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The High-Energy Dual-Beam Facility

A KfK Contribution to the Programme on Radiation Damage in Fusion Materials

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THE HIGH-ENERGY DUAL-BEAM FACILITY

A KfK Contribution to the Programme on Radiation Damage in Fusion Materials

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Abstract

This proposal presents a new experimental facility at the Kernforschungszentrum Karlsruhe (KfK) to study the effects of irradiation on the first wall and blanket materials of a fusion reactor. A special effort is made to demonstrate the advantages of the Dual Beam Technique (DBT) as a future research tool for materials development within the European Fusion Technology Programme.

The Dual-Beam-Technique allows the production both of helium and of damage in thick metal and ceramic specimens by simultaneous irradiation with high energy alpha particles and protons produced by the two KfK cyclotrons.

The proposal describes the Dual Beam Technique the planned experimental activities and the design features of the Dual Beam Facility presently under construction.

Zusammenfassung

Die hochenergetische Dual-Beam-Anlage -
Ein KfK-Beitrag zum Programm der Strahlenschädigung in Fusionswerkstoffen

Die Arbeit berichtet über eine neue experimentelle Einrichtung im Kernforschungszentrum Karlsruhe (KfK), mit der die Wirkungen einer Bestrahlung auf Erste-Wand- und Blanket-Werkstoffe eines Fusionsreaktors untersucht werden können. Im besonderen werden die Vorteile dieser Dual-Beam-Technik (DBT) als ein künftiges Forschungsinstrument für die Werkstoffentwicklung innerhalb des europäischen Fusionstechnologie Programms aufgezeigt.

Die Dual-Beam-Technik ermöglicht die gleichzeitige Erzeugung von Helium und Strahlenschäden in dicken metallischen und keramischen Proben durch die simultane Bestrahlung mit hochenergetischen Alpha-Teilchen und Protonen, die von den beiden KfK-Zyklotrons geliefert werden.

Die Arbeit beschreibt die Dual-Beam-Technik, die geplanten Experimente und die wesentlichen Konstruktionsmerkmale der Dual-Beam-Anlage, die gegenwärtig im Bau ist.

Contents

1. Scope and Objectives

Materials for the first wall of fusion reactors have to fulfill a number of requirements such as high strength properties, corrosion resistance, good neutronic properties and radiation damage resistance.

An adequate choice of materials largely influences the performance of a fusion reactor system. But there exists two main difficulties. One is the interdependence of fusion devices design criteria and material properties, while the other is a fundamental lack of knowledge on materials performance under fusion conditions.

Assuming a tokamak-type fusion device based on the (d,t) reaction as one of the most promising systems to be realized at present the loading of first wall materials is in principle a combined effect of cyclic stress, temperature and flux loadings. The irradiation effect itself can be subdivided in the damage by displacements due to the impact of neutrons carrying 80% of the kinetic energy produced by the fusion reaction and by the production of He due to various transmutation reactions of the 14 MeV neutrons.

In view of the absence of intense neutron sources of fusion neutrons an acceptable approach to the investigation of irradiation effects in the materials under consideration is the use of the available materials testing reactors based on thermal and/or fast fission neutrons.

Even if those reactors allow for relatively large quantities and volumes of specimens to be irradiated at the same time, the transfer of results on fusion conditions, however, is problematic since

(1) the 14-MeV neutrons produce a different recoil spectrum, i.e. 60% of the damage is caused by recoils above 0.1 MeV energy compared with a value of 2.5% for a fast breeder neutron spectrum,

(2) due to the large cross-sections of some impurities and alloying elements the 14-MeV neutrons generate CTR-parameters (Controlled Thermonuclear Reactor parameters defined as the relation of transmutation product to displacement damage), which typically are 100 times larger than those of fission reactors.

In particular the He-CTR-parameter (amount of He/damage) seems to play an important role due to the insolubility of the helium precipitating at grain boundaries or in the matrix, thus, causing embrittlement of the materials,

(3) there is only little experience in the effect of a pulsed neutron flux on the thermo-mechanical failure behaviour and the radiation damage phenomena.

There have been several attempts to overcome these fundamental difficulties by using other irradiation facilities like neutron generators based on the (d,t) fusion reaction, high voltage electron microscopes, x-ray sources and accelerators that simulate certain aspects of irradiation damage by bombardment or implantation of charged particles.

In particular, light-ion accelerators built mainly for nuclear physics or industrial research often have the penetrating power and intensity to produce high amounts of damage, helium or hydrogen in thick samples suitable for mechanical in-beam tests.

For all these devices it must be clearly seen that the number and volume of specimens and even the fluence or dpa-range are restricted. On the other hand, light ion irradiation reveals a unique feature in its possibilities for independently varying nuclear, mechanical and thermal parameters at the same time, especially if a dual-beam technique is applied.

In this proposal a high-energy dual-beam facility is presented which allows for simultaneous production of damage and helium over a wide range of helium/damage ratios (0.3-10^4 appm He/dpa) and which produces high amounts of damage (~10 dpa) and helium (up to the end-of-life content: several 1000 appm) in bulk samples.

Four fields of activity are specified for which the dual-beam technique (DBT) is intended to use:

(1) Helium embrittlement

Due to the large variability of the He-CTR-parameter this DBT is predominantly suited to investigate the specific effect of helium on damage properties at high levels in order to study its influence on embrittlement phenomena and to correlate it with experiments done by a fixed He-CTR-parameter.

(2) Influence of pulsed load

The facility can also be driven in a pulsed irradiation mode (with pulse-lengths of 10 ms to hours) in order to simulate different operational conditions of fusion devices.

(3) Helium and hydrogen production

By periodically degrading both the alpha-particle and/or the proton energy, arbitrary amounts of helium and/or hydrogen can homogeneously be introduced into materials, thus allowing the study of synergistic effects of damage, helium and/or hydrogen (dual-beam with H-implantation = quasi"triple-beam" technique). This technique becomes very important in low- or non-nickel containing alloys (ferritic steels or refractory metals). In these cases there is no chance to simulate the proper He-CTR parameter in fission reactor irradiations by utilizing the effective Ni-2-step reaction (if not doped by Ni or B might affect the alloys´ properties or yield helium on "wrong" sites).

(4) Thick sample tests

Due to the high energy of the ions mechanical in-beam tests become available using bulk samples (i.e. flat sheets of 1 mm thickness or tubular specimens up to 6.8 mm outer diameter and 0.4 mm wall thickness).

The proposed programme as outlined in the following chapters is part of the KfK-activities investigating the influence of combined non-stationary stress- and temperature loadings on the deformation- and failure behaviour of first wall materials under irradiation. It is intended to be incorporated into the European Fusion Technology Programme. The programme will contribute to the topics of mechanical properties and dimensional changes under continuous and pulsed irradiation conditions and will especially concentrate on the investigation of the effect of He/dpa ratio on tensile and fatigue properties and on swelling behaviour (gas- or vacancy-driven). The main effects to be studied are:

(1) Tensile strength and ductility
(2) Helium-embrittlement
(3) Fatigue behaviour
(4) Gas bubble and void swelling

The next chapter specifies the role of the dual-beam technique as simulation technique in a general way with respect to first wall or blanket loadings quoted for INTOR. Chapter 3. describes the experimental programme of the KfK and reports both the status and future activities including their supporting background. In Chapter 4. the dual beam facility and the target station are presented from a more technical point of view.

2. The Dual-Beam Technique (DBT)

Calculations of the radiation damage in a first wall of a fusion reactor of a Tokamak-type have shown that wall loadings of 1 MW/m^2 produce in stainless steel

(1) a damage of typically 12 dpa/a

(2) helium gas by transmutations of an amount of 120 appm He/a, and

(3) hygrogen gas of an amount of about 1200 appm H/a.

These values scale with the magnitude of wall loading in a linear manner.

Beside the wall-loading due to neutrons (disregarding here the plasma-wall interaction) the first wall and to a lower extent the blanket structure suffer further loadings due to requirements from the reactor design.

With respect to INTOR the concept assumes that there will be $7x10^5$ load-cycles up to the end-of-life of the machine. During each cycle having a burn-time of about 100 s the temperature of the first wall rises by more than 100 K [1]. During the plasma-on phase the thermally induced stress has a compressive component up to -300 MPa at the plasma-side of the wall and a tensile component up to +500 MPa at the cooling-side of the wall, whereas during the plasma-off phase only a tensile component of 10 MPa is maintained throughout the wall [2].

Both the burn-on and off times are large compared with the characteristic life-times of point defects and sufficient to allow significant diffusion of helium-vacancy clusters. Theoretical approaches [3] as well as first experiments predict and indicate, respectively, a pronounced effect of cycling and helium on the microstructural evolution [4,5] and the fatigue behaviour [5,6].

Thus, the INTOR first wall requirements characterized by a pronounced cyclic loading exceed the present knowledge on the fatigue behaviour even of unirradiated materials. Nearly no experience on fatigue exists for irradiated structures.

A response to this situation is the KfK-task studying the inelastic behaviour of first wall materials under non-stationary stress- and temperature loadings after and during irradiation. The task provides high-dose in-reactor and in-beam experiments.

The proposed programme is based on the simulation technique with light ions and utilizes a high-energy dual-beam facility in order to study the synergistic effects of radiation damage (simulated by protons), of helium (introduced by alpha-particles), of hydrogen (introduced by protons), and of the applied mechanical load.

Using the dual-beam technique, any helium/dpa ratio can be adjusted between 0.3 and 10^4 .

The wide range in simulating the amount of helium to dpa seems to be very important from different points of view:

(1) Usually a value of 12 appm He/dpa (in stainless steel) is reported in the case of fusion neutrons having an energy of about 14 MeV. The neutrons, however, as seen by the first wall or blanket structure, have an energy spectrum from thermal values to 14 MeV. The shape of of this spectrum and consequently the value of the He-CTR-parameter, depend on the actual reactor design parameters. Hence, DBT can be used to simulate the He-CTR-parameter variation over the whole range (from first wall to blanket structures).

(2) Complex reaction paths, i.e. a non-linear build-up of helium due to different burn-up processes can be followed. This technique becomes important in cases where certain impurities such as boron or nitrogen can significantly contribute to the helium content before they have been burnt-up.

(3) Since no intense fusion neutron source is available, different types of irradiation sources have to be considered to simulate the fusion effect. Each source, however, yields a specific, but nevertheless different value for the He-CTR-parameter. The dual-beam technique inherently allows an investigation of the effect of varying values for the helium/dpa ratio at the same irradiation conditions (damage, spectrum etc.). Thus, providing an important tool for comparing different fusion relevant sources in terms of their CTR-parameter.

(4) A further advantage of the dual-beam technique implicitly is its capability to allow the "Triple-Beam Technique" by degrading in energy a fraction of the incident protons to produce an uniform hydrogen concentration profile in addition to the damage and helium levels. A calculation is in progress to investigate the enhancement of damage by this technique due to the fact that the effective end-of-range part of the protons can be utilized.

In Fig. 1 the typical dpa- and helium-production rates in an austenitic steel were sketched for various irradiation facilities and fusion devices which are available presently or in the next future.
Mixed or thermal fission neutron spectra yield high helium/dpa ratios (but only in Ni-rich alloys, such as austenitic stainless steels), whereas fast fission spectra give low ratios compared with that resulting from fusion neutrons.

Proton irradiations produce helium/dpa ratios above and below that of 14-MeV neutrons depending on the proton energy.

These facilities, however, are typical single-particle sources producing the helium via different nuclear reactions. Therefore they can only be adjusted to a fixed He-CTR-parameter, which makes it very difficult to discuss irradiation experiments in terms of a He-CTR-parameter: A variation of the amount of helium (if possible) changes either the irradiation parameters (e.g. the proton energy) or the material state (if doped with B or alloyed with nickel).

It is evident that only experiments using a dual-beam facility with two independent sources can vary the amount of helium to damage without changing other parameters.

It has also to be emphasized that the utilization of a facility with high-energetic particles is important, because it allows mechanical in-beam tests. Therefore its capability to irradiate thick samples is a further important feature in order to approach engineering data sets. From this point of view facilities being limited to microstructural studies were disregarded. Only these light-ion sources available in Europe are compared, which are to be used for similiar type of experiments.

Tab. I summarizes the main features of the different European facilities located at Harwell (GB), SIN (CH), and KfK (D).

The VEC-experiment at Harwell offers an adjustable CTR-parameter such as the DBT-experiment at KfK (but limited to 20 appm He/dpa) by degrading in energy a fraction of the incident helium ions. Due to the moderate helium ion energy only very thin samples (25 - 50 microns) can be irradiated in this manner.

In contrast, the PIREX-experiment at SIN has the potential to allow the irradiation of thicker specimens (up to 10 mm), but the high heat deposition in thick samples causes so large temperature gradients, that due to the requirement of constant temperature across the sample the maximum specimen thickness is practically limited to about 2 mm. The high-energy protons will generate a different spectrum of primary recoils and therefore a somewhat different damage structure. They also generate transmutation products and helium in excess.

The largest flexibility of these different facilities clearly provides the DBT-facility at Karlsruhe allowing either

(1) the generation of large damage (in a few samples) or

(2) the production of large amount of helium or

(3) mixed conditions over a wide range.

The sample thickness is sufficient to test bulk samples, either

(1) flat specimens of 1 mm thickness or

(2) round specimens of 1 mm diameter or

(3) tubes with 6.8 mm outer diameter and 0.4 mm wall thickness.

The values given in Tab. I for the dpa and helium are conservative ones in the case of the dual-beam facility. The beam current of both cyclotrons can be enhanced by a factor of 2-3, but this improvement shall not be discussed at present in order not to run into problems associated with the large heat transfer from beam to target.

Apart from these advantages the simulation technique with light ions involves many well-known features, which are only listed for completeness:

(1) easy sample access

(2) outstanding instrumentation possibilities

(3) similiar recoil-spectrum compared with that of 14-MeV neutrons, apart at low-energy recoils, where the protons have a larger component

(4) damage rates comparable with neutron damage rates or higher, therefore allowing fast damage accumulation

(5) simple techniques to simulate flux pulsing

(6) pre-implantation of helium and/or hydrogen.

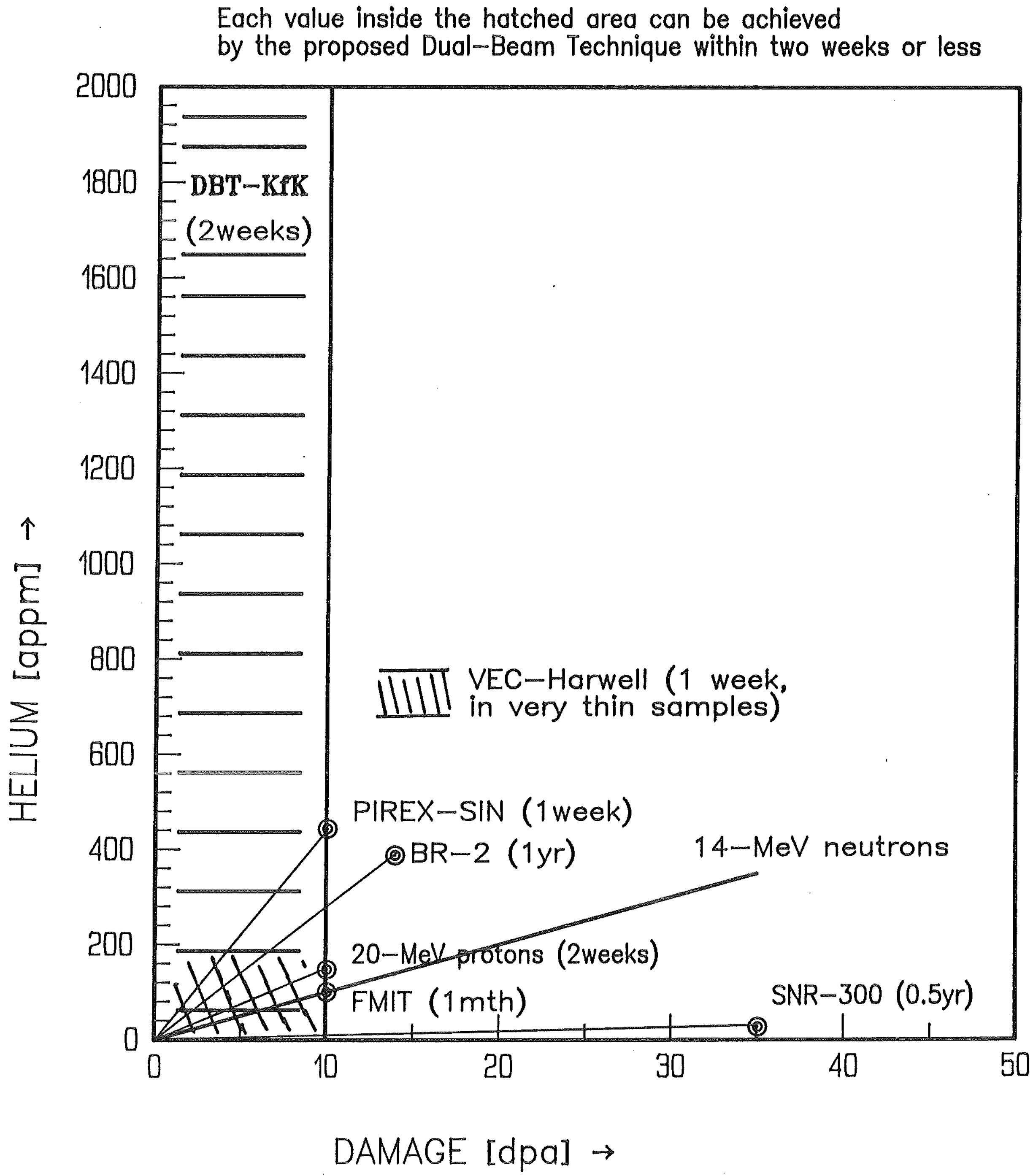

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Fig.1 Facility comparison in terms of the production of damage and helium for stainless steel.

Tab. I Comparison of different facilities suitable for studying synergistic effects of helium and damage (values calculated for stainless steel)

	Single beam	Second beam	appm He/dpa	dpa/week	appm He/week
VEC–Harwell	15 MeV He	./.	0– 20 adj.	10	200
PIREX–SIN	600 MeV p	./.	50– 100 fix'd	0.3 10	30 low beam area 1,000 high beam area
DBT–KfK	15–45 MeV p	0–104 MeV α	1–2000 adj.	5	10,000

	Specimen thickness	Heat transfer	Simulation of fusion recoil spectrum
VEC–Harwell	0.025– 0.05 mm	>1.0 kW/cm^2	suitable
PIREX–SIN	0.3 – 2. mm	~0.5 kW/cm^2	poor
DBT–KfK	0.2 – 1.3 mm	~0.5 kW/cm^2	best

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3. The Experimental Programme

3.1 Results from current programmes

The investigation of radiation damage in metals is a basic programme of KfK-IMF (IMF= Institut für Material- und Festkörperforschung) since nearly two decades. With respect to fusion the attention was focussed on pure vanadium and vanadium base alloys and a series of experiments were performed in order to study especially the effect of helium on the material properties [7-13]. The irradiations were done at the GSI-Darmstadt, the Ruhr-Universität Bochum, and at the Lawrence Livermore Laboratory in Livermore (USA).

Three topics have been investigated or are under investigation

(1) The effect of helium on the microstructure

(2) The effect of helium or damage on the microstructure under pulsed beam and/or temperature conditions

(3) The effect of helium or 14-MeV neutrons on tensile properties

(1) The study of the microstructural evolution was primarily done with pure vanadium irradiated by either 200- or 2000-keV helium ions over a broad dose (~10 at.%He) and temperature range (300-1100 K).
The effect of irradiation has been investigated by means of scanning electron microscopy and microhardness techniques in the case of surface effects [7] and by transmission electron microscopy in the case of volume effects [8]. Special experience has been obtained by studying these effects as a function of sample depth by using the step-by-step preparation technique.

Two recent review papers highlight the main results [9,10]. With respect to the helium bubble growth at higher temperatures (>$0.4T_m$, T_m melting temperature in K) the occurence of a bimodal bubble size distribution could be confirmed by experimental and theoretical approaches.

(2) The effect of beam and/or temperature pulsing is being under investigation. The beam on/off time can vary between 10 ms and hours and the ΔT-period can be varied independently of and simultaneously with the beam period. As supported by numerical approaches to the growth behaviour of defect clusters by applying the fully dynamic rate theory [3], the holding time and temperature between two cycles seem to play an important role in governing the defect evolution under beam cycling conditions.

From the experiment can be concluded that the behaviour of helium gas bubbles is in contrast to that of helium-free cavities. In the latter case a reduction of swelling can be achieved under certain experimental conditions. The experimental program runs into a final phase and will be finished in 1984.

(3) Several years ago, the effect of helium on tensile properties of pure vanadium and of different V-base alloys was studied. The helium (0-104 MeV alpha-particles from the cyclotron) ions were homogeneously implanted at 550 K and the flat tensile specimens (0.5 mm thick) were tested up to temperatures of 1323 K.

Up to the achieved amount of 20 appm He no significant effect on tensile properties could be found at elevated test temperatures, when the yield-strengths of the alloys were comparable to that of pure vanadium [11].

Currently a series of tensile tests carried out in the hot cells have been completed in order to study the effect of 14-MeV neutrons on the deformation behaviour of vanadium [13]. The irradiation with 14-MeV neutrons was done at the RTNS II source of Livermore.
Special attention was paid to the microstructure, i.e. the identification and classification of loops in order to get cross-points for the comparison of simulation- and neutron-induced defects.

3.2 Future Experimental Activities

3.2.1 The Experimental Test Matrix

The planned activities provide a two-step programme. In a first step the respective properties of unirradiated materials *) due to temperature pulses and stress-cycling will be investigated in terms of specimen sizes suitable for in-reactor as well as high-energy in-beam irradiations (MAT 1). In a second step the material response to radiation damage and helium loading under in-beam conditions will be tested (MAT 9&13).

Although one can establish a large experimental matrix in principle as is shown in Tab. II which can be used to fulfill the requirements of the different MAT-tasks (i.e. MAT 9, 10, 11, 13, and 14) of the European Fusion Technology Programme 1982-1986, the KfK-activities have been limited to MAT 9&13 due to capacity reasons.

Tab. II General experimental test matrix for DBT-KfK

1.0 Transient behaviour
1.1 Transient behaviour due to a stress ramp
1.2 Transient behaviour due to a temperature ramp
1.3 Transient behaviour due to combined stress and temperature

2.0 Failure behaviour
2.1 Failure behaviour under cycling stresses
2.2 Failure behaviour under temperature pulses
2.3 Failure behaviour under combined cycling loadings

3.0 In-situ irradiation behaviour
3.1 Continuous dual-beam irradiation
3.2 Pulsed dual-beam irradiation
3.3 Continuous single-beam irradiation
3.4 Pulsed single-beam irradiation

4.0 Pre- and post-irradiation tests

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*) The material will be defined by the NET-team. Metallic materials being proposed are the austenitic steel AISI 316L or the martensitic steel 1.4914 optimized by KfK [14].

KfK will work with priority on the following experiment:

According to the proposed NET-requirements concerning the fatigue behaviour, KfK will focus the experiments on in-beam fatigue tests (10^3 - 10^5 cycles) by simulating the temperature, stress and flux behaviour as a function of time. Depending on dose a series of 10-15 in-beam fatigue tests per year are planned.

The parameters for these experiments are specified in Tab. III.

Tab. III Experimental parameter ranges of the planned low-cycle in-beam experiment (1983-86)

stress	up to ± 500 MPa
Total strain range	1 %
cycle length	100 s (1000s)
holding time	100 s (1000 s)
temperature	500 - 1000 K
specimen size	77 mm length, 6.6 mm outer diameter,
(tube)	0.3 mm wall thickness
material	see remark on page before
damage rate	~ 1 dpa/day (continuous mode)
He/dpa	10, 100 ,1000 [appm He/dpa]

During the first phase we look for a specimen geometry (size and shape) suitable for in-situ and post-irradiation experiments. Preliminary results from fatigue tests with unirradiated specimens indicate, that even large bulk samples (as used in tests for fast breeder programme) can be used in fatigue tests designed for DBT-experiments after the rod specimens have simply been drilled out to wall thicknesses allowing the penetration of the high-energy light ions (s. next Chapter).

In a second phase the samples will be damaged by a continuous dual-beam irradiation. After 1986 pulsed irradiations will also be undertaken.

3.2.2 Post Irradiation examinations

After the tests the samples will be investigated by means of transmission and scanning electron microscopy in order to get information from the microstructural evolution. Due to the radio-activity of the samples the tests have to be carried out in the hot cells of the KfK. The equipment for analysing the microstructure (the sample preparation laboratories, the electron microprobes and the electron microscopes) already exists in the hot cells. In the case of mechanical post-irradiation experiments, the hot cells are also well equipped with many testing machines suitable for tensile, creep or fatigue tests at different temperatures and in different enviroments such as air, vacuum, gas-mixtures and liquid metals.
The sample output from dual-beam experiments to the hot cells has already been involved in their current 5-year programme.

3.3 Supporting Background and Joint Programmes

The dual-beam experiments are an integral part of the KfK-IMF activities and are supported by the existing knowledge from fast breeder and the European Fusion Technology Programme.

Both accelerators are operated by a well experienced staff who make the accelerators available to the different experimental groups since nearly twenty years.

Tab. IV gives an overview of the participating scientists and their program responsibilities.

Tab. IV Activities and responsibilities

DBT-PROGRAM (MAT 9)		
(1)	Accelerator equipment & beam line	H.Schweickert
(2)	Design of DBT experimental set-up	D.Kaletta
(3)	In-beam fatigue tests Out-of-beam fatigue tests	D.Kaletta R.Schmitt
(4)	Creep-rupture, Temperature transients	K.Herschbach
(5)	Post-irradiation investigations Microstructure, Bubbles, Voids Mechanical properties	 D.Kaletta N.N.
(6)	Theory (mech.prop.under irradiation, rate equations)	D.Preininger

JOINT PROGRAMMES (MAT 1,2,6&13)			
(1)	Post irradiation testing	(MAT 1)	M.Bocek
(2)	In-pile fatigue tests	(MAT 2)	K.Ehrlich
(3)	In-pile ceramics tests	(MAT 6)	G.Grathwohl
(4)	In-beam ceramics tests	(MAT13)	G.Grathwohl

4. Description of the Dual Beam Facility

4.1 Accelerator and Beam-Line Characteristics

KfK operates two cyclotrons for research in nuclear physics, for medical isotope production and for industrial applications. A summary of the characteristics of the two accelerators is given in Table V. at present.

Tab. V Characteristics of cyclotrons forming the dual-beam facility

	Isochron cyclotron (KIZ)	Compact cyclotron (KAZ)
ion species	alpha-particles	protons
ion energy	104 MeV	15-45 Mev
beam current	5 microamps	100 microamps
beam spot	> 1 cm^2	> 1 cm^2

To accomodate the Dual Beam Facility it is necessary to extend the Experimental Hall. The dimension of the new annex building will be 13.8x23.5 m^2 , which gives a free surface of 320 m^2 , available for installation of the target station with its shielding and large rotating door. Power supplies, cooling system, data acquisition for the experiment are arranged on several floors on the length side of the building accessible by stairs. For location and relative position with regard to the two cyclotrons see Fig. 2a.

The existing beam-lines must be extended by roughly 20 m each. They are shown with their magnetic guidance system and their diagnostic instrumentation in

Fig. 2b and 2c. The angle between the two beam lines is only 10 degrees which leads to a fair coincidence across the target thickness.

The magnets and diagnostic instruments are standardized components generally used in the KfK cyclotron beam-line systems. Operation of the system and beam quality is guaranteed by computer control. A common control area has been established for both beam-lines. In order to have a fast and convenient access to all compenents of the two beam guidance systems, touch-panels have been installed serving menu-programs for remote control and access. The system response can be checked by status signals displayed on coloured block diagramms as well as by TV-supervision in a direct manner.

The avaibility of the two beams will be 1500 hours/year, when used for material research.

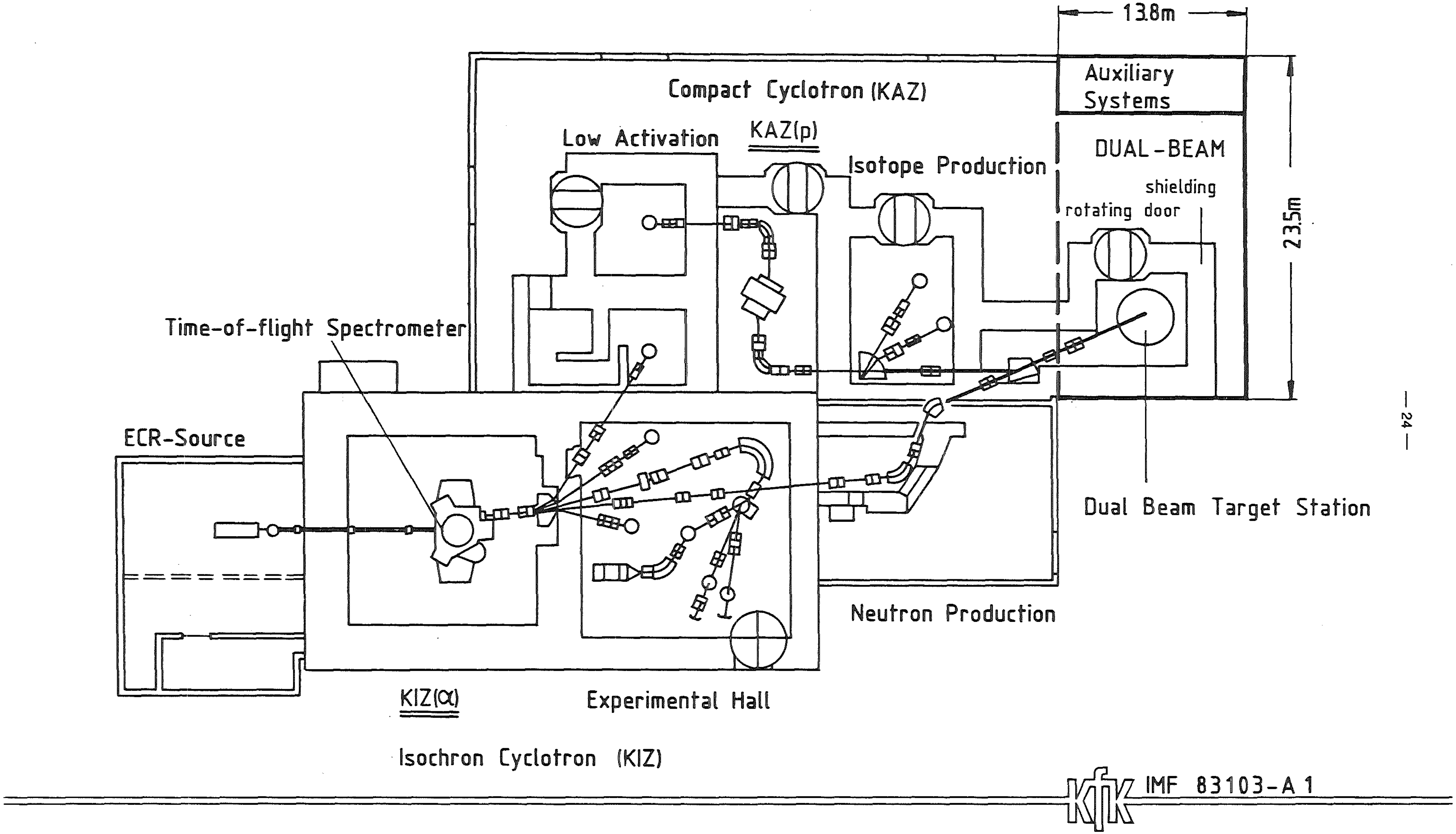


Fig. 2a Karlsruhe Cyclotron Plot Plan

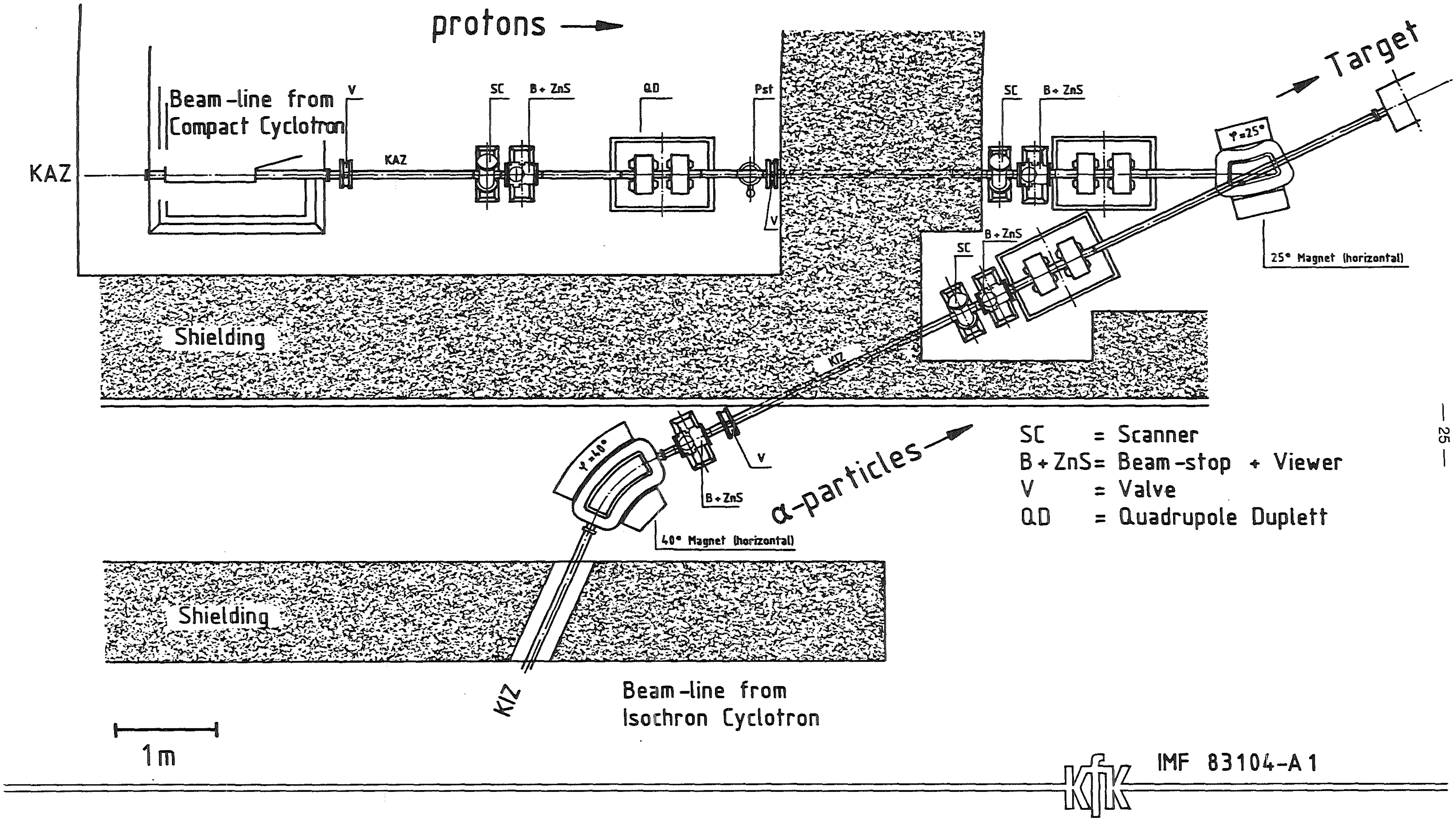
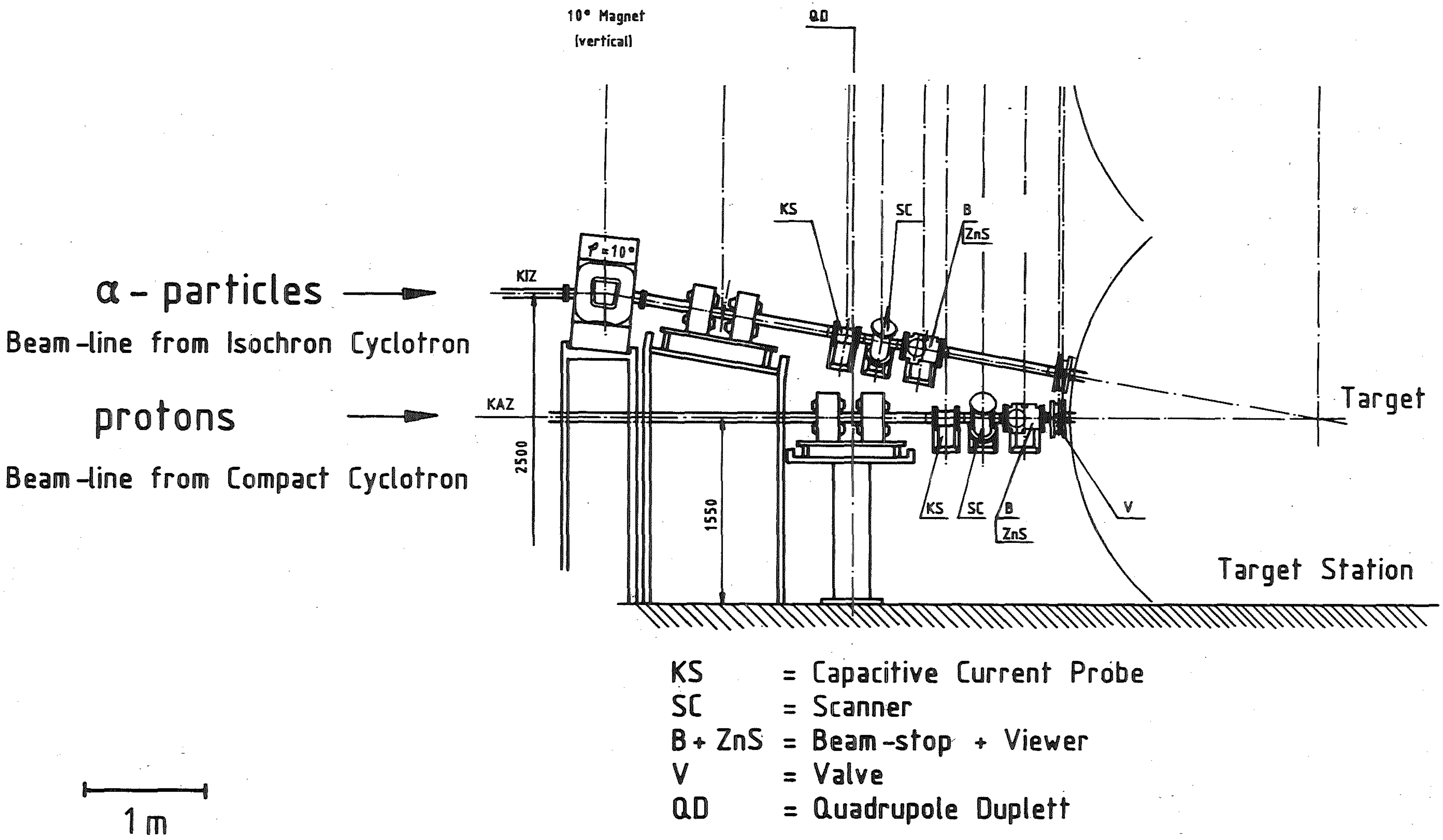


Fig. 2b Top view of the two beam-lines and the required diagnostic components



KS = Capacitive Current Probe
SC = Scanner
B + ZnS = Beam-stop + Viewer
V = Valve
QD = Quadrupole Duplett

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Fig. 2 c Side view of the two beam-lines and their diagnostic components

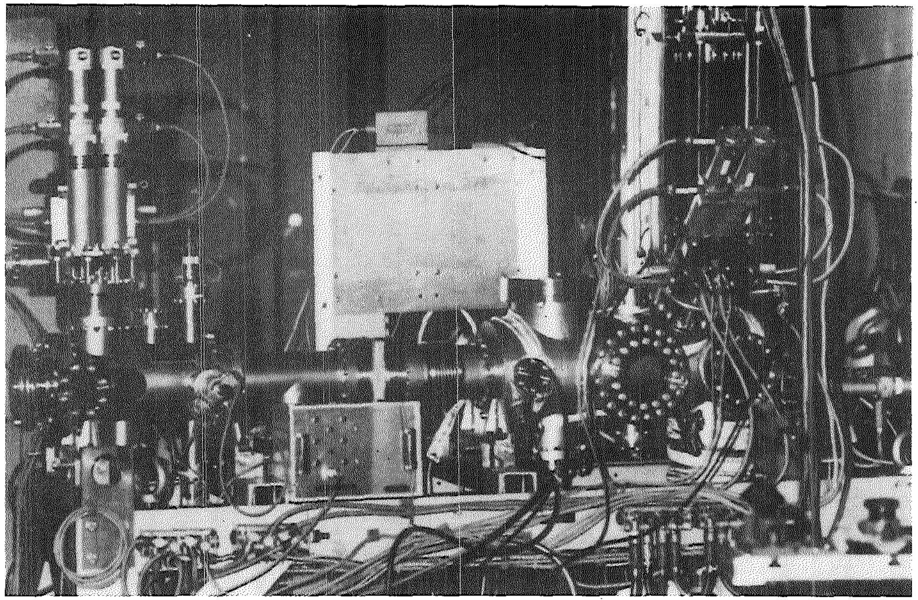
4.2 Target Station and Specimen Specification

The target station inside the shieldings (s. Fig. 2a) covers an free area of 4 m in diameter. The irradiation chambers, the endurance machine, the beam diagnostic components are adjustably mounted on lorries which can be moved on a crossed track system. This technique allows a fast and convenient exchange of components and irradiation chambers wether for a diffent type of experiment or for easy maintenance which becomes very important due to the activity of components after high-dose irradiation experiments.

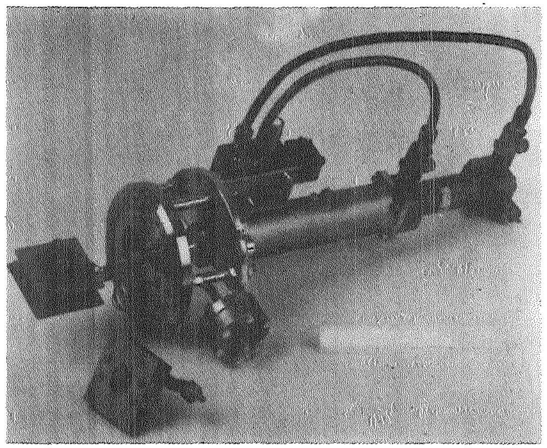
4.2.1 The Beam Diagnostic Components

The beam diagnostic instrumentation inside the target station will mainly consist of the entrance slit diaphragms, the gauge apertures, the beam profile measurement system consisting of the profile grid ("harps") and the cooled Faraday cup with secondary electron suppressor. Additionally a beam energy moderator will be mounted into the alpha-particle beam to degrade the energy from 104 MeV to zero continuously in order to achieve a homogenous helium concentration profile in the irradiated specimens. These components partially developed for the high-intense beam of the UNILAC accelerator at GSI-Darmstadt have successfully been used in irradiation experiments over a period of many years.

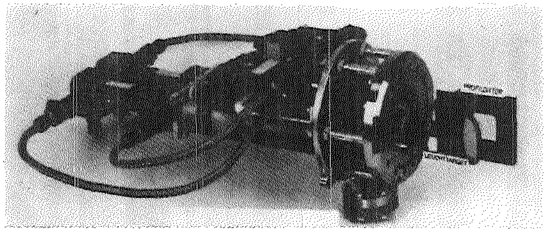
Fig. 3 presents photographs of such a beam diagnostic system and several of its components as used by KfK in irradiation experiments at Bochum. This system is going to be copied for use in DBT-experiments.



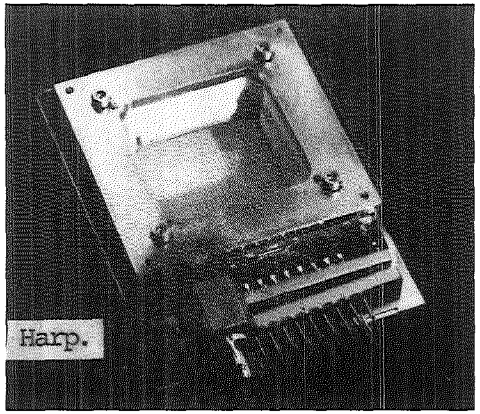
UHV irradiation chamber and different beam diagnostic components.



Single feedthrough with faraday cup.



Double unit with harp and viewing screen.



Harp.

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Fig.3 Several components of the beam diagnostic system as used by KfK in high–current ion simulation experiments.

4.2.2 The irradiation chamber for in-beam fatigue tests

The irradiation chamber for in-beam fatigue tests is a KfK-development and will be mounted in an INSTRON testing machine of type 1121 presently used for tests with unirradiated samples. The testing machine is suited for tensile, creep or endurance tests.

The main features of the chamber being under construction are:

(1) Ultra-high vacuum (10^{-11} bar)

(2) Temperature control up to 1773 K

(3) Easy sample access and easy change to different specimen geometries

(1) The body of the irradiation chamber is constructed from intersecting stainless steel tubes, the outer ends of which terminate in standard UHV (copper gasket) flanges. Clean ultrahigh vacuum is provided by a 1000 l/s turbomolecular pump together with a large LN_2 - trap. The chamber can completely be baked out up to 673 K in order to achieve a vacuum of about 10^{-12} bar. At high temperatures (>1500 K) a vacuum of 10^{-11} bar can be maintained. The irradiation chamber is separated by 6-um thick foil from the beam-line vacuum system.

(2) The temperature control system is based on the variation of the specimen temperature monitored by a thermocouple at the back-surface of the specimen. The position of the thermocouple is adjustable in x-y-direction by a precision feedthrough (it is known from earlier experiments that a 104-MeV alpha-particle beam does not cause decalibration of the thermocouples). The temperature gradients along the height and width of the specimen can be monitored by a movable infrared pyrometer having a resolution of $\pm$ 1 K. Due to the serious

complication of changing emissivity with material and time the pyrometer will not be used for absolute temperature measurements, but serves as a device for monitoring gradients or changes in gradients.

The temperature of the specimen is maintained by a combination of two heating systems (s.Fig.4). The first couples the heat via conduction to the specimen by ohmic heating of the specimen holder (inner heating system), while the second transfers the heat via radiation to the specimen by heating a system of 6 wire-spirals surrounding the specimen and the holder (outer heating system). The inner system establishes the base load, whereas the outer one ensures a homogeneous temperature over a distance of 50 mm in axial direction. At 823 K the input power is about 2 kW. Under irradiation an additional load of about 0.5 kW is provided which can be balanced by the outer heating system, if the specimen temperature is at 823 K or higher. At specimen temperatures below 823 K heat removal becomes necessary. In the case of a tube specimen, which will be used in fatigue experiments, a cooled helium jet is pressed through the tube removing the heat most effective just at the inner surface of the tube, where the heat load due to the beam is the largest.

(3) The backside of the irradiation chamber is closed by a large door, on which one half of the outer heating system and heating shieldings has been mounted. Thus, after opening the door, free access to the specimen is ensured. The clamping of the specimen (as sketched in Fig.4) is only due to a clamping ring allowing an easy and fast demounting. This technique has successfully been proved even under the more difficult condition of remote handling in the hot cells.

By changing the adapter (s.Fig.4), different specimen geometries can be mounted.

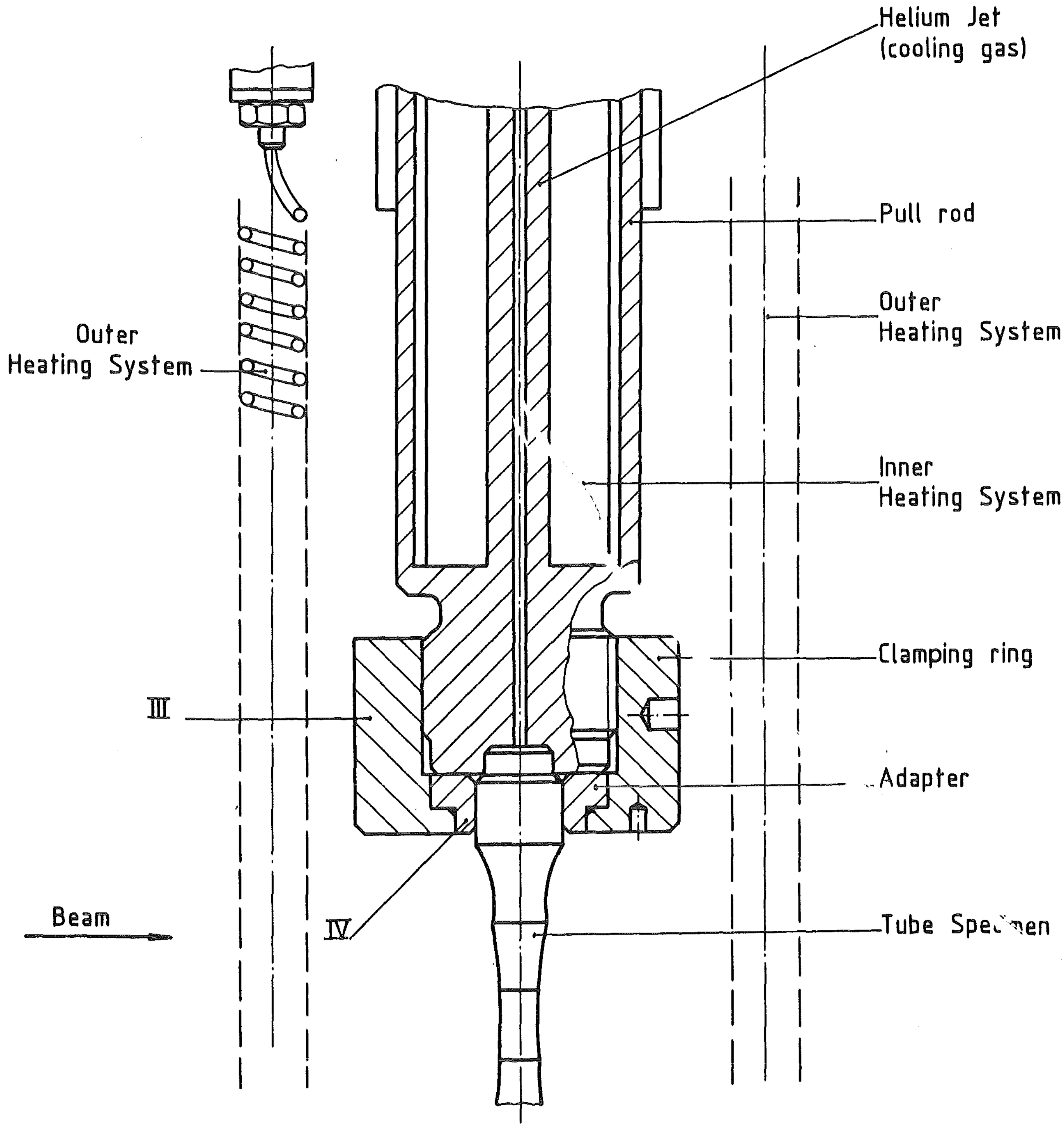

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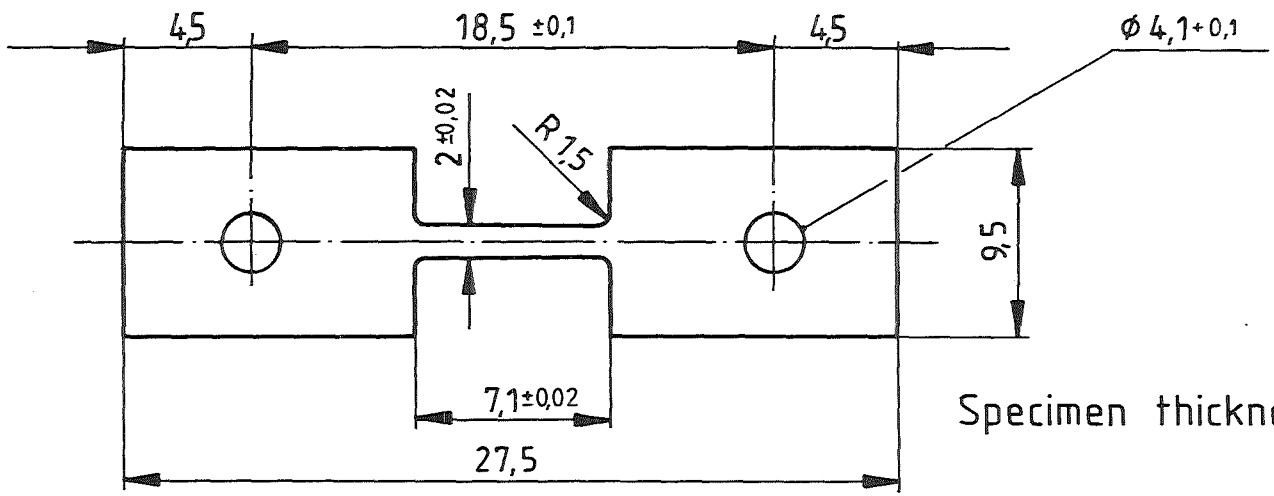
Fig. 4 Part of the interior of the irradiation chamber for in-beam fatigue tests. The sketch shows the heating/cooling system for the tube specimen, the clamping device and the pull rod.

4.2.3 The Geometry of Samples for mechanical tests

For tensile testing of ion or neutron irradiated specimens the geometry shown in Fig. 5a has been used in KfK-experiments. The comparison of tensile data obtained with thin flat samples down to 0.2 mm thickness with those of standard-sized specimens has shown for vanadium that no significant difference could be found as long as both the temperature was not higher than 1023 K and the test was conducted under vacuum conditions. At higher temperatures (due to the moderate vacuum in the testing furnace) impurity absorption caused a scatter of data in the thin specimens.

In order to design a sample being penetrable by light ions and being suitable for fatigue tests, an investigation has been started using the so-called GRIM-geometry - a sample shape, which is used in the fast breeder project (s.Fig. 5b). Primarily results indicate that drilled-out GRIM-specimens (tubes) have an excellent deformation behaviour in fatigue tests, which is similiar to that of bulk specimens as seen in Fig. 6. The reduced number of cycles to failure observed in the tube specimen can mainly be attributed to the higher applied stress. Further tests are in progress investigating different effects (i.e. temperature, gauge length, wall radius, wall thickness and strain range) on the fatigue behaviour of tube specimens.

A Sheet Specimen for Tensile Testing



B Tube Specimen for Low-Cycle Fatigue Testing

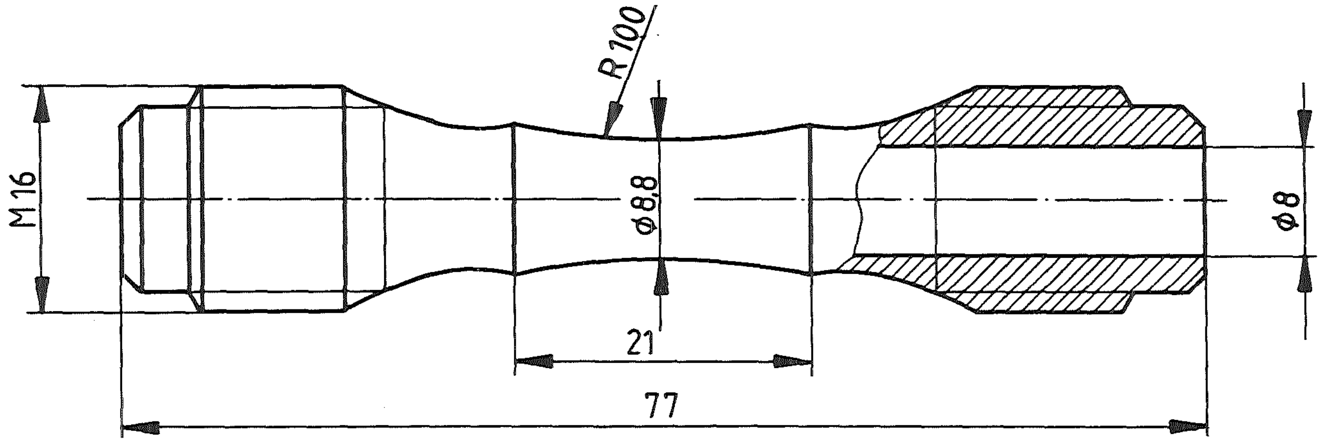


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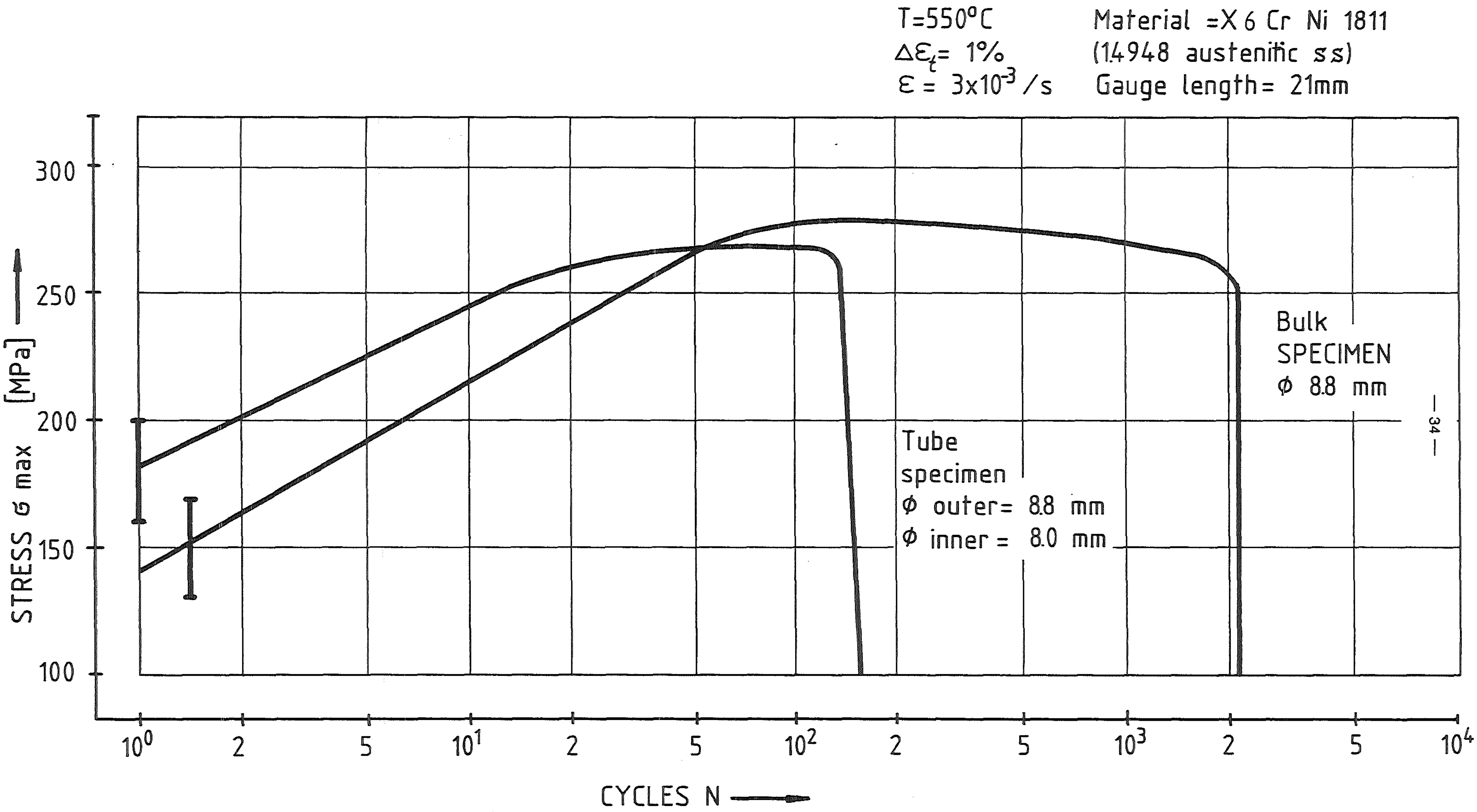
Fig. 5. Schematic drawing of a sheet tensile specimen and a tube specimen to be used in dual beam experiments of KfK



KfK IMF 83107- A1

Fig. 6 Comparison of the low-cycle behaviour (LCF) of 1.4948 ss at 823 K for a bulk specimen and a tube specimen of 0.4mm wall thickness

4.2.4 The Data Acquistion System

The data acquisition system for the irradiation experiments consists of a diverse collection of instruments designed to monitor the conditions of the specimen and its enviroment as well as to control them. The information from each of the various transducers is (if necessary) amplified, digitized and made available to a computer-based multi- programmer system. A block diagram is shown in Fig. 7 and each of the various subsystems is briefly described below.

The beam current and the beam shape are periodically measured by Faraday cups and by a profile grid (s.Fig. 3), which are positioned in the beam directly in front of the specimen by means of pneumatically actuated bellows arrangements. A rotating wire (0.2 mm Ta) continuously scans the beam and this output is calibrated to the current output from the Faraday cup at each period. The profile shape as seen by the specimen can be monitored very accurately due to the easy alignment of the specimen center with the beam center by means of the grid center.
The position and delay-time of the beam energy degrader (wedge) for the alpha-particle beam is computer-controlled to ensure a homogeneous helium implantation across the sample thickness (beam intensity and penetration depth do not vary with the wedge position in a linear manner).
The beam information is routed to the process-computer as well as to the computer of the cyclotron control area.

Temperature control begins with signals from the different PtRh-Pt thermocouples monitoring the temperature of the outer and inner heating system, of the helium gas and of the specimen at different positions. Although the constancy of temperature is electronically maintained by PID-controllers (driving thyristor devices), by stabilized power supplies and by a valve regulating the cooling gas throughput, a trial-and-error routine is used to calculate the different set-values for each heating/cooling device in order to achieve the given "irradiation temperature" at the specimen. These set-values are converted into analog output signals and are sent to the PID-controllers, the stabilized power-supplies and the regulating valve. All these controllers are operating in the cascade control mode.

The vacuum control is mainly established to shut down the heating system in a case of emergency (for example, leakage).

The endurance machine is operating in a closed loop, therefore, only the signals mentioned in Fig. 7 have to be recorded. A simple curve-fitting program checks for the stress decay (in the strain-controlled mode) and can stop the machine in order to prevent a complete fracture of the specimen. The complete fracture occuring during the last cylce often destroys the original fracture surface.

All the input/output signals described above are monitored and controlled by a buffered Hewlett&Packard 2240A Measurement and Control Processor. The communication of the micrprocessor-based HP 2240A with the HP 1000 control computer is based on tasks delegated with a simple program statement in FORTRAN-written programs.
The sampling rate of the data acquisition is very high (up to 20,000 readings per second), but the overhead (tasks, low-level voltage integration, file manipulation etc.) reduces the rate to about 100 Hz.

Several of the electronic devices sketched in Fig. 7 have been used in current irradiation experiments and the corresponding software for the data acquisition has been proved. The set-up of the complete data acquisition system as presented in Fig. 7, however, has to be undertaken in 1984/85.

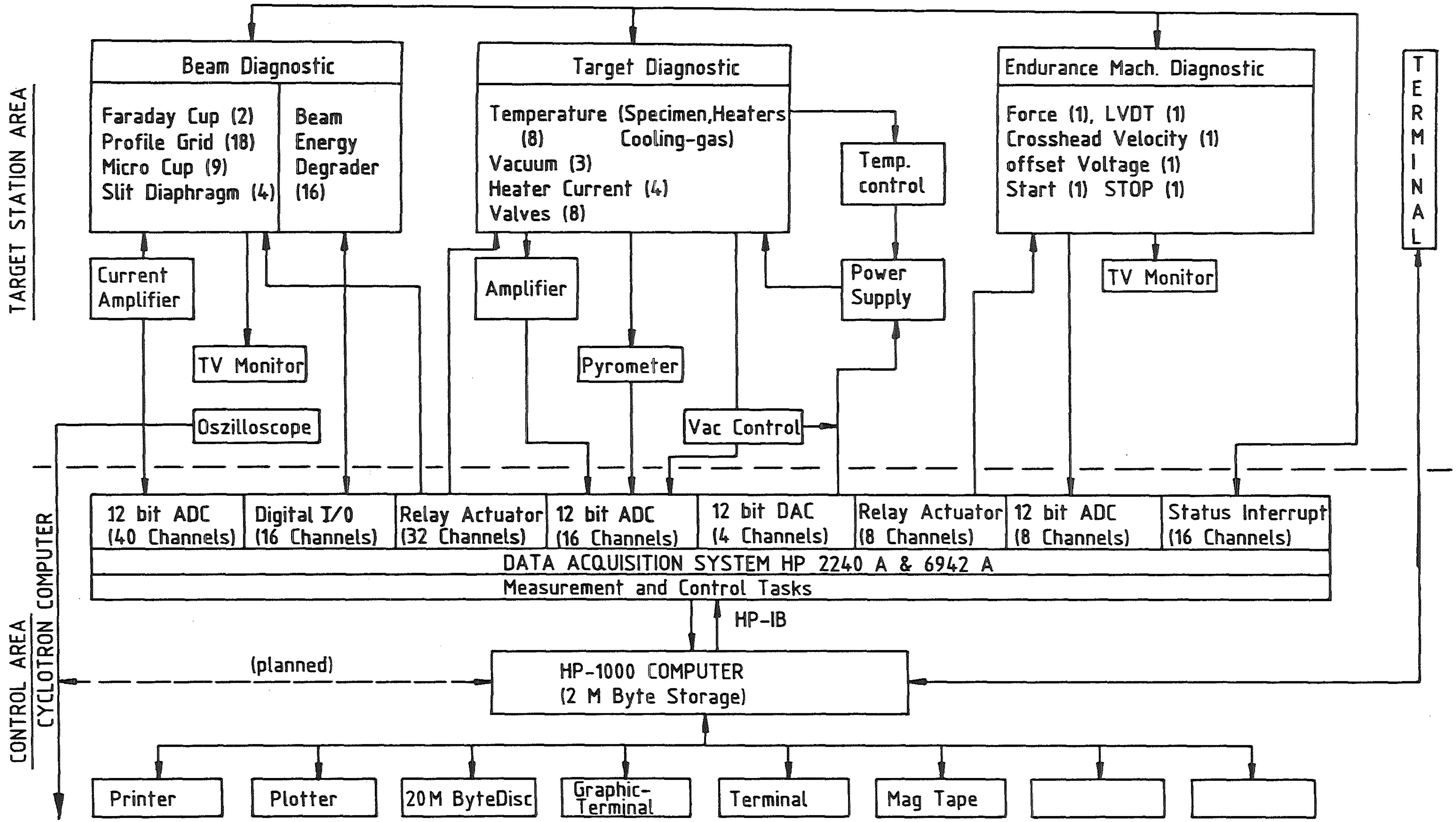


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Fig. 7 DATA ACQUISITION SYSTEM

Block diagram of electronics for the beam-,target-, and endurance machine diagnostics and their routes to the measurement device and computer (in brackets the number of signals to be transmitted are given)

References

[1] INTOR-Study, Phase I, 1982, IAEA; STI/PUB 619

[2] R.D.Watson and W.G.Wolfer, SMIRT-6 Seminar, Paris (F) Aug.24-25, 1981

[3] N.M.Ghoniem and G.L.Kulcinski, Nucl.Techn. 2 (1982) 165

[4] D.Kaletta, J.Nucl.Mater. 85&86 (1979) 775

[5] K.Sonnenberg and H.Ullmaier, J.Nucl.Mater. 103&104 (1981) 859

[6] R.Schmitt and W.Scheibe, Transactions of the 7th Intern. Conf. on Structural Mechanics In Reactor Technology, Chicago, Il (USA) Aug. 22-26, 1983, vol. L

[7] D.Kaletta, J.Nucl.Mater. 103&104 (1982) 907

[8] D.Kaletta, KfK-Bericht 2282 (1976)

[9] D.Kaletta, Radiat.Eff. 47 (1980) 237

[10] D.Kaletta, Radiat.Eff. 78 (1983) 245

[11] K.Ehrlich and D.Kaletta, Proc.International Conf. on Radiation Effects and Tritium Technology, Gatlinburg, TN (USA), Oct. 1-3, 1975, vol.II,289

[12] D.Preininger and D.Kaletta, J.Nucl.Mater. 117 (1983) 239

[13] D.Kaletta and W.Schneider, J.Nucl.Mater. 122&123 (1984) 418

[14] K.Anderko, K.David, W.Ohly, M.Schirra, and C.Wassilew, Top.Conf. on Ferritic Alloys in Nuclear Energy Techn., Snowbird (USA), Juni 1983

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