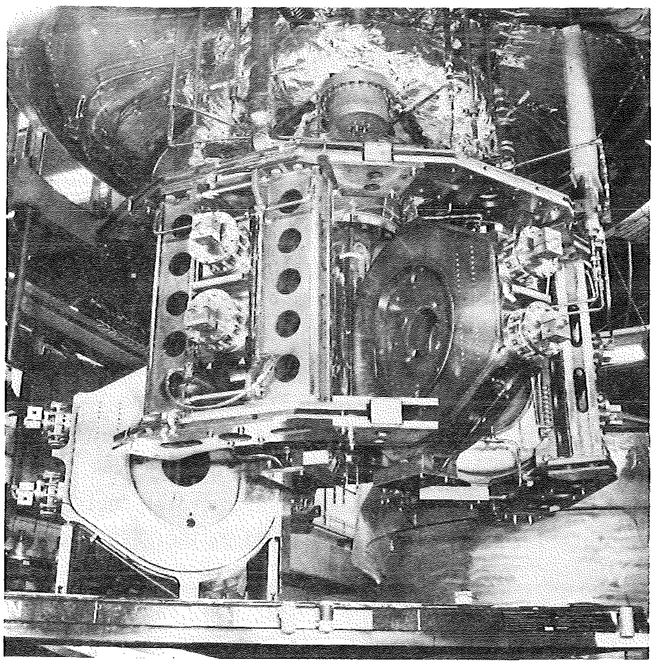

Fig. 7: Assembly of the six-coil torus.

Publications:

18 225
18 944
18 952
V 19 877
V 19 957
V 20 029
V 20 175
V 20 189
V 20 219
V 20 266

Staff:

G. Aupelt
H. Bayer
M. Beckenbach
P. Duelli
S. Förster
G. Friesinger
W. Geiger
A. Grünhagen
W. Heep
R. Heil
W. Herz
K.P. Jüngst
H. Katheder
H. Kiesel
P. Komarek
H. Krauth
M. Kutschera
J. Lühning
Y. Luguang
G. Nöther
A. Nyilas
G. Obermaier
U. Padligur
K. Rietschel
L. Schappals
C. Schmidt
L. Siewerdt
E. Specht
H.J. Spiegel
E. Süß
M. Süßer
A. Ulbricht
H. Veit
R. Wagner
D. Weigert
F. Wüchner
G. Zahn
H. Zehlein

M 3 Development of High Field Composite Superconductors

In view of the use of A 15 conductors in NET coils, the experimental work was centered on the characterization and optimization of Nb_3Sn wires with and without additives. The superconducting behaviour of the basic conductor including stabilizer and steel reinforcement has been studied. Adequate high field test facilities for characterizing the current carrying capacity and stability of composite wires and conductors have been developed.

1. Characterization and Optimization of alloyed Nb_3sn wires

A series of 19 core Nb_3Sn wires with Ta, Ti and Ni+Zn additions produced by the bronze route was found to exhibit maximum critical currents in the A 15 layers of $J_c = 2.1 \times 10^5$ A/cm^2 at 11 T and $J_c = 1.0 \times 10^5$ A/cm^2 at 16 T, showing considerable enhancement, over binary Nb_3Sn wires for fields above 11 T. At 12 T, the highest field at the conductor in NET coils, the improvement of J_c for alloyed wires is of the order of 30 %(for 4.2 K).

For optimizes wires, it is remarkable that independently of the different chemical nature of the additives, J_c vs. B_o, but also J_c vs. ε (ε is the unaxial strain) and the upper critical magnetic field, Bc_2*, are almost identical. After having, shown by Auger-spectroscopy that the composition of the additive is constant across the A 15 layers of all investigated wires, the electrical resistivity ρ_o at T_c was measured on fully reacted filaments ($\sim$5 µm) after etching away the bronze matrix. It was found that optimum conditions of J_c of alloyed Nb_3Sn wires are always reached for ρ_o = 35 µΩcm, i.e. nearly twice the value for binary Nb_3Sn filaments. This is the reason why the enhancement of J_c above 11 T is almost independent on the chemical nature of the additive.

2. High Field Test Facility for Studying J_c vs. ε

The experimental possibilities for measuring the strain sensitivity of J_c, i.e. J_c vs. ε at high fields (up to 14 T) have been extended. Actually, a set of strain rigs permits to apply forces of 1, 5 and 10 kN and currents of 300, 1500 and 3000 A, respectively, in the conductors. Their cross sections can vary from 1 mm^2 (Nb_3 Sn composite wire) to 50 mm^2 (Nb_3Sn conductor, comprising superconductor, Cu-stabilizer and steel reinforcement).

All these strain rigs can be inserted from the top of the cryostat into the 69 x 10 mm gap of the superconducting magnet, the latter remaining in liquid He during the sample changes. The 5 kN strain rig is schematically shown in figure 8, together with experimental results at 11.3 T on various reinforced Nb_3 Sn conductors with 15 mm^2 cross section.

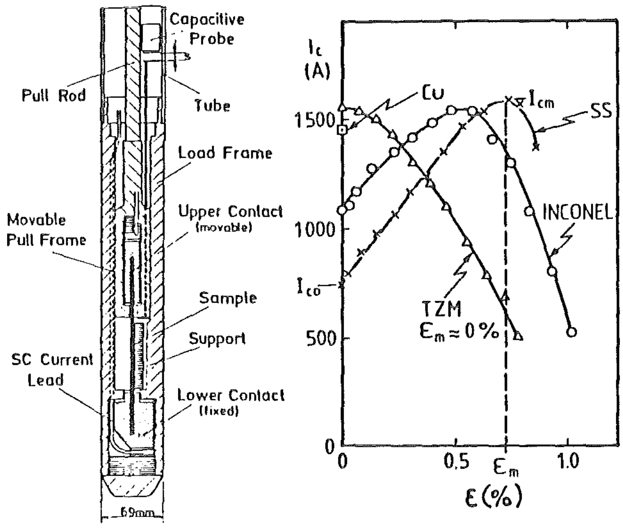

Fig. 8: 5 kN strain rig and J_c vs. ε measurements at 11.3 T on reinforced Nb_3Sn conductors with 15 mm^2 cross section.

In order to test subsize conductors for fusion coils (as for example NET), a larger strain rig for 100 kN and 10 kA on conductors with > 100 mm^2 cross section is actually under construction.

3. 12 T-Completion of the HOMER Test Facility

A first goal of completion of HOMER was to achieve 12 T in a bore of 300 mm. At the moment the magnet system is running at 10 T in a 1.8 K pressurized He II bath. The planning is to generate the additional field by using alternatively an internally reinforced monolithic Nb_3 Sn conductor or a NbTi Hf conductor at the operational temperature of 1.8 K for a pair of insert coils. The development work for the internally reinforced Nb_3 Sn conductor could be finished now. Last tests on a monolithic conductor sample (Airco) with a central reinforcement wire of Incoloy 907 gave adequate critical current values. To make sure, that also under tensile force load the good critical current values will be maintained, a Lorentz force test was made too.

For this purpose a conductor length of 2 m was wound to a coil of 250 mm diameter with three turns. This coil was tested in the HOMER test facility under the Lorentz forces generated by the sample current and the external field. The maximum applied force was 150 N/mm^2 at 8 T and the critical currents under the tensile stresses were slightly higher than those without force load. This indicates a small prestress in the conductor which prevents a surpassing of the maximum current according to the I_c versus ε characteristic of the Nb_3Sn-conductor. This conductor configuration will be manufactured in the required length of several hundert meters now.

The delivered NbTi Hf conductor (Toshiba) was disappointing in the critical current values. Because of the lack of a suitable test facility at the manufacturer the performance of the final size conductor was extrapolated from the results of a subsize conductor. Our measurements revealed that discrepancy. Together with the manufacturer we carried out a short test program on conductors of different size and found out that there exists a dependence of the critical current density on the filament size. This led in the final conductor to a reduced critical current due to the bigger filaments. A proposal for a new conductor will be worked out now at the manufacturer. With the delivered conductor a trial coil to achieve fields in the range of 11 T will be made and used in the meantime.

4. 15 T-Nb_3 Sn insert coil for HOMER

The fundamental development work of a convenient Nb_3Sn composite conductor for the field regime of 15 T, concerning the optimized heat treatment, the copper clad aluminium tape and the soldering procedure was finished as reported in the last period /19 969/.

The manufacturing of the Nb_3Sn flat cable conductor, the soldering procedure, the drawing and calibrating of a copper cladded aluminium tape is be carried out now in industry (VAC). The heat treatment for that flat cable Nb_3 Sn conductor will be done at KfK. At present heat treatment experiments in a big oven are running.

Publications:

18 793
18 794
18 856
19 966
20 028
V 19 662
V 19 663
V 19 775
V 19 872
V 19 873
V 19 875
V 20 027
V 20 115
V 20 154
V 20 155
V 20 156

Staff:

W. Barth
M. Beckenbach
R. Berggötz
N. Brünner
E. Drost
P. Duelli
R. Flükiger
S. Förster
F. Gauland
E. Gorenflo
P. Komarek
W. Lehmann
B. Lott
G. Nöther
A. Nyilas
H. Orschulko
J. Pytlik
H. Raber
A. Rung
T. Schneider
E. Seibt
W. Specking
S. Stumpf
D. Tabarsi
M. Thöner
P. Turowski

M 4 Superconducting Poloidal Field Coils

A major activity was the performance and preparation of further experiments to verify the cooling principle with the two kinds of He in the PF coil-conductor, prelimenary selected. One of the design principles used as reference is sketched in figure 9. With the primary coolant (stagnant He I) surrounding the superconducting wires, high heat transfer for short heat pulses (e.g. plasma disruptions) is provided, making use of the latent heat of LHe. In order to remove a steady state heat load of 0.2 W/m due to continous a.c. losses by field oscillations for plasma position control, a separate cooling channel with a two phase flow of He I is included in the conductor.

The transient heat transfer to subcooled He was measured in a new test device with He-volume to surface ratios, which are comparable to those of the chosen conductor design which has a few hundred wires. The theoretical understanding of the envisaged physical behaviour of the heat transfer to a closed volume has been confirmed /V 20 030/. Some further experiments are necessary to fix the operational range where the subcooled He is advantageous to the single phase supercritical He and to make a final decision on the applicability of the new cooling system.

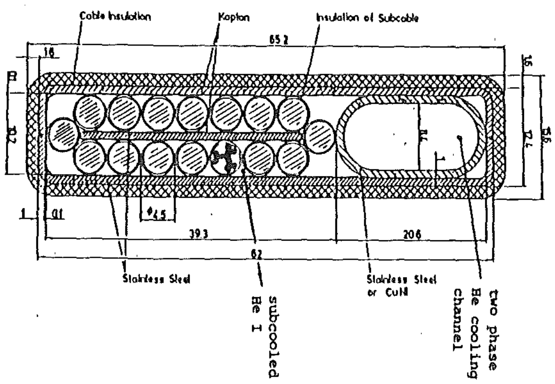

Fig. 9: Poloidal field coil conductor design (one reference case).

Experimentes to measure the two phase flow behaviour of He in channels which are several hundred meters long, were designed and first componenents of the cryogenic supply and control system of the test loop are under construction. Preparation of these experiments will be a major task in the next months.

A Cu/CuNi dummy wire was ordered to serve for gaining conductor fabrication experience and to perform realistic heat transfer experiments from the subcooled He system of the conductor to the heat removing forced flow channel. Two cable designs were considered more deeply. The discussion of the cable manufacturing aspects has been started with industry.

A second major activity was the preparation of sample tests with mixed matrix superconducting wires. To confirm the design principles, further comparative calculations were carried out for the different ordered wires. Measurements of the conductor losses were performed with a similar but not equivalent mixed matrix conductor in order to confirm the design principles by comparison with the calculations. First test samples of the ordered wire were received. There are still a lot of problems which have to be overcome. They are connected to the complicated matrix structure, especially to the rather big difference in the elastic moduli and the distribution of the used materials Cu, CuNi and NbTi. Discussion of the fabricational problems is going on with industry.

A test device for the stability measurements of strands and cables is under design, components of a dipole to create the pulsed field for these measurements have been ordered.

To prepare for the test coil operation, a 20 kV, 30 kA power switch and the associated electrical discharge circuit are under consideration and discussion with industry has been started. The predesign of the test coil has been started too.

Publications:	Staff:
18 952	F. Becker
18 955	M. Beckenbach
V 20 030	S. Förster
V 20 175	G. Friesinger
	A. Hofmann
	U. Jeske
	H. Katheder
	H. Kiesel
	P. Komarek
	H. Krauth
	W. Lehmann
	J. Lühning
	B. Manes
	W. Nick
	A. Nyilas
	H. Raber
	L. Schappals
	C. Schmidt
	L. Siewerdt
	E. Specht
	A. Ulbricht
	H. Veit
	D. Weigert
	H. Zehlein

B1 Blanket Design Studies

The design studies for a NET blanket with Li_4SiO_4 breeder, helium coolant and poloidally arranged pressure tubes were continued. The version primarily investigated during this reporting period consisted of four rows of 150 mm diameter tubes at the outboard side and two rows of 126 mm diameter tubes at the inboard side of the torus. The tubes are filled with a mixture of beryllium and Li_4SiO_4 particles and are penetrated by coolant tubes. The purge gas flows through the particle bed. In the outer rows the coolant tubes are surrounded by zirconium hybride to reduce neutron losses into the shield and to flatten the power density profile.

The neutronics and detailed thermohydraulics analysis indicated a principle feasibility of the concept within the constraints of the NET boundary conditions including tritium losses, first wall temperature etc. However the tritium breeding rate was relatively low (TBR < 1.1 for 100 % coverage).

Thus, the possibility of a lead or a lead alloy multiplier was taken up again and small scale fabricability tests were made of lead-zirconium and lead-calcium alloys to find a material with higher melting point than lead even if the multiplication is somewhat lower.

For comparison neutronic calculations were also done for a finger type arrangement (radial direction of coolant) as proposed by CEA and for a lobular arrangement as proposed by General Atomics. 20 vol. % Li_4SiO_4 and 80 vol. % Be were used for the breeder/multiplier material in all cases and $ZrH_{1.7}$ was added to improve the breeding rate. The highest breeding rate was obtained for the lobular and the lowest for the finger concept.

Work has started to discuss the influence of different operating conditions of helium-cooled solid breeder blankets on the design of the tritium recovery systems from the coolant and purge helium flows. To separate the tritium from the helium flows molecular sieves are considered which are regenerated by means of cold traps.

In addition a blanket concept was studied where liquid metal is used as breeder material and coolant simultaneously. In order to minimize MHD pressure losses the liquid metal is circulated slowly in the poloidal direction where the movement is perpendicular to the main magnetic field direction and is turned to the toroidal direction for first wall cooling where a high velocity is needed and can be tolerated when the magnetic field direction is parallel to the direction of flow.

This concept - originally proposed by ANL - was modified to fit to the NET design requirements (inlet and outlet of flow at the same end) and was improved in the region of flow reverse. It looks much simpler than most of the other concepts.

First estimates indicate the feasibility of the concept with $Li_{17}Pb_{83}$, the total pressure drop being 3 MPa and the pumping power 1 % of the thermal power.

The tritium breeding rate is with TBR = 1.32 (100 % coverage) better than that of the other designs considered so far. For liquid lithium the breeding rate would be TBR = 1.2. Engineering aspects will be subject to further studies.

Publication:	Staff:
20 035	I. Broeders
	M. Dalle Donne
	S. Dorner
	U. Fischer
	M. Küchle
	S. Malang
	J. Reimann

B 2 Development of Computational Tools for Neutronics

The work on improving the neutron data base for the fusion neutronics calculations is being continued. A KfK-report on the status of (n,2n) cross sections was issued /19 962/. One of the actions agreed to at the last B-2 meeting in Garching (March 1984) was the calculation of the KERMA-factors for Zr by KfK. The ENDF/BV evaluation of Zr is not available. The latest Livermore evaluation does not conform to the ENDF/B format as required by the code MACK-IV. Therefore, some adhoc calculations have to be performed. A programme to calculate the dpa rates for ceramic materials has been set up. The spectrum averaged displacement cross-sections can also be calculated with this programme. The NRT-model is used to calculate the number of displacements for each primary knockon atom. The displacement cross-sections are calculated for neutrons as well as for α-particles and tritons produced in the $^6Li(n,\alpha)t$ reaction. These data are useful for assessing the capability of fission reactors, LWRs and FBRs, as material testing facilities for fusion reactor blanket materials. The developed programme enables the calculation of dpa rates for individual isotopes as well as chemical compounds. Calculations have been performed for Li_2SiO_3, Li_4SiO_4, AlO_2 and Li_2O in ceramic fusion blanket and in LWR and FBR neutron spectra. Results for Li_2SiO_3 and Li_2O in different spectra are shown in table 1.

Spectrum	Li_2SiO_3		Li_2O	
	$\langle\sigma_d\rangle$ Neutr.	$\langle\sigma_d\rangle$ α + t	$\langle\sigma_d\rangle$ Neutr.	$\langle\sigma_d\rangle$ α + t
FBR	465	9.1	274	11.3
LWR	380	389	211	480
fusion blanket I	236	311	134	384
fusion blanket II	464	9.2	255	11.4

I = Pb-multiplier outer blanket region
II = Be-multiplier inner blanket region

Table 1: Spectrum Averaged Displacement Cross Sections for Li_2SiO_3 and Li_2O.

The Los Alamos Monte Carlo code MCNP has been implemented at KfK for the calculation of the neutronics and photonics of fusion blankets. The first phase of testing, adopting and improving its functioning on the local computer (Siemens 7890) has been completed. Calculation for a proposed Be-sphere experiment has been performed and results compared with those of the neutron transport code ONETRAN. For a Be-sphere of 22 cm radius with an aluminium core of 5 cm radius, covered with 0.5 cm thick Al, neutron multiplication by a factor of 2.10 is obtained for a centrally placed source. The corresponding value with ONETRAN is 2.27. Figure 10 compares the group fluxes at the surface of the sphere calculated with MCNP and ONETRAN. Observed differences may be due to the calculational method and/or due to the data base. An investigation of the reasons for these differences is being performed.

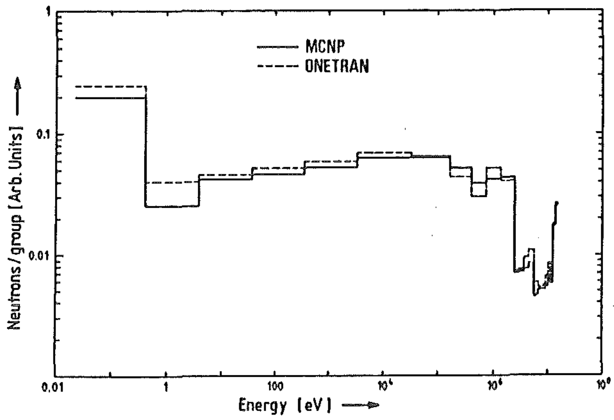

Fig. 10: Neutron Flux from a Be Sphere

It is well known that the transport codes like ONETRAN treat the anisotropy of neutron scattering only in an approximate manner. To treat the anisotropy rigorously a scheme for a code system GANTRAS (generalised anisotropic transport system) is being finalized. This code system will be based on the I*-method and will be incorporated in the existing KAPROS-system.

To establish an appropriate data base for the fusion neutronics calculations the nuclear data library VITAMIN-C will be transformed to the KAPROS-system. This will allow an easy use of local tools to modify and improve the data base. First efforts in this respect have been done.

Publication:	Staff:
19 962	I. Boeders
	U. Fischer
	B. Goel
	H. Küsters
	A. Schwenk (IAEA Fellow)
	E. Stein
	E. Wiegner

B 6 Corrosion of Structural Materials in Flowing $Li_{17}Pb_{83}$

The construction of the pumped $Li_{17}Pb_{83}$ loop for corrosion and chemical tests, the description of which was given in the preceding progress report /19 969/ was completed by mounting the heaters and the insulation. The loop is prepared for being filled with the lithium-lead alloy, which is already ordered. The dry argon glove box and the device for melting of the alloy prior to the filling into the loop are also ready for operation.

A second test section of ferritic steel is under construction. It should replace the first test section of austenitic steel after the first period of operation.

In the next future the first test runs for getting experience on the loop operation and studying chemical problems of the lithium-lead alloy will be started.

Publication:	Staff:
19 969	H.U. Borgstedt
	G. Drechsler
	G. Frees
	M. Grundmann

B 9 Tritium Extraction based on the Use of Solid Getters

Several methods were proposed to extract tritium from the liquid $Li_{17}Pb_{83}$ getter material. Task B 9 will study the use of solid getters. The advantage of this method is its simplicity and a low tritium inventory in the blanket, while most of the breeded tritium is fixed in the getter.

In order to study the compatibility of getter metals with $Li_{17}Pb_{83}$, the alloy has to be removable from the surfaces. Several methods were investigated for this purpose. The most promising ones were the dissolution of the alloy in liquid mercury and the electrolytic dissolution. For the first tests pure lead was used instead of $Li_{17}Pb_{83}$.

The dissolution rate of lead in mercury is sufficient by high for an application of the amalgamation method. Using freshly distilled mercury 160 mg lead/cm^2 · h could be dissolved at 20 °C. Rising the temperature to 60 °C gave a dissolution rate of 1050 mg/cm^2 · h. To use this method for the study of compatibility of materials, however these materials have to be stable in mercury themselves. Very low dissolution rates at 60 °C of less than 0.001 mg/cm^2 · h were found for such metals as Ti, Zr, Hf, V, Nb, Mo, Ni and stainless steel. Y-foils however desintegrate in mercury completely within 16 hours.

The second tested method was the electrolytic dissolution of the lead. The best electrolyte found was a solution of 20 % ammonium acetate. At room temperature in a stirred bath, using the lead as an anode and stainless steel as the cathode, the following dissolution rates were observed:

At 0.3 volts	48 mg/cm^2 · h
0.5 "	94 mg/cm^2 · h
1.0 "	195 mg/cm^2 · h
1.5 "	330 mg/cm^2 · h

There is a possibility to avoid the dissolution of the getter metal by keeping the voltage lower than the redox-potential of the metal. As with the amalgamation method the behaviour of the metals Ti, Zr, Hf, V, Nb and Ni was good, the dissolution rate at 0.3 to 0.5 volt was less then 0.001 mg/cm^2 · h. Again, Y is quickly oxydized.

Chemical analysis of the $Li_{17}Pb_{83}$ alloy was done using the ICP-AES-method with a Perkin Elmer ICP-6000 analyzer. Two gram samples of lead were dissolved in nitric acid and diluted to 100 cm^3. Without further chemical treatment the following concentrations of the metals in lead have be determined:

Ti	0.2	ppm
Zr	0.1	ppm
V	2	ppm
Nb	1	ppm
Mo	250	ppm
Ni	10	ppm
Y	0.05	ppm

These sensitivities may be improved by chemical separation of the metals from the lead-nitrate solution if required.

During the next reporting period the compatibility of some getter materials with the liquid alloy will be studied.

Staff:

H. Gräbner
H. Feuerstein
J. Oslinski

B 11 - B 16 Ceramic Breeder Materials

1. Preparation of Li_2SiO_3 Irradiation Test Pellets

Within the French-German irradiation experiment COLIBRI the behaviour of Li_2SiO_3 shall be tested as blanket material for fusion reactor systems. The experiment is planned to be started in October 1984 and shall be carried out in the OSIRIS Reactor in Saclay/ France.

Cylindrically shaped Li_2SiO_3 pellets with a density of 65 % and 85 % th.d. were prepared for this experiment in our laboratory. The Li_2SiO_3 powder, as the starting material, has been obtained by methods described within the last report. The powder has been mechanically granulated, calcinated at 700 - 800 °C, pressed into pellets and sintered at a temperature of 1100 °C. Granulation of the powder leads to an open structure of the pellets, i.e. a nearly complete open porosity, which is assumed to be necessary for the release of tritium built up under neutron irradiation. Due to the irradiation concept 33 test pins have been assembled by canning Li_2SiO_3 pellet columns in stainless steel tubes under very pure dry helium. The pellets of 18 of the test pins were heated up to 600 - 700 °C and transferred as hot pellets into the tubes to obtain extremely dry conditions, while the pellets of the other test pins have been encapsuled without special drying. The assembling of the test pins has been carried out in dry glove boxes (< 10 ppm H_2O) filled with pure helium. In addition, six further uncladded pellet columns have been prepared for testing under "open irradiation" condition. Chemical analysis of the sintered Li_2SiO_3 pellets showed a molar ration Li:Si of 1:0.49. The total amount of the metallic impurities is rather low, from which no heigher activation of the material under neutron irradiation is expected.

A typical chemical analysis of metallic impurities is given in table 2.

Li = 16.0 ± 0.03	Na = 0.015 ± 0.002
Si = 30.6 ± 0.3	
Fe = 0.005 ± 0.002	Co < 0.005
Cr < 0.003	Mn < 0.002
Ni < 0.01	Mo < 0.01

Table 2: Typical chemical analysis in the Li-metasilicate pellets for colibri irradiation. Values are given in weight percents.

Further characterization of the Li_2SiO_3 pellets are under preparation.

2. Preparation of Li_4SiO_4 Powders

With respect ot the high lithium content the orthosilicate, Li_4SiO_4, is of high interest as a blanket material. The Li_4SiO_4 powder can be prepared in a similar way as the lithium metasilicate, Li_2SiO_3. In a first step the reaction of amorphous silicate with the stoichiometric amount of lithium hydroxide in aqueous solution leads to the formation of $Li_2SiO_3 \cdot x\,H_2O$ due to the equation

$$4\,LiOH + SiO_2 \rightarrow Li_2SiO_3 + 2\,LiOH + H_2O.$$

After oxidizing of the excess lithium hydroxide in the aqueous solution by H_2O_2

$$2\,LiOH + H_2O_2 \rightarrow Li_2O_2 + 2\,H_2O,$$

and spraydrying of the suspension one obtains a mixed powder containing $Li_2SiO_3 \cdot x\,H_2O$ and Li_2O_2 in stoichiometric amount.

During calcination of powder at 500 - 600 °C, the orthosilicate, Li_4SiO_4, is formed. X-ray examination and chemical analysis have shown the orthosilicate to be single phase in structure with a molar Li:Si ratio of 1:0.25. In Fig. 11 and 12 scanning electron micrographs of a spray dried and a calcinated powder are shown. First experiments have shown that these powders can be pressed into pellets and sintered at a temperature of 1100 °C. Further characterization experiments with the prepared powders and pellets are planned.

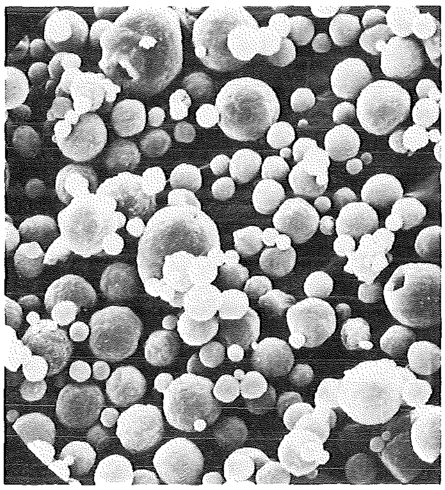

Fig. 11: Electron micrograph of Li_4SiO_4 as spray-dried (600 x).

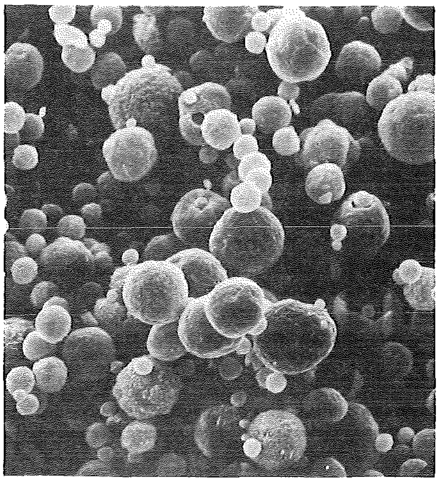

Fig. 12: Electron micrograph of Li_4SiO_4, calcinated at 500 °C (600 x).

3. Constitution and Thermodynamics

High temperature X-ray diffraction studies on the phase transformation and thermal expansion of Li_4SiO_4 were conducted, in order to check the results of earlier investigators. A material was used which was fabricated by precipitation with subsequent sintering instead of a solid state reaction via Li_2CO_3, as it was used by /1,2/. The unit cell constants at ambient temperature vary somewhat from the data given by Hollenberg /2/ (Table 3). Fig. 13 shows values of the

	25°C			800°C		
	/1/	/2/	this work	/1/	/2/	this work
a_o	5.30	5.3266	5.297	5.45	5.423	5.423
b_o	6.10	6.136	6.106	6.32	6.289	6.269
c_o	5.14	5.1774	5.144	5.30	5.213	5.218
β	90.5°	(~90°)	90.30°	(~90°)	(~90°)	90.85°

Table 3: Comparison of the unit cell parameters (in Å) of Li_4SiO_4 at different temperatures with literature data.

linear thermal expansion of this material, computed from the volumetric expansion of the unit cell, in comparison to literature data. The deviation at temperatures above 550 °C is perhaps due to a possible influence of the preparation process. The temperature range of increased bulk expansion is not in agreement with the temperature of the phase transformation measured by differential thermal analysis (665 °C) and with the temperature range of decreasing cell constant c_o (600 - 700 °C). This contradiction needs further investigations.

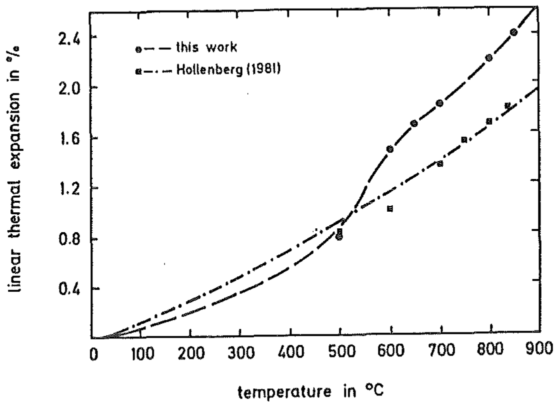

Fig. 13: The linear thermal expansion of Li_4SiO_4, computed from the unit cells volumetric expansion (crystallographic expansion).

4. Physical and mechanical properties

The thermal expansion of $LiAlO_2$ was determined with a Netzsch differential dilatometer using Saphir (NBS) as reference material. The heating of the samples was performed stepwise, and the expansion taken only from the temperature constant parts of the measurements. The results together with literature data are shown in Fig. 14 /3,4/.

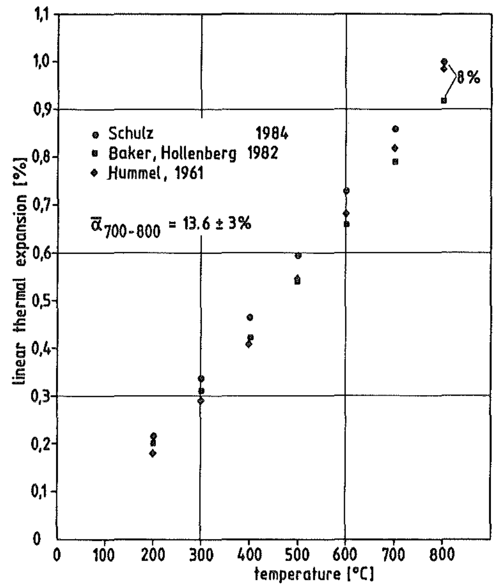

Fig. 14: Relative linear thermal expansion of $LiAlO_2$

The continuation of the measurement of mechanical properties, like elastic moduli, creep behaviour and thermoshock resistance is still depending on the purchase, delivery, installation or testing of the appropriate equipment. Thus remarkable new results could not be obtained in the reporting period, but can be expected for the next one, especially concerning Li_2SiO_3 samples.

5. Compatibility of ceramic breeder materials with cladding materials

In the preceding semi-annual report, literature results on the penetraton of cladding attack with oxide breeder materials were presented by the lines and scattering bands in figure 15. In this report, a comparison is given with results of our own compatibility tests. These annealing tests were conducted with powder samples of Li_2O, $LiAlO_2$, Li_2SiO_3 and Li_2ZrO_3 in capsules of 17Cr-13Ni stainless steel, for 125 and 500 h at 500 and 700 °C. The breeder material samples were undried, carefully dried (2 h at 900 °C) or with controlled H_2O or LiOH additions.

Chemical analysis of the breeder materials consisted mainly of determining the H_2O and CO_2 content of the as-fabricated powders. Commercial powders contained 1.2 to 1.9 wt% H_2O. Lithium silicates produced by spray-drying from aqueous suspensions contained 12 to 18 % H_2O. The CO_2 content was found between 0.4 and 9 %. By annealing the powders at 900 °C and storing under inert gas the H_2O and CO_2 content could be lowered to < 0,1 %.

The comparison in figure 15 indicates that the scattering range of cladding attack given for Li_2O can be roughly correlated with a H_2O impurity range of about 0.2 to 1 mol %. At higher H_2O content still larger cladding penetration depth can occur. Up to 1 mol % H_2O per mol Li_2O, the penetration depth with the Li double oxides appears to keep at the very low values indicated in figure 15. The dried Li compounds did not produce any noticeable reaction. Figure 16 shows the cladding penetration depth produced by Li_2O and Li_2SiO_3 with various H_2O additions. Concerning the time dependence of cladding penetration, saturation occurred between 125 and 500 h.

Heavy cladding attack seems to depend on the formation of condensed LiOH. Thus the lower reactivity of the double oxides could be due to their weaker tendency towards LiOH formation.
The compatibility tests will be continued with a comparison of Li_2SiO_3 and Li_4SiO_4, also extending to longer time and higher temperature.

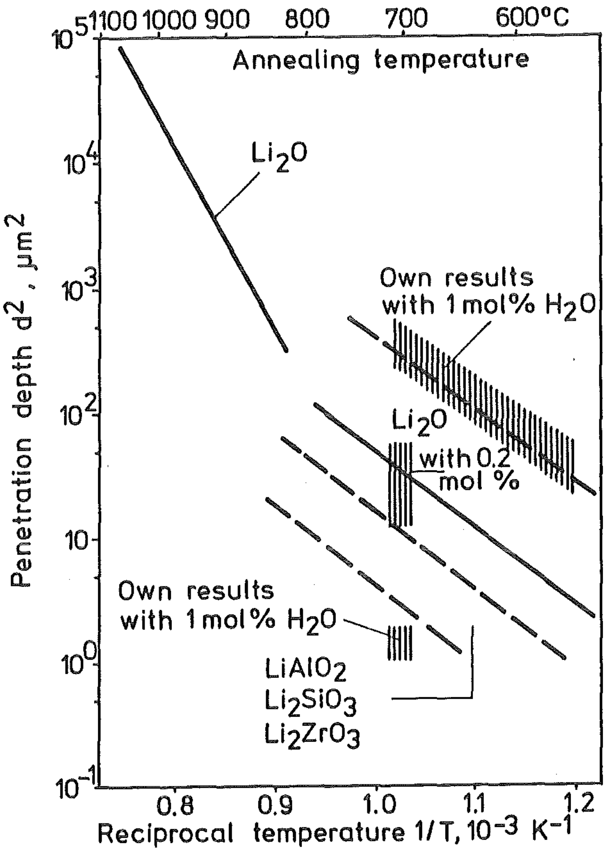

Fig. 15: Chemical reaction of oxide breeder materials with stainless steel in 100 h. Level of literature data and own results (hatched).

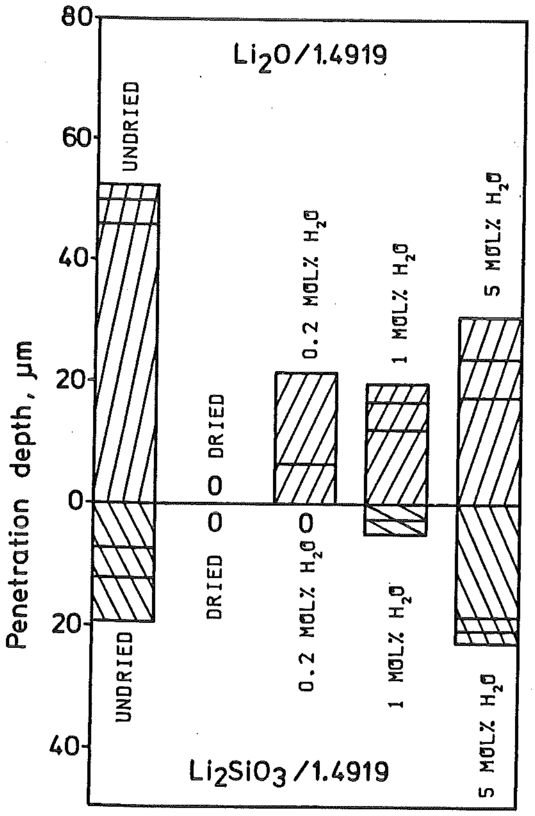

Fig. 16: Cladding attack by Li_2O and Li_2SiO_3 with various H_2O additions, in 500 h at 700 °C.

6. Irradiation Testing of Ceramic Breeder Materials

The contract covering the irradiation of at first two modified COLIBRI test rigs for lithium silicate samples in the OSIRIS reactor has been sent to CEA Saclay in May 1984. In the meantime CEA has provided us with the description and with the thermal design of the first capsule DELICE 01 for 45 samples. In June 1984 the Li_2SiO_3 pellet columns (33 with a stainless steel cladding and twelve without cladding) each with a length of about 45 mm have been handed over from KfK to CEA together with the detailed loading plan. The irradiation conditions have been specified and an analysis and evaluation program is in preparation. Under the foreseen irradiation conditions specific power rates will be reached between 6 and 60 W/cm^3 in a neutron flux from 0.8 to 8 x 10^{13} cm^{-3}s^{-1}.

The fabrication of the test rig has been started and the first irradiation is planned for a duration of one reactor cycle (26 days) within the next reporting period. The second irradiation will be performed about six months later.

Provisions are made for return transport of the samples to KfK and for post-irradiation examination.

7. Tritium recovery from Ceramic Breeder Materials

A facility for continuous monitoring of tritium release during irratiadion of fusion blanket materials has been installed at the SILOE reactor in CEA Grenoble. Mid of June 1984 a contract covering the irradiation of two first CHOUCA rigs each with six columns of samples has been sent to CEA. A first irradiation (LILA 1) with lithium aluminate samples has been performed in this facility. After evaluation and interpretation of the results decisions will be taken on necessary improvements of the facility and on the further irradiation program with German lithium silicate samples.

Literature:

/1/ West, A.R. and Glasser, F.P., J.Mat.Sci.5 (1970) 557
/2/ Hollenberg,G.W., J.Nucl.Mat. 103+104, (1981) 591
/3/ Hollenberg, G.W. and Baker, D.E., Report HEDL-SA-2674-FP (1982)
/4/ Hummel, F.A., J.Amer.Cer.Soc. 34 (1951) 234-239

Staff:

Ch. Adelhelm
W. Breitung
W. Dienst
H. Elbel
E. Günther
H.E. Häfner
R. Hanselmann
I. Heger
P. Hofmann
E. Kaiser
W. Laub
G. Nagel
H. Nagel.
G. Reiser
G. Reimann
R. Scherwinsky
G. Schlickeiser
B. Schulz
A. Skokan
G. Streib
H. Wedemeyer
H. Werle
M. Wittmann
D. Vollath

T 1 Fuel Clean-up System

Impurity removal from the D-T fuel stream of a fusion reactor by metallic getter materials is investigated in laboratory scale at KFA Jülich. Based on the KFA-results, KfK Karlsruhe considers the development of a technical scale fuel clean-up unit and test it finally under D-T conditions.

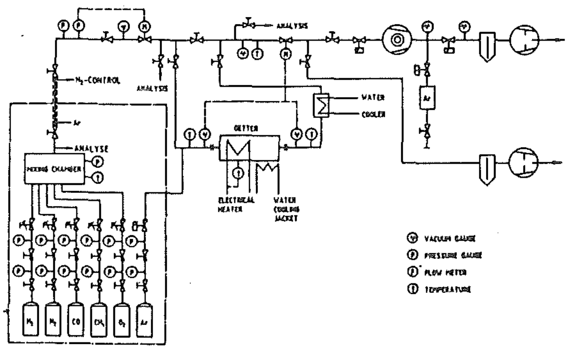

Fig. 17: Fusion Fuel Clean-up System by Getters (FUGE)

The flow-sheet of a test-unit has tentatively been set up (fig. 17). The main features are:

Getter bed
- Pressure: 1 mbar up to 1 bar
- Operating temperature: up to 600 °C
- Design temperature: 800 °C (conditioning of the getter)

Flowrate: About 12 l(STP)/h in a first scale-up step up to about 360 l(STP)/h (NET-like condition); continuous througput.

Pumping system: Turbomulecularpump.

The unit will be cleaned by heating at high vacuum. For working under high pressure, another pumping system will be used.

A premixed process gas containing variable fractions of impurities in hydrogen shall be flown through the getter module. The effectiveness of the getter will be measured by a mass spectrometer.

The experimental program should include

- investigating study the removal of impurities like O_2, CO, N_2, CH_4 from the hydrogen stream, the impurity concentrations from 0.1 % to 10 % in total;
- studying the influence of pressure and temperature with the aim to achieve atmospheric pressure as operation condition;
- varying the type of materials (alloy-composition) and configuration (powder, pellets, strips), beginning with the ZrAl-getter material St 101, SAES Milan, to compare with KFA-results.

Staff:

J. Hanauer
E. Hölzchen
E. Hutter
G. Neffe
U. Tamm

T 5 Development of Tritium Decontamination Systems

To investigate and develop methods for the removal of tritium from the atmosphere of glove boxes, appropriate experimental equipment was built. The main component of the arrangement is a 238 l chamber made up of two 100 l glass vessels with an intermediate metal cylinder tightened by two large O-rings. The chamber, which can be evacuated to 10^{-4} mbar, is used to contain representative gas mixtures. The peripheral equipment consists of various calibrated flow meters, vacuum pumps, circulating pumps and a small glass apparatus for volumetric gas measurement.

First efforts have been devoted to quantitatively determine the content of water in an argon atmosphere. Moisture monitors the response of which is based on the electrolysis of a H_3PO_4 solution were found to be inadequate for closed loop operation. These monitors caused a significant reduction of water concentration due to moisture decomposition into H_2 and O_2. When tested with commercially available calibrated gas mixtures, large differences in response were observed between the various instruments. These differences (up to a factor of 3) were attributed to equipment malfunction as well as gas transport effects. In another series of measurements H_2O/Ar mixtures were prepared by sweeping with Ar carefully weighed samples of liquid water into the chamber. The mixtures were analyzed with a water monitor which measures the conductivity of a porous alumina layer being proportional to the partial water pressure in the carrier gas.

Even though good linearity between the theoretical water partial pressure in the gaseous mixture and the response of the monitor was obtained, also in this case a significant calibration factor was required. Presently, other potential impurities of glove boxes, such as NH_3, CH_4, H_2, etc. are being analysed and calibrated by gas chromatography.

Staff:
M. Sirch
E. Willin

T 6 Industrial Development of Large Components for Vacuum Systems

1. Components

The technical specifications for the gate valves and turbomolecular pumps of the torus vacuum system were discussed with manufacturers. As a result of these discussions, various changes had to be made on these specifications.

The NET team defined in a preliminary form the NET requirements. As some of these parameters were different from the INTOR data, further changes of the specifications became necessary.

The technical specifications for the roughing pumps of the torus vacuum system were elaborated.

In discussions with potential manufacturers of the components the following problems were inter alia treated:

Gate Valves
It seems feasible from the engineering point of view to achieve the desired tightness of 10^{-7} mbar l/s in the seat for seat diameters between 1.5 and 2 m unless solid particles are deposited on the valve seat. A combination of discs capable of elastic deformation and sealing layers capable of plastic deformation seem to be the most promising solution. It will probably not be possible to achieve the desired value in one development step. It is intended to prove the performance first with a gate of NW 800...1000 mm before construction of the prototype will start.

A pull gate could offer some advantages over a pendulum gate regarding the disc driving system.

The largest problem related to seat tightness will probably consist in solid material transport. Should the solid particles produced in the plasma discharges be relatively small, there is some chance of maintaining the seat tight, if these particles can be successfully embedded in a layer capable of plastic deformation. In case of a bare metal seat an instantaneous reduction in the tightness of the seat must however be expected.

By use of double-seat valves and evacuation of the intermediate space it is possible to guarantee the requested leak rate across both valve seats even at reduced tightness of the two seats.

Turbomolecular Pumps (TMP)
To achieve the high gas throughput of 165 mbar l/s at 4×10^{-3} mbar, the diameter of the pump rotor must be greater than 1000 mm. The pump must operate up to a pressure which is unusually high for a TMP. This is caused by the limitation of pumping speed of the oil free roughing pumps at pressures $< 10^{-3}$ mbar. To attain the high pressure, a large number of stages (>10) are required.

If aluminum is used, the rotor mass will exceed 1000 kg. This results in problems connected with the oil free bearing of the rotor for which an extremely small gap must be maintained between the rotor and the stator.

An unsettled problem is the high radiation dose. With an assumed total dose of 10^{10} rad no organic insulators can be used for the electric lines. Investigations are needed to find out whether the dose can be diminished by staggered routing of the lines.

2. Testing Facility

Prior to exposure of the completed prototypes of the components to tritium containing process gas in operation in a tritium laboratory comprehensive tests must be performed without tritium. These include long-term endurance tests in a cyclic mode of operation, measurement of the operational behaviour under normal and disturbed conditions and investigations into the influence of plasma disruptions, solid materials transport and magnetic fields.

It is intended to perform long-term endurance tests with tritium containing process gas as a final step of prototype testing. Possibilities are not available in Europe at the time being to perform final tests on the prototypes.

Specification of testing facilities has started.

3. Prospects

Provided that the necessary funds will be available, contracts for studies will be placed with potential manufacturers of gate valves, TMPs and roughing pumps during the period until March 1985. Further technical specifications will be prepared and discussed with the industrial firms. Planning work will be continued on the testing facilities.

Staff:

J. Hanauer
W. Höhn
H. Lukitsch
A. Mack
D. Perinić

MAT 1 Post Irradiation Testing of Stainless Steel

The activities concentrated on the development of nonstandardized specimens for fatigue testing. Hollow hour glass shaped specimens, so called GRIM-H specimens, have been considered as appropriate for investigations of inelastic behaviour for materials subjected to complex loading conditions (i.e. fatigue loading superimposed by ion bombardment). Results of preliminary LCF tests concucted at room and higher temperature have shown that the handling of these specimens (also in remote operation) does not pose larger difficulties. The reproducibility of the number of cycles to failure N_f turned out to be as good as that obtained on the corresponding solid spedimens (GRIM-S specimens). However, particularly the cyclic work hardening behaviour of the GRIM-H specimens seems to be sensitively influenced by the fabrication process. Thermal treatments, by which the specimens could be "normalized", are investigated at present.

To compare results from test specimens of different shape (used in different laboratories) it was agreed upon (see workshop at KfK 14 - 15 February, 1984) to perform calculations of the stress distribution for specimens used in the respective laboratories. Results of such calculations for elastically loaded GRIM-H and GRIM-S specimens are now available. They show that in elastic loading the "active zone" of the GRIM-H specimen can be very well approximated by a hollow cylinder. Elasto-plastic calculations are on the way. Preliminary results indicate that in this case the stress distribution in the GRIM-S as well as in the GRIM-H specimen is in a complicated manner dependent of the cyclic work hardening behaviour.

In the final "in situ experiment" to be conducted in the dual beam facility, LCF loading is superimposed by irradiation. The latter is expected to cause an azimuthal temperature gradient in the active zone of the GRIM-H specimen. In this connection experiments are necessary to assure whether under such conditions the GRIM-H specimens are mechanically stable during tension/compression loading. Moreover one is faced with the problem of the genuine influence of thermal gradients upon the lifetime of fatigue loaded specimens. These questions will be examined by a means of a test which allows to simulate the heat (and the mechanical loading) conditions in the irradiated specimen fairly well. Equipment for this test has been recently installed and experiments will be started during October.

Complex loading conditions are expected to establish in the first wall, therefore calculations /1/ have been carried out which allow to predict the lifetime as well as the thermal creep behaviour of materials loaded by superimposed time variable stress and temperature. In the model the high temperature creep (cavitation) damage has been taken into account as a variable "structure parameter".

The following activities are planned for the next reporting period: Creep and LCF experiments on the "new heat" of SS 316 under prototypical loading conditions. Conducting LCF tests under biaxial stress conditions (on internally pressurized GRIM-H specimens). Verification of lifetime calculations (already available) for creep at superimposed time variable load and temperature (verification of the life fraction rule). Elaborating lifetime prediction for post irradiation loading. Continuing in stress distribution calculations and comparison of LCF results from test specimens with different geometry.

Publication:

/1/ M. Boček and M. Hoffmann
High Temperature Thermal Creep of Materials Under Non-Stationary Stress and/or Temperature Loading Conditions, Nucl. Eng. Design/Fusion, in press.

Staff:

W. Baumgärtner
M. Boček
C. Petersen
W. Scheibe
R. Schmitt
R. Tinivella (guest)
M. Pfeifenroth

MAT 6/MAT 13 Ceramics for First Wall Protection, Insulators and Windows

Ceramic parts will be required in various areas of a fusion machine and their properties may be critical for the life-time of the elements in which they are used. Since the two principal areas for application of technical ceramics, i.e. first wall protection, and insulators and windows, need completely different types of ceramics and different types of tests, the denomination of the actions MAT 6 and MAT 13 has been changed in the way mentioned above. The investigations are coordinated with CEA-Paris, UKAEA-Harwell (MAT 6) and CEA-Paris, CEN/SCK-Mol, KFA-Jülich and IPP-Garching (MAT 13) respectively.

In expert meetings between the partners and with the NET-team at Garching the following programmes have been established:

MAT 6:

Materials: Fine grain graphites, silicon carbide (SiC) and graphite silicon-carbide composites. With minor priority fibre-reinforced materials and sprayed SiC.

Reactor irradiation: Two different types of reactor irradiation experiments are envisaged: High temperature irradiation (1200 °C) up to ∿ 10 dpa (E >0.1 MeV) in a MTR and high fluence irradiation (up to 30 dpa) in a fast reactor at ∿ 500 °C).

Investigations before and after irradiation: Dimensions, electrical properties (resistivity), thermal properties (expansion and conductivity), mechanical properties (dynamic Young's modulus, bending strength, creep behaviour, thermal shock), micrography.

Charged particle irradiation: With the Dual Beam Facility at KfK simultaneous damage with protons (15 - 45 MeV) and He-implantation (104 MeV) is possible. A limited number of specimens should serve as a basis to compare neutron and proton and helium damage in ceramics.

Hydrogen recycling tests: The characterstics of the retention and release of hydrogen will be investigated at KFA and IPP.

MAT 13:

Materials: Alumina, magnesia, MgAl-spinel, aluminium nitride and oxinitride, and silicon nitride.

Reactor irradiation: A fission reactor irradiation in a MTR at 400 °C up to 10 dpa (E > 0.1 MeV) is proposed.

Investigations before and after irradiation: The main emphasis is laid on properties of ceramics for RF-windows. Thus, the measurement of dimensions, thermal conductivity, thermal shock resistance, dielectric properties (loss tg δ, dielectric constant) are necessary, and in addition strength tests for insulator materials will be performed.

Charged particle irradiation: Since the instantaneous effect of an ionizing radiation field on electrical properties cannot be derived from post-irradiation tests, an in-beam test in the Dual Beam Facility at KfK is planned. At the moment the feasibility of in-beam measurement of RF properties up to 150 GHz is examined.

All materials to be tested within both tasks are, if possible, commercial grades in order to get well defined materials. Several types of materials are tested before irradiation. The choice between grades to take part in the irradiation loadings will be decided after the pre-irradiation examination phase. The irradiation of the materials could start in the middle of 1985.

The results obtained from these irradiation experiments will contribute both to the design data base for NET and to a more fundamental knowledge of ceramics for more advanced fusion systems.

Publication:	Staff:
20 073	Ch. Adelhelm
	G. Grathwohl
	H. Iwanek
	R. Porz

S+E 1 Radioactive Effluents

An agreement has been attained with the French colleagues also working on this task to study at KfK the behaviour of gaseous tritium after an accidental release in the lower atmosphere and the interactions between atmosphere and the soil/plant system.

The establishment of a working team could be accomplished and after a literature survey on the dispersion of HT in the atmosphere and on the reactivity of HT in the soil/plant system the experimental program was defined and equipment was purchased.

The construction of a climatic chamber for plant fumigation experiments has been finished, whereas the installation of lysimeters for soil sampling and the purchase of some special analytic equipment, in particular a gas chromatograph and a liquid scintillation counter, is still taking place.

The climatic chamber, after functional tests and preliminary non-radioactive measurements, will be used for exposure of different types of vegetables in order to study tritium uptake and fixation either by isotopic exchange or via photosynthesis. Gaschromatography and liquid scintillation counting will allow for studies on the permeation of elemental hydrogen isotopes into different kinds of soils.

Staff:

D. Honig
U. Kara
L. König
H. Schüttelkopf

S+E 2 Accident Analysis

As described in the preceding semi-annual report /19 969/ the current investigations of KfK are related to:

- Functional and qualitative analysis of the protection system for a neutral beam injector (NBI);
- investigation of the thermal stress of the neutral beam injection shine-through area during normal operation and in the case where the absorption by the plasma breaks down;
- analysis of buckling phenomena of a vacuum container.

1. Analysis of the Protection System of a NBI

Because of the fact that well supported reliability data for the sophisticated components as the high voltage tubes are not available, first attempts were made to parametrize these data appropriately.

Reliability data for the electronic equipment and the sensors of the control system have been taken from risk analyses of nuclear power plants. One can assume that the components used in fusion plants will not have a reliability standard less than those used in operational nuclear facilities. The next step will be the completion of data selection in order to perform the pametric analysis. It is intended to terminate the investigation about the NBI protection system within the next half year.

2. Stress Analysis of the First Wall

For investigations of the stress behaviour of the first wall structure the short- and long-term version TSTRELT had been developed, bases on the short term code TSTRESS (see /19 969/). In the mean time this code has been extended to the boundary conditions of a "complete free plate" besides the formerly implemented conditions of a "free plate, constrained from bending" and of a "clamped plate". On this occasion also some numerical algorithms have been stream-lined and additional input and output data have been provided.

The extended code has been used for investigations of the neutral beam shine through area of the JET vacuum chamber. The shine through area of the JET design will be protected by carbon tiles which are merely passively cooled by radiation to the torus wall. They are loosely attached to the first wall.

In order to find the point out the most severe heat load an additional computer program has been written, called NBWALL, which uses as input the geometrical data of the first wall (including the tiles) and the neutral beam data (source grid data, power density, beamlet divergence). The result is the power density distribution of the surface heat loads of the structure due to all beam sources (there are eight sources at each neutral beam injector, each source providing 262 beamlets). The density decrease due to the finite angles between beam direction and surface normal direction has been taken into account.

The surface area which undergoes the most severe loading has been found to be one of the carbon tiles opposite of the torus port where the neutral beam injector is connected to the torus. For this area, the time-dependent temperature distribution across the tile has been determined using the finite element code ADNAT, both, for cyclic operation (cycle time ten minutes, duty time 15 sec, beam shine through power 20 % of the beam power at inlet) as well as for an accidental situation where the full beam power reaches the first wall due to an unprovided shut down of the plasma.

Using the temperature distributions from ADINAT, the resulting stresses inside the tile have been determined using TSTRELT. Two sets of calculation have been performed, using the boundary conditions "completely free plate", and "free plate constrained from bending", respectively. (The tiles themselves are mounted to the wall without bending constraints; however, the power and temperature distribution across the tile surface is not uniform. Therefore some weak constraints may arise from the neighbouring elements, and the resulting stresses will be found in between the calculated extremal conditions.)

Figure 18 and 19 show the development of residual stresses across the plate in the progress of 10.000 operational cycles, mainly due to swelling (the swelling law for carbon /1/ which has been implemented gives negative swelling rates for moderate fluences, at least in the considered range of temperatures).

In figure 18 the "free plate" conditions are employed, whereas the plate is constrained from bending in figure 19.

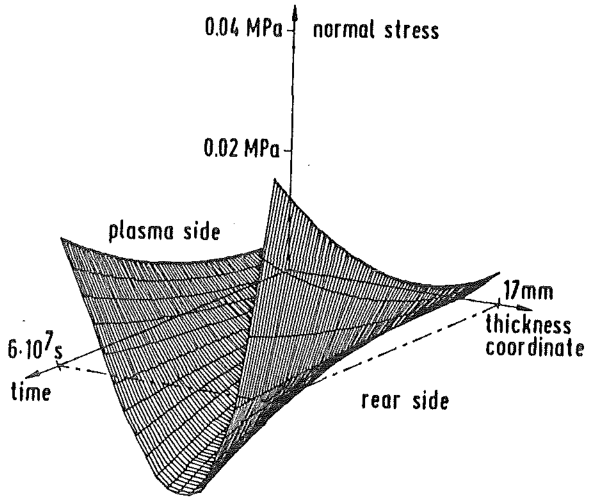

Fig. 18: Development of the residual stress distribution across the thickness of a carbon tile of JET. Boundary condition: Completely free plate.

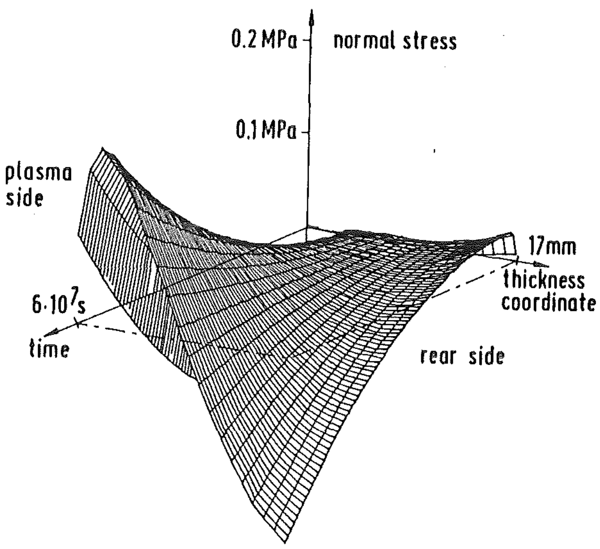

Fig. 19: Development of the residual stress distribution across the thickness of a carbon tile of JET.
Boundary condition:
Free plate constrained from bending.

It turns out that the stresses remain well below the tensile strength of carbon also in the duty time of cyclic operation (tensile strength ≈ 50 MPa; maximal cyclic stresses ≈ 1 MPa for "free" and ≈ 8 MPa for "constrained" conditions). However, if the plasma is shut down, the thermal stresses increase considerably within one half second ("free": ≈ 7 MPa; "constrained": ≈ 25 MPa), regardless whether the accident occurs before or after radiation loads due to burning plasma. Therefore, there is a considerable probability that the tiles will be destroyed during one such accident.

The statements above have not taken into account fatigue phenomena. It is not intended to include this question in the frame work of the present task, though TSTRELT provides output data which may serve as the basis of a fatigue analysis. With this exemplary application the ability of the developed codes was demonstrated. They are now ready for further use.

3. Analysis of Buckling Phenomena

The development of an approximative method for the bucklung analysis of the complex vacuum containment (bell jar) has been continued.

The method is related to the Southwell procedure /2/, an approach originally developed for the experimental determination of the critical load of rods. In this experimental procedure small elastic deformations of an initially slightly curved beam under subcritical axial compression are determined. In the numerical method under development Southwell's experiment is replaced by a linear finite element calculation of a geometrically imperfect structure. Thus, the eigenvalue problem is replaced by a boundary value problem.

In continuing the work the applicability of the method to rings (curved bar) and thin plates has been established. The application of the method to more complex geometrics and the influence of different parameters (e.g. the Finite Element Approximation and the initial choice of imperfection) on the accuracy of the results will be studied. In parallel some specific bucklung experiments will be envisaged.

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Publication:	Staff:
19 969	W. Kramer
	R. Krieg
	A. Ludwig
	S. Raff
	H. Schnauder

Development of ECRH Power Sources at 150 GHz

Design and construction activities on gyrotron components and preparation of the test facility are progressing.

Particular effort was devoted to the optimization of the resonator design. Measurements on a large scale model resonator operated at 2.5 GHz proved to be very useful for the verification of field profile calculations and for the study of the high mode density in the overmoded cavity.

The gyrotron components ordered from industry are in production. The gun section and the output window are already assembled. A new heatable ball valve, which will protect the gun section, has been designed and will be manufactured at KfK.

In view of the severe technological problems of a cw operating output window, an accompanying research activity on microwave dielectric materials was initiated in conjunction with the MAT 13 task.

The computation of the superconducting magnet system and the design of the cryostat were completed. Industrial production will start soon.

In order to facilitate the construction and the long term operation of the gyrotron test facility, a new experimental area was made available and was prepared for installation of the test components. General equipment for the gyrotron test is under construction. An additional short pulse HV power supply is now at disposition, which will be used for beam diagnostics and initial gyrotron tests.

Staff:

E. Borie
G. Dammertz
S. Fenyi
P. Grundel
R. Hietschold
G. Hochschild
A. Hornung
K. Jentzsch
M. Kuntze
R. Lehm
W. Maurer
N. Münch
G. Redemann
G. Schaffer
H. Stickel
R. Vincon

External contributors:
K. Behm and team, (Valvo, Hamburg)
E. Jensen, (TU Hamburg-Harburg)
M. Thumm (IPF Stuttgart)

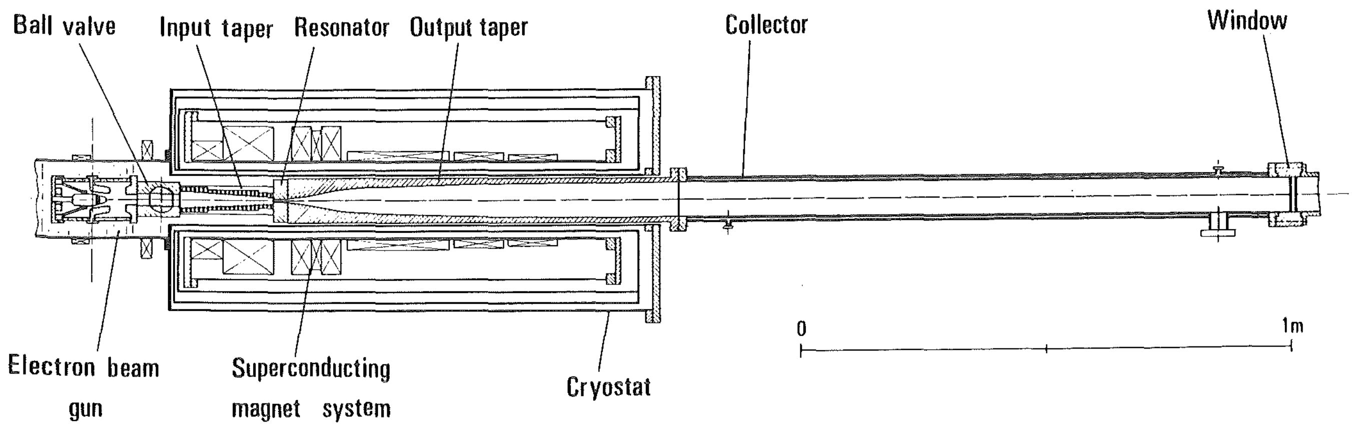

Fig. 20: 150 GHz-Gyrotron

Studies for NET/INTOR

Several NET study contracts are proceeding or have been started recently.

Already in the final state is the study "A15-type conductor development and design implications for the NET-TF coils". Based on the successful test of the Euratom LCT coil, the attempt has been made to keep the conductor design philosophy also for the A15-NET conductor design. These principles are

- forced flow cooling for ensured electrical insulation, effective force transmission, full predictable thermohydraulics and simplified winding fabrication;
- large wetted perimeter for a given hydraulic diameter to provide optimal stability;
- mechanically fixed conductor strands to avoid disturbance energy created by mechanical movement;
- strand separation or resistive barriers for minimal a.c. losses;
- steel reinforcement for force transmission and support or the hoop stresses.

The conductor design proposed in the earlier INTOR study was already based on these principles, but the further investigations carried out now indicate that an economic fabrication process might be rather difficult. Thus, a new conductor still based on the above mentioned LCT philosophy has been introduced and investigated in this study. Fig. 21 shows the principles of this conductor, designed for 20 kA operation current, with B_{max} = 12 T at the conductor.

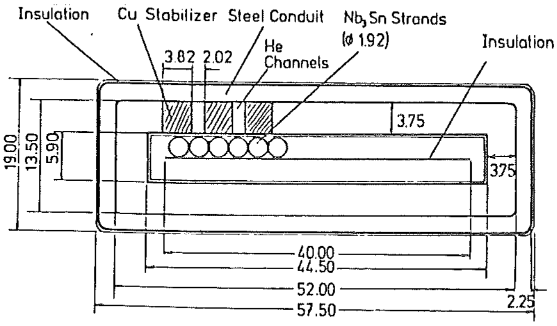

Fig. 21: NET conductor design.

The Nb_3Sn strands are wound around a thin, electrically insulating sheet, placed at the neutral axis of the conductor, thus resulting in bending strains < 0.2 %. A CuNi- (or steel) envelope separates the strands from the Cu stabilizer. In order to minimize ac-losses, the stabilizer consists of individual Cu-rods, the space between the rods serving as a channel for the He-flow. The mechanical stability against Lorentz forces is obtained by an external stainless steel conduit.

The task also comprised a study about the fabricability and the economical aspects of such a NET conductor, including the winding process. A particular attention is given to the successive "react and wind" processing of the reacted Nb_3Sn-strands. It takes indeed three different procedures to mount the high resistivity barrier, the Cu-stabilizing rods and the external steel conduit on the reacted Nb_3Sn-strands, requiring each extensive experimental work. A very important aspect of a NET conductor design is the minimization of ac-losses and the enhancement of thermal stability. Both requirements lead usually to an enhanced complexity of the design, thus causing higher fabrication costs. Thus, the final design is a reasonable compromise between acceptable ac loss and stability conditions on one hand and affordable production costs on the other. A way to achieve this goal is the production and high field testing of such conductors at a subsize scale (see testing facilities in M 3).

Another study approaching the final stage concerns "Fatigue data compilation and evaluation of the impact of fatigue on design". Beside a general survey on fracture mechanics principles, the data compilation concerns structural materials at ambient and low temperature for use in the magnet system design. As an example, figure 22 shows the fatigue crack growth rate of the steel 316 LN, based on measurements carried out at KfK recently /V 20 189/. Beside austenitic materials, several ferritic materials, Inconel, Al- and Ti-alloys and copper have been considered.

Pipe and vaccum duct connections with respect to remote maintenance are studied since May. The first part, reviewing the present state of the art, is finished. One must conclude that connections available for specific mediums (He, H_2O, LiPb, etc.) in most cases are not suitable for remote handling. Concerning welding techniques for pipe connections the study is supported by experiments running now.

In June a study to investigate CAD techniques for NET has been started with two issues. Firstly, modelling of the NET-2 magnet system and vacuum vessel; secondly, a combination of DATEX-P and EARN (European

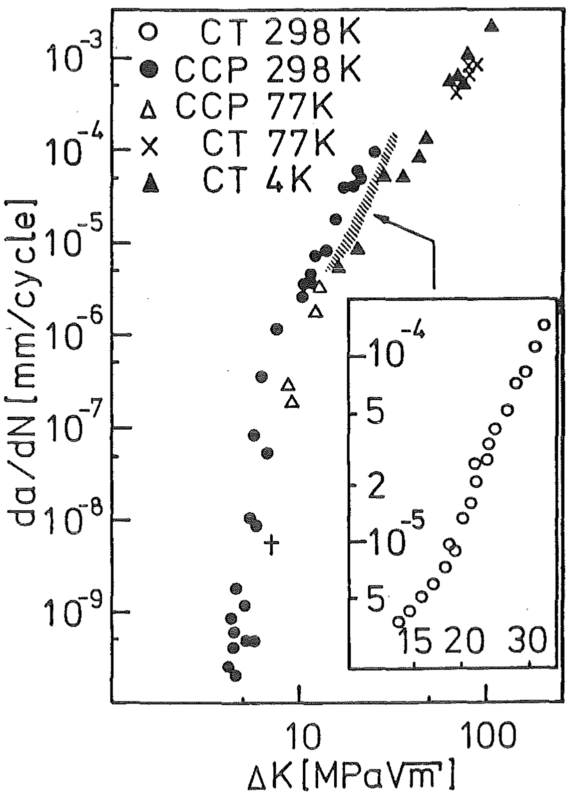

Fig. 22: Fatigue crack growth rate of the steel 316 LN.

Academic and Research Network) has been identified as the suitable way for data exchange between KfK Karlsruhe and IPP Garching.

Studies for the electron cyclotron wave launcher for NET/INTOR have been started in June, too. A preliminary report on launcher design and technology (launching structure, transmission line, gyrotrons) is prepared for the next INTOR workshop.

Further studies mainly concerning materials problems have just been started. They will contain initial design equations for martensitic steel 1.4914, data base for silicates, and stress and lifetime calculations for first wall and blanket structural components in NET. Contributions to the NET vacuum and exhaust system and the EF- coil system are under discussion.

Staff:

F. Arendt
M. Boček
G. Böhme
K. Ehrlich
T. Fett
R. Flükiger
L. Gumb
B. Haferkamp
A. Hofmann
U. Jeske
P. Komarek
H. Krauth
M. Kuntze
K. Leinemann
J. Lühning
U. Marek
W. Maurer
D. Munz
A. Nyilas
E.G. Schlechtendahl
M. Selig
P. Turowski
H. Zehlein

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Appendix I: Participation of KfK Departments in the Fusion Technology Programme

Task Code No.	Title	KfK Departments	Partners
M 1	Large Coil Project	Institute for Technical Physics (ITP) Institute for Data Processing in Technology (IDT)	IEA agreement: USA, Japan, Switzerland, EC; Industry
M 3	Development of High Field Composite Superconductors	Institute for Technical Physics (ITP)	CEA; ENEA; FOM/ECN; SIN/EIR
M 4	Poloidal Field Coils	Institute for Technical Physics (ITP)	CEA
B 1	Blanket Design Studies	Institute for Neutron Physics and Reactor Engineering (INR) Institute for Reactor Components (IRB)	CEA; ENEA; JRC Ispra; KFA; UKAEA; Industry
B 2	Development of Computational Tools for Neutronics	Institute for Neutron Physics and Reactor Engineering (INR)	CEA; ENEA; FOM/ECN
B 6	Corrosion of Structural Materials in Flowing $Li_{17}Pb_{83}$	Institute for Materials and Solid State Research (IMF)	CEA; SCK/Mol
B 9	Tritium Extraction Based on the Use of Solid Getters	Central Engineering Department (IT)	JRC Ispra; SCK/Mol
B 11-B 16	Ceramic Breeder Materials	Institute for Materials and Solid State Research (IMF) Institute for Neutron Physics and Reactor Engineering (INR) Institute for Radio Chemistry (IRCh)	CEA; ENEA; FOM/ECN; KFA SCK/Mol; UKAEA
T 1	Fuel Clean-up System	Central Engineering Department (IT)	CEA; KFA
T 5	Decontamination System	Institute for Radio Chemistry (IRCh)	CEA
T 6	Industrial Development of Large Components	Central Engineering Department (IT)	CEA
MAT 1	Post Irradiation Testing of SS	Institute for Materials and Solid State Research (IMF)	CEA; FOM/ECN; SCK/Mol; Studsvik
MAT 6/ MAT 13	Ceramics for First Wall Protection, Insulators and Windows	Institute for Materials and Solid State Research (IMF)	CEA; SCK/Mol; UKAEA
S+E 1	Radioactive Effluents: Behaviour of Gaseous Tritium in the Air, Plant, Soil System	Central Safety and Security Department (HS)	CEA; Studsvik
S+E 2	Accident Analysis	Institute for Reactor Development (IRE)	CEA; FOM/ECN; JRC Ispra; Risø
Gyrotron Studies		Institute for Nuclear Physics (IK) Institute for Data Processing in Technology (IDT)	Industry; Universities

Appendix II: Table of NET Contracts

Theme	Contract No.	Currency
A15 Type Conductor Development and Design Implication for the NET T.F. Coils	144/83-11/FU-D/NET	12/83 - 9/84
Fatigue Data Compilation and Evaluation of the Impact Fatigue on Design	151/84-4/FU-D/NET	4/84 - 10/84
Stress and Life-Time Calculations for First Wall and Blanket Structural Components in NET	155/84-5/FU-D/NET	6/84 - 5/86
Initial Investigation of CAD Techniques for NET	164/84-7/FU-D/NET	6/84-5/85
Electron Cyclotron Wave Launcher for NET/INTOR	162/84-6/FU-D/NET	6/84 - 6/85
Evacuation Behaviour of NET Design Alternatives	NET/84-043/NPE	8/84 - 12/84
Pipe and Vacuum Duct Connections	158/84-5/FU-D/NET	9/84 - 12/84
Design of the NET Equilibrium Poloidal Field Coils	NET/84-035/TE	9/84 - 2/85
Formulation of Initial Design Equations for Type 1.4914 Martensitic Steel	NET/84-038/T	10/84 - 3/85